BMJ Open Sport & Exercise Medicine

Energy expenditure, dietary intake and energy availability in female professional football players

Marcus Smavik Dasa ,[1] Oddgeir Friborg,[2] Morten Kristoffersen,[3] Gunn Pettersen,[1] Guy Plasqui,[4] Jorunn Kaiander Sundgot-Borgen,[5] Jan H Rosenvinge [2]

To cite: Dasa MS, Friborg O, Kristoffersen M, *et al*. Energy expenditure, dietary intake and energy availability in female professional football players. *BMJ Open Sport & Exercise Medicine* 2023;**9**:e001553. doi:10.1136/bmjsem-2023-001553

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjsem-2023-001553).

Accepted 15 February 2023

[1]Department of Health and Care Sciences, UiT The Arctic University of Norway, Tromso, Norway
[2]Department of Psychology, UiT The Arctic University of Norway, Tromso, Norway
[3]Department of Sport, Food and Natural Sciences, Western Norway University of Applied Sciences, Bergen, Norway
[4]Department of Nutrition and Movement Sciences, Maastricht University, Maastricht, Netherlands
[5]Department of Sports Medicine, Norwegian School of Sports Sciences, Oslo, Norway

Correspondence to
Marcus Smavik Dasa;
marcus.smavik.dasa@uit.no

ABSTRACT

Objectives To quantify energy expenditure and intake in professional female footballers playing on a national and/or international level. Second, to determine the prevalence of low energy availability among these players, defined as <30 kcal/kg fat-free mass (FFM)/day.

Methods Fifty-one players completed a 14-day prospective observational study during the 2021/2022 football season. Energy expenditure was determined using the doubly labelled water method. Energy intake was assessed using dietary recalls, while global positioning system determined the external physiological load. Descriptive statistics, stratification and the correlation between explainable variables and outcomes were conducted to quantify the energetic demands.

Results The mean energy expenditure for all players (22±4 years) was 2918±322 kcal. Mean energy intake was 2274±450 kcal, resulting in a discrepancy of ~22%. Carbohydrate intake was below the recommended guidelines on match day at 4.5±1.9 g/kg. The mean energy availability was 36.7±17.7 kcal/kg FFM/day on matchday and 37.9±11.7 kcal/kg FFM/day on training days, resulting in a prevalence of 36% and 23% for low energy availability during the observational period, respectively.

Conclusion These elite female football players displayed moderate energy expenditure levels and failed to meet the recommended levels of carbohydrate intake. In conjunction with inadequate nutritional periodisation, this will likely hamper performance through inadequate muscle glycogen resynthesis. In addition, we found a considerable prevalence of low energy availability on match and training days.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Female international players show inadequate energy intake in relation to their energy expenditure.
⇒ Evidence on the prevalence of low energy availability in female football players is currently conflicting due to few high-quality studies.
⇒ No studies have investigated in-season energy requirements and practices in both national and international level players using doubly labelled water.

WHAT THIS STUDY ADDS

⇒ Considering current guidelines, domestic and international female football players display reduced carbohydrate intake independent of player position.
⇒ Female football players may be at risk for low energy availability; however, the prevalence is likely inflated due to under-reporting energy intake.
⇒ There were no positional differences in total daily energy expenditure.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Players and team support staff should focus on nutritional periodisation to increase energy intake, notably through carbohydrates, to maximise performance and reduce negative health consequences associated with low carbohydrate and energy availability.

INTRODUCTION

Professional female football players generally cover 9–11 km during a match, with 22%–28% in high-intensity running and sprinting.[1 2] A typical 7-day in-season period may consist of 1–2 matches plus 4–6 additional training sessions.[3] Adequate energy intake (EI) (minimum above 30 kcal/kg fat-free mass (FFM)/day) is paramount to optimally performing and maintaining immune and metabolic functions.[4] Correct information about energy expenditure (EE) is essential for quantifying food requirements[4] to sufficiently fuel the energetic demands during matches and training. Although the physiological demands of female football are established in the literature,[2 5] studies regarding EE are scarce, and most estimates rely on accelerometers or global positioning systems (GPS).[3 6–8] In contrast, studies on male professional football players have used the gold standard method of doubly labelled water (DLW) and dietary information to quantify the daily energetic requirements.[9 10] Only one study using DLW in female football players exists to date.[11] Yet, this sample of players on international duty limits the findings, as it transfers less well to in-season national-level teams. Hence,

scaled up DLW studies are needed to ascertain the energetic requirements of elite female football players.

