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Original Research

Sleep, Dietary Patterns, and Energy Availability Status in Adolescent Female Artistic Gymnasts

Hannah K. Eberhardt*[1,2], Michael J. Ormsbee‡[2,3], Patrick G. Saracino‡[1]

[1]Department of Human Performance and Health, University of South Carolina Upstate, Spartanburg, SC, USA; [2]Department of Nutrition, Food and Exercise Sciences, Institute of Sports Sciences and Medicine, Florida State University, Tallahassee, FL, USA; [3]School of Health Sciences, Discipline of Biokinetics, Exercise and Leisure Sciences, University of KwaZulu-Natal, Durban, South Africa

*Student Investigator, ‡Established Investigator

Abstract

International Journal of Exercise Science 19(2): 2018, 2026. Low energy availability (LEA), which represents inadequate energy intake relative to exercise energy expenditure (EEE), is associated with adverse physiological and performance outcomes, yet limited data quantifying LEA prevalence in women's artistic gymnasts exists. This study assessed LEA prevalence in adolescent female artistic gymnasts and compared diet and sleep characteristics between those with and without LEA. Twelve female gymnasts (15 ± 1 y; 160.6 ± 5.5 cm; 55.8 ± 4.6 kg; 14.9 ± 6.4% body fat; 47.4 ± 4.3 kg FFM) completed body composition testing, questionnaires, and a three-day observation of activity and dietary patterns. Mean EA was 28.9 ± 13.5 kcal $\cdot$kg^{-1} FFM, with six athletes classified as having LEA (≤ 30 kcal $\cdot$kg^{-1} FFM). Compared with athletes without LEA, those with LEA consumed less calories (1451 ± 447 vs 2388 ± 458 kcal; $p = 0.005$), protein (0.8 ± 0.2 vs 1.5 ± 0.4 g $\cdot$kg^{-1}; $p = 0.007$), and carbohydrate (3.1 ± 0.8 vs 4.8 ± 0.8 g $\cdot$kg^{-1}; $p = 0.004$), while exercise energy expenditure did not differ. Athletes with LEA spent less time in bed (389.8 ± 55.7 vs 498.2 ± 35.2 min; $p = 0.002$) and had lower total sleep time (345.8 ± 57.2 vs 439.3 ± 32.8 min; $p = 0.006$), despite experiencing fewer awakenings (17 ± 6 vs 24 ± 4; $p = 0.035$). Most gymnasts experienced sleep impairments and failed to meet recommended intakes for protein and carbohydrate, underscoring the need for targeted nutritional interventions and education in this population.

Keywords: Adolescent Athlete, low energy availability, gymnastics, female physiology, musculoskeletal injury

Introduction

Low energy availability (LEA), the etiological factor of both the female athlete triad and Relative Energy Deficiency in Sport (REDs), occurs when energy intake (EI) remaining after exercise energy expenditure (EEE) is insufficient to support essential physiological functions.[1] Energy availability (EA) is calculated by subtracting EEE from EI relative to fat-free mass (FFM).[1] Therefore, a LEA state may occur as a result of insufficient EI, elevated EEE, or a combination of both.[1] In females, decrements in health and performance are commonly observed at an EA ≤ 30 kcal $\cdot$kg^{-1}, which has been established as the cutoff for LEA.[1,2] Acute LEA can disrupt endocrine and metabolic function within 4–5 days, while sustained LEA further contributes to menstrual

*Corresponding Author: Patrick G. Saracino; Email: Saracinp@uscupstate.edu

dysfunction, impaired bone health, reduced muscle protein synthesis, greater injury risk, immune suppression, and diminished cognitive and physical performance.[1–4]

High prevalences of LEA have been consistently reported across various sport and tactical populations.[5,6] However, limited data exist regarding LEA prevalence in adolescent athletes. Adolescence represents a critical period of growth and development characterized by rapid changes in body composition, hormonal milieu, and metabolic demands.[7] During this stage, energy needs must support both training and physiological maturation, potentially increasing susceptibility to energy deficits, and therefore LEA.[8] This risk may be further magnified in aesthetic sports such as gymnastics, where an emphasis is placed on maintaining a lean physique.[9] In a previous study, women's artistic gymnasts demonstrated the highest LEA risk among 19 NCAA Division I sports, with 76.5% classified as at risk based on the Low Energy Availability in Females Questionnaire (LEAF-Q).[10] Though given the differing energetic demands of physiological maturation in adolescent athletes, and that physical demands vary based on competitive level,[11] data in collegiate athletes may not translate to adolescents, further highlighting the need for research in this population.

