Prevalence of low energy availability and burnout syndrome in female athletes

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Running title: LEA and burnout in female athletes

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Abstract

BACKGROUND: Optimal athletic performance requires balancing training with adequate recovery and energy intake. Failure to do this can result in low energy availability (LEA). This study investigated the prevalence of LEA and burnout syndrome in an athletic population and explored potential relationships between these conditions.

METHODS: In this cross-sectional study, online surveys including two validated questionnaires (LEAF-Q and ABQ) and questions relating to LEA risk factors were distributed via email and social media. 139 females (39 ± 13 years, 1.67 ± 0.11 m, 68.0 ± 17.8 kg, 24.4 ± 6.4 BMI) completed the survey. Participants were categorised as either at risk or not at risk of LEA based on their LEAF-Q scores.

RESULTS: 89 female athletes (64%) were categorised as at risk of LEA. There was no significant relationship between LEAF-Q and ABQ scores, nor significant difference between athletes categorised as at risk and not at risk of LEA in sleep, dietary habits, perceived pressure to perform, and training history.

CONCLUSIONS: Risk of LEA was widespread in this heterogeneous female athletic population. There were no relationships between LEA and burnout, suggesting that despite overlapping symptoms, pathways are independent, or these questionnaires measure different parameters. Understanding the distinction between burnout and LEA is critical, and properly diagnosing the specific condition is key to effective management. This will ensure that interventions are appropriately tailored to address the correct issues, thereby optimising recovery and performance.

Keywords: low energy availability, LEA, burnout, LEAF-Q, ABQ

Introduction

Optimal training adaptation and peak performance requires a healthy body and an effective training programme that balances appropriate training with adequate recovery and energy intake. Energy availability refers to the dietary energy remaining for optimum function of body systems after accounting for the energy expended from exercise. Low energy availability (LEA) occurs when there is insufficient energy to support these functions, leading losses in lean mass, performance impairment, and deterioration of health[1]. The threshold commonly used to define LEA is below 30 kcal/kg fat-free mass per day, although this may vary in male athletes and children[2]. Athletes, particularly those in endurance or aesthetic sports, are at greater risk of LEA due to high energy expenditures and the pressures of weight management and body image[3].

Training volume is a well-recognised predictor of endurance performance[4], therefore endurance athletes often implement periods of increased training workloads, often without concurrent increase in energy intake[5]. While short and/or managed periods of LEA are not detrimental and can enhance performance[6], extended durations can have negative effects on health and performance. The prevalence of LEA/REDs varies significantly across sports, ranging from 23% to 80% in female athletes, with the highest risk observed in endurance athletes[3]. These prevalences are affected by a variety of factors, with highest values usually seen in elite or professional athletes[7,8], and in younger age-groups (<25 years)[9,10]. Prolonged periods of LEA can lead to the development of Relative Energy Deficiency in Sport (REDs), which affects both male and female athletes[3]. This encompasses various symptoms, such as hormonal and metabolic dysfunctions, compromised bone health, and psychological disturbances, some of which could be confused with symptoms of burnout[11].

Burnout syndrome of athletes (BSA) is a psychological condition caused by chronic stress and insufficient recovery, leading to feelings of exhaustion, reduced accomplishment, and a diminished sense of sporting identity[12]. Individual-sport athletes and those involved in elite-level competitions are at increased risk of burnout, with higher rates observed in endurance sports[13]. BSA can develop over varying timeframes, often correlating with prolonged periods of physical stress and inadequate recovery[14,15].

Although LEA and BSA are distinct conditions, they share common symptoms such as fatigue, reduced performance, and psychological disturbances. This overlap can complicate their diagnosis and management, especially as it is unclear whether these conditions occur simultaneously. While much research has focused on the physical health impacts of LEA, little is known about how it interacts with psychological stressors like burnout. This study aims to bridge the gap in understanding by investigating the prevalence and potential interactions between LEA and BSA in a general female athletic population, providing insights into whether these conditions coexist independently or if they have overlapping pathways that influence athlete health and performance. By exploring these interactions, this research addresses a critical gap in current literature and offers novel insights that could significantly impact athlete health and performance management strategies. We hypothesise that female athletes with LEA will experience symptoms of BSA.

Materials and Methods

Participants

Female athletes aged 18 and over from sports clubs, athlete forums, and University performance centres who engaged in regular physical activity, recreationally or competitively, were invited to participate in the study. A sample size calculation was not performed given the primarily descriptive and exploratory nature of this study. A total of 139 female athletes (39 ± 13 years, 1.67 ± 0.11 m, 68.0 ± 17.8 kg, BMI 24.4 ± 6.4) participated in the study. The study was approved on behalf of the University of Essex Ethics Sub-Committee 2 by the School of Sport, Rehabilitation, and Exercise Sciences Ethics Officer (ETH2122-1137) and was conducted in accordance with the principles set forth in the Helsinki Declaration. All participants gave informed, written consent prior to completing the survey and confirmed that they had no underlying health conditions.

