Received: 16 June 2023 | Revised: 8 May 2024 | Accepted: 9 May 2024

DOI: 10.1002/ejsc.12129

ORIGINAL PAPER

Official ECSS Journal Open Access WILEY

Risk and prevalence of Relative Energy Deficiency in Sport (REDs) among professional female football players

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Funding information

Tromsø Forskningsstiftelse; Universitetet i Tromsø

Abstract

A high prevalence of low energy availability (LEA) has been reported in female football players. This is of concern as problematic LEA may evolve into a syndromic pattern known as relative energy deficiency in sport (REDs). Given the difficulties in accurately assessing LEA, our study shifts emphasis to measurable indicators of REDs, serving as proxies for health detriments caused by LEA. The present cross-sectional study aimed to quantify the risk of REDs and to assess the prevalence of indicators indicative of the syndrome. 60 players (tiers 3 and 4) from three Norwegian football teams were analyzed as a single cohort but also stratified based on player position and menstrual status. The proportion of players at risk for REDs was 22%, that is, 17% with mild, 3% with moderate to high, and 2% with very high/extreme risk, respectively. The majority of the cohort (71%) presented with no primary indicators, while 20%, 7%, and 2% presented with one, two, and three primary indicators, respectively. Regarding secondary indicators, 57% had none, 33% had one, and 10% had two indicators. For associated indicators, 30% had none, 42% had one, 18% had two, 8% had three, and 2% had four indicators. Player position did not affect the prevalence of REDs indicators. Among noncontraceptive users (n = 27), secondary amenorrhea (AME) was reported by 30%. These findings indicate that health and performance teams should prioritize universal health promoting strategies rather than selective or indicative strategies. Particularly, focus on nutritional periodization to secure sufficient energy availability, mitigating the risk of problematic LEA and REDs should be addressed.

KEYWORDS

female athlete, football, low energy availability, relative energy deficiency in sport

Highlights

- Of the total cohort (n = 60), 22% of players were classified as at risk for REDs, among which 5% demonstrated high to severe risk, while 78% were not at risk.

- Amenorrhea (AME) was reported by 30% of noncontraceptive users.
- An individual risk potential for REDs aside, our findings argue for health and performance teams prioritizing universal interventions such as nutritional periodization to decrease unwanted exposure to problematic low energy availability (LEA).

1 | INTRODUCTION

Relative energy deficiency in sport (REDs) describes a syndrome that emanates from low energy availability (LEA) which is situated on a continuum ranging from adaptable to problematic LEA (Mountjoy et al., 2023). Adaptable LEA entails benign and readily reversible effects, whereas problematic LEA and subsequently REDs are characterized by enduring the disruption of physiological and/or psychological function (Mountjoy et al., 2023). REDs can manifest with or without disordered eating (DE) behaviors and have severe health and performance consequences affecting several body systems such as metabolic, bone, reproductive, psychological, and endocrine functions (Melin et al., 2023; Mountjoy et al., 2023). Controlled laboratory studies indicate that energy availability <30 kcal/kg^{-1} fat-free mass (FFM)/day^{-1} may lead to physiological impairments, including changes in luteinizing hormone pulsatility (Areta et al., 2021). Prolonged disruption in the expression of this hormone can result in secondary Amenorrhea (AME), which is considered to be the principal indicator of REDs in female athletes (Areta et al., 2021). Several studies have also identified a higher prevalence of additional REDs indicators in AME compared to eumenorrheic (EUM) women (Christo et al., 2008; Loucks et al., 1992; Melin et al., 2015). This pattern suggests that AME could be indicative of a wider array of REDs indicators and should warrant further investigation if present.

The risk of REDs across various athletic populations appears to be modulated by a range of factors, encompassing both the inherent characteristics and the cultural milieu surrounding the sport (Langbein et al., 2021; Sundgot-Borgen et al., 2013). For instance, many sports domains emphasize low body weight and leanness as performance indicators, albeit lacking empirical support (Mathisen et al., 2023). This focus on body composition has been linked with psychological distress outlined in the REDs model, although its direct association with REDs needs further exploration (Mountjoy et al., 2023). Evidence from football suggests that players' attitudes toward nutrition and its impact on body composition can be problematic, underscoring the significant role of cultural influences within a sport (McHaffie et al., 2022).

