*Scoping Review*

# Role of Nutrition Education in Preventing Low Energy Availability Among Adolescent Female Athletes: A Scoping Review

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*Relative Energy Deficiency in Sport (REDs), a health-deteriorating syndrome caused by problematic low energy availability (LEA), is increasingly prevalent among adolescent athletes. LEA may stem from intentional and unintentional energy deficits, often linked to poor nutrition knowledge and practices, as well as body image concerns. Although nutrition education has been proposed as a strategy to prevent and manage LEA, evidence of its effectiveness in this vulnerable population remains inconclusive. This scoping review synthesized the existing literature on nutrition education interventions related to LEA in adolescent female athletes and identified gaps for future research and interventions. A systematic search was conducted across 4 databases (PubMed, Web of Science, Scopus, and EBSCOhost). Studies were included if they involved adolescent female athletes (mean age: 10–19 years) and had at least 1 intervention group receiving nutrition education covering either LEA, REDs, or Female Athlete Triad (Triad). Of the 7 eligible studies, education was mostly delivered face-to-face, combining interactive lectures and practical activities (n = 3). Nutritionists/dietitians were frequently involved in the development of educational materials and/or content delivery (n = 5). Limited use of digital technology and behavioral frameworks was observed. All studies reported immediate gains in both LEA/REDs/Triad knowledge and general sports nutrition following the interventions. Higher adherence (≥80%) and lower attrition were observed in shorter programs, face-to-face dietitian-led education, and those adopting a multicomponent approach, such as school-based integration. However, long-term impacts and LEA-specific outcomes, such as energy availability, were rarely evaluated. Finally, the considerable variation in the outcome measurements, intervention designs, and education delivery approaches restricted the ability to draw firm conclusions about overall effectiveness. Findings of this review highlight the need for more methodologically rigorous research to develop effective*





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***nutrition education programs that address the prevention and management of LEA in adolescent female athletes.***

***Key words: low energy availability, relative energy deficiency in sports, nutrition intervention, nutrition education, adolescent female athlete.***

## INTRODUCTION

Since the first introduction of the concept of Relative Energy Deficiency in Sport (REDs), a more comprehensive and gender-inclusive term than the Female Athlete Triad (Triad),[1] a growing body of research has highlighted its high prevalence and associated adverse health and performance effects.[2] Relative Energy Deficiency in Sport is a clinical syndrome characterized by impaired physiological functions and compromised athletic performance effects due to problematic low energy availability (LEA), a manifestation of a prolonged mismatch between energy intake (EI) and exercise energy expenditure (EEE) relative to fat-free mass (FFM), leaving the body with insufficient energy available (EA) to support its basic physiological functions.[2] Low energy availability can develop from intentional energy restriction driven by a desire to achieve a specific body weight and unintentional energy deficit as a byproduct of high EEE and inadequate dietary EI.[3,4] Low energy availability can lead to a continuum of health-related deterioration in various body systems, including metabolism, reproduction, and musculoskeletal, which may eventually compromise sports performance.[5,6]

The prevalence of LEA varies across genders and age groups and is often higher among the female population. Recent studies estimate the prevalence of LEA and REDs symptoms ranging from 23% to 79.5% in female athletes and 15% to 70% in male athletes.[2] Females appear to be more susceptible to low energy states than males, as even short-term exposure to low EA (<30 kcal/kg FFM/day) can disrupt endocrine and metabolic function, including hormones involved in menstrual regulation and bone formation.[7,8] Emerging evidence highlights a similarly concerning pattern among children and adolescents (aged 10–19 years),[9,10] with more than 50% of female and 30% of male adolescent athletes reported to be at risk of LEA or experiencing any symptoms of REDs.[11–13] These findings underscore the significance of addressing LEA in younger athletes, where the increasing prevalence of disordered eating/eating disorder and negative body image can further exacerbate their risk of developing LEA.[9,14] The concern of LEA among adolescent athletes is further heightened, given the negative impact on growth and development[10,15] and association with shortened sports careers.[16]

The International Olympic Committee (IOC) has proposed a tiered framework to prevent REDs, comprising primary, secondary, and tertiary strategies. While tertiary approaches primarily involve clinical interventions, primary and secondary strategies emphasize the prevention of LEA and early identification of REDs signs and symptoms.[17] These early strategies can help address commonly observed modifiable risk factors, including inadequate nutrition knowledge, maladaptive attitudes, and limited awareness of the potential consequences of LEA among young athletes and their coaches.[4,17] Previous research has documented gaps in understanding and applying general and sports-specific dietary guidelines and recommendations,[12,18–20] as well as recognizing signs and symptoms of LEA and REDs.[5,21–23] Accordingly, nutrition education programs have been designed and implemented for adult athletes to increase nutrition knowledge and awareness of LEA. These interventions often focused on personalized fueling strategies to optimize athletic performance, with few studies directly addressing LEA and REDs. Notably, both face-to-face and remote nutrition education delivered by clinicians with expertise in sports nutrition had similar favorable outcomes, with remote delivery preferred due to its flexibility in accommodating athletes' training and competition schedules. However, despite these promising findings, most studies have examined only short-term impacts, and evidence regarding the long-term effectiveness of such educational interventions remains limited.[24]

Recent reviews have called for more research on the effectiveness of nutrition interventions in adolescent athletes,[25,26] particularly those aimed at preventing or treating problematic LEA.[5,9] However, designing effective interventions for adolescents presents unique challenges. Adolescents are increasingly autonomous in their dietary choices and are influenced by social norms, environment, and peer-related factors.[27,28] Additionally, technology-based interventions may offer unique advantages, given that adolescents are digital natives and the increasing integration of digital tools in health promotion.[29,30] To optimize impact, it is essential to identify the most effective frequency, duration, and delivery methods of educational interventions tailored to this population,[31] especially in light of inconsistent and unsynthesized evidence. Therefore, this scoping review aimed to (1) synthesize the current evidence on the role of nutrition education interventions that covered at least 1 of the topics of LEA, REDs, and Triad among female adolescent athletes and (2) identify the methodological gaps to inform future research and practice in the prevention and management of LEA in this vulnerable population.

## METHODS

This scoping review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines and checklist.

