INTERNATIONAL JOURNAL OF -EXERCISE SCIENCE-

Original Research

Self-reported Fueling During Training and Racing is not Associated with Low Energy Availability, Disordered Eating, or Exercise Dependence in Female Cyclists

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Abstract

International Journal of Exercise Science 19(2): 2022, 2026. ***https://doi.org/10.70252/IJES2026222***

Under-fueling, disordered eating (DE), weight dissatisfaction (WD) and exercise dependence (EXD) may increase the risk of low energy availability (LEA) in cyclists. This study examined the prevalence of risk for LEA and its association with risk of DE, EXD, weight dissatisfaction and self-reported fueling habits during training and racing in female cyclists. Competitive and recreational female cyclists between the age of 18-40 (n = 153) completed a 45-question Qualtrics survey that included self-reported training and racing characteristics, questions regarding carbohydrate intake during training and competition, the Low Energy Availability in Females Questionnaire (LEAF-Q), the Disordered Eating Screen for Athletes (DESA-6), and the Exercise Dependence Scale-21 (EDS-21). Among the cyclists, 47.7% (n = 73) were at risk for LEA and 75.8% (n=116) reported weight dissatisfaction. Cyclist category (recreational or competitive) was not associated with risk of LEA ($\chi^2(1) = 0.7$, $p = 0.09$). Cyclists at risk for LEA were more likely to be at risk for DE ($\chi^2(1)$ 22.5, $p < 0.001$, $\varphi = 0.38$) and more likely to be at risk for EXD ($\chi^2(2)$ 6.58, $p = 0.04$, Cramer's V= 0.21) Furthermore, cyclists at risk for LEA were more likely to be moderately and severely dissatisfied with their weight ($\chi^2(3)$ 13.1, $p = 0.004$, Cramér's V = 0.30). However, there was no association between risk for LEA and meeting fueling recommendations during training or racing sessions of any duration. Nearly half the surveyed population of female cyclists were at risk for both LEA and DE behaviors. Furthermore, meeting fueling recommendations during training and races does not appear to mitigate the risk for LEA, highlighting the need for routine screening for LEA in female cyclists, even among those who appear to meet fueling recommendations during training and racing.

Keywords: Cycling, energy availability, disordered eating, exercise dependence, carbohydrate availability

Introduction

Low energy availability (LEA) results from insufficient energy intake relative to energy expenditure leading to impaired physiological processes in physically active individuals.[1] In females, menstrual irregularities, decreased libido, gastrointestinal discomfort, and impaired bone health are some of the physiological consequences associated with persistent LEA.[1] Relative Energy Deficiency in Sport (REDs) is a syndrome characterized by a range of negative health and performance outcomes, possibly resulting from extended periods of problematic

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LEA in athletes or exercising individuals,[2] and impacts reproductive function, bone health, immunological function, protein synthesis, and cardiovascular health.[3]

Beyond its physiological consequences, LEA is closely associated with psychological and behavioral factors, including disordered eating (DE), weight dissatisfaction (WD), and exercise dependence (EXD), which may contribute to and result from chronic energy deficiency in endurance athletes.[4,5] DE describes eating habits that are dysfunctional and have the potential to become pathological, including fasting, dieting, vomiting, overeating, binge eating, and the use of laxatives or diet pills, but do not meet the *Diagnostic and Statistical Manual of Mental Disorders*, Fifth Edition (DSM 5) criteria for an eating disorder (ED).[6,7] DE may occur in athletes due to the desire to attain a sport-specific body ideal and relieve sport-specific body dissatisfaction.[6] Furthermore, body or weight dissatisfaction may further reinforce DE behaviors and directly reduce energy intake thus contributing to risk for LEA and REDs.[4]

Exercise dependence (EXD), also known as exercise addiction and compulsive exercise, is characterized by a need for physical activity or uncontrollable excessive exercise behavior with an inability to reduce exercise amounts, leading to potentially dangerous outcomes such as injury, impaired social relationships, and depression.[10] Perfectionism and ED pathology are frequently linked to EXD in females.[11] Thus, when examining the etiology of LEA, EXD must be considered given that energy availability is influenced by exercise energy expenditure.[5]

In addition to behavioral factors associated with LEA, fueling during exercise represents another modifiable component of energy availability in endurance athletes. Low carbohydrate availability, or a diet with reduced CHO to support training and recovery, paired with LEA has been proposed to amplify the negative hormonal consequences of REDs.[25] Previous research on soccer players has shown increased risk for LEA with the consumption of lower energy dense meals post-match.[26] In ultra endurance athletes, inadequate carbohydrate ingestion during long training runs correlated to increased risk of LEA; however, this relationship has not been evaluated in cyclists.[13] The American College of Sports Medicine (ACSM) and Academy of Nutrition and Dietetics (AND) joint position paper on Nutrition and Athletic Performance recommends 30-60 grams of carbohydrates (CHO) per hour for exercise up to 2.5 hours, or 60-90 grams of CHO per hour for >2.5 hours during endurance exercise.[27] However, a study by Lanpir et al (2025) concluded that most endurance athletes were not following their carbohydrate ingestion plan on race day, and Viner et al. (2015) found that most male cyclists did not meet carbohydrate recommendations during training.[19,28] Thus examining self-reported fueling practices during and races in conjunction with LEA, DE, EXD, and WD may help determine whether fueling behaviors isolated to during exercise is related to risk for LEA or whether risk is associated with behaviors outside of the exercise bout.