Study design

A cross-sectional, observational study utilising two validated questionnaires (LEAF-Q and the ABQ) and supplementary questions was conducted. Surveys were completed anonymously using online software (Qualtrics, Provo, UT). Surveys were distributed via emails sent to clubs/coaches and through social media platforms between January 2022 and July 2022. Participant information sheets and consent forms were built into the surveys, and surveys took approximately 20-30 minutes to complete.

Questionnaires

The 25-item LEAF-Q was developed to identify athletes at risk of LEA by utilising subsets of gastrointestinal symptoms, injury frequency and menstrual dysfunction. Female athletes were categorised as at risk of LEA when scores were $\geq$8 (16% of total marks available)[16]. The internal consistency of the LEAF-Q was confirmed with a Cronbach's alpha of 0.75, 0.79 and 0.61 for gastrointestinal symptoms, injury frequency and menstrual dysfunction respectively, and test-retest reliability showed stability over a 2-week interval (ICC = 0.79)[16].

The 15-item Athlete Burnout Questionnaire (ABQ) consists of three subscales: reduced sense of accomplishment (RA) (e.g., "I am not performing up to my ability in my sport."), emotional/physical exhaustion (E) (e.g., "I feel so tired from my training that I have trouble finding energy to do other things and devaluation (D) (e.g., "I am not enthusiastic about my sport practices or competitions" and was scored according to a five-point Likert scale ranging from one (almost never) to five (almost always). ABQ was scored by taking a mean of the mean score from each three subsections of the ABQ. Scores near or above three on all three subscales were categorised as high risk of BSA. The ABQ has demonstrated strong reliability with Cronbach's alpha values greater than 0.86[17], and its utility as a valid and reliable measure of athlete burnout has been confirmed by several studies[18,19]. Athletes were asked to categorise their trained status as recreational (train for fun and not competition), trained/developmental (committed to regular training with goals that include competitions), highly-trained/national (compete in national age-group teams), elite/international (compete as a professional or for national elite teams), or world-class (compete in top international competitions including World Championships and Olympics). Additional questions were included to assess typical behaviours, sleep patterns, frequency of breakfast consumption, injury history, fuelling, food restriction and pressures to train and perform. All measures were self-reported and questions were designed to explore potential contributing factors and effects of LEA[3].

Statistical analysis

Data were manually checked for erroneous or missing data, and incomplete surveys were removed. The mean (±SD) values for the dependent variables (LEAF-Q and ABQ) were calculated for each sub-section as well as the total score. The distribution of normality was assessed for each dependant variable using the Shapiro-Wilk test. In instances where the distribution of normality was violated, a non-parametric approach was taken.

Participants were dichotomously categorised into at risk of LEA 'LEA' and not at risk of LEA 'EA' groups as determined by LEAF-Q score, and by possible perimenopausal status (<35 years – not perimenopausal, ≥35 years – possibly perimenopausal[20]. Differences between athletes at risk of LEA and not at risk of LEA for variables were analysed for the whole group and by perimenopausal status using Mann-Whitney U tests. Effect sizes were reported using Cliff's delta (0.15 = small, 0.33 = medium, 0.47 = large) due to the non-parametric nature of these data[21].

Plausible associations between LEAF-Q score and ABQ, sleep, illness, dietary habits, and external pressure were determined by assessing Spearman's-rank correlations. Spearman's-rank correlation coefficient (r_s) was used to measure the strength and direction of association between variables. Chi-squared test of independence (X^2) was used to assess associations between frequencies of supplementary dichotomous questions. In all cases, the minimum *p*-level for statistical significance was set at 0.05. All statistical analyses were performed using Statistical Package for Social Sciences (SPSS) version 28 (IBM Corp., Armonk, N.Y., USA).

Results

Participant demographics are reported in Table 1. Initially, 271 athletes agreed to participate and started the survey, however, 132 responses were incomplete or duplicated and were excluded. A total of 139 completed responses were eligible for analysis.

Sport and self-reported trained status of athletes can be seen in Table 2.A total of 89 female athletes (64%) were categorised as being at risk of LEA using a cut-off score of over 16% of total available marks. When analysed by perimenopausal status, 66.4% of non-perimenopausal (<35 years) athletes, and 56.2% of perimenopausal (≥35 years) athletes were characterised as at risk of LEA. The LEAF-Q had three scored subcategories including injury, gastrointestinal dysfunction and menstrual dysfunction. These were significant differences between EA and LEA groups for total LEAF-Q score as well as for menstrual dysfunction score and gastrointestinal function score. There were no significant differences between groups for injury score (Table 3)

Table 1 Descriptive statistics (mean ± SD).