During a football match, 60%–70% of the total energy requirements are supplied by carbohydrates (CHO),[12] making it the most important macronutrient for performance.[4 10] A recent expert group statement from UEFA recommends a daily CHO intake of 3–8 g/kg/day, depending on the intensity and volume of the activity (ie, training or match).[12] Previous studies among professional male[9 10] and female[11] players have shown that the total CHO intake is well below the recommended guidelines. In addition to CHO, protein is also essential to support skeletal muscle recovery and adaptation following exercise.[13] In contrast to CHO, the daily recommendations of 1.2–1.6 g/kg protein are generally met among female football players.[3 11]

There is an increasing focus on implementing female-specific research within sports medicine and nutrition.[14] This includes the female athlete triad and the Relative Energy Deficiency in Sports (RED-S),[15 16] in which low energy availability (LEA) is the main aetiological factor. As CHO constitutes the main macronutrient to meet total energetic needs in football players, the subsequent low intake reported in recent literature may not only reduce performance but also cause the development of negative symptoms described by the RED-S model.[3 11 17] To date, prevalence estimates of LEA among female football players are wide-ranging, between 20% and 80%,[3 6 11 18] and require more and larger high-quality studies. The primary aim of the present study was to quantify the total daily EE (TDEE) and EI in national and international female football players. Second, we aimed to estimate the prevalence of LEA in this sample.

MATERIAL AND METHODS

Participants

Fifty-one players from the Norwegian premier (two teams) and first division (one team) were included (table 1). Eight players were currently representing their national team, while seven players represented their designated youth national team. Using the recently published participant classification framework,[19] players were classified at tier 3 (national) or 4 (international) level. All players agreed to and signed a written consent form before partaking in the study. Inclusion criteria were as follows: (1) above 16 years of age, (2) no injury or illness affecting normal activity level and (3) being eligible for first-team competition matches. Seven players were excluded due to reported injury or illness during the study period (see online supplemental material for participant information).

Study design

Using a prospective observational study design, data collection occurred in three phases during the 2021 and 2022 Norwegian season (October–May). During the 14-day study period, players continued their regular living patterns, including training and match obligations.

Body composition

Body composition was measured using whole body fan beam dual-energy X-ray absorptiometry measurement (Prodigy, Encore, SP 4.1, V.18, GE medical systems, Madison, Wisconsin, USA) by a certified technician, following recommended guidelines.[20] All participants received a personal scale (Logic, London, UK) to which they were able to measure their body mass (BM) at home. BM was measured in the morning after the first voiding on days 1, 7 and 15 to the nearest±0.1 Kg. Before the data collection, participants were instructed to complete the measurement and send the results to a research team member following each weigh-in.

Training and match load

Training sessions and match performance were monitored using a GPS placed between the player's scapulae in a custom vest (Statsports, Newry, Ireland). Predetermined variables were recorded to quantify the total distance covered and metres in speed zones to determine the external physiological load. Standardised thresholds to determine workload intensity were used (table 2 specifies the various speed zones ranging from 1 to 5, coinciding with the measurement of EE by DLW). The coaching staff were familiar with the usage of the GPS; however, it was not applied to recovery sessions related to matchdays. Goalkeepers were excluded from the training and match load analysis.

Energy intake

EI was assessed by three 24-hour diet recalls, conducted using nutritional analysis software developed for research purposes with access to the Norwegian nutritional register (Myfood24, Leeds, UK). The software has previously been

Table 1 Participant characteristics

	Total (n=51)	Defender (n=15)	Midfielder (n=20)	Attacker (n=11)	Goalkeeper (n=5)
Age	22±4	23±4	21±3	21±5	20±3
Height (cm)	169±7	167±6	168±6	168±6	173±3
Body mass (kg)	63.9±6.6	62.4±5.9	62.9±5.2	63.4±5.8	75±6.4
Free fat mass (kg)	49.3±4.9	48.7±5.2	48.1±3.7	49.2±4.9	56.8±2.1
Body fat%	24.6±4.2	23.6±3.2	24.7±3.2	23.6±4.4	30.4±4.2