In addition to energy availability, other lifestyle factors such as dietary habits and sleep play key roles in managing health and performance in athletes. Nutrient timing and distribution impact substrate availability, perceived exertion, and fatigue, while sufficient sleep is essential for recovery, endocrine regulation, and cognitive development.[7,12] The National Sleep Foundation recommends 8–10 hours of sleep per night for adolescents.[13] However, in a recent systematic review, 79% of adolescent athletes reported sleeping < 8 hrs per night.[14] Further, LEA may be associated with poorer sleep quality or quantity.[15] Yet little is known regarding sleep patterns among adolescent female gymnasts, particularly in relation to EA.

Limited data exist quantifying the prevalence of LEA in adolescent female artistic gymnasts. Furthermore, no studies to date have examined associations between sleep, dietary habits, and energy availability in this population. Understanding these relationships is essential for guiding nutritional education and recovery strategies tailored to adolescent athletes. Thus, the present study aimed to assess the prevalence of LEA among female adolescent artistic gymnasts and to examine sleep and dietary patterns in this population. It was hypothesized that LEA would be present in this population, with most gymnasts failing to meet recommendations for dietary intake and sleep.

Methods

Participants

This was an observational study consisting of one laboratory visit followed by three continuous days of assessing EI and EEE under free-living conditions. As the study was designed to assess EA status, dietary habits, and sleep patterns in female gymnasts under observational, free-living conditions, a control group was not included. Additionally, due to the observational nature of the present study, no α priori power analysis was performed. However, the final sample size is aligned with previous work examining LEA, dietary habits, and sleep in female athletes.[5,16] A convenience sample of 13 adolescent female artistic gymnasts from local gymnastics clubs participated in the study during their off-season in the Summer of 2024. One participant was excluded due to incomplete dietary records, resulting in a final sample size of 12 gymnasts (15.1 ± 0.9 yrs, 160.6 ± 5.5 cm, 55.8 ± 4.6 kg). Participant characteristics are presented in Table 1. To be included in the study, participants were 14-17 years old and competed in artistic gymnastics. Participants were excluded if they had a current musculoskeletal injury preventing participation in regular training. As all participants were under 18 years old, written and oral parental consent was provided, while minors provided assent. This study was approved by the Institutional Review Board (Pro00137254) and was therefore performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. This research was carried out fully in accordance with the ethical standards of the *International Journal of Exercise Science*.[17]

Protocol

Participants arrived at the laboratory in the morning following an overnight fast, having abstained from caffeine (12h) and strenuous exercise (24h). Pre-testing conditions were verbally confirmed with participants. After having a chance to void their bladder and bowel, participants were asked to remove their shoes, socks, and any jewelry. Height was then recorded to the nearest 0.1 cm (InBody BSM 270B, USA) and body mass was recorded via a calibrated scale (Bod Pod, Cosmed, USA). Next, wearing compression clothing and a swim cap, body composition was assessed via Air Displacement Plethysmography (Bod Pod, Cosmed, USA). As all participants were adolescents, the Lohman equation was used. Prior to all measurements, the Bod Pod was calibrated according to manufacturer instructions.

Following body composition assessment, participants completed the 25-item Low Energy Availability in Females Questionnaire (LEAF-Q; ICC = 0.79), which has been validated[18] in athletic females to assess LEA risk based on symptoms associated with LEA. A total score ≥ 8 indicates a high risk for LEA. Next, participants completed the 19-item Pittsburgh Sleep Quality Index (PSQI; ICC = 0.82) and the 18-item Athlete Sleep Behavior Questionnaire (ASBQ; ICC = 0.87), validated to assess sleep quality[19] and behavior,[20] respectively, in adolescents. A global score ≥ 5 on the PSQI indicates sleep disturbance. A total score of ≥ 42 on the ASBQ indicates impaired sleep behaviors.

EI was assessed over three consecutive days using the National Institutes of Health Automated Self-Administered 24-h Dietary Assessment Tool (ASA24), which provides visual cues to aid portion-size estimation. Participants were provided with private login credentials. A three-day observation period was chosen to maximize compliance,[21] and to align with previous literature on adolescent athletes.[22] Dietary intake was averaged across all three days and evaluated against the International Society of Sports Nutrition (ISSN) dietary recommendations for athletic populations.[12,23] During the same three-day period, EEE and sleep parameters were assessed via triaxial accelerometry (GT3X-BT, ActiGraph, USA), except for while bathing or other activities in which the accelerometer would be submerged in water. Participants were fitted with hip- and wrist-worn monitors on their non-dominant side. Two monitors were used as EEE measurements are more accurate with a hip-worn placement[24] while wrist-worn placements are more accurate for assessing sleep.[25] EEE was calculated from the hip-worn device using the Freedson VM3 Combination equation.[26] Sleep was scored from the wrist-worn device using the Sadeh algorithm,[27] which provided time in bed, total sleep time, wake after sleep onset (WASO), number of awakenings, average awakening time, and sleep efficiency data each night. The accelerometer data (30 Hz, 60 second epochs) was processed with ActiLife v6.13 software. To estimate energy balance, resting metabolic rate was estimated using the Cunningham equation.[28] Participants were required to complete all three days of food logs to be included in the final analysis. Due to the free-living nature of the study, participants were asked not to alter their normal behaviors (eating, activity, sleep, etc.).