	Female Athletes (*n*=139)
Age (years)	39 ± 13
Weight (kg)	68.0 ± 17.8
Height (cm)	1.67 ± 0.11
BMI (kg/m^2)	24.4 ± 6.4
Mean LEAF-Q SCORE (% of total marks available)	25.0 ± 17.3
Mean ABQ Score	2.4 ± 0.5

Table 2 Sport, self-reported trained status, and perimenopausal status of athletes split by LEA categorisation.

		At risk of LEA (n (%))	Not at risk of LEA (n (%))
Sport (*n*)	Weight-dependent	2 (66.7%)	1 (33.3%)
	Combat and weightlifting	3 (75.0%)	1 (25.0%)
	Cycling	1 (100%)	0 (0%)
	Running	53 (63.9%)	30 (36.1%)
	Swimming	1 (50%)	1 (50%)
	Team (football, lacrosse, basketball, tennis)	4 (40.0%)	6 (60.0%)
	Triathlon	25 (69.4%)	11 (30.6%)
Trained Status (*n*)	Recreationally active	26 (65.0%)	14 (35.0%)
	Trained/ Developmental	35 (63.6%)	20 (36.4%)
	Highly trained/ National	9 (64.3%)	5 (35.7%)
	Elite/international	19 (65.5%)	10 (34.5%)
	World-class	1 (100%)	0 (0%)
Perimenopausal Status (n)	<35 years	71 (66.4%)	36 (33.6%)
	≥35 years	18 (56.2%)	14 (43.8%)

Table 3: Results of LEAF-Q (with sub-scores) and ABQ with results split by LEA categorisation.

		At risk of LEA (n=89)	Not at risk of LEA (n=50)	*p*	Cliff's delta
Score	LEAF-Q Score (% of total available marks)	25.9 ± 4.5	10.0 ± 2.4	<0.01***	-
	LEAF-Q: Injury Score	2.4 ± 2.1	1.7 ± 1.7	0.09	0.05
	LEAF-Q: GI score	2.3 ± 2.2	0.8 ± 1.2	<0.01**	0.14
	LEAF-Q: MD score	4.3 ± 3.1	0.2 ± 0.7	<0.01**	0.27
	ABQ Score	2.4 ± 0.1	2.5 ± 0.5	0.42	0.08
Weight	BMI (kg/m^2)	24.1 ± 6.2	25.1 ± 6.6	0.31	0.03
	Highest weight (kg)	74.6 ± 20.3	78.1 ± 25.1	0.60	0.03
	Lowest weight (kg)	61 ± 17.1	62.7 ± 19.4	0.54	0.02
Sport	How many years have you been doing your main sport (years)	9.3 ± 6.7	9.1 ± 9.7	0.21	0.0
	Training hours per week (h)	9.15 ± 5.0	8.0 ± 3.6	0.27	0.05
Sleep	How many hours of sleep do you get a night (h)	7.2 ± 1.1	7.1 ± 1.2	0.60	0.02
Dietary	Breakfast on weekdays (days)	4.4 ± 1.3	4.4 ± 1.4	0.79	0.0
Habits	Breakfast on weekends (days)	1.7 ± 0.6	1.7 ± 0.6	0.99	0.0
Illness	Days lost to illness (days)	2.2 ± 3.2	2.3 ± 3.3	0.77	0.0

$p < 0.05$; **, $p < 0.01$; and ***, $p < 0.001$There was no significant relationship between LEAF-Q and ABQ scores (r_s (139)=-0.09, p=0.30).

There were no significant differences in BMI, lowest weight, highest weight, sleep duration, frequency of upper respiratory tract infections, and days of training lost to illness (without injury or incidences of COVID-19) in a typical month between female athletes categorised at risk and not at risk of LEA, regardless of whether data were analysed as a whole group (Table 3), or categorised by age to account for perimenopausal status ($p>0.05$).

FIGURE 1 ABOUT HERE

Figure 1 - Percentage of female athletes categorised as not at risk of LEA (EA) and at risk of LEA (LEA) who reported (a) pressure to perform, (b) feeling forced to train, (c) they fuelled well, and (d) they restricted dietary intake at times.

Chi-square tests of independence was conducted between pressure to perform, feeling forced to train, feeling they fuelled well, and restricted dietary intake at times for males and females according to LEA categorisation (Figure 1). All expected cell frequencies were greater than five. There was no statistically significant association in female athletes for feeling pressured to perform ($X^2(1)=0.50$, $p=0.48$), feeling forced to train ($X^2(1)=0.03$, $p=0.86$), restriction of dietary intake for($X^2(1)=3.79$, $p=0.15$) for, or feeling they fuelled well ($X^2(1)=2.06$, $p=0.15$).