Table 2 Total distance and time in speed zone on training and match days

	Training (n=51)	Match (n=38)**
Total distance, meters (m)	5063±982	10309±1080
Speed zone 1, m (0–5.4 km/hour)	1975±360	2766±391
Speed zone 2, m (5.4–10.8 km/hour)	1867±432	3894±506
Speed zone 3, m (10.8–14.4 km/hour)	705±212	2072±345
Speed zone 4, m (14.4–19.8 km/hour)	379±146	1269±296
Speed zone 5, m (>19.8 km/hour)	90±91	323±169
Exercise energy expenditure (kcal)	422±83	826±98

Note: **p<0.01.
**p<0.001 for all comparisons.

validated against traditional dietary recalls and weighted dietary records in adults and adolescents, and details regarding the completion are explained elsewhere.[21 22] The recall method was chosen to ensure compliance. Before the data collection, the players were allowed to test the software, received general usage guidance and could ask questions to settle uncertainties. For players unable to conduct the diet recall in their native language (n=4), a registered dietician conducted the diet recall with the participants in English using video or in-person meetings. A registered dietician reviewed completed recalls. If any part of the registered EI was deemed insufficient or unclear, the dietician would validate this with the participant via telephone or text. The diet recalls were performed on random days corresponding to one match, training and rest days. Match days were considered valid if a player completed 60 min of the game. For players not fulfilling this requirement, two diet recalls were conducted on training days to ensure an equal number of completed diet recalls.

Energy expenditure

TDEE was measured using DLW. The protocol used is developed by Maastricht university and described elsewhere.[23] In brief, individual doses were calculated from total body water, estimated from body mass index). The players collected a baseline urine sample at home, following training, in the evening before going to bed (day 0). After collecting the baseline sample, the participants consumed a weighted amount of $^{2}H_2O$ and $H_2{}^{18}O$, providing a body water enrichment of approximately 155 p.p.m. for H^2 and 235 p.p.m. for ^{18}O. Following this, urine samples were collected on days 1, 7 and 14 from the second voiding in the morning. A second urine sample was collected in the afternoon or evening on the same days. Participants were instructed in urine sample collection and conducted this procedure at home using standardised urine cups. Urine samples were stored in the participants' homes refrigerators for no longer than 24 hours. A research team member then collected the urine sample within the given time frame. Urine samples were immediately taken to the lab, aliquoted to a 2 mL airtight glass vial and stored in a −20°C fridge until analysis. Urine samples were analysed with an isotope ratio mass spectrometer (Thermo Scientific Delta V Advantage; Thermo Fischer Scientific, Bremen, Germany). Carbon dioxide production was calculated from the difference between the elimination rates of ^{2}H and ^{18}O using the equation as recommended by the IAEA DLW database consortium.[24] TDEE was calculated from carbon dioxide production, assuming a respiratory quotient of 0.85. Exercise EE (EEE) was also collected from match and training GPS data to quantify the players' EA using the metabolic power equation calculated by GPS software.[25] Physical activity level (PAL) was calculated from TDEE (DLW) and measured resting metabolic rate (RMR) (Vyntus CPX, CareFusion, Hoechberg, Germany, Sentrysuit v. 2.21.4), as well as the Cunningham and Harris Benedict equations, for comparative purposes. This was possible as players completed RMR measurements during the data collection, following the best practice guidelines for RMR measurements,[26] as part of a larger project.[27] A more thorough methodological description is available elsewhere.[28]

Energy availability

EA on match and training days were calculated using the estimated EEE derived by the GPS using the formula (EA = [EI – EEE] / FFM (Fat-free mass)).[29] The estimation of the average EA during the 14 days was calculated using the method described by Morehen *et al*.[11] Specifically, the thermic effect of food (TEF) was assumed to be 10% across individuals,[30] estimating activity EE (AEE) possible through the formula (AEE=TDEE – [RMR+TEF]) and subsequently EA (EA=EI – [AEE/FFM]). LEA was defined as <30 kcal/kg FFM/day, consistent with previous literature.[15 29]

