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Relative Energy Deficiency in Sport (RED-S): Scientific, Clinical, and Practical Implications for the Female Athlete

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Summary

Problem: If athletes develop low energy availability (LEA), it can lead to a Relative Energy Deficiency in Sport (RED-S) syndrome which has severe health consequences if not treated.

Methodology: A narrative review of the most recent and pertinent literature on the topic, with special emphasis on women.

Results: In assessing the current literature, we have synthesized: i) the scientific implications of LEA and RED-S, ii) the clinical manifestations of the conditions currently available for detection, as well as iii) the practical implications for healthcare and support for female athletes and teams in planning intervention or prevention strategies (maintaining EA >45 kcal/kg FFM/day).

Discussion: The 'Female Athlete Triad" emerged in the 1990s as researchers understood more of the etiological adaptation of female athlete health to sports training. In the last 10 years, the scientific community has recognized that the 'Triad' approach was too narrow in focus, and the broader concept of RED-S emerged. Both the Triad and RED-S are consequences of a frequently prevalent LEA in athletes (<30 kcal/kg FFM/day). Developing LEA and RED-S compromises training adaptation, performance capacity, and health in athletes. For these reasons, it is critical that an athlete's support team recognize the behaviors that may indicate RED-S evolution. In this way, we can assist female athletes in reaching their full potential in sports while protecting their health.

Zusammenfassung

Kommt es bei männlichen oder weiblichen Athleten zu einer dauerhaft niedrigen Energieverfügbarkeit (low energy availability, LEA), steigt das Risiko eines Relative Energy

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Conflict of Interest
The authors have no conflict of interest.

Deficiency in Sports (RED-S) Syndroms, welches unbehandelt schwerwiegende kurz- wie langfristige gesundheitliche Konsequenzen haben kann.

Ein narratives Review der aktuellsten und relevantesten Literatur mit besonderem Fokus auf weibliche Betroffene.

Aus der verfügbaren Literatur haben wir i) wissenschaftliche Implikationen von LEA und RED-S, ii) klinische Manifestationen und iii) praktische Implikationen für die medizinische Behandlung, Unterstützung betroffener Teams, sowie präventive Strategien herausgearbeitet.

In den 1990er Jahren erfasste mit zunehmendem Verständnis um die frauen-spezifischen Anpassungen an sportliche Aktivität das Phänomen der "Female Athlete Triad" die Aufmerksamkeit von Wissenschaftlern und Medizinern. In der vergangenen 10 Jahren zeigte sich, dass der "Triad"-Ansatz zu kurz greift und es wurde stattdessen das breiter gefasste Konzept des RED-S etabliert. Sowohl die "Female Athlete Triad", als auch RED-S sind letztendlich Konsequenzen der häufig prävalenten LEA in Athletinnen mit weitreichenden Konsequenzen auf die Trainingsadaptation, Wettkampfleistung und kurz-, wie langfristige Gesundheit der Betroffenen. Aus diesem Grund ist das Erkennen von Verhaltensweisen, welche auf ein RED-S hindeuten durch Trainer und weiterer Stakeholder einer Athletin beziehungsweise eines Teams essenziell für eine gesundheitsund leistungserhaltende Betreuung von betroffenen Athletinnen.

Keywords

Energy Availability; Stress; Performance; Hormones; Menstrual Health

SCHLÜSSELWÖRTER:

Energieverfügbarkeit; Stress; Leistung; Hormone; Menstruationsgesundheit

Introduction

Energy availability (EA) is a human nutritional concept defined as the difference between daily Energy Intake (EI) – Exercise Energy Expenditure (EEE) and expressed in relation to fat-free mass (FFM) (30). Inadequate EA in the sports-athletic context has been termed low energy availability (LEA). Chronic (weeks to months) and/or acutely severe (a few days with large energy deficits) LEA can lead to increased detrimental health outcomes in athletes and has been termed as the "Relative Energy Deficiency in Sport" syndrome (RED-S; defined by a 2014 International Olympic Committee Medical Commission) (38). Specifically, the RED-S condition arises when there is insufficient EI consumption to support daily EEE of an athlete resulting in the state of LEA, which leads to various physiological/psychological dysfunctions and these in turn can culminate in decrements in sports performance.

One sign of LEA in women can be menstrual irregularities, which reflects LEA facilitated changes in reproductive hormone production. These hormonal changes can in turn can lead to an anovulatory state (see Definitions, Table 1). The health concerns associated with longstanding LEA and RED-S, in general, include gastrointestinal, cardiovascular dysfunction, hypogonadotropic hypogonadism, psychological sequelae, and compromised bone health, all of which can contribute to impaired training adaptation in the athlete, increase the risk of injury or illness, and ultimately sports performance being compromised (16, 23, 40).