Discussion

This study aimed to investigate the prevalence of LEA and BSA in a widespread athletic population and explore possible relationships between LEA and BSA. Noteworthy findings were that 64% of female athletes, including 64% of runners, and 69% of triathletes were categorised as at risk of LEA. This is in agreement with previous studies reporting 64.7% of young female footballers[22], 44.1% of female ultra-marathon runners[23], and 38% of female weight-cutting athletes[24] were categorised as at risk of LEA according to their LEAF-Q scores despite differences in participants' age and BMI. When analysed by perimenopausal status, 66.4% of non-perimenopausal athletes (<35 years) and 56.2% of perimenopausal athletes (>35 years) were characterised as at risk of LEA. This suggests that while LEA is prevalent across all age groups, younger athletes may be at a slightly higher risk. This is in agreement with previous studies[9,10] and highlights the need for further research into the factors influencing LEA susceptibility at different life stages.

Diagnosing REDs is complex and typically requires comprehensive clinical evaluation, which is impractical for most amateur athletes[25]. As a result, questionnaires like the LEAF-Q, validated to identify LEA risk, are more widely used. However, there are limitations to the LEAF-Q, as it may tend to over-diagnose LEA in certain populations. The questionnaire assesses a broad range of symptoms, such as menstrual irregularities and gastrointestinal issues, that could arise from other factors like stress or temporary dietary changes, which may not necessarily indicate chronic LEA. Furthermore, in some populations, athletes might be categorized as "at risk" despite not showing significant physiological dysfunction (e.g., low bone density or metabolic suppression)[26,27]. Although LEAF-Q is a valuable screening tool, it should therefore be used alongside other diagnostic methods for a more accurate assessment of LEA.

No participants in this study were categorised as having ‘burnout’, and ABQ scores did not differ between athletes categorised as at risk and not at risk of LEA. This contrasts with previous literature where prevalence’s of BSA of 1–9% in female athletes have been reported[13]. Athletes can develop BSA as a result of excessive stress and pressure related to training, competition, and performance expectations [29,30]. Training stress is emphasised less, and it has been suggested that psychological factors are the most prominent in the development of BSA. Symptoms of LEA and BSA can overlap, but results showed no relationship between scores of ABQ and LEAF-Q indicating that athletes who scored higher on ABQ did not necessarily score higher on LEAF-Q. It is possible that LEA might be a precursor to BSA rather than a parallel condition. Although symptoms of LEA and BSA can overlap, the lack of correlation between ABQ and LEAF-Q scores highlights the need for more rigorous tools to assess BSA in relation to LEA. This supports the call for longitudinal research to clarify the causal relationship between LEA and BSA. Additionally, developing more sensitive and specific screening tools for LEA and BSA in female athletes would be beneficial.

Internal pressure refers to the self-imposed drive to perform, stemming from personal goals, values, or emotions, such as the need to excel in sport to maintain a positive self-image, achieve personal aspirations, or avoid feelings of guilt or responsibility if training is missed. Unlike external pressure, which comes from coaches, teammates, or social expectations, internal pressure is athlete-driven and can strongly influence training and competitive behaviours[29]. Studies have found that athletes with LEA experience significant performance pressure, which affects their eating and training behaviours and contributes to stress stemming from self-comparison and heightened self-consciousness[31]. Extreme pressure to perform could be a risk factor for LEA and linked to poor mental health, which may affect sleep, illness, and eating habits, potentially increasing the risk of LEA developing into REDs[32]. Results were in agreement with this, showing that a greater proportion of athletes at risk of LEA reported feeling of greater pressure to perform than athletes not at risk of LEA. These athletes, however, did not feel as though they were forced to go to training, suggesting that there was greater internal pressure to perform than external pressure from sources such as coaches, teammates, or social expectations (Figure 1).

As LEA is a factor of both energy intake and energy expenditure, both dietary and exercise behaviours need be considered, including problematic exercise behaviours such as exercise dependence. Exercise dependence, or addiction, can contribute to high internal pressure to perform, with athletes often feeling guilty for not exercising and neglecting recovery[33,34]. Results showed that female athletes at risk of LEA trained more hours than those not at risk (Table 3). In endurance athletes, the development of LEA is often attributed to excessive energy expenditure from prolonged exercise[35]. Research shows that each additional hour of exercise per week increased the likelihood of being at risk of LEA by 1.06 times[36]. Since many symptoms of LEA and over-training overlap, it is suggested that LEA plays a significant role in cases of over-training, especially when carbohydrate intake is insufficient [5]. It is therefore important to monitor training load and ensure fuelling increases concurrently with training load to reduce the risk of developing LEA.