### Search Strategy

The search strategy was developed based on the PCC (Population, Concept, Context) framework, targeting studies in adolescent female athletes (who reported a mean age of 10–19 years, as defined by the World Health Organization) across various sports disciplines and calibers, investigating the role of nutrition education covering topics including LEA, REDs and/or Triad in sports-related settings, such as sports clubs, training academies, and schools. A systematic literature search was then conducted in 4 electronic databases, including PubMed, Web of Science, Scopus, and EBSCOhost, on March 20, 2025. The search used Boolean operators (AND, OR), with the following combination of key words: "nutrition* intervention" OR "nutrition* education" OR diet* AND "energy availability" OR "relative energy deficiency in sports" OR "female athlete triad" OR "menstrual dysfunction" OR "menstrual irregularit*" OR "bone mineral density" AND athlete AND adolescent OR young OR student OR junior OR "high school." No date restrictions were applied. However, only studies published in English in peer-reviewed journals were included due to the global recognition of REDs. All included articles had to include nutrition education, which covered any of these topics: LEA, REDs, and Triad. Initially, the search yielded 1517 articles across all databases (see **Figure 1**). Additionally, a manual search of reference lists from retrieved articles was performed to identify any studies that may have been missed in the systematic search. All articles were then imported into EndNote (Clarivate Analytics, Philadelphia, USA) for deduplication. After removing 831 duplications, 690 articles remained for screening.

### Screening and Selection of Articles

A single reviewer (R.M.) initially screened titles and abstracts for relevance. Full-text articles were subsequently assessed for eligibility. Studies were included if they aligned with the population of interest and included at least 1 intervention group receiving nutrition education, which covered any of these topics: LEA, REDs, and Triad. We did not include interventions that involved only dietary supplementation or individualized counseling with personalized dietary plans, as these approaches differ substantially from group-based education in both delivery and participant engagement, limiting comparability. Both experimental and quasi-experimental studies were considered, including randomized controlled trials (RCTs) and non-RCTs, single-arm designs, and studies comparing different types of nutrition education. Exclusion criteria included incorrect study designs (eg, animal studies, observational studies, and any types of reviews), populations (eg, male-only), and formats (eg, theses/dissertations, book chapters, letters to editors, short communications, and conference abstracts). Following title and abstract screening, 25 articles were selected for full-text review. Of these, 7 articles were included in the present review.

### Collating Data and Reporting of Results

Data extraction was conducted by 1 author (R.M.) and reviewed by all authors. Extracted information included the following: (1) study details (author, year of publication, and country), (2) study design, (3) population and participants (eg, number of participants, age), (4) outcomes and key findings, (5) details of intervention (intervention types and duration), and (6) details of education (frequency, duration, topics, mode of delivery, and theoretical framework). If a study contained both male and female participants, only data from female participants were included (if available); otherwise, data for males and females were included. Data were collated and summarized in tables and reported descriptively. In RCTs, between-group differences in outcomes were extracted and reported to preserve the strength of the study design, while, in single-arm studies, time effects within groups were reported. Due to the varied outcome measures and reporting formats across studies, percentages of changes were self-calculated to facilitate comparison.

### Assessment of Quality and Risk of Bias

The included studies were critically appraised for methodological quality and risk of bias using the Joanna Briggs Institute (JBI) tools. The JBI Checklist for Randomized Controlled Trials was applied to studies using an RCT design,[32] while the JBI Checklist for Quasi-Experimental Studies was used to assess quasi-experimental designs.[33] Two reviewers assessed the quality of the included studies independently, with a final consensus reached through discussion for any disagreement between reviewers (see **Appendixes S1** and **S2**).

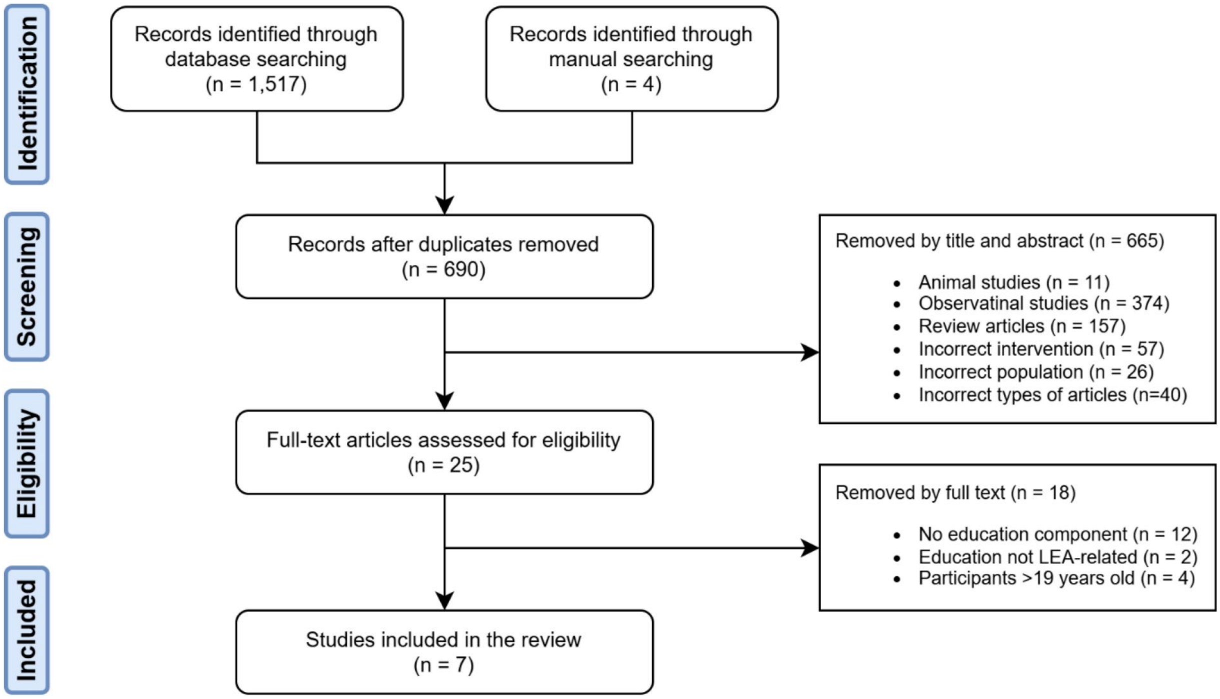


**Figure 1.** Flow Diagram of the Study Search and Selection

Abbreviation: LEA, low energy availability.