EA was categorized as optimal (≥ 45 kcals$\cdot$kg^{-1} FFM), suboptimal (30-45 kcals$\cdot$kg^{-1} FFM), or clinically low (LEA; ≤ 30 kcals$\cdot$kg^{-1} FFM). EA was calculated using the following equation[1]:

$$\text{Energy Availability} = \frac{(\text{Energy Intake (kcal)} - \text{Exercise Energy Expenditure (kcal)})}{\text{Fat Free Mass (kg)}}$$

Statistical Analysis

All data were analyzed using SPSS (version 29) Statistics software package (IBM, USA). To address the primary aim of the present study, participant characteristics, EA status, dietary patterns, and sleep parameters are presented using descriptive statistics. As an exploratory analysis, two-tailed independent samples t-tests were used to detect differences between gymnasts with and without LEA. Normality was assessed using Shapiro-Wilk tests. If normality was violated, Mann-Whitney U tests were utilized. To better interpret group comparisons, Cohen's d effect sizes were used, with effect sizes defined as small ($0.2 < d < 0.5$), medium ($0.5 < d < 0.8$), and large ($d \geq 0.8$). Exploratory analyses were also performed using Pearson correlation coefficients to examine relationships between EA and body composition, dietary habits, EEE, and sleep. Correlations were defined as small ($r < 0.3$), moderate ($r = 0.3 – 0.5$), and strong ($r > 0.5$).[29] Linearity was assessed by visual inspection and normality was tested via Shapiro-Wilk test. If normality was violated, Spearman's correlations were utilized. Significance was set at $p < 0.05$. All data are presented as mean ± standard deviation.

Results

Participants

Participant characteristics are presented in Table 1. There were no differences between those with and without LEA for any anthropometric or body composition variable. Mean wear times for the hip- and wrist-worn monitors were 93.9% and 90.1%, respectively.

Table 1. Participant Characteristics.

Characteristic	Total (N = 12)	LEA (n = 6)	No LEA (n = 6)	p-value	Cohen's d
Age (yrs)	15.1 ± 0.9	15.0 ± 1.1	15.2 ± 0.8	0.765	0.18
Height (cm)	160.6 ± 5.5	157.7 ± 5.6	163.5 ± 4.0	0.067	1.19
Weight (kg)	55.8 ± 4.6	55.0 ± 5.8	56.7 ± 3.4	0.551	0.36
Body Fat %	14.9 ± 6.4	13.9 ± 6.7	16.0 ± 6.5	0.595	0.32
FFM (kg)	47.4 ± 4.3	47.3 ± 6.2	47.5 ± 1.2	0.958	0.03
FM (kg)	8.4 ± 3.9	7.7 ± 3.7	9.2 ± 4.3	0.509	0.40
BMI (kg/m^2)	21.7 ± 1.5	22.1 ± 1.5	21.2 ± 1.5	0.355	0.56

Data are presented as mean ± SD. FFM = fat-free mass; FM = fat mass; BMI = body mass index. There were no differences between athletes with or without LEA.

Energy Availability

Mean EA was 28.9 ± 13.5 kcals$\cdot$kg^{-1} FFM, with 6 of 12 (50%) gymnasts experiencing LEA, and an additional 5 (41.6%) in a suboptimal EA state. Mean energy balance was -206 ± 582 kcals$\cdot$d^{-1}, EI was 1920 ± 653 kcals$\cdot$d^{-1}, and EEE was 540 ± 131 kcals$\cdot$d^{-1}. Mean LEAF-Q scores were 7.3 ± 3.6, with 6 of 12 gymnasts at risk for LEA. However, only three gymnasts who presented in an LEA state scored ≥ 8 on the LEAF-Q. LEAF-Q responses indicated that one gymnast used oral contraceptives while the rest reported no contraceptive use. Nine gymnasts reported the age of menarche between 12-14 yrs, while three reported reaching menarche at 11 yrs or younger. Three gymnasts reported having one injury in the previous 12 months that prevented participation in normal training, while another five gymnasts reported having two injuries during the previous

12 months. Refer to Figure 1 for EA, EI, EEE, and energy balance information, and Table 2 for EA and energy balance parameters by EA status.