Statistical analyses

Descriptive statistics are presented separately for the total training load on match and training days. Average daily EI was calculated using the weighted mean from training, match and rest days. EI on different days was allocated a percentage weight based on their frequency during the

Table 3 Energy and macronutrient intake on training, match and rest days

		Training	Match	Rest
Energy intake	Kcal/day	2247±485	2468±834	2195±834
Carbohydrate	g	253±73	289±115	244±101
	g/kg	4.0±1.3	4.5±1.9	3.9±1.6
Protein	g	102±23	105±40	95±35
	g/kg	1.6±0.4	1.7±0.7	1.5±0.6
Fat	g	85.3±25	93±1.4	86±42
	g/kg	1.3±0.4	1.4±0.7	1.3±0.7

study period. The difference between TDEE and EI, physiological load, and the differences between energy and macronutrient intake on training, match and rest days were analysed using paired Student's t-tests, corrected for familywise error and the Holm's test. The mean EI and positional differences in TDEE and EI were assessed using one-way analysis of variance (ANOVA) or repeated measures ANOVA. Post hoc Holm's correction was made if a significant main effect was present. The relationship between TDEE and possible explanatory variables was tested using Pearson's r. The statistical analysis followed best practice guidelines[31] and was conducted with JASP (V.0.16.4). The alpha level was set to p<0.05, and all data are presented as mean±SD unless otherwise specified.

RESULTS

Training and match load

Table 2 presents the average physiological work completed by the players on match and training days. The mean number of match and training days were 1.7±1.5 and 10.7±0.9, respectively. For all speed zones (1–5), the intensity was higher (p<0.001, table 2) on the match vs training days. There was also a statistically significant difference in the total distance on the match vs training days (p<0.001).

Energy intake

The average weighted EI was 2274±450 kcal. Table 3 provides an overview of the energy and macronutrient intake on training, match and rest days. There was significantly higher EI on match (2468±834 kcal) vs rest days (2195±834 kcal, p=0.046), but not for training (2247±485) vs match (p=0.094) or training vs rest days (p=0.647). For CHO intake, there was a significant difference between training (4.0±1.3 g/kg) and match days (4.5±1.9 g/kg, p=0.025) and match vs rest days (3.9±1.6 g/kg, p=0.004). There was no significant difference between training and rest days (p=0.429).

We found no statistical differences in protein or fat intake on match (protein 1.7±0.7 g/kg, fat 1.4±0.7 g/kg), training (protein 1.6±0.4,) g/kg, fat 1.3±0.4) g/kg) and rest days (protein 1.5±0.6 g/kg, fat 1.3±0.7 g/kg) or in terms of energy and macronutrient intake according to player positions. Table 4 provides an overview of EI and macronutrient distribution for the different groups. For macronutrient and caloric distribution, see online supplemental figures 1 and 2, online supplemental file 1.

Energy expenditure

The average TDEE was 2918±322 kcal (45.4 kcal/kg). During the measuring period, the players' BM did not significantly change, with a mean of 65±7.9 kg and 64.7±7.8 kg for days 0 and 14 (p>0.05), respectively. Hence, the discrepancy between EE and EI indicates under-reporting nutritional intake by ~22%. The average PAL value was 2.0±0.3 (measured RMR), 1.98±0.2 (Harris-Benedict equation) and 1.89±0.2 (Cunningham equation), respectively, all displaying moderate PAL (table 4 and figure 1). There was a statistically significant positional difference in TDEE between goalkeepers and defenders (p=0.010), midfielders (p=0.001) and attackers (p=0.008), respectively (table 4). The analysis demonstrated statistically significant differences in BM between goalkeepers and defenders (p<0.001), midfielders (p<0.001) and attackers (p=0.001), respectively. Lastly, we

Table 4 Daily energy expenditure and macronutrient intake for the whole group and different player positions