The prevalence of LEA in different female athlete populations has been the focus of recent investigations and varies from 22% to 58% depending on the tool or method used to detect risk of LEA in athletes competing in sports that emphasize leanness or have high energy demands from training (e.g., 22% of ballet dancers, 53% of elite soccer players, 58% of junior national level soccer players and 31% of elite distance athletes).[12] Henninger et al. (2024) found that LEA, DE, and EXD were all prevalent in the endurance running population, and Torres – Mcgee et al. (2021) found increased prevalence of LEA (81%) and ED risk (76%) across various sports (equestrian, volleyball, softball).[13,14] In a scoping review by Roberts et al. (2022), it was suggested that cyclists may be at high risk for DE.[15] Cyclists may also be at risk of EXD, with some stating

that cycling helps regulate mood, and others demonstrating withdrawal symptoms when unable to cycle. [16] Further, due to the potential for high training loads, increased energy expenditure relative to energy intake, under-fueling and other DE-associated habits, LEA may be problematic in the cycling population.[17] Keay et al. (2018) identified 28% of male cyclists at risk for LEA using the Sport-specific questionnaire and clinical interview (SEAQ-I).[18] Viner et al. (2015) found that 70% of a group of male and female adult cyclists consciously restricted energy intake for weight control.[19] Another study examined 45 competitive female endurance cyclists and found that 57.8% of female cyclists in the population were at risk for LEA based on LEAF-Q scores.[20] Furthermore, recent longitudinal observational studies have highlighted that female cyclists may have suboptimal energy availability during a racing season based on calculated assessments of energy availability using diet and activity records.[21,22]

Recent evidence shows that recreational athletes may have a heightened or similar risk of LEA compared to elite athletes. Lichenstein et al. (2024) found that recreational athletes were more likely to have an ED compared to elite female athletes (37.4% v. 23.4%).[23.] Whereas, Dervish et al. (2022) found only modest predictability between competition level and prevalence of LEA in female endurance runners, with competitive and recreational having similar risk of LEA.[24] Despite the importance of understanding these risks for practitioners and coaches working with this population, research has yet to examine the prevalence of LEA, DE, and EXD in female cyclists and compare the risk between recreational and competitive female cyclists.

LEA is not solely a consequence of inadequate fueling during exercise but rather reflects the imbalance between energy intake and exercise energy expenditure that may arise through multiple behavioral pathways including DE, EXD, and WD. Therefore, examining these behavioral factors together may provide a more comprehensive understanding of factors associated with LEA risk. The primary aim of this study is to examine the risk for LEA, DE, EXD and WD in a female cyclist population, including comparisons between recreational and competitive cyclists. Furthermore, the second aim is to compare the risk for DE, EXD, and fueling habits during races and training between cyclists identified as at risk versus not at risk for LEA. It was hypothesized in this study that recreational and competitive cyclists will display similar risks for LEA, and that cyclists at risk for LEA will be at risk for DE and EXD and display higher prevalence of under fueling during racing and training compared to female cyclists not at risk for LEA.

Methods

Participants

Female cyclists between the age of 18-40 years based on the applicability of the Low Energy Availability in Females Questionnaire (LEAF-Q) tool and for menstrual cycle considerations were recruited for this study. Participants self-reported as either competitive or recreational in any discipline of cycling (e.g., mountain biking, road cycling). A total of 153 female cyclists (n = 85 recreational, and n = 68 competitive) completed the survey in its entirety. Incomplete responses were not included in this analysis. Participants who reported the use of contraceptives were included in this study.

Protocol

Participants in this cross-sectional study answered 45 questions via a Qualtrics survey that was advertised through social media from July to September 2023. A link to the study was advertised

on social media platforms that contained both the informed consent and questionnaire on the Qualtrics website for individuals choosing to participate. Participants were informed that they could opt out of the study at any time. All the information gathered was anonymous, and the study was approved for exemption status by the Human Subjects Review Committee (HSRC) (study #2023-092) and the research was conducted fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[16]

The survey included three previously validated and reliable instruments in athletes and physically active individuals, the Exercise Dependence Scale-21 (EDS-21), the Disordered Eating Screen for Athletes DESA-6, and the Low Energy Availability in Females Questionnaire (LEAF-Q) to assess risk for EXD, DE, and LEA, respectively.[17] Category of cyclist (competitive, recreational), weekly time spent cycling (< 4 hrs to > 30 hrs), primary race focus (track racing, road racing, road time trial, cyclocross, mountain bike xc, mountain bike enduro, mountain bike DH, ultra-distance trail, gravel, other), and overall energy intake throughout the day, and carbohydrate consumption during training and competition were included in the survey questions. These are outlined in Table 1 below.

Table 1. Survey questions targeting fueling strategies, carbohydrate consumption, and evaluation of fueling strategies.