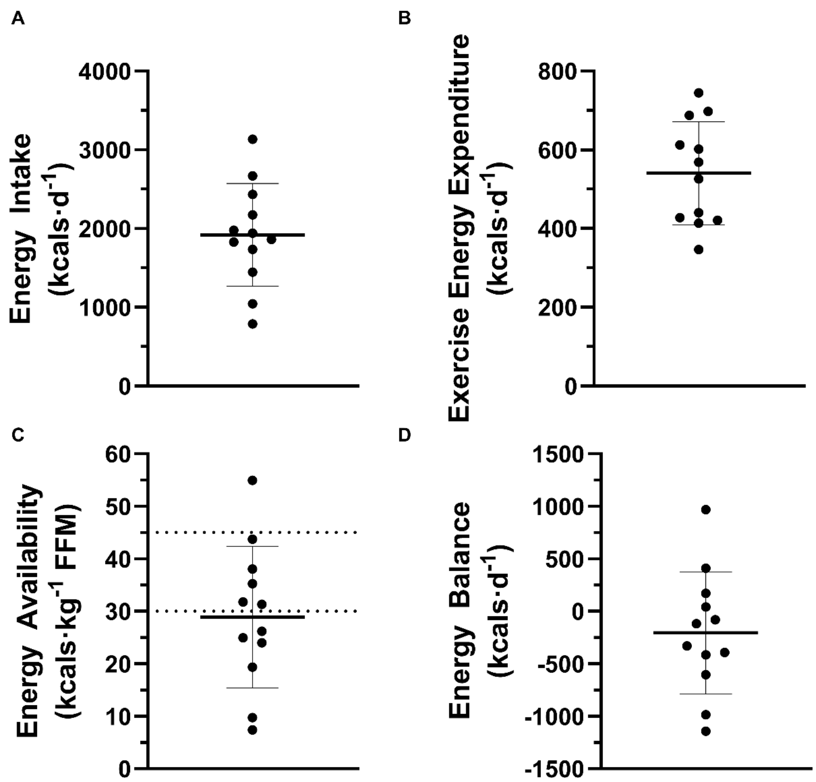

Figure 1. Energy intake (A), exercise energy expenditure (B), energy availability (C), and energy balance (D) in adolescent female artistic gymnasts. Data are presented as mean ± SD. Dashed lines represent optimal (≥ 45 kcals ·kg^{-1} FFM), suboptimal (30-45 kcals ·kg^{-1} FFM), and low (≤ 30 kcals ·kg^{-1} FFM) energy availability.

Table 2. Energy Availability, Energy Balance, and Macronutrient Intakes in Adolescent Female Artistic Gymnasts.

	Total (*N* = 12)	**LEA (*n* = 6)**	**No LEA (*n* = 6)**	***p*-value**	**Cohen's *d***
Energy availability (kcals ·kg^{-1} FFM)	28.9 ± 13.5	18.6 ± 8.1	39.2 ± 9.0**	0.002	2.40
Energy intake (kcals ·d^{-1})	1920 ± 653	1451 ± 447	2388 ± 458**	0.005	2.07
Relative energy intake (kcals ·kg ·d^{-1})	34.3 ± 11.7	26.2 ± 7.0	42.5 ± 9.7**	0.008	1.92
CHO intake (g ·d^{-1})	221 ± 64	173 ± 50	268 ± 35**	0.003	2.21
Relative CHO intake (g ·kg^{-1})	3.9 ± 1.1	3.1 ± 0.8	4.8 ± 0.8**	0.004	2.15
PRO intake (g ·d^{-1})	64 ± 27	45 ± 17	83 ± 22**	0.008	1.93
Relative PRO intake (g ·kg^{-1})	1.1 ± 0.5	0.8 ± 0.2	1.5 ± 0.4**	0.007	1.95
Fat intake (g ·d^{-1})	86 ± 38	65 ± 26	107 ± 39	0.054	1.26
Fat intake (% kcals)	39.7 ± 7.1	39.9 ± 7.2	39.4 ± 7.7	0.091	0.07
Predicted RMR (kcals ·d^{-1})	1394 ± 92	1392 ± 134	1395 ± 27	0.958	0.03
EEE (kcals ·d^{-1})	540 ± 131	559 ± 140	522 ± 132	0.655	0.27
TEF (kcals ·d^{-1})	192 ± 65	145 ± 45	239 ± 46**	0.005	2.07
Total energy expenditure (kcals ·d^{-1})	2126 ± 156	2147 ± 218	2104 ± 71	0.661	0.26
Energy Balance	-206 ± 582	-645 ± 342	232 ± 408**	0.002	2.33

Data are presented as mean ± SD. CHO = carbohydrate; PRO = protein; RMR = resting metabolic rate; EEE = exercise energy expenditure; TEF = thermic effect of food (estimated as 10% of energy intake). ** Indicates significant difference from LEA ($p < 0.01$).