Women's football is rapidly evolving and players are exposed to increasing physiological demands, which contingent upon player position, may modulate the risk of LEA (Winther et al., 2022). Contemporary professional players will generally play 1–2 games per week, in addition to four to six training sessions, emphasizing the importance of "fueling for the work required" (Anderson et al., 2022; Moss et al., 2020). While studies have reported a prevalence of LEA ranging between ~20 and 80% in female footballers (Dasa et al., 2023; Morehen et al., 2022; Moss et al., 2020), direct measurement of energy availability poses challenges due to the high risk of measurement error particularly in intermittent team sports (Burke et al., 2018). For instance, Moss et al. (2020) reported that 23% of elite players had LEA, while 62% had reduced energy availability during a 5-day in-season period. However, the association between LEA and other risk factors was low. Despite the limited sample size, this study highlights the challenge in ascertaining the segment of athletes grappling with problematic LEA and consequently may face an elevated risk of developing REDs (Moss et al., 2020). Identification of symptoms outlined by the REDs model likely offers a more nuanced assessment of the health challenges faced by athletes, circumventing the methodological constraints of directly measuring energy availability. Therefore, adopting this symptom-focused approach may provide better knowledge of possible prevention strategies for REDs among female football players (Burke et al., 2018). In accordance with the request for additional research in this domain (Moss et al., 2020; Mountjoy et al., 2018), the primary aim of this study was to assess the proportion of players at risk for REDs and to assess the prevalence of its indicators within a cohort of professional female football players. Secondly, we aimed to explore if the prevalence of REDs indicators varied across player positions as well as between AME and EUM players.

2 | MATERIAL AND METHODS

2.1 | Study design and participants

Using a cross-sectional observation design, all data were collected between October 2021 and May 2022 (Rosenvinge et al., 2022). In total, 60 female football players participated. They were recruited from three Norwegian teams competing in the premier league and first division (second level). Eight participants were currently representing their senior national team, while another eight represented their designated youth national team. The participants were classified as tier 3 (national level) or four (international level), respectively (McKay et al., 2022)

2.2 | Clinical measures

The clinical measures were conducted across two consecutive days. A schematic overview of the study protocol is presented in Figure 1. All testing was completed following an overnight fasted state between 06 and 10 a.m.

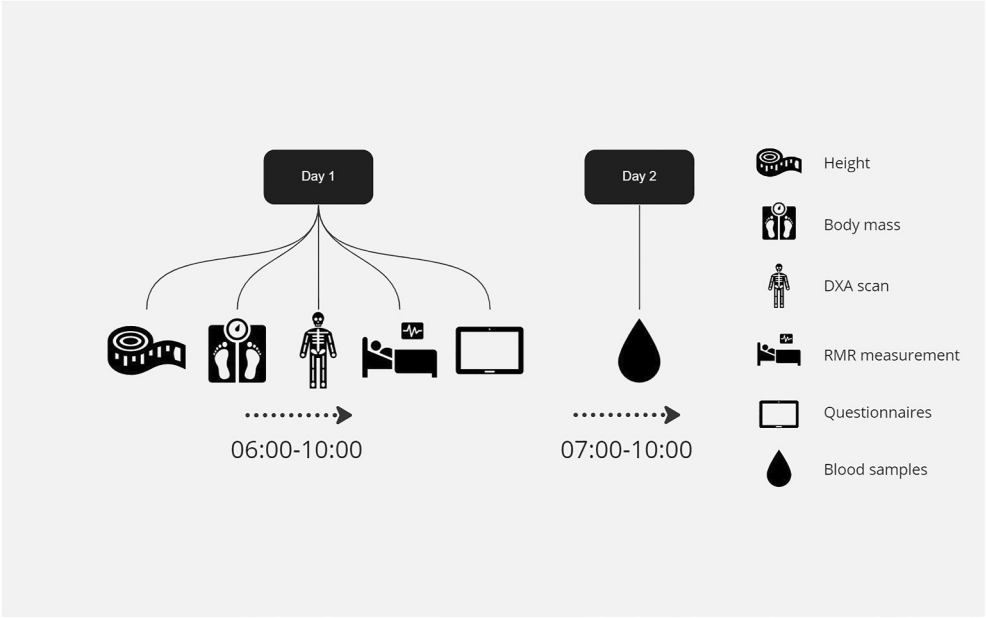

FIGURE 1 Schematic overview of the testing protocol completed by the participants.