Over a third of participants reported self-restricted eating and inadequate fuelling (Figure 1), suggesting possible disordered eating behaviours and high levels of self-control. Previous research using the Female Athlete Screening Tool questionnaire reported that nearly half of ultra-endurance athletes restricted their diet and one-third demonstrated disordered eating behaviours[23]. Although our study did not use a validated disordered eating questionnaire, similar trends emerged, with a significant proportion of athletes limiting their intake relative to training demands. Athletes often practice periodized nutrition, intentionally fasting or reducing carbohydrate intake during certain sessions to enhance training adaptations[2,37] with the aim of improving performance and body composition[38]. However, without proper guidance, athletes can unintentionally enter a state of LEA while attempting these advanced nutritional strategies. Female distance athletes, despite having similar capacities for carbohydrate storage and utilisation during exercise as males[39], tend to consume less carbohydrate than males, although this difference diminishes when carbohydrate intake is adjusted for training volume[40]. The prevalence of LEA linked to restrictive diets highlights the need for better nutritional education to prevent unintentional LEA and its negative impact on health and performance[41].

There were no differences in BMI between female athletes categorised as at risk or not at risk of LEA (Table 3). Athletes self-reporting as “trained/developmental” and “recreationally active” were most commonly categorised as at risk of LEA while “highly-trained/national” were least at risk (Table 2). This supporting previous findings that LEA affects athletes across all levels, not just elites[3]. Endurance and weight-sensitive sports athletes are particularly vulnerable due to excessive energy expenditure and restrictive diets (particularly those low in carbohydrate), often linked to insufficient knowledge about fuelling[5]. Studies have found that athletes in weight sensitive or leanness-focused sports are at increased risk of developing LEA whether or not disordered eating is present[42]. Low BMI can result from low energy intake, high energy expenditures, or a combination of both, with prolonged periods of energy deficits potentially leading to LEA and REDs[43]. Because nearly all participants in this study had a BMI in the normal range (18.5-24.9 kg/m^2), it is likely that that food restriction in our participants may have been short-term, linked to dietary periodisation rather than chronic energy restriction, though further research is needed to verify this. No significant relationship was found between illness and LEA category in this study . However, previous studies suggest that LEA is associated with an increased likelihood of upper respiratory infection and gastrointestinal symptoms, bodily aches and head-related symptoms in elite athletes[3]. Studies have linked LEA to increased upper respiratory infections in Olympic athletes, possibly due to weakened immune function from inadequate energy intake[44]. Military studies also showed compromised immune function in recruits with LEA, though increased caloric intake helped restore immune responses during high training loads[45]. Components of health are inter-related, highlighting the need for multidisciplinary prevention and management programmes in high-level sports[46]. More research is needed to confirm these effects in broader athletic populations.

This study has several limitations. Data were self-reported and therefore dependent on participants' understanding of questions and honesty of completion. Under-reporting of symptoms due to denial of problems or over-scoring on questions to meet a norm is common in research and it is possible that participants provided socially desirable responses despite the survey being anonymised[47]. A significant number of participants started but did not complete the survey, possibly due to the length and personal nature of some questions which may have introduced bias. Future research should consider using qualitative data capture methods, such as semi-structured interviews, alongside surveys to provide a more comprehensive understanding. No differences were observed in some measures, such as sleep, injury, and illness, despite other studies reporting otherwise. This may be due to the use of dichotomous questions which limited responses to yes or no, restricting detailed insights. Future research should consider using Likert scales with open-text options to allow for more nuanced data collection. Although participants were grouped by age to try and account for perimenopausal status, the survey did not include a question about perimenopausal/menopausal status which could have led to the presence of oligomenorrhea or amenorrhea unrelated to LEA. Menopause is defined as the absence of menstruation for one year; however, there is no definitive medical diagnosis of perimenopause which is instead identified by a cluster of symptoms, including menstrual irregularity, sleep disturbances, and hot flashes[48]. Outside of hormonal biomarker assessment, which can be costly and invasive, perimenopause is usually classified based on The Stages of Reproductive Aging Workshop (STRAW+10) Criteria [20], with menstrual cycle variability or absence serving as the main indicator. Since these changes overlap with symptoms of LEA, caution is warranted when interpreting LEAF-Q results in athletes aged 35 and older, as perimenopausal hormonal fluctuations may confound assessments of energy availability.

Conclusion

There was a high prevalence of female athletes categorised as at risk of LEA across a variety of sports, but no significant relationships were observed between LEA and BSA, despite symptoms often overlapping. Factors such as BMI, dietary habits, sleep, illness, or pressure in sport were not significantly different in athletes classified as at risk or not at risk of LEA. Given the significant proportion of athletes categorised as at risk of LEA, further research is needed to investigate whether self-reported symptoms of LEA in a non-elite athlete population correspond with physiological symptoms (i.e., low bone mineral density) and mental health parameters.