Topic	Survey Question	Response Option
Overall fueling strategies	*Do you intentionally eat less on easy training days?* *Do you intentionally train in the FASTED state?*	Yes No
Athlete evaluation of adequate fueling for their sport	*I feel like I fuel adequately to support my training and racing needs*	Always Sometimes Never
Carbohydrate consumption during exercise	*Do you consume carbohydrates during your workouts?*	Yes Sometimes No
Quantify how many carbohydrates they eat during workouts	*How many grams of carbohydrate (via liquids, gels, gummies, solid foods) do you consume on average during the following? (Training or Racing efforts: 1-2.5 hours, >2.5 hours)*	I do not fuel 30-60g/hour 60-90g/hour > 90g/hour

Questions regarding weight dissatisfaction (WD) and race weight were also included and asked through the following:
"In the past three months have you been dissatisfied with your weight, meaning have you wanted to weigh less?" (no, slightly dissatisfied, moderately dissatisfied, markedly dissatisfied)
"In the last three months were you trying to achieve or maintain a specific weight?" (Y/N)

LEAF-Q.
The LEAF-Q includes questions regarding menstrual dysfunction (MD), GI symptoms, and injury frequency to identify athletes at risk for LEA.[29] The LEAF-Q score was used to categorize participants as not at risk (< 8) or at risk (≥ 8) for LEA.[29] The LEAF-Q has been validated in elite female endurance athletes to identify LEA against clinically verified REDs conditions and biomarkers such as current reproductive function and screen at-risk groups for amenorrhea with 78% sensitivity and 90% specificity.[29] Prior work has shown that LEAF-Q scores correlate with both disordered eating and exercise dependence risk in female endurance athletes.[13] Participants who reported having four to nine periods in the preceding 12 months but did not miss three consecutive cycles, and participants who indicated not currently menstruating for three or more consecutive cycles without being caused by "Other" variables (history of ovaries removed or

hysterectomy, nursing, use of hormonal IUD, usage of contraceptive implants, or other hormone treatments that could modify menstruation), were classified as having MD unless they were receiving hormone therapy. Participants were able to specify if their menstrual cycle interruption was affected by peri-menopause or post-menopause and were excluded if this was the case.

DESA-6.

The Disordered Eating Screen for Athletes (DESA-6) was used to determine participants' risk for DE. The DESA-6 screening tool evaluates factors such as the frequency and severity of injuries, the existence of dieting, the pressure to lose weight, happiness with current weight, fear of gaining weight, and the degree of dissatisfaction with present weight.[30] A score ≥ 3 indicates that a participant was at risk for DE. The DESA-6 has demonstrated a 92% sensitivity and 85.96% specificity in accurately identifying DE in adolescent athletes across all sports.[30] When compared to the Eating Disorder Examination (EDE-Q), higher DESA-6 scores are linked to a higher likelihood of ED in females (r = .08, p < .001).[30]

EDS-21.

Following the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V) criteria for drug dependency, the Exercise Dependence Scale (EDS-21) assesses the risk for EXD and has demonstrated strong reliability (Cronbach's alpha > 0.90) and construct validity in physically active populations.[31] Based on average total score for symptoms of EXD the survey instrument distinguishes between (a) individuals at risk for EXD or dependent-symptomatic, (b) nondependent-symptomatic, and (c) nondependent-asymptomatic.[31] EDS-21 score also indicates signs of either (a) physiological dependency based on signs of withdrawal or tolerance or (b) no physiological dependence. [31] Participants who score ≥ 3 meet the criteria (lack of control, tolerance, withdrawal, intention effect, significant amount of time spent on physical activities, reductions in other activities, and continuance) for dependence and are categorized as at risk for EXD. A score between 5 and 6 is defined as "dependent symptomatic".[31] Scores between 3 and 4 indicate a "non-dependent symptomatic" individual.[31] Participants with a score between 1 and 2 are considered asymptomatic (EDS-21 Manual).[31] Athletes were analyzed separately as asymptomatic, non-dependent symptomatic and dependent symptomatic.

Carbohydrate Consumption During Training and Competition.

Participants were asked to indicate how many grams of CHO per hour they consume during training and competition (1 to 2.5 hours, and > 2.5 hours). The answers were compared to the evidence-based recommendations from the Academy of Nutrition and Dietetics and American College of Sports Medicine Position Paper on Nutrition for Athletic Performance for the consumption of CHO during exercise, which state that 30 to 60 grams of CHO per hour should be consumed during exercise that lasts 1-2.5 hours, and 60 to 90 grams of CHO per hour should be consumed during activities > 2.5 hours in duration[27] Based on duration and the evidence-based recommendation, fueling responses were rated as either "insufficient" or "sufficient" (e.g., consuming < 60 g CHO/hour for endurance events lasting longer than 2.5 hours was considered "insufficient" and < 30 g/hour for endurance activities lasting less than 2.5 hours was considered "insufficient").[22]

Statistical Analysis

Data cleaning and statistical analyses were conducted in Jupyter Notebook (version 7.4.5) with pandas for database management and SciPy for statistical testing, including chi-square analysis and calculation of p values. Results with a significance level of p < 0.05 were considered statistically

significant. Effect sizes were calculated using phi coefficients for 2×2 tables and Cramér's V for larger contingency tables. Odds ratios were calculated with 95% confidence intervals for each 2x2 comparison to characterize the strength and direction of the associations between risk categories; a Haldane-Anscombe correction was applied if a contingency table contained a cell count of zero. Frequencies were displayed as percentages to represent the individuals at risk for LEA, DE, EXD, and WD.