2.2.1 | REDs indicators and pooling

Indicators were categorized as primary, secondary, or associated in accordance with the latest IOC consensus statement on REDs (Mountjoy et al., 2023; Stellingwerff et al., 2023). Primary indicators comprised secondary AME (including oligomenorrhea) based on self-reported menstrual status from the LEA in Females questionnaire (LEAF-Q) (Loucks et al., 2003), low levels of free triiodothyronine (FT_3) (Elliott-Sale et al., 2018), elevated score on the Eating Disorder Examination Questionnaire 11 (EDE-Q-11) (Friborg et al., 2013), and bone mass density (BMD) Z-score at the hip or lumbar spine (L1-4) < -1 [24], respectively (Tenforde et al., 2022). The secondary indicators comprised elevated low-density lipoproteins (LDL) or total cholesterol (Rickenlund et al., 2005), a history of stress fracture and major reduction in athlete availability caused by illness/sickness measured by the Oslo Sports Trauma Research Center Questionnaire (OSTRCQ) (Clarsen et al., 2020). Associated indicators included low resting metabolic rate (RMR) (defined as < 30 kcal/kg^{-1} FFM/day^{-1} (Sterringer et al., 2022)), insulin-like growth factor 1 (IGF-1) (Elliott-Sale et al., 2018), blood glucose (Melin et al., 2015), thyroid-stimulating hormone (TSH) (Loucks et al., 1992), ferritin (Heikura, Burke, et al., 2018), leptin (Elliott-Sale et al., 2018), free thyroxine (FT_4) (Elliott-Sale et al., 2018), procollagen type 1 N-propeptide (P1NP) (Vasikaran et al., 2011); elevated C-terminal telopeptide of type 1 collagen (CTX-1) (Vasikaran et al., 2011), and cortisol (Elliott-Sale et al., 2018), respectively.

The clinical findings from the screening process were scored dichotomously as present (1) or absent (0) similar to the outline described elsewhere to provide prevalence for each indicator (Heikura, Uusitalo, et al., 2018). Symptoms consistent with REDs and cut-off values were determined based on previously published literature and expert opinions (Mountjoy et al., 2023; Rogers et al., 2021; Stellingwerff et al., 2023). Additionally, the severity and risk associated with REDs for each player were assessed using the recently developed IOC REDs clinical assessment tool version 2 severity/risk assessment and stratification calculator, which underwent validation via the Delphi method (Stellingwerff et al., 2023). This tool allocates weighted scores of the primary and secondary indicators, stratifying athletes within a quadripartite traffic light model that extends from no or mild risk/severity to very high risk/severity. Pertaining to associated indicators delineated by the latest IOC guidelines, these indicators exhibit either inconsistent or inadequate evidential support, suboptimal validity, or scarce accessibility for practitioners and are therefore not incorporated within the REDs CAT 2 assessment (Stellingwerff et al., 2023).

Since there may be variation in laboratory reference ranges and absolute values depending on factors such as pre-analytic conditions and instrumentation (Lippi et al., 2006), we consequently applied the clinical reference values of the testing laboratory (Analyseoversikten). As for leptin, our laboratory did not provide a standardized reference range. Therefore, the cut-off value was determined based on the effect of induced LEA on this hormone demonstrated in previous literature (Elliott-Sale et al., 2018).

2.2.2 | Resting metabolic rate

The players conducted an indirect calorimetry protocol using a ventilated canopy hoodie (Vyntus CPX, CareFusion, Hochberg, Germany, SentrySuit v. 2.21.4). They were instructed to arrive at the laboratory facility using motorized transportation providing minimal physical strain. On arrival, participants were placed in a silent room in the supine position for 5 min before the canopy was positioned. Oxygen consumption (VO_2) and carbon dioxide production (VCO_2)

were measured over a 25-min period where the last 20 min were used to assess RMR.

2.2.3 | Body composition and bone mineral density

Body composition including BMD was measured using dual-energy X-ray absorptiometry (DXA) (Prodigy, Encore, SP 4.1, version 18, GE medical systems, Madison, Wisconsin, USA). The Z-score values were determined from the lumbar spine (L1-4) and hip and followed the recommended guidelines for best practice (Nana et al., 2015). All measurements and analyses were conducted by the same certified technician to avoid inter-rater variability.

2.2.4 | Hormonal markers

After an overnight fasting period (8–10 h), blood was collected for both plasma and serum samples. These samples were stored in Biobank Haukeland, Laboratory Medicine and Pathology, Haukeland University Hospital, Bergen, Norway before analyses. All analytes were assayed at the Department of Medical Biochemistry and Pharmacology, Haukeland University Hospital, Bergen, Norway. The laboratory is accredited in compliance with ISO 15189:2012. Glucose, Total cholesterol, and LDL were analyzed using Cobas 8000 c702, whereas TSH, FT_3, FT_4, and ferritin were assayed using Cobas 8000 e801. CTX-1 and P1NP were assayed using Cobas c602. Insulin and IGF-1 were analyzed using Immulite 2000 Xpi, whereas leptin was assayed using an enzyme-linked immunosorbent assay kit (Mediagnost Cat#E07, Research Resource Identifiers: AB_2813737) (not accredited analysis). Serum cortisol was analyzed using an in-house-developed high-performance liquid chromatography–tandem mass spectrometry (Methlie et al., 2013).