## RESULTS

### Characteristics of the Included Studies and Participants

A total of 7 studies were included in this scoping review. Baseline characteristics of the participants and study characteristics are provided in **Table 1**. Most of the studies were either controlled RCTs ($n=3$)[34–36] or single-arm studies ($n=3$),[37–39] while 1 study compared different modes of education.[40] Geographically, 4 studies were conducted in the United States,[35–37,40] and 1 study each was conducted in Australia,[38] Germany,[39] and Turkey.[34]

Collectively, the studies involved 695 adolescent athletes at baseline, of whom 655 were females. Four studies were conducted exclusively among female athletes,[34,35,37,40] while 3 studies involved both male and female athletes.[36,38,39] Due to inconsistent reporting, in particular the use of varying sample sizes across different outcome analyses in some studies,[38,40] a pooled attrition rate of all the included studies could not be calculated. However, postintervention attrition was reported or could be calculated in 6 studies, with rates ranging from 4.3%[35] to 40.8%[37] (mean: 18.6%). Attrition at follow-up was reported in only 2 studies, with rates ranging from 18.5%[39] to 36.8%.[36] Adherence to the education program was rarely reported, with only 2 studies documenting rates ranging from 80%[39] to 100%.[34]

### Assessment of Risks of LEA and Indicators of REDs at Baseline

Four studies reported participants' characteristics related to risks of LEA and REDs at baseline,[34,37,39,40] including screening for LEA ($n=2$)[34,39] and disordered eating/eating disorder ($n=3$)[34,39,40] and assessment of physical symptoms relevant to REDs diagnosis ($n=3$).[37,39,40] Baseline risk of LEA was assessed in 2 studies using the Low Energy Availability in Females Questionnaire (LEAF-Q) and the Dance-Specific Energy Availability Questionnaire (DEAQ). The average LEAF-Q scores indicated a high risk of LEA for participants in both intervention and control groups,[34] while the DEAQ classified 37% of female athletes as high risk.[39] Conversely, screening for eating disorder/disordered eating generally yielded low-risk scores,[34,39] although 1 study reported that 10.3% of the participants had a diagnosed eating disorder.[40] Menstrual-related REDs indicators were noted in 3 studies,[37,39,40] with primary amenorrhea affecting 4% to 32% and oligomenorrhea affecting 21% to 54%. Additionally, a history of secondary amenorrhea was reported in 23% of participants.[37] Injury-related indicators of REDs were also documented: 10.3% of participants had a history of bone stress injury[40] and 24% reported previous stress fractures.[37] However, low bone mineral density (BMD) appeared to be uncommon, with 1 study

**Table 1.** Characteristics and Main Findings of Included Studies ($n = 7$)

| Study (year), country | Study design | Population | Outcomes measured | Main findings |
|---|---|---|---|---|
| Doyle-Lucas and Davy (2011), USA[36] | Quasi-experimental study with control group | Pre-professional adolescent ballet dancers<br>Age (mean ± SEM): I, 15.4 ± 0.1 y; C, 15.4 ± 0.1 y<br>*n*: Baseline, 321 (I, 231; C, 90; F, 301; M, 20); postintervention, 221 (intervention group only); follow-up, 210 (I, 146; C, 64)<br>Attrition rate: postintervention, I, 4.3%; follow-up, I, 36.8%<br>Adherence, not reported | Pre- and postintervention (intervention group only): SNK (3 sections), self-developed validated questionnaire (SNKBQ); dietary intake, FFQ<br>Preintervention and 6-wk follow-up (intervention and control group): SNK (3 sections), SNKBQ, dietary intake, FFQ | Mean change postintervention from baseline[a,b] (within-group significance, $P < .05$ for all):<br>SNK score: overall, ↑ (40.7%); Female Athlete Triad, ↑ (15.6%); Healthy Habit, ↑ (15.5%)<br>Dietary intake: total fat, ↓ (-2.1%); total saturated fat, ↓ (-4.0%); percent fat ↓ (-2.0%); fried fast food, ↓ (-20.0%); candy, ↓ (-16.7%); water, ↑ (5.9%)<br>Mean change follow-up from baseline[a] (between-group significance, $P < .05$ for all):<br>SNK score: overall, I, ↑ (36.8%), C, ↑ (13.1%); Female Athlete Triad, I, ↑ (12.9%), C, ↑ (1.3%); Healthy Habit, I, ↑ (12.3%), C, ↑ (3.9%)<br>Dietary intake: candy, I, ↓ (33.3%), C, ↓ (11.1%); milk, I, ↑ (8%), C, ↓ (4%) |
| Krick et al (2019), USA[35] | RCT | Female high school endurance athletes<br>Age (mean ± SD): 15.9 ± 1.2 y<br>*n*: Baseline, 93; analysis, 89 (I, 46; C, 43)<br>Attrition rate, not reported<br>Adherence, not reported | Pre- and postintervention: Triad knowledge (7 true-or-false questions), modified questionnaire from a previous study by a different research group[67] | Mean change pre- and postintervention[a] (between-group significance):<br>Triad knowledge score, I: ↑ (148%, 2.5 ± 1.3 to 6.2 ± 1.2), C: ↔ ($P < .001$) |
| Tektunali Akman et al (2024), Turkey[34] | RCT | Female high school endurance athletes<br>Age (mean ± SD): 17.2 ± 2.0 y<br>*n*: Baseline, 100 (I, 50; C, 50); analysis, 83 (I, 45; C, 38)<br>Attrition rate, I, 10%; C, 24%<br>Adherence,100% | Pre- and postintervention: SNK (4 sections), SNKQ; risk of low EA, LEAF-Q; EA, calculation (EI –EEE/FFM); anthropometry and body composition (height, weight, BMI, total %BF, FM, FFM), stadiometer and BIA; dietary intake, 3-d food record; eating disorder, EAT-26 | Mean change pre- and postintervention[a] (between-group significance, $P < .05$ for all):<br>SNK score: I, ↑ (20.9%), C, ↓ (-0.7%)<br>Risk of LEA: I, ↓ (-20.4%), C, ↑ (36.2%)<br>BMI: I, ↑ (2%), C, ↓ (0.1%)<br>FM: I, ↑ (3.5%), C, ↓ (-4.9%)<br>EEE: I, ↑ (1.8%), C, ↓ (-0.7%)<br>EA: I, ↑ (33.7%), C, ↓ (-0.2%) |

(continued)