Dietary Habits

On average, gymnasts consumed 34.3 ± 11.7 kcal ·kg^{-1}, with macronutrient intakes of 3.9 ± 1.1 g ·kg^{-1} CHO, 1.1 ± 0.5 g ·kg^{-1} PRO, and 39.7 ± 7.1% of total calories from fat. Relative to the ISSN recommendations, 8.3% met intake recommendations for CHO (5-8 g ·kg^{-1}), 33.3% met intake recommendations for PRO (1.4-2.0 g ·kg^{-1}), and 100% met or exceeded intake recommendations for fat (20-35% kcals). Those with LEA consumed significantly fewer calories (absolute and relative, $p < 0.05$), protein (absolute and relative; $p < 0.05$), and CHO (absolute and relative; $p < 0.05$) compared to those without. Fat intake was not different between those with and without LEA. Refer to Figure 2 for relative energy and macronutrient intakes and Table 2 for dietary intakes by EA status.

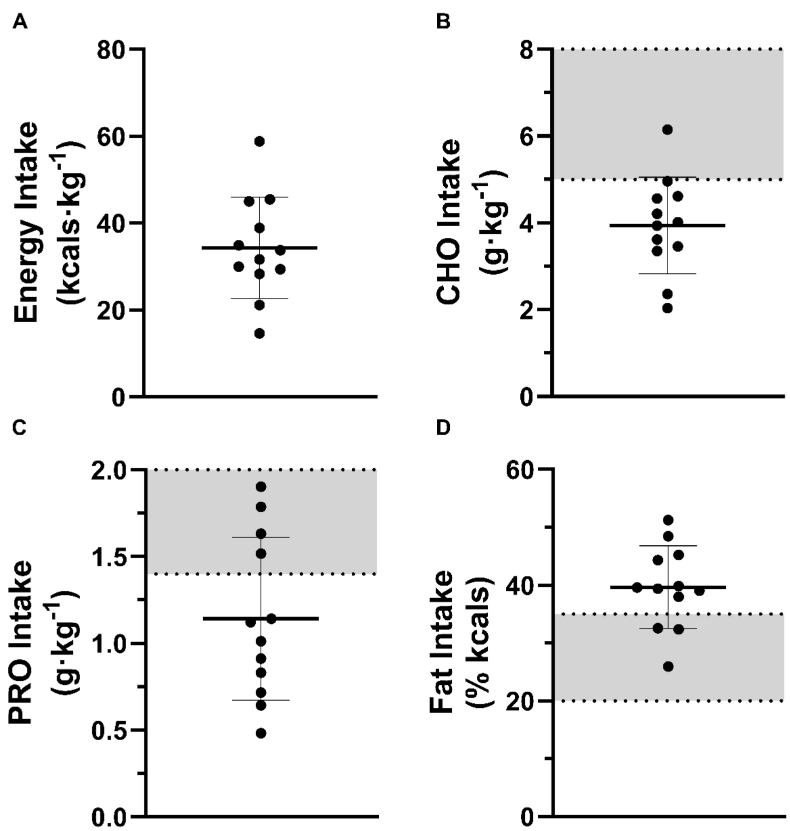

Figure 2. Relative energy and macronutrient intakes in adolescent female artistic gymnasts. Data are presented as mean ± SD. The shaded areas (B-D) represent the ISSN recommendations for carbohydrate (CHO, 5-8 g ·kg^{-1}), protein (PRO, 1.4-2.0 g ·kg^{-1}), and fat (20–35% kcals).

Meal consumption patterns are shown in Table 3. Of the possible opportunities to consume each meal, gymnasts skipped breakfast on 33.3% of occasions, lunch on 27.8% of occasions, and dinner on 22% of occasions. All gymnasts reported consuming a snack on at least one day. Nine gymnasts reported consuming ≥ 1 snack on all three days, while the other three reported consuming ≥ 1 snack on 2/3 days. There were no differences in the number of meals or snacks consumed between those with and without LEA. Calorie intake did not differ between meals or snacks. However, gymnasts with LEA consumed fewer calories at breakfast compared to those without (299 ± 99 vs. 597 ± 238 kcals; $p = 0.018$). There were no other differences in calories or macronutrient consumption between those with and without LEA.