2.2.5 | Self-reported physiological and psychological indicators

After completing the RMR and DXA measurement, the players were given breakfast and instructed to complete an electronic questionnaire administered on a portable tablet (iPad pro, Apple, California, USA). All individuals completed a survey consisting of several questionnaires which included the LEAF-Q (Melin et al., 2014), the EDE-Q 11 (Friborg et al., 2013), the Bergen Insomnia Scale (BIS) (Pallesen et al., 2008), the Chalder Fatigue Scale (Chalder et al., 1993), the 12-item General Health Questionnaire (Jackson, 2007), as well as an adapted version of the OSTRCQ (Clarsen et al., 2020). Further, customized questions regarding diet and energy intake (EI) on match, training, and rest days were administered as well as questions specifically inquiring about history of stress fractures. All questionnaires were completed using an encrypted digital platform (Nettskjema, University of Oslo, Norway).

2.2.6 | Statistical analyses

Data analyses were conducted using the open software R (version 4.2.2). All participants were treated as a single cohort with additional stratification related to player position. Continuous data were compared using the Welch's *t*-test, analysis of variance, or Pearson's correlation coefficient, while categorical data were evaluated using the chi-square test. The risk/severity of REDs was assessed using the CAT2 calculator before summating the point prevalence of each REDs indicator for the entire cohort and subgroups using individual criteria for each condition. Data are presented as mean ± standard deviation.

Since AME is considered the principal indicator of LEA (Mountjoy et al., 2014), the subgroup of players not using hormonal contraception (n = 27) was analyzed separately and divided into an EUM and AME group based on menstrual status retrieved from the LEAF-Q (Melin et al., 2014).

3 | RESULTS

The 60 participants' mean age was 22.5 ± 3.7 years, with a mean height of 168.9 ± 6.0 cm, a mean body mass of 64.1 ± 6.3 kg, a body mass index of 22.4 ± 1.7 kg/m^2, percentage fat mass of 24.7 ± 4.2%, and a FFM of 49.3 ± 4.7 kg. The self-reported weekly training volume was 12.5 h ± 3.2, excluding games.

Overall, 22% of the cohort were classified as at risk for REDs. The proportion of participants presenting with mild, moderate to high, and high to extreme risk/severity were 17%, 3%, and 2%, respectively (Table 1). In total, 71% of the players did not present with any of the primary indicators. Moreover, 20%, 7%, and 2% presented with one, two, and three primary indicators, respectively. In terms of secondary indicators, 57% presented with no indicators, 33% presented with one indicator, and 10% with two indicators. Lastly, for the associated indicators, 30% of the participants presented with none, 42% presented with one, 18% with two, 8% with three, and 2% with four, respectively. We found a 12% prevalence of players with combined primary and secondary indicators. A distribution of all REDs indicators is presented in Figure 2, while the prevalence for each is presented in Table 2. We found no significant correlations between the number of primary and secondary (r = 0.10 and p = 0.437), primary and associated (r = 0.24 and p = 0.057), or secondary and associated (r = 0.07 and p = 0.592) indicators, respectively. On the other hand, we found that DE as measured by the primary indicator EDE-Q 11 was positively correlated with sleep disturbances (BIS) (r = 0.33 and p = 0.01), general health (r = 0.43 and p < 0.001), and fatigue (CFI) (r = 0.04 and p = 0.002). Additionally, 42% reported no increase in EI on match and hard training days, while 22% reported deliberately decreasing their EI on rest days and easy training days.

The prevalence of primary, secondary, or associated indicators of REDs was unrelated to players' position. However, defenders

TABLE 1 Risk assessment table: Color coding signifies the associated risk level based on the prevalence of REDs indicators.

Severity/risk	Prevalence (%)	Clinical criteria	Recommendations
None to very low	78%	No primary indicators Maximum 1 secondary indicator	-No treatment required -Full training and competition clearance
Mild	17%	1 or 2 primary indicators ± 1 secondary indicator OR ≥ 2 secondary indicators	-Treatment, monitoring, and regular follow-up at appropriate intervals -Full training and competition
Moderate to high	3%	3 primary indicators ± max 1 secondary indicator OR 2 primary and ≥2 secondary indicators	-Treatment, dose monitoring, and follow-up required (e.g., monthly) -Some aspects of training and/or competition may need to be modified
Very high/extreme	2%	≥4 primary OR 3 primary and ≥2 secondary indicators	Immediate treatment required by frequent monitoring at ~ daily to monthly intervals depending on severity -Significant training and competition modification required, and in the majority of cases, removal from all training and competition is indicated

Note: The clinical criteria and recommendations presented in the table are derived from Mountjoy et al. (2023).