**Table 1.** Continued

| Study (year), country | Study design | Population | Outcomes measured | Main findings |
|---|---|---|---|---|
| | | | | EI: I, ↑ (17.6%), C, ↓ (-0.8%)<br>Protein intake: I, ↑ (20.0%), C, ↑ (1.4%)<br>Carbohydrate intake: I, ↑ (23.7%), C, ↑ (4.5%)<br>Fat intake: I, ↑ (8.2%), C, ↓ (-9.4%) |
| Brown et al (2016), USA[37] | Quasi-experimental, 1-arm study | Female high school track and field athletes<br>Age: median (range), 15 (14–18) y<br>*n*: Baseline, 49; analysis, 29<br>Attrition rate, 40.8%<br>Adherence, not available | Pre- and postintervention: SNK (Triad knowledge), modified questionnaire from a previous study by a different research group[67] | Mean change pre- and postintervention[a] (within-group significance):<br>SNK, Triad knowledge score: ↑ (4.7 ± 2.6 to 7.6 ± 1.7; 62.7%; $P < .0001$) |
| Meyer et al (2025), Germany[39] | Quasi-experimental, 1-arm study | Elite ballet students<br>Age (mean ± SD): F, 17.5 ± 1.05 y; M, 17.4 ± 0.31 y<br>*n*: Baseline, 27 (F, 19; M, 8); postintervention, 24 (F, 17; M, 7); follow-up, 22 (F, 14; M, 8)<br>Attrition rate: postintervention, 7.4%[c]; follow-up, 18.5%<br>Adherence, 80% | Pre- and postintervention: self-efficacy and knowledge (7 items), self-developed questionnaire; eating disorder attitudes, EDE-A; anthropometry and body composition (BMI, %BF, LBM), BIA<br>3-Mo follow up: eating disorder attitudes, EDE-A; anthropometry and body composition (BMI, %BF, LBM), BIA | Percentage of change pre- and postintervention[a] (within-group significance):<br>Height[d]: ↓ (0.7%, $P = .006$); weight, ↑ (1.3%, $P = .008$); BMI, ↑ (2.2%, $P = .011$); LBM, ↑ (1.4%, $P = .002$)<br>EDE-A score[b]: eating concern, ↓ (50%, $P = .039$)<br>Self-efficacy and knowledge[b]: confidence in choosing a healthy breakfast, ↑ (25%, $P = .001$); knowledge about recommended servings of calcium foods, ↑ (67%, $P < .001$); when you eat affects your dancing, ↑ (25%, $P = .033$); what you eat affects your dancing, ↑ (0%, $P < .001$); confidence in bringing a snack to the ballet school, ↑ (100%, $P < .001$); importance of nutrition education in professional ballet training, ↑ (20.0%, $P < .001$)<br>Percentage of change between baseline and |

(continued)

**Table 1.** Continued

| Study (year), country | Study design | Population | Outcomes measured | Main findings |
|---|---|---|---|---|
| | | | | follow-up[a] (within-group significance): Weight: ↑ (4.2%, $P = .001$); BMI, ↑ (4.3%, $P = .001$); LBM, ↑ (1.9%, $P = .012$) |
| Tan et al (2022), Australia[38] | Quasi-experimental, 1-arm study | Junior elite triathletes<br>Age (mean ± SD): 18.9 ± 1.6 y<br>*n*: Baseline, 21 (F, 9; M, 12)<br>Attrition rate, 33%<br>Adherence, not reported | SNK, modified SNKQ; dietary and food-group intakes, 4-d food diary | Mean change pre- and postintervention[a] (within-group significance):<br>SNK score (n = 14)[b]: total, ↑ (15.0%, $P < .001$); nutrients, ↑ (12.4%, $P = .010$); hydration, ↑ (19.0%, $P = .001$); training nutrition, ↑ (17.2%, $P = .001$)<br>Food-group intake ($n = 18$)[b]: fruit, ↑ (42.1%, $P < .05$); milk and alternatives, ↑ (25.0%, $P \leq .05$) |
| Roche et al (2024), USA[40] | RCT, 2-arm study comparing video-based (I) vs hand-out-based (C) education | Female high school track and field athletes<br>Age (mean ± SD): I, 15.7 ± 1.0 y; C, 16.0 ± 1.4 y<br>*n*: Baseline, 84 (I, 45; C, 39)<br>Attrition rate, I, 16%; C, 15%<br>Adherence, not available | Pre- and postintervention: SNK (5 sections), self-developed questionnaire | Mean change pre- and postintervention[a] (between-group significance): NS |

[a]Percentage of change was derived from dividing the mean change by preintervention measurements.
[b]Data are available for female and male participants combined.
[c]Due to dropping out of the university rather than dropping out of the program specifically.
[d]Decrease in height velocity was due to participant dropout rather than a physiological effect of the intervention.
Abbreviations: BIA, bioelectric impedance analysis; BF, body fat; BMI, body mass index; C, control; EA, energy availability; EAT-26, the 26-item Eating Attitude Test; EDE-A, Eating Disorder Examination—Adolescent; EEE, exercise energy expenditure; EI, energy intake; F, female; FFM, fat-free mass; FFQ, food-frequency questionnaire; FM, fat mass; I, intervention; LBM, lean body mass; LEAF-Q, Low Energy Availability in Females Questionnaire; M, male; NS, not significant; RCT, randomized controlled trial; SEM, standard error of the mean; SNK, sports nutrition knowledge; SNKBQ, Sports Nutrition Knowledge and Behavior Questionnaire; SNKQ, Sports Nutrition Knowledge Questionnaire; Triad, Female Athlete Triad; ↑, increase; ↓, decrease; ↔, no change.

reporting no history of reduced BMD among its participants.[40]

## Characteristics of Nutrition Intervention and Education

Among the 7 studies, 5 studies implemented nutrition education as the only intervention component,[34–37,40] while 2 studies combined education with individual counseling for an additional individualized approach.[38,39] The duration of the intervention programs varied, ranging from 1 session[35] to 1 academic year (9 months)[39] (mean duration: 67 days). Session frequency also varied, including more than once a week,[36,40] weekly,[34,38] every 2–3 weeks,[37] or monthly.[39] Face-to-face was the predominant method of delivery ($n = 3$), typically through interactive lectures or practical activities.[34,37,39] The remaining studies used either online-based lectures[38] or self-directed learning without facilitator involvement.[35,36,40] The duration of the face-to-face sessions ranged from 60 minutes[34] to a maximum of 90 minutes[39] (**Table 2**).