Table 3. Meal Consumption Patterns in Adolescent Female Artistic Gymnasts.

Meal	**Reported**	**Kcals**
Breakfast (%)	66.7%	400 ± 185
Breakfast Skipped (%)	33.3%	
Lunch (%)	72.2%	574 ± 224
Lunch Skipped (%)	27.8%	
Dinner (%)	78.0%	713 ± 302
Dinner Skipped (%)	22.0%	
Snack (%)	91.7%	612 ± 277
Snack Skipped (%)	8.3%	

Data are presented as a percentage of all 36 possible eating opportunities.

Sleep

Mean total time in bed was 444 ± 72 min (7.4 ± 1.2 hrs), total sleep time was 393 ± 66 min (6.6 ± 1.1 hrs), WASO was 52 ± 15 min, number of awakenings was 20 ± 6, awakening time was 3 ± 1 min, and sleep efficiency was 88.1 ± 3.2%. Significant differences were observed where those with LEA had less total time in bed ($p = 0.002$) and total sleep time ($p = 0.006$), yet fewer awakenings ($p = 0.035$). Only one gymnast achieved the National Sleep Foundation's recommendation of 8-10 h of sleep for adolescents,[30] over the three-day observation window. PSQI scores were 5.3 ± 2.4, with 5 of 12 (41.6%) gymnasts experiencing poor sleep quality as indicated by a global score ≥ 5. ASBQ scores were 39.6 ± 6.3, with 4 of 12 gymnasts (33.3%) experiencing poor sleep behavior as indicated by a total score ≥ 42. No differences were observed in subjective sleep metrics between those with and without LEA. Refer to Table 4 for sleep metrics by EA status.

Table 4. Sleep Metrics in Adolescent Female Artistic Gymnasts.

	Total (N = 12)	**LEA (n = 6)**	**No LEA (n = 6)**	***p*-value**	**Cohen's *d***
Time in bed (min)	444 ± 72	390 ± 56	499 ± 35**	0.002	2.33
Total sleep time (min)	393 ± 66	346 ± 57	439 ± 33**	0.006	2.01
WASO (min)	52 ± 15	44 ± 14	59 ± 14	0.092	1.07
Awakenings (#)	20.3 ± 6.2	17 ± 6	24 ± 4*	0.035	1.41
Awakenings (min)	3 ± 1	3 ± 1	3 ± 1	0.821	0.13
Sleep efficiency (%)	88.1 ± 3.2	88.4 ± 3.8	87.8 ± 2.8	0.738	0.20

Data are presented as mean ± SD. * Indicates significant difference from LEA ($p < 0.05$). ** Indicates significant difference from LEA ($p < 0.01$).

Correlations

There were no significant relationships between EA and body composition variables or EEE for those with and without LEA. There was a strong, positive relationship between EA and absolute ($r = 0.979$; $p < 0.001$) and relative ($r = 0.957$; $p < 0.001$) EI, absolute ($r = 0.880$; $p < 0.001$) and relative ($r = 0.882$; $p < 0.001$) PRO intake, absolute ($r = 0.973$; $p < 0.001$) and relative ($r = 0.976$; $p < 0.001$) CHO intake, as well as absolute ($r = 0.875$; $p < 0.001$) fat intake. A strong, positive relationship between EA and time in bed (r = 0. 590; $p = 0.044$) and total sleep time ($r = 0.601$; $p = 0.039$) was observed. No other correlations were found between EA and any other sleep parameter.

Discussion

This observational study is, to our knowledge, the first to examine the associations between energy availability, dietary habits, and sleep in adolescent female artistic gymnasts. The primary findings were that 50% of participants presented in an LEA state, with all but one gymnast experiencing low or suboptimal EA. Consistent with our hypotheses, gymnasts with LEA consumed less total energy, carbohydrate, and protein and obtained less time in bed and total sleep time compared to those without LEA.

In the present study, mean EA was 28.9 ± 13.5 kcal $\cdot$kg^{-1} FFM, with 50% of participants classified as having LEA. To our knowledge, only one study exists quantifying EA in adolescent female artistic gymnasts. Grompanopoulou et al. recently assessed EA in adolescent male and female artistic gymnasts aged 11–14 years using self-reported dietary and activity records.[31] They reported a higher mean EA of 43.7 ± 11.4 kcal $\cdot$kg^{-1} FFM despite similar EI (1865 ± 295 kcal). However, their cohort also demonstrated lower EEE and FFM compared to the present study, which likely accounts for the discrepancy in EA values. Given that our sample comprised older adolescents (14–17 years), age-related differences in training volume, physiological demands, and maturation status may further explain the lower EA observed. Collectively, these findings highlight the importance of considering developmental stage and training load when comparing EA across gymnast populations.