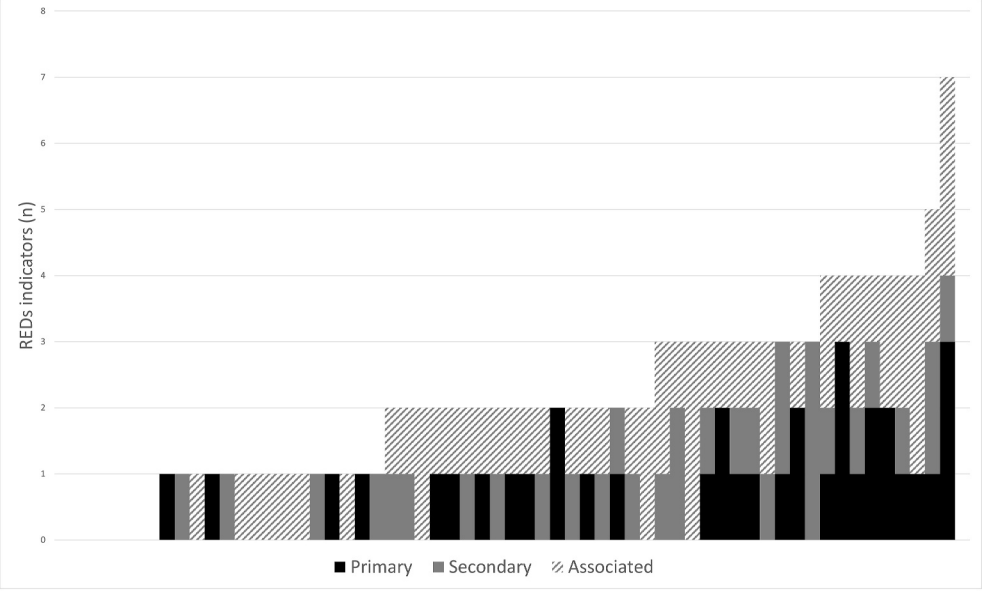

FIGURE 2 Distribution of primary, secondary, and associated REDs indicators arranged from minimum to maximum prevalence.

displayed higher cortisol levels compared to all other player positions ($p = 0.034$) (Table 3).

We found no differences in anthropometric measurements or age between the AME and EUM groups (AME: age 20.0 ± 4.4, height 171.5 ± 5.3 cm, body mass 68.1 ± 4.5 kg, FM 24.7 ± 4.3%, and FFM 52.7 ± 5.8 kg; EUM: age 22.6 ± 4.2, height 167.7 ± 6.8 cm, body mass 63.6 ± 8.1 kg, FM 25.5 ± 5.1%, and FFM 48.8 ± 5.6 kg). Excluding menstrual dysfunction as an indicator, the AME group displayed a significantly higher number of overall combined REDs indicators (2.9 ± 1.4) compared to the EUM group (1.6 ± 0.6); ($p = 0.048$). There were no significant differences for any of the individual REDs indicators, although the AME group consistently displayed unfavorable outcomes compared to the EUM group (see Supporting Information S1). In addition, the AME group reported a higher prevalence of stress fracture history (AME 38% vs. EUM 16% and $p > 0.005$), while the proportion of major time loss due to illness/sickness was 0% and 26% in the AME and EUM groups, respectively ($p > 0.005$).

4 | DISCUSSION

In a cohort of female football players, the present study is, to our knowledge, the first one to explore the prevalence of a diverse array of indicators outlined by the REDs model and the subsequent risk for REDs, enhancing our understanding of the implications of prior estimates of LEA.

TABLE 2 Prevalence of indicators associated with REDs among participants.

Primary indicators	Prevalence % (n)	95% CI
Amenorrhea[a]	30 (8)	(0.12, 0.47)
FT_3 < 4.0 pmol/L[b]	13 (8)	(0.05, 0.22)
EDE-Q > 2.5	10 (6)	(0.02, 0.18)
BMD Z-score < -1[c]	2 (1)	(0, 0.05)
Secondary indicators		
LDL ≥3 mmol/L	22 (13)	(0.11, 0.32)
Total cholesterol >6.1 mmol/L[b]	0	
History of stress fracture	22 (13)	(0.11, 0.32)
Time loss	10 (6)	(0.02, 0.18)
Associated indicators		
IGF-1 < 20.7 nmol/L[b]	10 (6)	(0.02, 0.18)
RMR <30 kcal/kg^{-1} FFM/day^{-1}	42 (25)	(0.29, 0.54)
Ferritin <18 μg/L	3 (2)	(0, 0.08)
Blood glucose <4 mmol/L	7 (4)	(0.04, 0.13)
Leptin <3.7 ng/mL	10 (6)	(0.02, 0.18)
FT_4 < 9.5 pmol/L	2 (1)	(0, 0.05)
TSH >4.5 mIU/L[b]	5 (3)	(0, 0.11)
CTX-1 > 0.69 μg/L[b]	8 (5)	(0.01, 0.15)
P1NP < 94 μg/L[b]	0	
Cortisol >600 nmol/L	25 (15)	(0.14, 0.36)

[a]Prevalence is based on noncontraceptive users.
[b]Age-specific reference ranges.
[c]At hip and/or lumbar spine.