The education programs included LEA, REDs, or Triad at least in 1 of their education sessions/topics.[34–40]

**Table 2.** Characteristics of Nutrition Interventions Used in the Included Studies ($n = 7$)

| Study (year) | Intervention component, duration | Session frequency, duration | Education topics | Media | Delivery of education | Theoretical framework |
|---|---|---|---|---|---|---|
| Brown et al[37] (2016) | Nutrition education only, 3 mo | Every 3 wk, 4 sessions | 1. Energy availability<br>2. Menstrual dysfunction<br>3. Bone health<br>4. Body image | Printed workbook<br>Video clips | Face-to-face<br>Practical activities<br>Peer-led (athlete to athlete) | Not specified |
| Doyle-Lucas and Davy[36] (2011) | Nutrition education only, 3 d | Daily, 60 min | 1. "An Overview: Nutrition for professional dancers and the importance of healthy behaviours" covering Female Athlete Triad and associated health risks<br>2. "Nutrition Principles for Dancers" covering basic nutrition principles, macronutrients and micronutrients<br>3. "Eating for Optimal Health and Performance" covering the importance of adopting healthy behavioral habits, maintaining and monitoring hydration, eating for optimal health and performance | 10 to 20-min videos developed by registered dietitians<br>Handout<br>Worksheet | In-class<br>Session led by a researcher | HBM, SCT |
| Krick et al[35] (2019) | Nutrition education only, one-time intervention | One-time education | 1. Triad etiology and progression<br>2. Triad sharing personal stories by former athletes<br>3. Commentary from coach<br>4. Dietary strategies | 10-min video developed by dietitian/nutritionist | Individual learning | SCT |
| Meyer et al[39] (2025) | Nutrition education and counseling, 9 mo | $2 \times 90$-min workshops ($+1 \times 60$-min for females only), $4 \times 90$-min cooking classes, $2 \times 60$-min individual counseling | 1. Basic nutrition<br>2. Sports nutrition<br>3. Impact of LEA on menstrual function (females only)<br>4. Cooking class (tips for healthy meal and snack | Not specified | In-class workshop<br>Cooking class<br>In-person counseling | 5As |

(continued)

**Table 2.** Continued

| Study (year) | Intervention component, duration | Session frequency, duration | Education topics | Media | Delivery of education | Theoretical framework |
|---|---|---|---|---|---|---|
| | | | planning, shopping on a budget, basic cooking skills and meal preparation, safe food handling and storage)<br>5. Counseling (health history and nutrition screenings, personalized nutrition plans) | | | |
| Roche et al[40] (2024) | Nutrition education only, 1 wk | 5 modules to complete in 1 wk | 1. The Triad and REDs<br>2. Nutrition for health and performance<br>3. Building strong bones<br>4. Periods are powerful<br>5. Mental health and body image | 7–10-min video (developed by researchers and dietitian/nutritionist) or online pamphlets, readings, blogs | Individual learning | Not specified |
| Tan et al[38] (2022) | Nutrition education and counseling, 8 wk | 5 weekly education sessions + a 30-min individual counseling | 1. Training nutrition<br>2. Energy availability<br>3. Hydration<br>4. Macronutrient (energy, carbohydrate, protein, and fat) and micronutrient (iron and calcium) requirements<br>5. Supplements<br>6. Food safety<br>7. Travel nutrition | Virtual meeting using Microsoft teams, Version 4.9.12.0. Microsoft, Sydney, Australia (visual aids, online chats, quizzes), electronic materials | Remotely delivered by a dietitian/ nutritionist | Not specified |
| Tektunali Akman et al[34] (2024) | Nutrition education only, 6 wk | Weekly, 60 min | 1. Energy metabolism in sports<br>2. Energy balance<br>3. Nutrition before and after training<br>4. Low energy availability<br>5. Macro- and micronutrients<br>6. Hydration<br>7. Supplements | Printed booklet | In-class<br>Practical activities<br>Delivered by dietitian/ nutritionist | Not specified |

Abbreviations: HBM, health belief model; LEA, low energy availability; REDs, Relative Energy Deficiency in Sport; SCT, social cognitive theory; Triad, Female Athlete Triad; 5As, ask, assess, advise, agree, and assist.

Specifically, 2 studies had a topic on energy availability,[34,38] while the remaining studies focused on Triad.[35–37,39,40] In 5 studies, educational materials were developed and/or delivered by dietitians or nutritionists.[34–36,38,40] One study implemented peer-led education where coach-selected athletes were trained to deliver the educational materials developed by researchers,[37] and 1 study did not specify the facilitators of the education, which was incorporated into the school's academic curriculum.[39] Multimedia tools were used in 4 studies using videos ranging from short clips to a 20-minute video.[35–37,40] Printed materials, such as modules and workbooks, were commonly used during in-class sessions.[34,36,37] Two studies combined various media such as printed workbooks and videos.[36,37] The only study delivered entirely remotely used various features such as visual aids, chats, and quizzes.[38] Only 3 studies integrated behavioral change theories (BCTs) in their interventions—for instance, social cognitive theory (SCT),[35,36] the health belief model (HBM)[36], and 5As (ask, assess, advise, agree, and assist)[39] (**Table 2**).

## Outcomes Measurements

The majority of studies ($n = 5$) assessed outcomes immediately pre- and postintervention,[34,35,37,38,40] while 2 studies additionally conducted follow-up assessments at 6 weeks[36] and 3 months[39] postintervention to evaluate longer-term impacts. All studies measured change in knowledge, with a few studies additionally evaluating changes in self-efficacy,[39,40] risk of LEA,[34] dietary intakes,[34,36,38] anthropometry and body composition,[34,39] and eating attitudes[34,39] (**Table 1**).

## Sports Nutrition Knowledge

All studies assessed nutrition knowledge using either self-developed,[36,39,40] modified,[35,37,38] or previously validated questionnaires such as the Sports Nutrition Knowledge Questionnaire (SNKQ).[34] Four studies used questionnaires that specifically measured Triad knowledge.[35–37,40] while 3 studies evaluated sports nutrition knowledge across multiple subdomains, including basic sports nutrition, hydration, and supplementation.[34,38,39] Knowledge was mainly assessed at baseline and postintervention, with 1 study conducting additional follow-up measurements at 6 weeks postintervention.[36] While 4 studies reported outcomes exclusively for female athletes,[34,35,37,40] 3 studies presented combined results for both males and females.[36,38,39]