Findings more consistent with the present study have been observed in other gymnastics disciplines. Besor et al. observed a higher LEA prevalence of 67% (mean EA: 27.0 ± 14.3 kcal $\cdot$kg^{-1} FFM) among adolescent female acrobatic gymnasts.[22] Interestingly, EI (1412 ± 445 kcals $\cdot$d^{-1}) was similar to that of the artistic gymnasts in the present investigation (1451 ± 445 kcals $\cdot$d^{-1}), whereas EEE was slightly higher in the acrobatic gymnasts (644 ± 148 vs 559 ± 140 kcals $\cdot$d^{-1}). However, in that study, EEE was assessed using a wrist-worn activity monitor, which has been shown to overestimate EEE,[32] potentially contributing to the lower mean EA. Silva and Paiva reported a higher average EA of 31.5 ± 11.9 kcal $\cdot$kg^{-1} FFM with a similar LEA prevalence of 44.8% in adolescent female rhythmic gymnasts.[6] To date, only one study has examined EA in collegiate artistic gymnastics, reporting an 85.7% LEA prevalence (mean EA: 30.5±4.5 kcal $\cdot$kg^{-1} FFM) among NCAA Division III male artistic gymnasts.[33] However, the use of 30 kcals $\cdot$kg^{-1} FFM as a cutoff for LEA in males is debated, as men may be able to withstand greater energy deficits before experiencing adverse outcomes.[1] Further, men's and women's artistic gymnastics comprise different events with distinct physical demands, likely resulting in differing EEE. Collectively, these comparisons suggest that EA among female artistic gymnasts is similar to that in other female gymnastics disciplines, underscoring the need for early identification and targeted intervention.

The LEAF-Q is a validated questionnaire for assessing the risk of LEA of female athletes based on LEA symptoms.[18] In the present study, the mean LEAF-Q score was 7.5 ± 4.6, with 50% of gymnasts scoring ≥ 8, the established threshold for LEA risk. Notably, concordance between LEAF-Q classification and EA status was limited. Of the six gymnasts who exceeded the LEAF-Q threshold, only half (3/6) had LEA, and the tool failed to identify three other athletes who were classified as having LEA. Of the other three gymnasts who scored ≥ 8, two presented with suboptimal EA and one with optimal EA. Several factors may explain these discrepancies. First, the absolute threshold of 30 kcals $\cdot$kg^{-1} FFM for defining LEA has been questioned due to individual variability in metabolic needs.[1] Alternatively, gymnasts with LEA who scored below the LEAF-Q threshold may have been experiencing "adaptable LEA," a short-term deficit associated with periods of intensified training or intentional restriction, with minimal physiological consequences.[1] Conversely, gymnasts who experienced many LEA symptoms but were not in an LEA state during the three-day observation window may have previously been in an energy-deficient state for an extended period, which could have led to adverse symptoms. Furthermore, the LEAF-Q was originally validated in endurance athletes and dancers rather than gymnasts, which may limit its applicability within this population, however it has since been used across various female athlete populations.[5,10,16]

In addition to its physiological consequences, LEA is also associated with poorer athletic outcomes, including an increased risk of injury.[1,34] In total, 66.7% of gymnasts reported ≥ 1 injury in the previous 12 months that prevented them from normal training. Of those scoring ≥ 8 on the LEAF-Q, 100% reported injuries, while only 33.3% of those scoring < 8 reported an injury. Of the two gymnasts who scored < 8 on the LEAF-Q and reported an injury, one had LEA, and the other had suboptimal EA. This pattern aligns with prior research linking LEA and LEA risk to bone stress and soft tissue injuries in endurance and military populations,[35,36] as well as findings that adolescent female athletes scoring ≥ 8 on the LEAF-Q were 3.41 times more likely to sustain an injury than those scoring < 8.[34] This may be explained by the proposed LEA load model, which posits that both the magnitude and duration of energy deficit cumulatively contribute to physiological dysfunction.[37] Although not yet validated, this model offers a potential explanation for why athletes with elevated symptoms or injuries, but suboptimal EA, may still experience greater health consequences.