Regrettably while the concept of RED-S and its association with LEA has been articulated for nearly a decade, there are many athletes, coaches and health care providers who are unaware or have misconceptions about the syndrome (58). Awareness is increasing as more research is conducted on the topic (although much more is needed), and as this information is translated from scientists to the public at large; however, there continues to be a ‘information gap’ on the topic.

Therefore, this article was developed to help fill this gap and is structured as a narrative review; which intends to provide the sports practitioner, coach, and athletic medical team members with fundamental background knowledge and understanding concerning LEA and RED-S, specifically addressing health and performance implications. To this end, the article is organized into the following major sections; 1) low energy availability, 2) health implications of RED-S, 3) RED-S screening procedures, 4) prevention-treatment recommendations, and 5) practical applications. The information presented and discussed herein is based upon research study outcomes that are current, and involve evidence-based findings, focusing on women athlete as this group appears to have the most prevalence of RED-S (38).

In this article, the words ‘girl’ and ‘woman/women’ are used extensively. These terms are defined in reference to cis-gender females (girls being <18 years of age; women greater >18 years of age, but pre-menopausal). These interpretations are used due to the available research literature and are based on the self-identified gender identity. We are unaware of available research on the present topic that is more encompassing of ‘all females’ who engage in sport regardless of their gender identity or expression.

Definitions

The terminology used in the discussion of RED-S and LEA has been at times ambiguous. Therefore, the following key definitions of terms, based upon the work of Elliott-Sale et al. and McNulty et al. in several recently published papers, are presented (8, 9, 36) and appear in Table 1. It is important to note that all following definitions are only relevant to individuals not currently taking exogenous hormonal contraceptives [EHC; which includes oral contraceptive pills (OCP), implants, injections, intrauterine devices (IUD) /coils that are hormone-releasing, vaginal rings, and contraceptive transdermal patches]. This does, however, not include copper-based IUDs as they are not hormone-based.

Low Energy Availability (LEA): The Cause of RED-S

The underlying etiology of RED-S is LEA, which occurs when dietary intake is inadequate for an athlete’s level of physical activity. Energy availability (EA; Equation 1) as noted earlier is defined as energy from dietary intake minus exercise energy expenditure (30, 31).

$$\text{Energy availability (EA)} = \text{Energy Intake (EI; kcal)} - \text{Exercise Energy Expenditure (EEE; kcal/Fat} - \text{Free Mass [FFM; kg])} \quad \text{Equation 1}$$

N.B., 1 kcal=4.184 kJ

where exercise energy expenditure is calculated as the energy expended only during the exercise session, and the overall result is expressed relative to FFM, the body's most metabolically active tissue (30, 39).

Interestingly, evolving research suggests that the carbohydrate component of the EI can have a critical impact on the EA status of an athlete and suggest the consequences of LEA are not entirely driven by just caloric consumption (18, 35). However, additional evidence is warranted on this issue.

Obtaining a valid FFM measure provides the most accurate EA estimation. The use of body composition devices such as Dual Energy X-Ray Absorptiometry (DXA) or bioelectrical impedance analysis (BIA) can be utilized to measure FFM for EA calculations as well as to monitor body composition changes over time. If available, the DXA provides a more valid measurement, but BIA may be more accessible in many situations. However, BIA may underestimate FFM, especially in athletic populations, so greater caution should be taken when using BIA to measure FFM to determine EA estimates (2).

For athletes, EA is a more advantageous concept than energy balance, which is the difference between energy intake and total energy expenditure, this is due to the difficulties in measuring non-exercise energy expenditure in daily activities (30, 39). To this end, overall health, activities of daily living, and physiological processes are dependent on the amount of dietary energy remaining after exercise training is accounted for. In healthy adults, a value of 45 kcal/kg FFM/day provides sufficient energy (30).

When an athlete has LEA, there is insufficient energy to support the physiological functions necessary to maintain optimal health and performance. An EA <30 kcal/kg FFM/day for females, and EA <25 kcal/kg FFM/day for males have been proposed clinical thresholds for LEA, but an athlete can exptentenerience subclinical LEA even if they are above clinical levels yet below optimal levels of EA (37) (Figure 1). It is important to note that the available evidence for the threshold of LEA in men is extremely scant, and is an issue of debate. Furthermore, to date, no consensus has developed concerning LEA duration necessary for RED-S development and performance decline. Stellingwerff et al., however, has suggested; 1) short-term LEA=-days to ~1 month, 2) medium-term LEA=~1 to <3 months, and 3) Long-term LEA=>3 months (57).