Following the intervention, all studies reported increased knowledge in sports nutrition[34,38,39] or Triad knowledge.[35–37,40] However, there was a wide variety in the formats used to report the results, such as mean scores at pre- and postintervention and percentages of correct answers. Among controlled RCT studies, 2 studies reported time-by-group interactions, with intervention groups showing increases of 20.9% (from 29.1 ± 8.6 to 35.2 ± 7.1 out of 78; $P < .05$) in sports nutrition knowledge[34] and 148% (from 2.5 ± 1.3 to 6.2 ± 1.2 out of 7; $P < .05$) in Triad knowledge,[35] while control groups showed no significant change (**Table 1**). Meanwhile, among the 2-arm study comparing different interventions, no time-by-group interaction was reported[40] (**Table 1**). Results from single-arm studies reported that overall knowledge scores increased by at least 15% ($P < .001$)[39] with the largest improvement observed as a 62.7% increase in Triad knowledge (4.7 ± 2.6 to 7.6 ± 1.79 out of 10; $P < .0001$) (**Table 1**).[37] Additionally, the only study conducting follow-up assessments reported that knowledge improvements from baseline were generally sustained at 6 weeks postintervention.[36] Analysis across multiple knowledge subdomains predominantly showed improvement, except for sections about eating behavior,[36] supplements,[38] mental health, and body image.[40]

## Dietary Intake

Dietary intake was assessed as macronutrient intakes using food diaries[38] and food records[34] as well as food-group consumption using a food-frequency questionnaire[36] at baseline and postintervention,[34,36,38] and at follow-up.[36] Time-by-group interactions were observed in energy (1739.7 ± 396.6 to 2046.1 ± 448 ± 447.9 kcal; $P < .05$), carbohydrate (184.3 ± 54.6 to 228.0 ± 57.0 g; $P < .05$), protein (70.6 ± 22.0 to 84.7 ± 22.5 g; $P < .05$), and fat (76.5 ± 33.6 to 82.8 ± 25.91 g; $P < .05$) intakes after 6 weekly face-to-face education sessions (**Table 1**).[34] No such improvement in macronutrient and micronutrient intake was noted in a single-arm study using a remotely delivered program (**Table 1**).[38]

In terms of food-group consumption, a single-arm study reported increased daily intakes of milk (servings/day) and fruits (servings/day)[38] (**Table 1**). A controlled RCT demonstrated longer-term effects, with significant time-by-group interactions at the 6-week follow-up, showing decreased intakes of candy/sweets, fast food, total fat, and saturated fat, and increased milk consumption (**Table 1**). However, these findings were based on combined data from both female and male athletes.[36]

## Energy Availability and Risk of LEA

Only 1 study investigated the effects of interventions on LEA-specific outcomes, including EA, calculated as (EI – EEE)/FFM and risk of LEA using the LEAF-Q. The EEE value was obtained using a 3-day activity log, while FFM was derived from bioelectrical impedance analysis (BIA).

Time-by-group interactions were reported for these outcomes, where intervention groups markedly increased their EA from 24.1 ± 10.7 kcal/kg FFM to 32.2 ± 12.1 kcal/kg FFM ($P = .01$) and reduced the LEAF-Q score from 8.5 ± 4.3 to 6.8 ± 3.7 ($P = .01$),[34] indicating a clinically meaningful change[2,41] (**Table 1**).

## Anthropometry and Body Composition

Two studies assessed changes in anthropometry and body composition using BIA and reported results for female participants, identifying both within-group[39] and between-group[34] differences. Significant time-by-group interactions were observed in body mass index (BMI) and fat mass, with the intervention group showing increases of approximately 2.0% and 3.5% from baseline, respectively ($P < .05$ for all; **Table 1**).[34] Additionally, findings from a single-arm study demonstrated short-term and long-term increases in BMI by 2.2% ($P = .011$) and 4.2% ($P = .001$), respectively.[39] Lean body mass also increased by 1.4% ($P = .002$) following the intervention and 1.9% ($P < .05$) at 3-month follow-up (**Table 1**).[39]

## Self-Efficacy and Eating Attitude

Self-efficacy was assessed in 3 studies using self-developed instruments. One study measured self-efficacy at pre- and postintervention,[39] while the other assessed it only postintervention.[40] Following video-based education, participants reported higher self-efficacy related to Triad/REDs knowledge compared with those receiving online handouts (3.7 vs 3.3 out of 5; $P \leq .05$).[40] Eating attitude was measured in 2 studies.[34,39] One study used the 26-item Eating Attitude Test (EAT-26) and found no significant time-by-group interaction.[34] In contrast, a single-arm study using the Eating Disorder Examination—Adolescent (EDE-A) questionnaire found a 50% reduction in the risk score for 1 subsection regarding "eating concern." However, the analysis did not differentiate between female and male participants (**Table 1**).[39]

## Use of Theoretical Frameworks in the Development of Interventions

Among the 3 studies that reported the application of theoretical frameworks, short- and long-term positive effects were observed.[35,36,39] The use of SCT in developing educational videos led to a time-by-group interaction in increased Triad knowledge immediately after the program.[35] Studies incorporating SCT and the HBM demonstrated sustained improvements in knowledge at 6-week follow-up.[36] In terms of dietary intake, a combination of SCT and HBM elicited a long-term increase in milk intake and a decrease in candy/sweets, fast food, total fat, and saturated fat intakes.[36] Last, the integration of the 5As theoretical framework to guide individual counseling led to short- and long-term improvements in BMI and lean body mass.[39]

## Assessment of Quality and Risk of Bias

The methodological quality of the included studies ($n = 7$) was independently assessed by 2 reviewers using the JBI critical appraisal tools (**Appendix S1**). Among the 3 RCTs,[34,35,40] both reviewers selected "yes" for true randomization, consistency of treatment and outcome measurement across groups, adequate attrition reporting, and appropriateness of trial design and statistical analyses. Allocation concealment was unclear, while blinding of participants and research personnel was absent in all RCTs. Given the nature of the educational intervention, blinding was not possible, which may have introduced bias related to intervention delivery and outcome assessment. Furthermore, none of the RCTs used intention-to-treat analysis, and significant baseline differences were identified in 2 studies, including differences in EI and EEE[34] as well as participants' racial characteristics.[40] In all quasi-experimental studies ($n = 4$), both reviewers rated the appropriateness of temporal precedence, consistency of outcome measurement, and statistical analyses as "yes." Three trials used a single-group design without a control group.[37–39] In the only trial that used a control group, baseline characteristics were comparable.[36] However, attrition was not adequately reported in 2 studies,[37,38] and 1 study used nonvalidated instruments to assess the primary outcome.[39]

# DISCUSSION

Prolonged LEA presents substantial risks to adolescent athletes, potentially impairing physiological functions and compromising growth and development.[9,10] Although several studies have developed nutrition education interventions to address LEA, their effectiveness remains inconclusive. This scoping review found consistent short-term improvements in LEA-related knowledge; however, variability in the intervention designs, delivery approaches, and measurement tools limited cross-study comparisons and the ability to establish overall effectiveness.