4.1 | REDs indicators

Although one-third of the players presented with one primary indicator of REDs, the distribution of the secondary and associated indicators showed wider margins. Despite the lack of a significant correlation between the combined incidence of primary, secondary, and associated indicators, a notable segment of the cohort exhibited indicators across two or three of these defined categories. In alignment with the REDs CAT 2 risk stratification tool, 22% of the cohort was identified as at risk for the development of REDs. A more prevalent manifestation was observed for the associated indicators, which may be anticipated given the lesser degree of evidential support backing these indicators compared to primary and secondary indicators (Stellingwerff et al., 2023). Furthermore, many of the associated indicators are hormonal or metabolic markers possibly influenced by other biological processes unrelated to REDs (Elliott-Sale et al., 2018). Hence, in alignment with the recent guidelines on the diagnosis of REDs, these indicators should be further investigated to ascertain their validity (Stellingwerff et al., 2023). Moreover, 5% of those identified as at risk by the REDs CAT 2 showcased a clinical picture indicating that modifications in training/competition regimens are advised. This underscores that some female football players may be at risk for developing REDs.

The 30% prevalence of secondary AME among players not using hormonal contraceptives is akin to prevalence figures reported among elite endurance athletes and considerably higher than similar estimates in footballers (Heikura, Uusitalo, et al., 2018; Moss et al., 2020; Parker et al., 2022). This was unexpected, as endurance athletes generally are seen as more susceptible to menstrual disturbances, compared to team-sport athletes (Mountjoy et al., 2014). Similar to the findings from Rogers et al. (2021), other features of the female athlete triad (Triad) were less prevalent, that is, DE (10%) and attenuated BMD (2%), than several of the broader symptoms of REDs. Contrary to previous studies on elite athletes, we found no statistically significant differences between the AME and EUM groups for any indicators of REDs outside of menstrual status (Heikura, Uusitalo, et al., 2018; Tornberg et al., 2017). This underscores the challenges in accurately identifying athletes with REDs, such as the potential factors contributing to menstrual irregularities. Since many of the body systems outlined by the REDs model still lack robust evidence, future research should focus on solidifying the scientific basis for the numerous outcomes proposed by the REDs framework.

4.1.1 | Blood markers

Impairments to the hormonal and metabolic milieu following LEA have been described in detail previously (Areta et al., 2021; Elliott-Sale et al., 2018). Nonetheless, few large-scale studies have provided causal evidence for the broad range of hormonal markers linked to the syndrome (Elliott-Sale et al., 2018; Stellingwerff et al., 2023). The current cohort exhibited a considerable prevalence of attenuated FT_3 (i.e., 13), which is listed as a primary indicator of REDs. While studies have reported that T_3 may be affected by within-day energy deficiency, the observed attenuation in FT_3 is likely linked to metabolic downregulation caused by problematic LEA, given the close association of T_3 and TSH with metabolic function (Fahrenholtz et al., 2018; Stellingwerff et al., 2023).

Elevated LDL, which is considered a secondary indicator, had a prevalence of 22% in the current study. However, no difference between the AME and EUM groups was observed. Rickenlund et al. reported that AME was associated with unfavorable lipid profiles in female endurance athletes, analogous to findings reported among individuals with anorexia nervosa (Rickenlund et al., 2005). Nonetheless, the difference in body composition between the present investigation and that study is substantial. Therefore, it is unlikely that the relatively high occurrence of elevated LDL observed can be directly attributed to LEA but rather is normally distributed throughout the cohort in our study. Leptin, another important metabolic regulator associated with LEA has been highlighted as a promising indicator for REDs (Heikura et al., 2021). Again, our findings seem to coincide with those of Rogers et al. (2021) who observed no relationship between increased risk of REDs and

TABLE 3 Overall and position-specific characteristics and mean values.