Health care practitioners and coaches should take care to identify behavioral and psychological causes of LEA to prevent acute and long-term exposure. Acute LEA exposure can lead to metabolic and hormonal disruptions, which may lead to long-term LEA, resulting in severe metabolic and physiological adaptations to reduce the total energy available (i.e., as a resultant effect develop RED-S) (58). Low EA can occur resultant of a reduction in caloric intake, with or without an eating disorder, and/or an increase in daily exercise energy expenditure. Collectively, this underscores that health care providers

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and coaches need to understand and become knowledgeable about LEA/RED-S in order to properly take care of athletes (58).

Many athletes may be in unintentional periods of LEA during intense training periods, competitions, or in sports with high energy expenditure or involving weight restrictions. However, it is recommended athletes should keep their EA above 30 kcal/kg FFM/day, even if they trying to lose body weight or body fat. Clinical studies have exhibited negative health implications from LEA in as little as five days of <30 kcal/kg FFM/day (32, 37).

Disordered eating underpins many LEA cases often leading to severe chronic outcomes such as amenorrhea and osteoporosis. Disordered eating includes a range of irregular eating behaviors (such as restriction, binging, taking laxatives, etc.) that may not be severe enough to meet the criteria for eating disorders, such as anorexia nervosa, and bulimia nervosa; yet still lead to LEA (42). Weight-sensitive sports and sports with an emphasis on leanness have the highest prevalence of disordered eating and eating disorders (33). Additionally, disordered eating is more prevalent among athletes than non-athletes with a prevalence of 1–19% and 6–45% reported in male and female athletes, respectively (45), demonstrating the importance of this topic in the athletic community. Athletes may participate in disordered eating behaviors purposefully for reasons such as weight management, or unknowingly due to time constraints or lack of nutritional knowledge. Athletes tend to under-report disordered eating symptoms on questionnaires, yet symptoms like sudden weight changes, hair loss, irregular or missed menses, and stress fractures may be more recognizable as signs and symptoms (24).

Health Implications of RED-S

There are several acute and chronic health consequences related to RED-S, which encompass a myriad of physiological and psychological sequelae (Figure 2) and can further increase the risk of illness and injury. The effects of LEA on bone health have been extensively studied resulting in maladaptation (see the following references for an extensive discussion on the topic (3, 22, 55).

One of the most severe consequences of LEA in female athletes is menstrual dysfunction, which can manifest in its most severe form as amenorrhea (see Definitions, Table 1). As mentioned previously, primary amenorrhea is defined as no menarche by age 15, while secondary amenorrhea refers to an absence of at least three consecutive menstrual cycles post-menarche (12). Menstrual abnormalities are estimated to affect 20% of exercising females, with prevalence reported as high as 44% in ballet dancers and 51% in female endurance runners (12, 60, 61). While inadequate body fat stores, exercise stress, and abnormal hormone levels may contribute to menstrual dysfunction in athletes, LEA has demonstrated impairments in female reproductive function in both short-term and long-term exposures (32).

The effects of LEA on the hypothalamus and anterior pituitary have been well described with evidence demonstrating suppression of gonadotropin-releasing hormone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH), thereby suppressing endogenous estrogen and progesterone production; this is known as functional hypothalamic amenorrhea (FHA; 11) resulting in reproductive dysregulation. The long-term impact on fertility of FHA is currently unknown, but certainly has the potential to be consequential (32). Additional hormone changes associated with LEA, include a decrease in leptin which has been correlated with gonadal steroids (4), and an increase in ghrelin, which may suppress LH and FSH in women (26). Some of these hormonal alterations are also apparent in male athletes experiencing LEA. For example, studies observing LEA in male athletes have demonstrated decreases in leptin, insulin, 3–3’-5-triiodothyronine (T3), and testosterone levels resulting in a decrease in metabolic rate (26, 41). Although, these findings are not universally reported in the literature (29, 43).

In addition to female sex hormones, LEA alters levels of metabolic hormones and substrate utilization biomarkers such as such as insulin, cortisol, growth hormone, grehlin, leptin, fatty acids, ketones, and others (62). Similarly, FHA athletes demonstrated lower blood glucose during fasted and post-exercise conditions, indicating an impaired ability to sustain glucose homeostasis. Reductions in T3 as observed in athletes with LEA, negatively impact the ability of mitochondria to produce ATP from glycogen (64) also resulting in diminished regeneration of phosphocreatine (13). Elevated cortisol levels are a possible consequence of reduced availability of muscle glycogen, both of which have important implications for potential injury risk and, or performance (15). The suppression of endogenous estrogen and progesterone can also negatively impact cardiovascular health due to the impact of estrogen on vascular function (5, 44, 48). Menstrual cycle irregularities have been linked with an increased risk for cardiovascular disease and increased arterial thickness (21, 44, 46, 48). Though estrogen is a key component of flow-mediated dilation, endothelial dysfunction was observed in association with LEA, independent of diminished estrogen levels (21).