## Study Design and Population

Seven studies were included in this review, most of which used either controlled RCT ($n = 3$) or single-arm ($n = 3$) designs. The use of a single-arm design limited the ability to determine the effects of the interventions in the absence of a control group. This methodological choice may reflect ethical concerns about withholding potentially beneficial interventions, which could violate the principle of "do no harm."[42] To address this, 1 study adopted a comparative design, which was conventional vs technology-supported education (eg, audiovisual media), but found no significant differences in outcomes between the groups.[40] An alternative, ethical design could use a wait-list control group, in which participants in the control group receive the intervention after the study concludes, balancing ethical considerations with methodological rigor.[42]

The diverse instruments used to measure outcomes posed a major barrier to comparing and synthesizing the evidence of the effectiveness of the interventions. Knowledge was frequently assessed using either a self-developed questionnaire or modified tools with limited validation, while only a few studies used standardized tools such as the SNKQ. This variation resulted in inconsistencies in scales, scoring parameters, and reporting formats. Nevertheless, when reported as percentage changes from baseline, overall sports nutrition knowledge and Triad knowledge increased by at least 15.0%[38] and 15.6%,[36] respectively. Few studies extended their assessments beyond knowledge, and notably, only Tektunali Akman et al[34] reported increases in EI, BMI, and FM, which collectively led to clinically meaningful improvements in EA and shifted participants' LEA status from at-risk to not at-risk.

Follow-up evaluations were only occasionally conducted. These assessments are essential not only for evaluating the long-term impact of interventions but also for capturing delayed behavioral effects. For instance, a recent intervention addressing LEA in adult athletes demonstrated immediate gains in knowledge, whereas restorations in menstrual function and reductions in LEA risk emerged only at the 6- and 12-month follow-ups.[43] Given the limited number of studies assessing LEA-specific outcomes and longer-term effects, conclusions about intervention impact remain tentative.

## Alignment With the IOC's REDs Prevention Framework

Most included interventions aligned with the IOC's primary prevention strategies, aiming to avert LEA and physiological disturbances by improving athletes' knowledge before risk emerges.[17] All interventions primarily focused on enhancing sports nutrition literacy and understanding of LEA/Triad/REDs, with a few additionally targeting behavioral changes, such as dietary intake and eating behavior, suggesting an intention to encourage early lifestyle modification.[34,36,38,39]

However, elements of secondary prevention were also evident, particularly through baseline screening, which identified a notable proportion of participants already scoring high on LEA risk[34,39] and presenting with indicators of REDs, such as menstrual disturbances and a history of bone stress injuries or fractures.[37,39,40] Secondary REDs prevention focuses on early detection and targeted intervention among athletes already exhibiting early signs of REDs.[17] Consequently, 2 studies supplemented education with individual counseling to provide personalized support for athletes exhibiting REDs symptoms.[38,39] These findings reinforce the importance of routine screening to facilitate early management and to prevent progression to serious clinical outcomes.[17]

Furthermore, the presence of early symptoms may necessitate objective diagnosis using the IOC's REDs Clinical Assessment Tool 2 (CAT2) to guide effective secondary prevention.[44,45] This is particularly critical in female adolescents, as early indicators such as primary amenorrhea reflect LEA-driven pubertal delays, which can compromise peak bone mass development. Without intervention, these disruptions increase the lifelong risk of osteopenia, osteoporosis, and stress fractures,[46] alongside adverse cardiometabolic outcomes, such as impaired endothelial function.[47]

## Design and Delivery of Education Programs

All included studies had at least 1 education topic related to LEA/REDs/Triad,[34–40] which typically encompassed general information and consequences surrounding the issues, alongside nutrition guidelines and recommendations to prevent or alleviate their symptoms. However, discourse concerning the psychological aspects of this issue, such as body image and disordered eating, was notably lacking across the studies, despite the vulnerability of young athletes to developing these conditions.[48,49] This gap is particularly alarming given the critical role of psychological factors in exacerbating the risk of LEA and adversely affecting the health and performance of athletes across genders.[50] This is often mediated by an interplay of sports and societal pressures, body dissatisfaction, and the drive for leanness to escalate performance.[51–53] More importantly, the primary REDs prevention strategy emphasizes reducing the focus on body shape and leanness.[17] One of the reviewed studies that indicated an improvement in dietary intake and body composition demonstrated no reduction in eating disorder risk, potentially reflecting the inadequate attention to psychological components within its educational framework.[34] These findings highlight the necessity for future nutrition interventions to comprehensively address both the physiological and psychological consequences of LEA in adolescent athletes.

Intervention durations varied widely from a single session to a span of 9 months (mean: 67 days), with educational sessions conducted weekly, every 2–3 weeks, or monthly. These mostly brief durations suggest a primary focus of the interventions on knowledge acquisition rather than behavioral change. Previously, evidence from school-based, nonathletic demographics suggested that prolonged interventions (≥6 months) featuring weekly or biweekly sessions were more efficacious in improving eating behaviors and anthropometric outcomes.[54] However, in this review, a 6-week program involving 60-minute weekly sessions within a sports club environment improved a range of LEA-specific outcomes, such as EA, dietary intake, and body composition.[34] It is plausible that the structured and supportive nature of the sports environment may enhance intervention efficacy by fostering identity, self-esteem, and social connectedness,[19,55,56] potentially allowing for shorter durations to achieve behavioral modifications in adolescent athletes compared with their nonathletic peers. Moreover, shorter interventions appear to be more feasible. Among the reviewed studies, those with lower attrition featured shorter intervention duration[35,36] or school-based integration.[39]

The mode of delivery influenced engagement and intervention outcomes. The majority of studies used in-person sessions facilitated by nutrition professionals, while 4 other studies used self-directed learning, virtual education, and peer-led education, all of which produced comparable effects in elevating knowledge. Face-to-face education that included both didactic learning and practical activities, such as meal planning and cooking workshops, led to improved short- and long-term knowledge retention.[34,37,39] Age-appropriate, interactive methods (eg, role-play, peer-led discussions, games, and multimedia) were particularly effective for adolescents.[54] Self-directed and online education offered increased accessibility and participation, but intervention effectiveness was inadequately reported. Additionally, combinations of group-based and personalized approaches were observed in a few studies.[38,39] Remotely delivered education supplemented with individual dietary counseling facilitated by a sports dietitian over an 8-week period demonstrated increased knowledge and calcium intake from dairy products.[38] In another study, when education and counseling were delivered in-person over 9 months, short-term and long-term increments in body weight and BMI from increased lean body mass were reported among adolescent female athletes.[39] These findings highlight the importance of tailoring delivery modes to the target population and combining multiple strategies to optimize participant engagement and enhance the effectiveness of nutrition education interventions.