Measure	Overall (60)	Defender (20)	Midfielder (21)	Attacker (13)	Goalkeeper (6)	*p*-value
Height (cm)	168.9 ± 6.0	168 ± 6	169 ± 6	170 ± 7	173 ± 3	0.371
Body mass (kg)	64.1 ± 6.3	62.4 ± 5.6	62.9 ± 5.2	63.6 ± 5.3	74.7 ± 5.8	**<0.001**
%Fat mass	24.7 ± 4.2	23.4 ± 3.2	25.2 ± 3.5	23.8 ± 4.2	29.6 ± 6.3	**0.009**
BMI (kg/m^2)	22.4 ± 1.7	22.2 ± 1.1	22.1 ± 1.6	22.1 ± 1.2	25.1 ± 2.1	**<0.001**
FFM (kg)	49.3 ± 4.7	48.7 ± 4.9	47.9 ± 3.8	49.2 ± 5.0	56.5 ± 2.0	**<0.001**
RMR (kcal.kg/FFM/day)	29.2 ± 5.3	27.6 ± 7.2	29.3 ± 3.1	30.7 ± 5.5	30.4 ± 2.8	0.382
RMR_{Ratio}	0.96 ± 0.3	0.93 ± 1.0	0.94 ± 0.2	0.98 ± 0.2	1.1 ± 0.1	0.282
BMD hip Z-score	2.1 ± 1.0	2.2 ± 0.9	1.7 ± 1.0	2.1 ± 0.7	2.9 ± 1.1	**0.035**
BMD lumbar Z-score	1.2 ± 1.0	1.3 ± 0.9	0.9 ± 1.0	1.1 ± 0.9	2.1 ± 0.9	0.061
Blood glucose (mmol/L)	4.6 ± 0.5	4.8 ± 0.7	4.6 ± 0.5	4.5 ± 0.4	4.4 ± 0.3	0.251
TSH (mIU/L)	1.9 ± 1.1	1.9 ± 0.9	1.8 ± 1.1	1.8 ± 1.2	2.0 ± 1.3	0.983
FT_3 (pmol/L)	4.9 ± 0.7	4.9 ± 0.5	4.9 ± 0.5	5.1 ± 1.1	4.8 ± 0.6	0.873
FT_4 (pmol/L)	15.8 ± 1.9	16.6 ± 2.0	15.8 ± 1.9	15.3 ± 1.7	14.8 ± 0.6	0.133
Ferritin (μg/L)	50.8 ± 30.5	50.1 ± 30.0	57.8 ± 36.5	36.2 ± 10.0	61.2 ± 33.9	0.192
LDL (mmol/L)	2.5 ± 0.6	2.4 ± 0.4	2.4 ± 0.6	2.7 ± 0.7	2.3 ± 0.6	0.448
Leptin (ng/mL)	7.8 ± 5.5	7.4 ± 3.6	8.3 ± 6.2	6.2 ± 2.6	10.7 ± 10.8	0.389
Total cholesterol (mmol/L)	4.3 ± 0.6	4.2 ± 0.8	4.3 ± 0.5	4.5 ± 0.8	4.0 ± 0.7	0.285
Cortisol (nmol/L)	473.1 ± 231.2	599 ± 189	412 ± 227	408 ± 190	418 ± 140	**0.034**
IGF-1 (nmol/L)	29.1 ± 7.6	28.8 ± 9.4	29.6 ± 6.1	28.5 ± 9.4	29.1 ± 5.0	0.979
CTX-1 (μg/L)	0.75 ± 0.3	0.74 ± 0.4	0.76 ± 0.2	0.69 ± 0.3	0.81 ± 0.2	0.872
P1NP (μg/L)	103.9 ± 56.4	105.5 ± 78.0	104.8 ± 35.7	94.8 ± 48.5	115.7 ± 24.0	0.897

Note: *p* values represent the ANOVA analysis.

attenuated levels of leptin. Regarding cortisol, the fact that 25% presented with high levels should be interpreted with caution as this hormone is known to be sensitive to several factors, including stress, which may explain the high occurrence in the present study. We observed a statistically significant difference between defenders and other player positions for this hormone but cannot attribute this difference to any specific reason, highlighting the probability of a spurious finding.

4.1.2 | Bone health

Severe LEA is shown to have direct effects on BMD in female athletes (Mountjoy et al., 2018) and bone remodeling is influenced by factors such as mechanical loading and nutrition (Santos et al., 2017). A Z-score of < - 1 is usually applied when utilizing BMD as an indicator of REDs (Mountjoy et al., 2014). However, the universal application of this threshold regardless of sport and consideration of mechanical loading has been under scrutiny. Football is considered a high-impact sport, potentially making the usage of this threshold unsuitable due to the associated osteogenic effects. In this cohort, only one participant had compromised BMD using the < - 1 threshold. In total, seven players fell below the set threshold if applying a Z-score of <0 as proposed by Jonvik et al. (2022). As several of these players also elicited other signs of REDs, these findings could imply that a Z-score of <0 is more appropriate for detecting low BMD in football players. The support for a potential change in Z-score threshold is strengthened by the fact that 13 of the players in this cohort reported a history of stress fractures. DXA does not distinguish between cortical and trabecular bone mass, and bone morphology may also play a role in the development of stress fractures (O'Leary et al., 2021). Hence, the application of bespoke Z-score thresholds for impact sports such as football warrants further investigation. For markers of bone metabolism, the prevalence of compromised levels of P1NP and CTX-1 associated with bone remodeling and resorption was zero and 8%, respectively. Thus, regardless of the Z-score threshold applied, the bone markers confirm the low prevalence of compromised BMD, similar to what has been reported earlier (Moss et al., 2020). This also prompts the question of whether BMD is sensitive enough as an indicator of REDs in sports with high amounts of mechanical loading.