Performance and Injury Implications

The impact of LEA on athletic performance is complex and multifactorial. Many of the physiological sequelae resulting from extended periods of LEA contribute to a decrease in performance. Decrements in athletic performance are wide-ranging but can include increased susceptibility to injury and illness, impaired cardiovascular function, reduced neuromuscular capacities, and diminished adaptation to training (38, 39, 40). Reductions in athletic performance, often through downstream outcomes of dysfunction in physiological processes, may be more impactful for encouraging behavioral change in athletes with RED-S. Some athletes may be unable or unwilling to acknowledge the negative health consequences of LEA until their performance is negatively affected (27). Thus, understanding the impact of LEA on the maladaptive physiological and psychological processes of sports performance is imperative for sports practitioners.

LEA may be one of the strongest indicators of injury risk for athletes (17, 47, 59), with oligomenorrheic and FHA athletes reporting higher percentages of severe musculoskeletal injuries resulting in greater durations of time lost from sport (38, 39, 59, 61). Injuries and illnesses exert the biggest impact on training availability, with each week of modified training significantly reducing the chance of success for internationally competitive track and field athletes (47). Athlete availability for training has emerged as one of the strongest predictors of optimal performance at the highest level of sport, with a 7-time increase in the likelihood of achieving performance goals by athletes that completed more than 80% of planned training weeks (47). To this end, a reported 4.5 times increase in the prevalence of bone injuries in female and male athletes, with FHA and low testosterone respectively, resulted in a more than 4-fold increase in missed training time (23). Similarly, LEA was reported as the strongest predictor of illness in Olympic athletes before the 2016 Rio Olympic Games (6) with FHA athletes demonstrating higher frequencies of upper respiratory infection symptomology and suppressed immune function markers (52). The increased injury and illness likelihoods associated with LEA also impact acute physiological training responses, thus stifling long-term athlete development and competition availability. For example, Vanheest et al. (61) showed diminished adaptation to training was demonstrated in elite female swimmers over a 12-week training program, reporting an 8.2% increase and 9.8% decrease in time trial performance by adequate EA and LEA groups, respectively. Reductions in fat and lean body mass have also been observed in association with LEA (5, 6), suggesting the negative impact LEA has on muscular protein synthesis. Diminished body mass outcomes with reduced anabolic hormones and elevated cortisol levels represent the maladaptive responses to training resulting from effect lack of necessary energy to sustain training and performance demands (13, 14).

The psychological impact of RED-S can be both an outcome as well as an antecedent, providing a unique relationship of reciprocity between the cause and effect of LEA. With an increased prevalence of eating disorders in female endurance athletes, research on this population demonstrates the pervasiveness of negative psychological outcomes for athletes with RED-S. For some athletes, restrictive EI and excessive EEE behaviors manifest following adverse childhood or young adult experiences (27). The experience of this group when being asked to change eating and exercise habits to improve RED-S can induce severe anxiety, depression, and for some, suicidality thoughts (27). These results align with those found by Ackerman et al. (1), noting a 2.4 times increased likelihood of psychological disorders in athletes with LEA compared to those with adequate EA. Athletes with LEA demonstrated 2.4 times increased likelihood of psychological disorders, such as irritability, depression, impaired judgment, and decreased coordination and concentration (1). These factors can also contribute to an increased potential for injury. Similarly, survey and clinical testing of elite Australian female athletes reported an 80% prevalence of RED-S symptomology, 34% of whom met psychiatric disorder criteria, of which the most common condition was generalized anxiety (50). Some athletes may experience an acute increase in performance as a result of initial body weight loss at the onset of LEA (e.g., increased relative maximal oxygen uptake) (63). Although the elevated level of performance is ultimately unsustainable, some athletes attribute the acute increase in performance to excessive exercise and restrictive eating behaviors, causing a desire to pursue more rigid behaviors leading to long-term LEA (27). If psychopathologies are not considered and treated even after being classified as physiologically recovered from RED-S, the potential for an athlete to return to LEA-inducing behaviors is much greater (37, 38).