A sensitivity power analysis was conducted to evaluate whether the final sample of 153 participants provided adequate power to detect associations using chi-square tests. With alpha = 0.05 and n=153, the study had 80% power to detect an effect size of =0.23 for 2x2 comparisons and slightly larger effects (Cramer's V =0.25 - 0.27) for comparisons involving variables with more than two categories. This suggests that the final sample was adequately powered to detect small-to-moderate or larger associations between risk for LEA and the primary variables examined in this study.

Results

153 cyclists completed the survey. 44.4% (n = 68) of the cyclists self-reported as "competitive" and 55.6% (n = 85) self-reported as "recreational cyclist but rarely races." Of those who raced, road racing (n = 25), gravel racing (n = 24), and mountain bike/xc racing (n = 18) were the most common. There was a significant association between cyclist competition level and training hours ($\chi^2(5) = 53.11$, $p < 0.001$). The weekly (hours per week) training data are displayed in Figure 1.

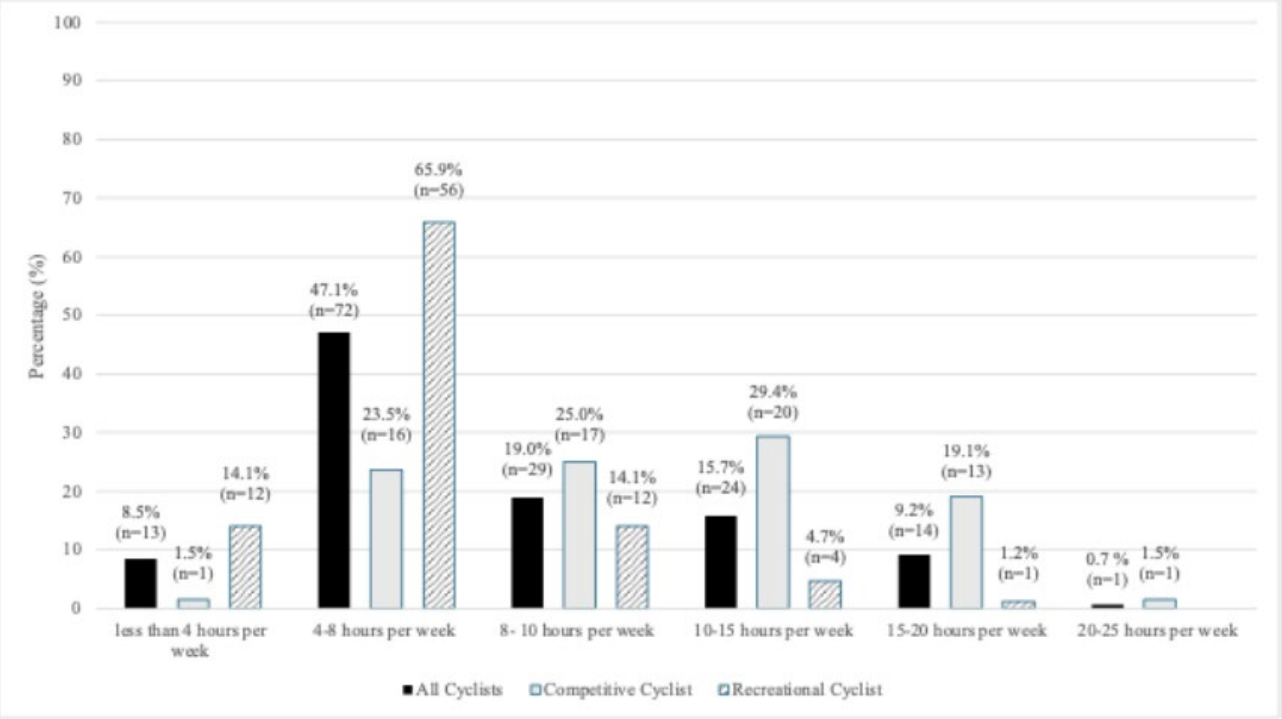


Figure 1. Self- reported training hours per week for competitive and recreational cyclists.

The most common reported cross-training activities were walking (n = 41) and strength training (n = 24). In the sample, 43.8% (n = 67) of cyclists reported taking one rest day per week, and 9.2% (n = 14) report taking zero rest days per week, and 13.2% (n = 9) of competitive and 5.8% (n = 5) of recreational cyclists reported taking zero rest days per week.

Out of all cyclists, 45.1% (n = 69) report using some form of hormonal birth control, 15.7% (n = 24) use oral contraceptives and 29.4% (n = 45) use other forms, with hormonal implants (62.2%) being most common. Out of the 84 cyclists who do not take birth control, 73.8% (n = 62) report having consistent menstruation every 21-35 days, and 10.7% (n = 9) report currently not menstruating and having less than three menstrual cycles over the past year.