Authors' Contribution

All authors read and approved the final version of the manuscript.

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References

1 Logue, Danielle, Madigan, Sharon M., Delahunt, Eamonn, Heinen, Mirjam, et al. (2018) ‘Low Energy Availability in Athletes: A Review of Prevalence, Dietary Patterns, Physiological Health, and Sports Performance’. *Sports Medicine*, 48(1), pp. 73–96.

2 Wasserfurth, Paulina, Palmowski, Jana, Hahn, Andreas and Krüger, Karsten (2020) ‘Reasons for and Consequences of Low Energy Availability in Female and Male Athletes: Social Environment, Adaptations, and Prevention’. *Sports Medicine - Open*, 6, p. 44.

3 Mountjoy, Margo, Ackerman, Kathryn E., Bailey, David M., Burke, Louise M., et al. (2023) ‘2023 International Olympic Committee’s (IOC) consensus statement on Relative Energy Deficiency in Sport (REDs)’. *British Journal of Sports Medicine*, 57(17), pp. 1073–1097.

4 Fokkema, Tryntsje, van Damme, Ankie A.D.N., Fornerod, Maarten W.J., de Vos, Robert-Jan, et al. (2020) ‘Training for a (half-)marathon: Training volume and longest endurance run related to performance and running injuries’. *Scandinavian Journal of Medicine & Science in Sports*, 30(9), pp. 1692–1704.

5 Stellingwerff, Trent, Heikura, Ida A., Meeusen, Romain, Bermon, Stéphane, et al. (2021) ‘Overtraining Syndrome (OTS) and Relative Energy Deficiency in Sport (RED-S): Shared Pathways, Symptoms and Complexities’. *Sports Medicine*, 51(11), pp. 2251–2280.

6 Melin, Anna K., Areta, José L., Heikura, Ida A., Stellingwerff, Trent, et al. (2024) ‘Direct and indirect impact of low energy availability on sports performance’. *Scandinavian Journal of Medicine & Science in Sports*, 34(1), p. e14327.

7 Melin, A., Tornberg, Å. B, Skouby, S., Møller, S. S., et al. (2015) ‘Energy availability and the female athlete triad in elite endurance athletes’. *Scandinavian Journal of Medicine & Science in Sports*, 25(5), pp. 610–622.

8 Sharps, Francis Robert Jose, Wilson, Laura Jane, Graham, Catherine Anna-Marie and Curtis, Christopher (2022) ‘Prevalence of disordered eating, eating disorders and risk of low energy availability in professional, competitive and recreational female athletes based in the United Kingdom’. *European Journal of Sport Science*, 22(9), pp. 1445–1451.

9 Heikura, Ida A., Uusitalo, Arja L. T., Stellingwerff, Trent, Bergland, Dan, et al. (2018) ‘Low Energy Availability Is Difficult to Assess but Outcomes Have Large Impact on Bone Injury Rates in Elite Distance Athletes’. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), pp. 403–411.

10 Dervish, R. A., Wilson, L. J. and Curtis, C. (2023) ‘Investigating the prevalence of low energy availability, disordered eating and eating disorders in competitive and recreational female endurance runners’. *European Journal of Sport Science*, 23(5), pp. 869–876.

11 Nazem, Taraneh Gharib and Ackerman, Kathryn E. (2012) ‘The Female Athlete Triad’. *Sports Health*, 4(4), pp. 302–311.

12 Smith, Ronald E. (1986) ‘Toward a Cognitive-Affective Model of Athletic Burnout’. *Journal of Sport and Exercise Psychology*, 8(1), pp. 36–50.

13 Gustafsson, Henrik, Kenttä, Göran, Hassmén, Peter and Lundqvist, Carolina (2007) ‘Prevalence of Burnout in Competitive Adolescent Athletes’. *The Sport Psychologist*, 21(1), pp. 21–37.

14 Dubuc-Charbonneau, Nicole M. and Durand-Bush, Natalie (2014) ‘Exploring levels of student-athlete burnout at two Canadian universities’. *Canadian Journal of Higher Education/La Revue canadienne d’enseignement supérieur*, 44(2), pp. 135–151.

15 Gustafsson, Henrik, Kenttä, Göran, Hassmén, Peter, Lundovist, Carolina and Durand-Bush, Natalie (2007) ‘The process of burnout: A multiple case study of three elite endurance athletes’. *International Journal of Sport Psychology*, 38(4), pp. 388–416.

16 Melin, Anna, Tornberg, Åsa B., Skouby, Sven, Faber, Jens, et al. (2014) ‘The LEAF questionnaire: a screening tool for the identification of female athletes at risk for the female athlete triad’. *British Journal of Sports Medicine*, 48(7), pp. 540–545.