4.1.3 | Self-reported data and psychological factors

In total, 10% of the athletes were categorized with DE as measured by the EDE-Q-11. This is consistent with recent findings by Abbot et al. measured with the Eating Attitudes Test 26 (Abbott et al., 2021). The present study revealed a generally low prevalence of psychological factors associated with REDs notwithstanding the correlations observed between measures of DE, anxiety and depressive symptoms, and sleep disturbances. These are all the variables outlined in the updated IOC consensus statement (Stellingwerff et al., 2023). Hence, our results indicate that DE should elicit a probing for other psychological problems or vice versa. Such intercorrelation aside, the notable low prevalence of psychological distress in our cohort and the modest correlation with other REDs indicators questions the presumed inherent relationship between psychological distress and REDs (Mountjoy et al., 2023). Several studies have reported that female football players exhibit insufficient energy and carbohydrate intake, including a recent investigation encompassing large parts of the present study cohort (Dasa et al., 2023; Morehen et al., 2022). Merely, 58% of individuals in the current study reported intentionally augmenting their EI in response to rigorous training sessions and matches. Whether deliberate or inadvertent, these findings underscore that female footballers do not adequately "fuel for the work required" (Dasa et al., 2023). In light of recent evidence delineating the adverse effects of low carbohydrate availability and its role in the emergence or REDs (Mountjoy et al., 2023), it is crucial to direct focus toward enhancing nutritional literacy among female football players in general.

4.1.4 | Methodological considerations

Due to our reliance on self-reported outcomes for certain variables, we did not distinguish between high and low-risk stress fractures or AME and oligomenorrhea (Stellingwerff et al., 2023). Moreover, self-reported data may not effectively capture subtle differences used to categorize individuals, leading us to categorize stress fractures as one group and all menstrual irregularities as AME. In sum, this could potentially lead to a higher reported prevalence of these measures. Although several teams testing at different times of the season were included in the study, our data only provide a "snapshot" of the physiological and psychological profile of the players. The prevalence of indicators associated with REDs may change during a season, and this should be acknowledged when interpreting our findings. This is pertinent considering a possible memory recall bias with respect to the subjectively assessed indicators (Pannucci et al., 2010). Contrarily, since most of the indicators outlined by the REDs model are hypothesized to result from problematic LEA (Mountjoy et al., 2014, 2018), the probability of capturing REDs even in a cross-sectional design should be good. Nevertheless, future prevalence studies should be prospectively designed using repeated measures to capture the evolvement of symptoms throughout the annual season.

5 | CONCLUSION

The observed prevalence of REDs indicators ranged from low to very high with a notable segment of the players exhibiting a combination of primary and secondary indicators. The high proportion of players exhibiting no primary (71%), secondary (57%), or associated (30%) indicators suggests that, on a group level, female football players are not at a pronounced risk for REDs. Nevertheless, the fact that 22% were identified as at risk for REDs by the CAT 2 stratification tool suggests that individual players may be susceptible to the development of the syndrome. Hence, team health and performance staff should be aware of indicators and their varying degree of association with REDs to facilitate individualized follow-up when necessary.

6 | IMPLICATIONS

We propose that incorporating universal health promotion strategies should be prioritized for female football players. Such strategies may include efforts to ensure adequate supply of carbohydrate intake before, during, and after matches or hard training sessions. This recommendation is supported by previous findings indicating that female footballers typically consume inadequate amounts of carbohydrates (Dasa et al., 2023; Morehen et al., 2022). Given that insufficient nutritional intake and lack of nutritional periodization can increase the risk of developing problematic LEA, addressing these measures will likely reduce the exposure to risk factors associated with REDs.

ACKNOWLEDGMENTS

The authors would like to thank the athletes, coaches and staff who made this study possible. Further, we would like to thank the Western Norway University of Applied Sciences and Haukeland University Hospital for the generous access to facilities and assistance in the data collection and analyses. This study was funded by the Tromsø Research Foundation and the UiT–Arctic University of Norway.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest.

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