Out of all participants, 73.9% (n = 113) reported never having a stress fracture and 79.7% (n = 122) decline having three or more injuries in the past training season.
Of the 153 participants, 47.7% (n = 73) were identified as at risk for LEA based on a score of ≥ 8 on the LEAF-Q. Additionally, 42.5% (n = 65) were identified at risk for DE based on DESA-6 score. However, only 14.4% (n = 22) of cyclists reported currently having an ED, and 28.1% had a previous ED diagnosis. Risk for LEA, DE, and EXD for the entire population, and comparisons between recreational and competitive cyclists are highlighted in Table 2.

Table 2. Risk Classification for LEA, DE, and EXD in Female Cyclists.

	Low Energy Availability		**Disordered Eating**		**Exercise Dependence**		
	at risk	**not at risk**	**at risk**	**not at risk**	**at risk**	**non-dependent symptomatic**	**non-dependent asymptomatic**
Entire Population (n = 153)	47.7% (n = 73)	52.3% (n = 80)	42.5% (n = 65)	57.5% (n = 88)	12.4% (n = 19)	77.1% (n = 118)	10.5% (n = 16)
Competitive Cyclists (n = 68)	55.9% (n = 38)	44.1% (n = 30)	47.1% (n = 32)	52.9% (n = 36)	19.1% (n = 13)	72.1% (n = 49)	8.8% (n = 6)
Recreational Cyclists (n = 85)	41.2% (n = 35)	58.8% (n = 50)	38.8% (n = 33)	61.2% (n = 52)	7.1% (n = 6)	81.2% (n = 69)	11.8% (n = 10)
Chi-Square (φ or Cramer's V)	1.7 (φ = .14)		0.74 (φ = .06)		5.14 (Cramer's V = .18)		
***p*-value**	0.10		0.39		0.08		

(LEA risk determined by LEAF-Q ≥ 8; DE risk determined by DESA-6 ≥ 3; EXD classification per Exercise Dependence Scale-21. Chi-square analysis are between competitive and recreational cyclists across all risk categories. *indicates significance if $p < 0.05$.

75.8% (n = 116) of cyclists reported WD in any respect. When asked about trying to achieve a specific weight in the past three months, 54.2% (*n* = 83) reported "yes," while 45.8% (n = 70) reported "no." 66.7% (n = 102) of cyclists report occasionally to daily restriction of calories to achieve a lower weight.

Out of all the participants, 11.8% (n = 18) reported fasting during training, 45.8% (n = 70) reported eating fewer carbohydrates on easy days, and 62.1% (n = 95) reported consuming carbohydrates during training. Cyclists were asked if they: "Adequately fueled enough to support their training demands," and 26.1% (n = 40) responded with "Always," 71.9% (n = 110) with "Sometimes," and 2.0% (n = 3) with "Never."

Table 3 displays the number of cyclists who self-reported fueling sufficiently or insufficiently for training rides based on duration (1-2.5 hours, and > 2.5 hours).

Table 3. Self-reported Carbohydrate Ingestion During Training and Racing by Cyclist Type and LEA Risk Status. Sufficient was determined by self-reporting consuming > 30grams of CHO per hour for exercise lasting between 1-2.5 hours and > 60grams of CHO per hour for exercise lasting > 2.5 hours.

			Fueling During Training		Fueling During Racing	
			1-2.5 hours	> 2.5 hours	1-2.5 hours	> 2.5 hours
Entire Population (n = 153)		**Sufficient**	75.8% (n= 116)	37.3% (n = 57)	46.4% (n = 71)	40.5% (n=62)
		Insufficient	24.2% (n=37)	62.7% (n = 96)	53.6% (n = 82)	59.5% (n=91)
Cyclist Category	**Competitive Cyclists (n = 68)**	**Sufficient**	79.4% (n = 54)	50.0% (n = 34)	51.5% (n = 35)	55.9% (n=38)
		Insufficient	20.6% (n = 14)	50.0% (n = 34)	48.5% (n = 33)	44.1% (n=30%)
	Recreational Cyclists (n = 85)	**Sufficient**	72.9% (n = 62)	27.1% (n = 23)	42.4% (n = 36)	28.2% (n=24)
		Insufficient	27.1% (n = 23)	72.9% (n = 62)	57.6% (n = 49)	71.8% (n=61)
	Chi-Square (φ)		0.55 (0.08)	7.55 (1.04)	.92 (0.13)	10.9 (0.27)
	***p*-value (* indicates significance < 0.05)**		0.46	0.006*	0.33	0.001*
LEA	**At Risk for LEA (n = 73)**	**Sufficient**	79.5% (n = 58)	41.1% (n = 30)	45.2% (n = 33)	41.1% (n = 30)
		Insufficient	20.5% (n = 15)	58.9% (n = 43)	54.8% (n = 40)	58.9% (n = 43)
	Not At Risk for LEA (n = 80)	**Sufficient**	72.5% (n = 58)	33.8% (n = 27)	47.5% (n = 38)	40.0% (n = 32)
		Insufficient	27.5% (n = 22)	66.2% (n = 53)	52.5% (n = 42)	60.0% (n = 48)
	Chi-Square (φ)		0.66 (0.05)	0.59 (0.04)	0.02 (0.01)	0.00 (0.00)
	***p*-value**		0.41	0.44	0.9	1.00
	OR		0.68	0.73	1.10	0.96