RED-S Screening Procedures

Early detection of athletes at risk for LEA is imperative to prevent and diagnose RED-S. Screening for RED-S should start with a detailed, guided personal history, including questions regarding physical activity, past, and current injuries, eating and diet behaviors, and menstrual cycle history (40). Ideally, clinicians and coaching staff will screen all athletes before the start of the season of play to have a historical record of the athletes' answers. Traditionally, the Pre-Participation Physical Evaluation developed by the American Medical Society for Sports Medicine and the American College of Sports Medicine has been utilized to identify disordered eating behaviors (23, 24). However, other validated questionnaires to identify LEA associated with disordered eating and eating disorders can be valuable. For a more comprehensive review of LEA screening tools see Knapp et al. (28) and Sim and Burns (53). The majority of these questionnaires were developed prior to the 2014 IOC consensus statement entitled "Beyond the Female Athlete Triad: Relative Energy Deficiency in Sport (RED-S)", which expands significantly on the Female Athlete Triad etiology and consequences (38). In turn, currently, the best approach to identify RED-S is through the "Relative Energy Deficiency in Sport (RED-S) Clinical Assessment Tool (CAT)" (40); although even this tool (comprised of questions plus a check list of symptoms) is limited and currently in the process of being revised.

The RED-S CAT is a clinical assessment tool used for the evaluation of athletes or active individuals who are suspected of having LEA and acts as a guide for clinicians and coaches for return-to-play decisions (40). Screening for RED-S is often undertaken as part of an annual Periodic Health Examination, as well as when an athlete presents with disordered eating/eating disorders, weight loss, lack of normal growth and development, endocrine dysfunction, recurrent injuries, and illnesses, decreased performance/performance variability as well as mood changes (40). However, the diagnosis of RED-S is a medical diagnosis that needs to be made by a trained health care professional. RED-S-associated diagnostic factors may include: chronic dietary restriction and/or extreme diets, drive for thinness, substantial changes in body weight or composition in short periods, training inconsistencies, prolonged fatigue, decreased libido, oligomenorrhea, two or more career bone stress injuries, and low bone mineral density for age (Z-score <-1.0) (22, 38, 39). Management of RED-S and return-to-play decisions should be made by a multidisciplinary team of sports professionals using the appropriate models as guides.

In the RED-S CAT, the three steps are to evaluate health status, evaluate participation in sports risk, and decision modifications (Table 2) (40). When identifying risk for sports participation, high-risk factors (within the CAT form this is deemed a red light [for stop] indicator relative to training) include anorexia nervosa and other serious eating disorders (which are medical conditions related to LEA), the use of extreme weight loss techniques, or electrocardiography abnormality. The use of a treatment contract in high-risk athletes is important. The treatment contract focuses on the use of a multidisciplinary team and specifies requirements the athlete must follow during treatment for eventual return to training and/or competition. High-risk athletes should not continue or start sports participation to receive necessary treatment and move towards recovery. Moderate risk factors (yellow light [caution] indicator) include low percent body fat, substantial weight loss, prolonged and/or severe LEA, delayed (no menarche by 15 years) or abnormal menstrual cycles/amenorrhea, reduced bone mineral density with or without stress fractures, and/or disordered eating contributing to LEA (40). Moderate-risk athletes can be cleared for sports participation and training as long as a treatment plan is followed, and medical supervision is provided. Low-risk factors (green light [go] indicator) include an appropriate physique that is managed without undue stress or unhealthy diet/exercise strategies and healthy eating with appropriate EA. Furthermore, maintaining a healthy endocrine function, musculoskeletal system, and bone density are vital. Low-risk athletes can proceed with full participation in sports (40).

The RED-S CAT is intended to be a tool that translates the science behind RED-S into practical formats that are applicable in 'real world' situations to ensure athlete care is both evidence-based and effective (40). Sports medicine clinicians and coaching staff can use RED-S 'Red Light – Yellow Light – Green Light' Risk Assessment and Return to Play models to assist with medical actions and care management of athletes. These models were developed to take a complex clinical matter and make a functional model with the flexibility to allow clinicians in the field the ability to adapt the model to their particular athlete situation. The RED-S CAT was developed to be applicable to both male and female athletes, except for the two points regarding the menstrual cycle. One limitation of the RED-S CAT is the lack of a standardized assessment for LEA via eating/exercise habits (40). It is recommended that the models are integrated into performance nutrition education approaches to encourage athletes to obtain optimal EA. Additionally, the use of clinical markers such as body composition and bone density from DXA, electrocardiogram, and hormone values should be part of a yearly physical assessment to provide longitudinal data and monitor risk assessment. Yet access to some of the clinical markers may be limited. Therefore, practitioners should utilize the applicable RED-CAT sections, but may also need to evaluate and monitor for other signs and symptoms.