TDEE	Kcal/day	2918±322	2926±274	2817±325	2874±325	3393±258
	kcal/kg	45.4	46.9	44.8	45.3	45.2
	$PAL_{Measured}$	2.0±0.3	2.1±0.3	1.9±0.3	2.0±0.2	2.0±0.4
	$PAL_{Harris\text{-}Benedict}$	1.98±0.2	2.0±0.2	1.9±0.1	2.0±0.2	2.1±0.2
	$PAL_{Cunningham}$	1.89±0.2	1.9±0.1	1.9±0.1	1.9±0.2	2.0±0.2
Daily EI	Kcal/day	2274±450	2393±516	2322±442	2137±321	1985±419
Carbohydrate	g	250±70	258±89	260±68	227±37	229±57
	g/kg	3.9±1.1	4.2±1.4	4.1±1.1	3.6±0.7	3.3±0.8
Protein	g	99±21	104±21	99±22	90±16	99±15
	g/kg	1.5±0.4	1.7±0.4	1.6±0.3	1.4±0.3	1.3±0.2
Fat	g	84±24	92±19	84±22	80±31	71±18
	g/kg	1.3±0.4	1.5±0.3	1.3±0.4	1.2±0.5	0.9±0.3

EI, energy intake; PAL, physical activity level; TDEE, total daily energy expenditure.

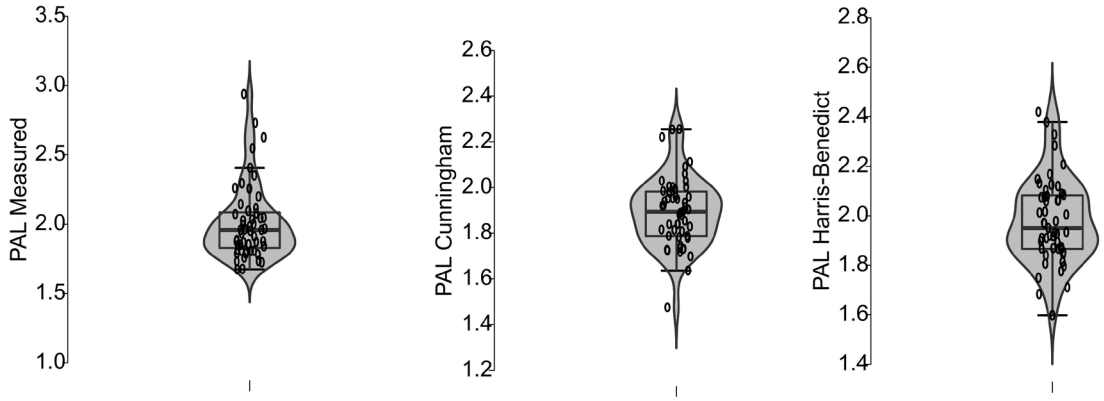

Figure 1 Mean and individual PAL based on measured RMR (A), the Cunningham equation (B), and the Harris-Benedict equation (C). PAL, physical activity level; RMR, resting metabolic rate.

found a significant linear relationship between TDEE-BM (r=0.64, p<0.001), TDEE-FFM (r=0.73, p<0.001), TDEE-height (r=0.49, p<0.001), TDEE-RMR (r=0.58, p<0.001) and TDEE -AEE (r=0.76, p<0.001) (figure 2). The corresponding non-linear quadratic effects were not significant.

Energy availability

EA derived from EEE (table 2) showed that the average EA was 36.7±17.7 kcal/kg FFM/day on matchday and 37.9±11.7 kcal/kg FFM/day on training days, with a prevalence of 36% and 23% for LEA, respectively. Average EA derived from AEE (TDEE – [RMR+TEF], was 21.6±10.7 kcal/kg FFM/day, indicating a prevalence of 74% for LEA.

DISCUSSION

This study aimed to determine TDEE through the DLW method, together with the quantification of EI and prevalence of LEA in professional female football players.

Energy expenditure

TDEE during the 14 days was 2918±322 kcal, which may be considered moderate.[32] Furthermore, the estimated PAL based on RMR demonstrates that the Harris-Benedict equation is more accurate for female players