* indicates significance if p < 0.05

There was a significant association between cyclist competition level and training hours ($\chi^2(5) = 53.11$, $p < 0.001$, Cramér's V = 0.59) with competitive cyclists reporting higher training volumes than recreational cyclists. Post hoc analysis of adjusted residuals indicated that competitive cyclists were overrepresented in higher training hour categories. However, there was no significant difference in number of rest days between competitive and recreational cyclists ($\chi^2(21) = 26.42$, $p = 0.191$, Cramér's V = 0.186). There was no difference in injury history between recreational (20.0%, n = 17) and competitive cyclists (20.5%, n = 14) ($\chi^2(5) < 0.001$, $p = 1.00$, Cramér's V = 0.00). Competitive cyclists did not have an increased likelihood for irregular menstrual cycles compared to recreational cyclists ($\chi^2(5)$ 1.68, $p = 0.642$, Cramér's V = 0.141), and cycling classification is not associated with WD ($\chi^2(3)$ 2.53, $p = 0.468$, Cramér's V= 0.129).

Cyclist type (recreational or competitive) was not associated with risk of LEA ($\chi^2(1) = 0.7$, $p = 0.09$); however, the effect size suggested a moderate association (φ = 0.28). There was no difference in risk of DE in competitive versus recreational cyclists ($\chi^2(1)$ .73, $p = 0.390$, φ = 0.07), and there were no differences in current or past eating disorder history between competitive and recreational cyclists ($\chi^2(14)$ 10.53, $p = 0.723$, Cramer's V = 0.262). Although the association was weak, competitive cyclists were not more likely to experience EXD compared to recreational cyclists ($\chi^2(2)$ 5.14, $p = 0.07$, Cramer's V = 0.18).

There was no association between cyclist category and frequency of fasting during training ($\chi^2(1)$ .06, $p = 0.80$, Cramer's V = 0.020), or adequately fueling enough to support their training demands ($\chi^2(2)$ 0.63, $p = 0.73$, Cramer's V = 0.153). Competitive athletes (76.5%, n = 52) were more likely to report consuming carbohydrates during workouts than recreational athletes (50.6%, n = 43) ($\chi^2(2)$ 12.8, $p = 0.0016$, Cramér's V = 0.289). Competitive athletes are more likely to sufficiently fuel compared to recreational athletes for both races ($\chi^2(1)$ 10.9, $p = 0.001$, $\varphi = 0.27$), or training efforts lasting longer than 2.5 hours ($\chi^2(1)$ 7.55, $p = 0.006$, $\varphi = 0.22$).

Cyclists at risk for LEA were more likely to be at risk for DE ($\chi^2(1)$ 22.5, $p < 0.001$, $\varphi = 0.38$, OR=5.47), and more likely to be at risk for EXD ($\chi^2(2)$ 6.58, $p = 0.04$, Cramer's V = 0.21). Those at risk for LEA were more likely to consciously restrict calories multiple times per week to reduce weight ($\chi^2(5)$ 13.2, $p = 0.02$, Cramér's V = 0.29) compared to those not at risk for LEA. Furthermore, cyclists at risk for LEA were more likely to report moderate and extreme weight dissatisfaction ($\chi^2(3) = 13.13$, p = 0.004, Cramér's V = 0.29).

However, there was no association between risk for LEA and meeting fueling recommendations during training or racing sessions lasting 1-2.5 hours or > 2.5 hours. No significant association was observed between LEA risk and adherence to fueling recommendations during training or racing sessions of 1-2.5 hours or > 2.5 hours duration (Table 3). Self-reported fueling adequacy during training and racing (1–2.5 hr and >2.5 hr) was similarly not significantly associated with risk for DE or EXD (all p > 0.10). Recreational cyclists not at risk for LEA (80%, n = 35) were most likely to insufficiently fuel for both racing ($\chi^2(3)$ 15.47, $p = 0.002$, Cramér's V = 0.244) and training ($\chi^2(3) = 12.11$, $p = 0.007$, Cramér's V = 0.29) sessions lasting > 2.5 hours compared to competitive cyclists and those recreational cyclists at risk for LEA.

Discussion

This study investigated the prevalence of LEA risk, DE risk, and EXD risk among both competitive and recreational female cyclists, along with the association between risk of LEA in relation to risk of DE, EXD, WD, and fueling habits. In the current study, half of the female cyclists were at risk for LEA, while three fourths of the population reported some form of WD. Most female cyclists did not meet the current fueling guidelines for carbohydrate consumption during training or racing, especially races of longer duration (>2.5 hours). Furthermore, meeting fueling recommendations during training and races does not appear to be protective against the risk for LEA in females cyclists.