17 Raedeke, Thomas D. and Smith, Alan L. (2001) ‘Development and Preliminary Validation of an Athlete Burnout Measure’. *Journal of Sport and Exercise Psychology*, 23(4), pp. 281–306.

18 Cresswell, Scott L. and Eklund, Robert C. (2005) ‘Motivation and burnout among top amateur rugby players’. *Medicine and Science in Sports and Exercise*, 37(3), pp. 469–477.

19 Lonsdale, Chris, Hodge, Ken and Rose, Elaine (2009) ‘Athlete burnout in elite sport: a self-determination perspective’. *Journal of Sports Sciences*, 27(8), pp. 785–795.

20 Harlow, Siobán D., Gass, Margery, Hall, Janet E., Lobo, Roger, et al. (2012) ‘Executive summary of the Stages of Reproductive Aging Workshop + 10: addressing the unfinished agenda of staging reproductive aging’. *Menopause (New York, N.y.)*, 19(4), pp. 387–395.

21 Meissel, Kane and Yao, Esther S. (2024) ‘Using Cliff’s Delta as a Non-Parametric Effect Size Measure: An Accessible Web App and R Tutorial’. *Practical Assessment, Research, and Evaluation*, 29(1). [online] Available from: https://openpublishing.library.umass.edu/pare/article/id/1977/ (Accessed 8 October 2024)

22 Łuszczki, Edyta, Jagielski, Pawel, Bartosiewicz, Anna, Kuchciak, Maciej, et al. (2021) ‘The LEAF questionnaire is a good screening tool for the identification of the Female Athlete Triad/Relative Energy Deficiency in Sport among young football players’. *PeerJ*, 9, p. e12118.

23 Folscher, Lindy-Lee, Grant, Catharina C., Fletcher, Lizelle and Janse van Rensberg, Dina Christina (2015) ‘Ultra-Marathon Athletes at Risk for the Female Athlete Triad’. *Sports Medicine - Open*, 1(1), p. 29.

24 Thomas, Sarah, Gonzalez, Adam M. and Ghigiarelli, Jamie J. (2021) ‘The Relationship between Weight Cutting and the Female Athlete Triad in Combat Sport Athletes’. *International Journal of Kinesiology and Sports Science*, 9(1), pp. 9–14.

25 Burke, Louise M., Lundy, Bronwen, Fahrenholtz, Ida L. and Melin, Anna K. (2018) ‘Pitfalls of Conducting and Interpreting Estimates of Energy Availability in Free-Living Athletes’. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), pp. 350–363.

26 Beals, Katherine A. and Hill, Amanda K. (2006) ‘The prevalence of disordered eating, menstrual dysfunction, and low bone mineral density among US collegiate athletes’. *International Journal of Sport Nutrition and Exercise Metabolism*, 16(1), pp. 1–23.

27 Lane, Amy R., Hackney, Anthony C., Smith-Ryan, Abbie E., Kucera, Kristen, et al. (2021) ‘Energy Availability and RED-S Risk Factors in Competitive, Non-elite Male Endurance Athletes’. *Translational Medicine and Exercise Prescription*, 1(1), pp. 25–32.

28 Lundy, Bronwen, Torstveit, Monica K., Stenqvist, Thomas B., Burke, Louise M., et al. (2022) ‘Screening for Low Energy Availability in Male Athletes: Attempted Validation of LEAM-Q’. *Nutrients*, 14(9), p. 1873.

29 Granz, Hanna L., Schnell, Alexia, Mayer, Jochen and Thiel, Ansgar (2019) ‘Risk profiles for athlete burnout in adolescent elite athletes: A classification analysis’. *Psychology of Sport and Exercise*, 41, pp. 130–141.

30 Thomas, Candice E., Gastin, Paul B., Abbott, Gavin and Main, Luana C. (2021) ‘Impact of the talent development environment on the wellbeing and burnout of Caribbean youth track and field athletes’. *European Journal of Sport Science*, 21(4), pp. 590–603.

31 Kuikman, Megan A., Mountjoy, Margo and Burr, Jamie F. (2021) ‘Examining the Relationship between Exercise Dependence, Disordered Eating, and Low Energy Availability’. *Nutrients*, 13(8), p. 2601.

32 Stickler, Laurie G., Thomas, M. and Morse, L. (2018) ‘Division I Female Cross-Country Runners’ Perception of Eating Behaviors and Attitudes Toward Health: A Pilot Study’. *International Journal of Exercise Science*, 11(3), pp. 941–956.

33 Berczik, Krisztina, Szabó, Attila, Griffiths, Mark D., Kurimay, Tamás, et al. (2012) ‘Exercise addiction: symptoms, diagnosis, epidemiology, and etiology’. *Substance Use & Misuse*, 47(4), pp. 403–417.