Prevention - Treatment Recommendations

The physician should monitor individual athletes during 'periodic health examinations, which can aid in identifying symptoms of overtraining syndrome and athletes' risk of RED-S. The physician's primary role is to diagnose RED-S and use the RED-S CAT to guide athletes to return to play as quickly as possible without causing undue risk of further injury or illness (5, 19). Additionally, physicians should evaluate the athlete's medical conditions, treat, and rehabilitate the athlete as part of an interdisciplinary team, and monitor the safe return of the athlete to play. Furthermore, physicians should advocate for the incorporation of RED-S educational programs in sports governing bodies nationally and internationally, as well as promote positive guideline changes in at-risk sports.

The role of a registered dietitian includes screening for/addressing eating disorders and disordered eating in athletes, as well as managing EA. The sports team dietitian should be involved in the interdisciplinary outpatient care for athletes with eating disorders. More severe eating disorder cases may need work with dietitians in intensive outpatient, residential, or hospitalization settings (19, 20). To aid in the prevention of LEA, dietitians should formulate performance nutrition education approaches to engage and encourage athletes to obtain optimal EA. Working with athletes one-on-one to promote the necessary micro-, and macronutrient consumption, the timing of food/meals, supplement choices, and establishing positive dietary habits is also imperative (49). Dietitians should advocate for the use of clinical measures such as DXA or BIA for body composition assessments to determine FFM more accurately for EA in athletes and to monitor changes in percent body fat, lean mass, and bone mineral density over time.

Additional healthcare providers may also serve as ancillary support to physicians and dietitians in the prevention and treatment of RED-S. Sports physiotherapists (athletic trainers in the USA) have such roles due to their frequent and near-daily interactions with athletes. Coaches and physiologists working with athletes also have responsibilities to be vigilant for behaviors and symptomology of RED-S and be in communication with the healthcare providers.

Practical Applications

Navigating the treatment process with an athlete in RED-S provides unique and potentially sensitive challenges in the pursuit of optimal EA and safe and appropriate training and sports participation. As a guide for this process, the authors propose the implementation of a High-Performance Model (HPM; 60), highlighting the value of an HPM's human development-centered priority. Characterized by its most integral outcome of holistic long-term development of athlete well-being and performance, a long-sighted and individualized approach is ideal. Within the HPM, the promotion of best practices through scientific management principles and outlining of a team's purpose, culture, values, and training philosophies to ensure an interdisciplinary team of practitioners ideally suit the unique demands of returning athletes with RED-S to optimal performance.

Long-term individualized approach. Individualized treatment contracts with the multidisciplinary team should be constructed and discussed to outline the care strategy for the athlete (as noted prior).

Scientific management principles for best practices. The employment of objective outcomes is critical for athlete success in cases of RED-S. Scientific management allows for evidence-based evaluation processes and treatment plans to be determined via statistical support, rather than individual opinion, prior traditions, or pre-existing beliefs (54). Data-informed decision-making allows for clear expectations and universal accountability, fostering trust and transparency between athletes and all practitioners.

Interdisciplinary team. Strong group identity and structured communication are associated with improved team performance (51). The functional diversity of sports performance team members aiding in RED-S athlete return to play should be maximized, as the distribution of practitioner experience over many functional domains is positively associated with information sharing and unified team performance (51). Sharing of knowledge through open communication and feedback allows for greater integration and collaboration, highlighting the progression of multidisciplinary practitioners to an interdisciplinary team (51).

Conclusions

It has been nearly 50 years since the identification of ‘athletic amenorrhea’ in the 1970s, which evolved into the ‘Female Athlete Triad” in the 1990s as researchers understood more of the etiological changes in female athlete health to sports training. In the last 10 years, the scientific community has recognized that the ‘Triad’ approach to examining this issue was too narrow in focus, hence the recognition of the broader concept of RED-S.

Currently, it is apparent that RED-S is a consequence of LEA in athletes, and the occurrence of LEA is far more prevalent than perhaps had been suspected. The consequences and developing LEA and RED-S compromises training adaptations, performance capacity, and many facets of health in athletes, particularly amongst females. Relative to the latter, bone health consequences can take months to years for full recovery once an intervention is implemented. This can curtail an athlete’s career and livelihood. These consequences indicate prevention has to be a paramount approach for all individuals working with athletes. An athlete’s support team must recognize the behaviors and actions that increase the risk of LEA development and the symptomology of RED-S evolution. In this way, we can allow athletes to reach their full potential in sport and assure their health during competition and beyond.