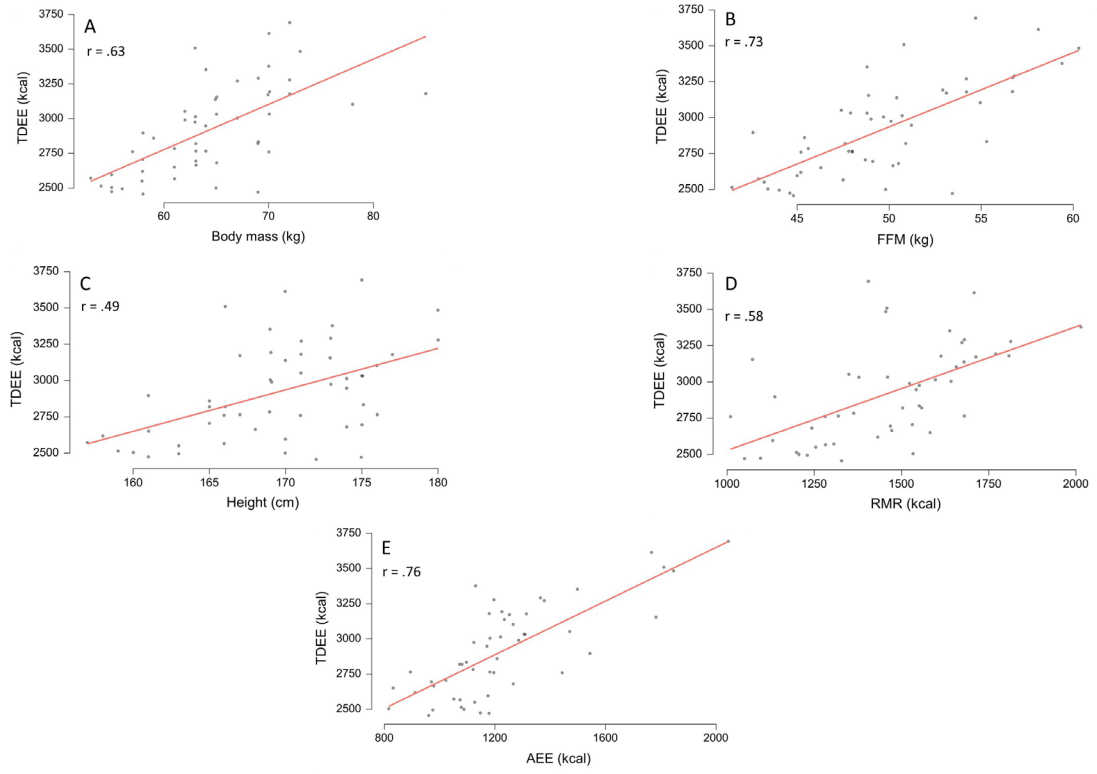

Figure 2 Correlation between TDEE (kcal) and explanatory variables body mass (A), FFM (B), height (C), RMR (D) and AEE (E). AEE, activity energy expenditure; FFM, fat-free mass; RMR, resting metabolic rate; TDEE, total daily energy expenditure.

than the Cunningham equation. Our results are similar to those of Morehen *et al*,[11] who speculated that energy requirements on the international level are greater than national-level teams. Our results contraindicate this statement and, as such, provide an evidence base for future nutritional guidelines, including both international and national level players. Our results also show that TDEE in elite female players ranges between 35.8 and 55.7 kcal/kg, analogous to elite male players.[9 10] These findings confirm that based on EE, nutritional recommendations should not differ between sexes.[12] Nevertheless, several mechanisms may affect substrate metabolism, and more research regarding potential sex differences is needed.[33] Although the energetic demand of female football seems moderate, the strain on muscles in terms of eccentric loading through repeated accelerations and decelerations is immense and must be accounted for.[34 35]

Energy intake

Given the mean EI of 2274±450 kcal, the use of DLW assessed TDEE as a reference, and the non-significant changes in BM, the level of under-reporting in EI (about 22 %), is comparable to other athlete studies.[36] Similar studies in elite female football players have reported estimated EI ranging from 1923 to 2387 kcal.[3 8 11 18] Thus, our findings converge with previous studies on the absolute level of EI and previous findings of under-reporting EI.[11] In the most recent UEFA expert group statement on nutrition in elite football, 6–8 g/kg of CHO is recommended on match day.[12] However, in our sample, only 24% of players met these recommendations. The same expert group statement recommends 3–8/kg on training days, depending on duration, intensity and player goals.[12] Our results show that over 50% of players had CHO intakes of 4 g/kg or lower on training days, which is likely inadequate for most of this cohort. If corrected for under-reporting by increasing EI by 22%, assuming equal distribution of macronutrient intake, the average CHO intake is still only 5.4 g/kg on match days, while over 30% of players still present with an intake of 4 g/kg or lower. These findings indicate that female elite football players generally consume inadequate amounts of CHO, which may hamper performance as muscle glycogen stores are unlikely to be adequately replenished for matches.[34 35] Our findings also provide evidence of minimal periodisation of caloric intake in relation to external work performed, contrary to current guidelines.[12 37] Conversely, protein intake was well within the recommendations for training, match and rest days. The disproportionately low CHO intake in the current study may be interpreted in light of recent findings among female professional football players,[38] stating that reduced adherence to current nutritional guidelines may be due to misconceptions about the impact of CHO on body composition, contributing to weight gain.