34 Cook, Brian, Hausenblas, Heather and Freimuth, Marilyn (2014) ‘Exercise addiction and compulsive exercising: Relationship to eating disorders, substance use disorders, and addictive disorders’, in *Eating disorders, addictions and*

substance use disorders: Research, clinical and treatment perspectives, New York, NY, US, Springer-Verlag Publishing/Springer Nature, pp. 127–144.

35 Burke, Louise M., Close, Graeme L., Lundy, Bronwen, Mooses, Martin, et al. (2018) 'Relative Energy Deficiency in Sport in Male Athletes: A Commentary on Its Presentation Among Selected Groups of Male Athletes'. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(4), pp. 364–374.

36 Logue, Danielle M., Madigan, Sharon M., Heinen, Mirjam, McDonnell, Sarah-Jane, et al. (2019) 'Screening for risk of low energy availability in athletic and recreationally active females in Ireland'. *European Journal of Sport Science*, 19(1), pp. 112–122.

37 Jeukendrup, Asker E. (2017) 'Periodized Nutrition for Athletes'. *Sports Medicine (Auckland, N.Z.)*, 47(Suppl 1), pp. 51–63.

38 Melin, Anna K., Heikura, Ida A., Tenforde, Adam and Mountjoy, Margo (2019) 'Energy Availability in Athletics: Health, Performance, and Physique'. *International Journal of Sport Nutrition and Exercise Metabolism*, 29(2), pp. 152–164.

39 Wallis, Gareth A., Dawson, Ruth, Achten, Juul, Webber, Jonathan and Jeukendrup, Asker E. (2006) 'Metabolic response to carbohydrate ingestion during exercise in males and females'. *American Journal of Physiology-Endocrinology and Metabolism*, 290(4), pp. E708–E715.

40 Burke, Louise M., Hawley, John A., Jeukendrup, Asker, Morton, James P., et al. (2018) 'Toward a Common Understanding of Diet–Exercise Strategies to Manipulate Fuel Availability for Training and Competition Preparation in Endurance Sport'. *International Journal of Sport Nutrition and Exercise Metabolism*, 28(5), pp. 451–463.

41 Peklaj, Eva, Reščič, Nina, Koroušic Seljak, Barbara and Rotovnik Kozjek, Nada (2022) 'Is RED-S in athletes just another face of malnutrition?' *Clinical nutrition ESPEN*, 48, pp. 298–307.

42 Torstveit, Monica Klungland, Fahrenholtz, Ida Lysdahl, Lichtenstein, Mia Beck, Stenqvist, Thomas Birkedal and Melin, Anna Katarina (2019) 'Exercise dependence, eating disorder symptoms and biomarkers of Relative Energy Deficiency in Sports (RED-S) among male endurance athletes'. *BMJ Open Sport & Exercise Medicine*, 5(1), p. e000439.

43 Hulley, Angela, Currie, Alan, Njenga, Frank and Hill, Andrew (2007) 'Eating disorders in elite female distance runners: Effects of nationality and running environment'. *Psychology of Sport and Exercise*, 8(4), pp. 521–533.

44 Drew, Michael K., Vlahovich, Nicole, Hughes, David, Appaneal, Renee, et al. (2017) 'A multifactorial evaluation of illness risk factors in athletes preparing for the Summer Olympic Games'. *Journal of Science and Medicine in Sport*, 20(8), pp. 745–750.

45 O'Leary, Thomas J., Wardle, Sophie L. and Greeves, Julie P. (2020) 'Energy Deficiency in Soldiers: The Risk of the Athlete Triad and Relative Energy Deficiency in Sport Syndromes in the Military'. *Frontiers in Nutrition*, 7. [online] Available from: https://www.frontiersin.org/articles/10.3389/fnut.2020.00142 (Accessed 7 September 2023)

46 Drew, Michael, Vlahovich, Nicole, Hughes, David, Appaneal, Renee, et al. (2018) 'Prevalence of illness, poor mental health and sleep quality and low energy availability prior to the 2016 Summer Olympic Games'. *British Journal of Sports Medicine*, 52(1), pp. 47–53.

47 Ferraris, Cinzia, Guglielmetti, Monica, Trentani, Claudia and Tagliabue, Anna (2019) 'Assessment of Dietary Under-Reporting in Italian College Team Sport Athletes'. *Nutrients*, 11(6), p. 1391.

48 Cunningham, Adam C., Hewings-Martin, Yella, Wickham, Aidan P., Prentice, Carley, et al. (2025) 'Perimenopause symptoms, severity, and healthcare seeking in women in the US'. *npj Women's Health*, 3(1), pp. 1–8.