The sport of cycling, characterized by high energy expenditure, presents unique challenges and opportunities for managing energy balance. Therefore, the management of energy will differ between training and competitive cycling given the fluctuation in cycling volume, motivations and performance-focus, and differences in fueling needs.[18,21,22] In the current study, almost half of the female cyclists surveyed were at risk for LEA based on LEAF-Q scores with a higher prevalence of LEA observed in the competitive cyclists (55%) versus the recreational the group (41%). Similarly, a study involving female endurance athletes (n = 202). which included cyclists (n = 45), in Norway, Sweden, Ireland, and Germany found that 57.8% of the cyclists in the study were at risk of LEA based on LEAF-Q scores.[20] Calculated assessments of energy intake and exercise energy expenditure as well as questionnaires have been used to assess LEA leading to the debate over the best method for determining an athlete's energy availability or risk for LEA. While calculated energy availability methods provide valuable insights, the LEAF-Q offers a holistic view by evaluating menstrual function, gastrointestinal function, and history of

stress fractures, thereby capturing multifaceted aspects that are sensitive to changes in energy balance.[32] The recent REDs update emphasizes the complexity of LEA and the importance of a comprehensive assessment, highlighting that LEA can impact not only athletic performance but also long-term health outcomes, requiring a broad and integrative approach to detection and management.[2,33] Our study aligns with previous research demonstrating a high prevalence of LEA in female athletes, particularly those in sports emphasizing leanness. It underscores the utility of the LEAF-Q as a specific tool tailored to the needs of female athletes.[13,20]

Research has suggested that most male and female cyclists agree that that "*cycling is a weight conscious sport*" and participants in the sport of cycling appear to be frequently dissatisfied with weight.[34,35] Sixty-five percent of elite Australian female cyclists (n = 32) reported currently or recently attempting to manipulate body weight throughout the training season with most common (76%) weight loss method being reduced energy intake.[34] In the current study, 75.8% of participants reported some form of weight dissatisfaction, and 54.2% reported trying to achieve a specific weight in the past three months, which is higher than findings reported by Berg et al. (2022) indicating one third of female Olympic Marathon trials qualifiers (n= 153) reported trying to achieve a specific race weight and half of participants reported some form of weight dissatisfaction.[8] To reach a particular body weight or composition thought to be optimum for their sport, athletes may resort to purging, binge eating, or restricted eating practices which can lead to low energy availability, delayed recovery, and an increased risk of injury.[36]

Participation in sports, such as cycling, where weight and power to mass ratio (Watts/kg) are emphasized has been suggested to increase the risk for DE.[36] Furthermore, additional factors such as body dissatisfaction, perfectionism, compulsive exercise, and striving for a "race weight" to enhance performance may contribute to the development of an ED.[8] In the current study, 42.5% of female cyclists were identified as at risk for DE based on DESA-6 scores and 14.4% reported currently having an ED. This is higher than previously reported studies (~25%) focusing on risk for ED using the Eating Attitudes Test 26 (EAT-26) in male cyclists, and higher than reported in female endurance athletes using the Eating Disorder Examination Questionnaire (EDE-Q).[15,19,20] It should be noted that most studies have focused on risk for an ED or DE in male cyclists.[15,19] The variation in results between these studies may be due to the type of assessment tool used to assess risk, participant characteristics (gender and sporting type), and whether the tool is assessing for risk of DE or ED. Based on previous literature and findings from the current study participating in the sport of cycling increases the risk for developing DE behaviors. DE can negatively affect one's physical and emotional well-being, impacting both performance and general well-being. Therefore, the prevention and treatment of DE in cyclists requires early intervention and identification of cyclists who may be at risk by using screening tools like the DESA-6 to provide the necessary resources.

In this study, 12.4% of cyclists were identified as "at-risk" and 77.1% "symptomatic" for EXD, respectively, indicating a notable prevalence of symptoms within the female cycling community. Another study done in female endurance athletes found a higher prevalence (23%) of female endurance athletes to be "at-risk" for exercise addiction, using the Exercise Addiction Inventory (EAI).[20] These discrepancies in findings may be due to the different tools to assess risk for EXD or population size. Due to past studies and the current findings, both competitive and recreational cyclists are risk for developing EXD, which can negatively impact training outcomes, energy availability, and injury prevention.

DE and EXD may may represent behavioral factors associated with increasing the risk of LEA. Thus, DE behaviors, such as restrictive eating, binge eating, or purging, and/or exercise dependence consisting of excessive exercise with addictive tendencies, may be present among athletes with LEA or at risk of LEA.[37] Similar to our findings, a study of 121 collegiate endurance athletes found that behaviors suggestive of DE are more common in athletes at risk for LEA.[13,38] This further suggests that LEA risk is strongly associated with DE tendencies, emphasizing the challenges female cyclists face in maintaining energy balance and managing associated behaviors off the bike.[39] Increased energy expenditure associated with EXD, represented by a constant need for physical activity, may increase the risk for LEA.[20] Past studies have shown athletes at risk or symptomatic for EXD may also be at risk for LEA and others have also shown the interplay between EXD, DE, and LEA in endurance athletes.[13,20]

The association between risk for EXD, DE, and LEA emphasizes the intertwined nature of psychological and physiological aspects of energy balance, emphasizing the need for holistic approaches including a multidisciplinary team (registered sports dietitian [RDN], sports psychologist, physician, certified athletic trainer [ATC]) to address training load, fueling, and overall health in female cyclists.[37,39]