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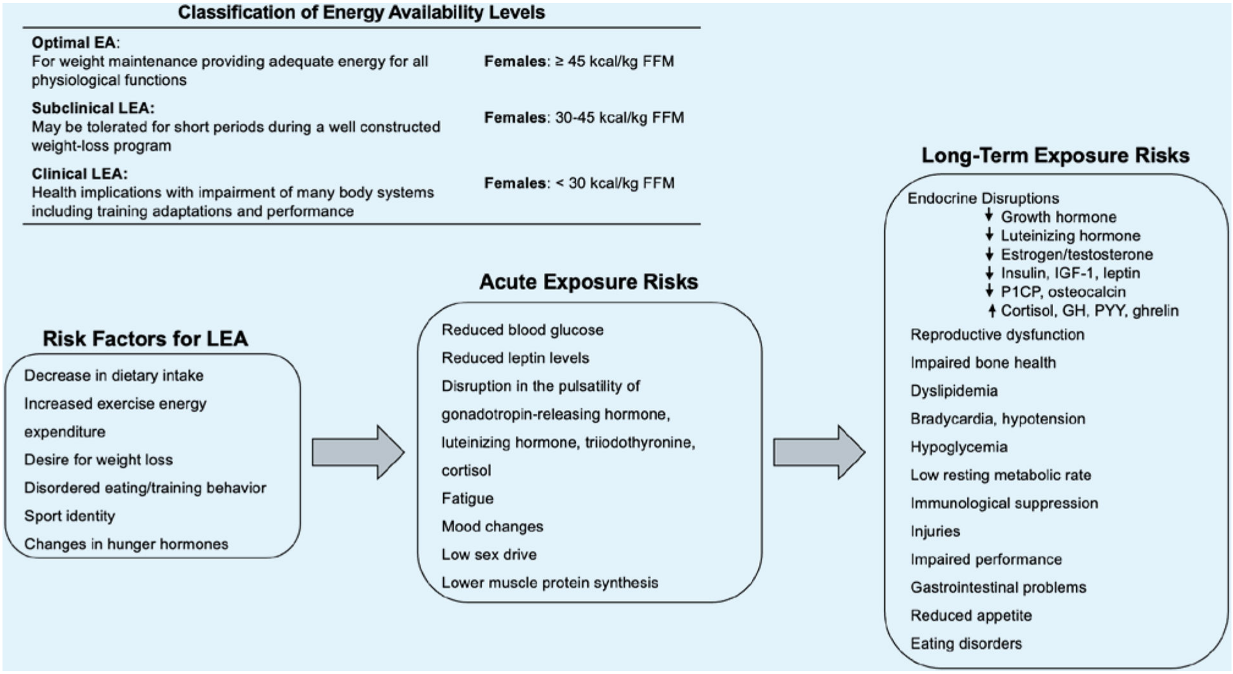

Figure 1.

Classification of energy availability levels and risk factors of LEA. The figure illustrates examples of psychological and behavioral causes of LEA and the potential acute and long-term risks associated with LEA as described in the literature (31). GnRH=gonadotropin-releasing hormone; LEA=low energy availability; LH=luteinizing hormone; T3=triiodothyronine; IGF-1=insulin-like growth factor 1; P1CP=carboxy-terminal propeptide of Type I procollagen in serum; GH=growth hormone; PYY=peptide YY; GLP-1=glucagon-like peptide-1.