## Integration of Digital Technology, BCT, and a Multicomponent Approach

Despite the widespread integration of digital technology in nutrition interventions, its application in nutrition education targeting adolescent athletes was surprisingly underrepresented across the reviewed studies. Most interventions relied on printed materials combined with interactive lectures and practical activities,[34,37,39] or short videos, with athletes given limited access to these resources.[35–37,40] While age-appropriate strategies are essential for engagement and effectiveness, only 1 study incorporated digital tools, such as virtual meeting platforms, highlighting a notable gap in the integration of technology.[38] The effectiveness of this virtual education appeared to rely on the inclusion of multiple interactive features, such as live discussions, multimedia content, and real-time feedback mechanisms, to sustain engagement and support learning outcomes.[38] One form of digital technology that remained unexplored across studies was the use of social media, a ubiquitous and popular platform among adolescents, as an educational platform, despite its potential to elevate both reach and effectiveness in nutrition education.[57]

The integration of BCT was underutilized among the reviewed interventions, although integrating theories into the design of nutrition interventions is essential to ensure the sustainability of behavioral change beyond the intervention period.[58] Notably, 3 studies that reported modest but sustained enhancement in both knowledge and eating behaviors incorporated SCT,[35] 5As,[39] and a combination of the HBM and SCT.[36] The observed effects can be attributed to specific behavior change mechanisms. For instance, the 2 studies developing their educational content in the form of videos[35,36] leveraged SCT constructs by allowing individuals to learn through the experiences of other athletes featured in the videos (observational learning and modeling).[59] When HBM was combined with SCT,[36] motivation was further enhanced by shaping individuals' perceptions of risk, benefits, and barriers.[60] Finally, the study that used the 5As framework facilitated change through a structured approach of assessment, personalized advice, and collaborative goal-setting through individual counseling.[39,61]

However, only a couple of studies integrating BCT investigated longer-term outcomes,[36,39] limiting the understanding of sustainable changes in outcomes resulting from behaviorally informed interventions. To date, only a limited number of available BCTs have been utilized in sports nutrition research, primarily focusing on short-term dietary behavior changes.[62] Furthermore, combining BCT with digital tools (eg, online platforms, mobile applications, social media) into nutrition interventions has shown promise across various populations for enhancing engagement and effectiveness,[57,63] including improvements in menstrual function and risk of LEA among adult athletes.[43] These findings suggest the potential of adopting such integrated designs in future nutrition education efforts to prevent and manage LEA.

Finally, another pivotal, yet underexplored strategy in promoting sustained dietary behavior change in adolescents is the involvement of multicomponent stakeholders, such as caregivers and teachers or coaches.[54,64] One of the reviewed studies demonstrated that integrating nutrition education into the school curriculum led to lasting improvements in nutrition knowledge and several anthropometric measures, along with high participant engagement, despite the intervention spanning an entire academic year.[39] Moreover, the prevention and treatment of LEA and REDs require a multidisciplinary approach that extends beyond the nutrition professionals.[64] Parental involvement may help reinforce key messages in the home environment by encouraging discussions, particularly for adolescents who are gaining independence but are not yet fully capable of managing their nutritional needs.[65] Meanwhile, coaches need to be well informed and vigilant about LEA and REDs, enabling early identification and intervention, while also fostering an environment that de-emphasizes body image pressures. Therefore, trust-based coach–athlete relationships are necessary for supporting athlete health and well-being.[64] Such proactive involvement aligns with the IOC's REDs primary and secondary prevention strategy, which aims to prevent the development of LEA-related behavior and the progression of LEA toward more severe health and performance consequences.[17]

### Strengths, Limitations, and Future Directions

This review is the first, to our knowledge, to comprehensively map and synthesize evidence on nutrition education interventions related to LEA among adolescent populations. The review assessed both immediate and longer-term (up to 3 months postintervention) effects, as well as the integration of BCT, offering valuable insights into mechanisms supporting sustained behavior change.

However, some limitations must be noted. Study screening and data extraction were conducted by a single reviewer rather than independently by 2 reviewers, which may increase the potential for selection or extraction bias. This risk was mitigated by the use of predefined extraction forms to promote consistent data extraction across studies. The exclusion of non–English-language publications introduced potential language bias and might limit the generalizability of findings. Geographically, the evidence was primarily concentrated in high-income countries, and given that sociodemographic elements are vital for developing successful nutrition interventions,[66] the implications of this review might be confined to their relevance to populations in high-income countries. As this study focused on female athletes, future reviews should be conducted with studies on male athletes. Finally, due to substantial variety in study designs, outcomes, and instruments, pooled analysis was not feasible, limiting conclusions on overall effectiveness.

Future research should move beyond the Triad to more inclusively address LEA and REDs across genders. There is a particular need to incorporate psychological dimensions and expand research into underrepresented geographic and cultural contexts. Additionally, future work should prioritize treatment-focused interventions for individuals already at risk of LEA, assessing markers of LEA and REDs pre- and postintervention. Multidisciplinary approaches that engage parents and coaches are recommended to enhance intervention effectiveness. Methodologically, the use of wait-list control designs and standardized behavioural outcomes (eg, dietary intake, eating attitudes, and body composition) will improve comparability across studies. Incorporating BCTs and assessing both short- and long-term outcomes will be essential. Finally, further exploration of digital technologies and blended delivery models is warranted to identify effective strategies and intervention dosages for sustained dietary behavior change in adolescent athletes.

## CONCLUSION

This scoping review offers initial insights into the existing evidence on the effectiveness of nutrition education targeting LEA among adolescent female athletes. Overall, we found consistent immediate improvements in sports nutrition and LEA-related knowledge, despite the large variation in intervention designs and instruments used to measure outcomes. However, LEA-specific outcome assessments were limited, and several promising strategies for delivering robust interventions, including the incorporation of digital technology, BCT, and relevant stakeholders, remain underutilized in this population. These findings highlight the need for more rigorous research to develop effective nutrition education programs aiming to prevent and manage LEA and REDs in adolescent female athletes.

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### Supplementary Material

Supplementary Material is available at *Nutrition Reviews* online.

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## Conflicts of Interest

None declared.

## Data Availability

Data is available on request.

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