Female cyclists, especially those who self-identify as competitive, engage in high training volumes; therefore, it is essential to pay careful attention to fueling habits to prevent LEA.[20,21] An imbalance between energy intake and expenditure is suggested by both the high risk of disordered eating and the inadequate fueling observed in our study, especially during longer training sessions and races, which can negatively impact several physiological systems.[17,21] In our study, only a small proportion of cyclists met current fueling recommendations for training (37.3%) or racing (40.5%) rides >2.5 hours long. These findings further emphasize the need to educate cyclists about the energetic demands of the sport impacting fueling and recovery both during and outside of training and competition sessions to avoid any potential negative performance or health outcomes associated with chronic under-fueling. However, there was no association between risk for LEA and meeting fueling recommendations during training or racing sessions of any duration. These findings suggest that nearly half the population of female cyclists who were at risk for LEA may be at risk due to under-eating outside of training and racing, and that meeting fueling recommendations during training and races does not ameliorate the risk for LEA. Similarly, the lack of association between sufficient fueling and risk for DE or EXD suggests that self-reported fueling behavior during training and racing may not accurately reflect total energy balance or individual's psychological and behavioral risk factors, reinforcing the need for fueling during exercise to be assessed alongside screening for risk of LEA, DE, and EXD. Although insufficiently fueling during training and racing was not associated with risk for LEA, DE, or EXD, body dissatisfaction, DE risk, and intentional weight manipulation were both associated with risk for LEA in this population of cyclists. This suggests that under fueling contributing to LEA risk may be occurring outside of designated training and racing windows, for example, through chronic caloric restriction driven by body image concerns or intentional weight control behaviors. This finding emphasizes the importance of both mental health support and RDN-led interventions or individualized fueling plans that address athletes' total daily energy needs, not strictly their fueling during exercise.

While this study offers valuable insights into the prevalence of LEA, DE, EXD, and fueling habits among recreational and competitive female cyclists, several limitations should be acknowledged. Firstly, the reliance on self-reported data via surveys introduces the potential for response

biases and inaccuracies, particularly regarding sensitive topics like fueling, DE, and EXD. In addition, while the LEAF-Q has been validated in elite endurance athletes and the DESA-6 is validated in adolescent athletes, these tools have yet to be validated specifically in female cyclists. Furthermore, the cross-sectional design provides only a small overview of LEA, DE, and EXD prevalence at a specific point in time, highlighting the necessity for longitudinal studies to solidify trends and changes over time. Although this study found no significant association between LEA risk and self-reported fueling sufficiency during training or racing, the sample size was likely underpowered to detect an effect of this magnitude. Therefore, this finding does not rule out a true association between within exercise fueling behavior and DE, LEA, and EXD risk. Despite these limitations, the study exhibits notable strengths, including the use of validated instruments such as LEAF-Q, DESA-6, and EDS-21, which ensure consistency and accuracy in assessing risk factors associated with LEA, DE, and EXD. In addition, its multifaceted approach, examining various factors such as fueling habits, training characteristics, and psychological variables, offers a comprehensive understanding of the complex interconnection between behaviors and outcomes among female cyclists who vary in goals (e.g., performance vs. general fitness). Finally, the study's realistic implications for coaches, sports dietitians, and healthcare professionals are significant, as identifying athletes at risk for LEA, DE, and EXD allows for tailored interventions to address their specific needs and promote overall health and performance.

This study reveals an association between risk of LEA, and weight dissatisfaction, disordered eating, and exercise dependence in both recreational and competitive cyclists. Nearly half the population of female cyclists were found to be at risk for LEA, which may be a result of inadequate energy consumption throughout the day, disordered eating behaviors, and/or excessive exercise. Notably, neither lower weekly training volume, self-reported cycling competition level, or meeting fueling habits during training and competition mitigated risk for LEA.

Furthermore, recreational athletes were less likely to consume adequate carbohydrates during exercise than competitive athletes, yet both groups have similar risk for LEA. This suggests that fueling outside of training and racing may play a bigger role in this population than in-exercise fueling alone. Competitive athletes may be less willing to sacrifice performance during training and races but may intentionally or unintentionally fail to maintain adequate energy availability throughout the rest of the day. Conversely, recreational athletes may benefit from optimization of both in-exercise and daily fueling practices. Even though sufficiently consuming adequate carbohydrates during exercise did not show a correlation with risk for LEA, many recreational and competitive cyclists did not meet fueling recommendations for endurance events lasting longer than 2.5 hours. Therefore, this is still an area that can be improved for all athletes and active females to maintain adequate energy levels on longer training or racing days.

To provide early intervention and support for athletes at risk for LEA, DE, and EXD, it is important that coaches, sports scientists, nutritionists, and mental health specialists collaborate. Practitioners and coaches who work with recreational athletes and active females should also do their best to screen for unhealthy behaviors and encourage proper carbohydrate ingestion during and outside of training and racing, irrespective of training load. Practitioners should always seek to use weight-inclusive and eating disorder-specific language when discussing nutrition and meal planning with athletes. In order for athletes to reach their potential, it is important that individuals in their training environment emphasize the promotion of a positive body image and appreciation for the strength and capabilities of the body independent of body weight, the development of a healthy relationship with food, and the reduction of stigma around getting support for mental health concerns.

Further investigation is required to examine the specific factors that increase LEA risk and to evaluate the effectiveness of prevention strategies. Managing the risk factors associated with LEA, DE, and EXD is critical to supporting female cyclists' health and performance, allowing them to reach their full athletic potential while prioritizing long-term well-being.

Acknowledgements

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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