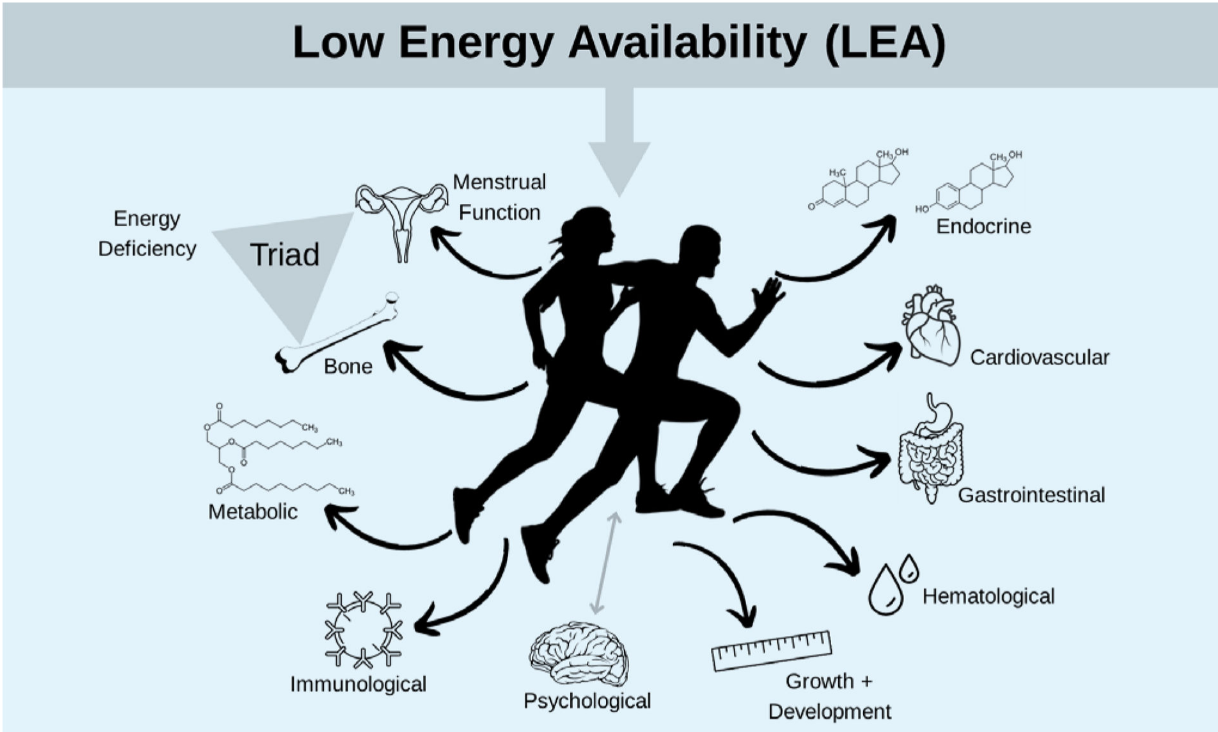

Figure 2.
A summary of the physiological effects of low energy availability (LEA).

Table 1

Operation definition for key terminology associated with female reproductive physiology.

TERM	DEFINITION
Anovulatory Cycle	Women who experience uterine bleeding but have not ovulated (ovulation cannot be detected by urinary LH surge or has not been confirmed by hormone concentrations via blood sample analysis).
Eumenorrhea	Women who experience menstrual cycle lengths ≥ 21 days and ≤ 35 days, resulting in 9 or more consecutive periods per year, plus recent evidence of a LH surge, correct hormonal profile, and no EHC use in the past 3 months.
Normal Menstruating	Women who experience menstruation, with menstrual cycle lengths ≥ 21 days and ≤ 35 days, but without confirmed ovulation (i.e., ovulation has not been confirmed by urinary LH surge or verified by hormone concentrations via blood sample analysis).
Oligomenorrhea	Women who experience fewer than 9 menstrual cycles per year or menstrual cycle length that is > 35 days.
Ovulatory Cycle	Women who experience menstrual bleeding with a confirmed urinary LH surge which indicates ovulation has occurred.
Polymenorrhea	Women who experience menstrual cycle length that is < 21 days on a regular basis.
Primary amenorrhea	Failure of a girl to reach menarche by age 15 years when the development of secondary sexual characteristics is evident, or by age 14 years when no secondary sexual characteristics are present.
Secondary amenorrhea	The absence of ≥ 3 consecutive menstrual periods in a non-pregnant woman who has a past normal menses history.

LH=luteinizing hormone; EHC=exogenous hormonal contraception.

Table 2

RED-S risk assessment decision making steps for determining readiness to play.

STEPS	RISK MODIFIERS	CRITERIA	RED-S SPECIFIC CRITERIA
STEP 1			
		Patient Demographics	Age, Sex
		Symptoms	Recurrent dieting, menstrual health, bone health
		Medical History	Weight loss/fluctuations, weakness
Evaluation of Health Status	Medical Factors	Sings Diagnostic Test	Hormones, electrolytes, electrocardiogram, DXA
		Psychological Health	Depression, anxiety, disordered eating/eating disorder
		Potential Seriousness	Abnormal hormonal and metabolic function
			Cardiac arrhythmia
			Stress fracture
STEP 2			
		Type of Sport	Weightsensitive, leanness sport
Evaluation of Participation Risk	Sport Risk Modifiers	Position Played	Individual vs. team sport
		Competitive Level	Elite vs. recreational
STEP 3			
		Timing and Season	In/out of season, travel, environmental factors
		Pressure from Athlete	Mental readiness to compete
Decision Modification	Decision Modifiers	External Pressure	Coach, team owner, athlete family, sponsor support
		Conflict of Interest	If restricted from competition
		Fear of Litigation	

DXA=Dual x-ray absorptiometry.