In addition to energy availability, lifestyle factors such as diet composition and sleep play a critical role in athletes' health. In the present study, only 8.3% of gymnasts met CHO recommendations (5-8 $g \cdot kg^{-1}$),[12] a finding consistent with previous research demonstrating that many female athletes consume insufficient CHO,[5,16] which can impair both physical and cognitive performance.[1] Likewise, only 33.3% of gymnasts met PRO recommendations (1.4–2.0 $g \cdot kg^{-1}$),[23] with three gymnasts failing to meet the RDA of 0.8 $g \cdot kg^{-1}$. In contrast, all gymnasts met or exceeded the recommended fat intake (20–35% of total EI). Our findings partially agree with a study examining adolescent acrobatic gymnasts, in which fat intake was adequate, but CHO intake fell below recommendations.[22] However, that study reported a higher average protein intake (1.4 ± 0.7 $g \cdot kg^{-1}$) regardless of EA status. Similar patterns were observed in collegiate male artistic gymnasts, who demonstrated adequate PRO (1.6 ± 0.4 $g \cdot kg^{-1}$) and fat intake (67.1 ± 16.8 g) but suboptimal CHO intake (3.7 ± 1.1 g/kg).[33] Insufficient protein intake can impair muscle growth and recovery, and these effects are especially concerning in adolescent athletes who require protein to support both training demands and ongoing growth and development.[7] Therefore, targeted CHO and PRO supplementation may be an effective strategy to improve EA and overall macronutrient distribution in adolescent female gymnasts.

Despite sleep being an essential component of growth and recovery, a recent systematic review reported that 79% of adolescent athletes slept < 8 hrs per night.[14] It has been previously suggested that LEA is associated with poorer sleep quality or quantity.[1,15] In the present study, those with LEA slept significantly less than those without (346 ± 57 vs 439 ± 33 min, respectively); however, regardless of EA status, only one gymnast met the recommended 8-10 hours of sleep.[13] Further, those with LEA had fewer awakenings per night and less total time in bed, with no differences in any other sleep metrics. Other studies have reported differences in sleep between individuals with and without LEA. Greater WASO and reduced deep sleep have been reported in adolescent male rugby players with LEA, though greater average sleep times were observed in these athletes (7.95 hours) compared to the present study.[15] Torres-McGehee and colleagues reported worse subjective sleep quality, as determined by the PSQI, in athletic trainers with LEA.[38] In contrast, our previous work in female ROTC cadets observed no differences in sleep metrics between cadets with and without LEA.[5] Taken together, existing evidence suggests a possible link between

LEA and disrupted sleep, but the findings are limited and inconsistent, highlighting the need for further research to clarify how inadequate fueling may influence sleep, particularly in adolescent athletes.

The primary strength of this study is that it is the first to characterize the prevalence of LEA among adolescent female artistic gymnasts, a population with limited empirical data. Given the limited evidence base surrounding LEA in youth athletes, additional research is warranted, and the present study directly addresses this gap. Further, the free-living conditions used in the present study enhance ecological validity by providing a more accurate representation of habitual EA status, dietary behaviors, and sleep patterns. Moreover, this study extends existing work in women's artistic gymnastics by incorporating objective, wearable technology and dietary records to quantify EA,[10] rather than relying on self-reported symptoms associated with an LEA state, thereby enhancing methodological strength.

There are also limitations to the present study that must be addressed. Self-reported dietary intake is prone to misreporting, particularly in adolescents,[39] potentially affecting our results. Conversely, the accelerometers used in this study have been shown to overestimate EEE at lower exercise intensities and underestimate EEE during higher-intensity or sport-specific movements, potentially affecting the accuracy of our EEE estimates.[40] Participants were recruited from local gymnastics clubs, and given the niche population studied, our sample size was limited. As a result, exploratory comparisons between gymnasts with and without LEA may be underpowered and should be interpreted cautiously. Future studies should examine the relationships between EA, dietary intake, and sleep using larger samples or multi-site designs. While the three-day observation period aligns with previous studies,[22] it may not capture long-term EA patterns or seasonal variations in training load. Thus, future research should evaluate LEA prevalence across multiple training phases or competition periods to better characterize the fluctuating physiological demands experienced by adolescent female artistic gymnasts.

LEA and inadequate sleep are known to impair health and performance outcomes. In this study, many gymnasts presented with LEA, alongside low carbohydrate and protein intakes and insufficient sleep. These findings underscore the need for the interdisciplinary performance team to prioritize nutrition and sleep education in adolescent female gymnasts. Given that most gymnasts did not consume enough calories, primarily from PRO and CHO, they would likely benefit from supplementation to increase intake of those macronutrients. Providing these extra calories at breakfast may be beneficial, as gymnasts with LEA consumed significantly fewer calories at breakfast than those without, and breakfast was the most commonly skipped meal among all gymnasts. Future research should evaluate the effects of nutrition interventions, including CHO and PRO supplementation and nutrition and sleep education, on energy availability and sleep in adolescent gymnasts.

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