Energy availability

Using the classification by Loucks *et al*,[29] our findings that 23% of the players presented with LEA on training days and 36% on match days align with previous findings among tier 3 and 4 athletes,[3 18] in principle supporting the notion that female football players may be at risk for LEA during the season. Applying the same correction factor by increasing EI by 22%, the prevalence of LEA was 7% on training days and 29% on match days, suggesting a considerable reduction in actual incidence. In terms of the estimated average EA for the entire 14-day period, 76% of the players presented with LEA. However, this number was reduced to 45% when applying the correction factor. Again, these numbers are comparable to recent findings using similar methods but higher than those reported using EEE to quantify EA.[3 6 39] As our estimates converge with previous findings, this indicates that under-reporting may also have been present in previous studies.

Strengths and limitations

Although being the first study to provide measures of TDEE using DLW in a sample of national and international female football players, there are limitations that need consideration. The first concerns the use of the self-reported dietary method for assessing EI. However, this generally applies to studies using dietary assessments. In addition, the 24-hour diet recall method has been shown to provide estimates ranging between 8% and 30% of under-reporting, thus, providing better accuracy than most comparable methods.[40] By applying average weighted EI based on match, training and rest days, similar to previous studies,[10] we were able to provide assessments of EI with a high degree of compliance from the participants. Nevertheless, there appears to be some systematic error related to the measurement of EI in this study.[36] A second possible limitation concerns the estimation of EEE, which was calculated using metabolic power based on GPS, as this device has been shown to underestimate high-intensity bouts of intermittent exercise.[41] Regarding EA, we acknowledge the methodological difficulties of applying overall AEE. However, we believe it provides insight for comparisons between different measures of EA. Lastly, our classification of LEA (<30 kcal/kg FFM/day) is based on laboratory studies with high internal validity, whereas new evidence suggests that daily EA is more heterogeneous.[42] This increases some uncertainty in the estimates of LEA.

CONCLUSION AND IMPLICATIONS

In conclusion, in-season international and national female football players show moderate levels of TDEE, comparable to what has been reported in professional males. The fact that female players fail to meet the recommended nutritional demands (notably CHO) should also be addressed by team supports staff and players. Lastly, our data indicate that the prevalence of LEA among

female football players may be inflated due to under-reporting of EI.

Twitter Marcus Smavik Dasa @marcusdasa

Acknowledgements The authors thank the athletes, coaches and staff who made the data collection possible through dedicated collaboration. We also thank the Western Norway University of Applied Sciences and the Haukeland University Hospitalfor the generous access to facilities during the data collection.

Contributors The study was designed by MSD, MK, JHR, GPe, JKSB and OF. Data collection and analysis was conducted by MSD, MK and GPl. MSD serves as guarantor. All authors have been involved in the manuscript preparation, revisions and they have all authorised the final version.

Funding The study received funding from the Tromsø Research Foundation and from UiT—The Arctic University of Norway.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study involves human participants and was approved by the Regional Committee for Medical and Health Research ethics (2016/787) and Norwegian Center for Research Data (807592). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. Data may be obtained from a third party and are not publicly available. Sharing of anonymous data will be considered on request.

ORCID iDs
Marcus Smavik Dasa http://orcid.org/0000-0002-0081-7753
Jan H Rosenvinge http://orcid.org/0000-0003-3485-9641

REFERENCES

1 Scott D, Haigh J, Lovell R. Physical characteristics and match performances in women's international versus domestic-level football players: a 2-year, league-wide study. *Science and Medicine in Football* 2020;4:211–5.
2 Randell RK, Clifford T, Drust B, *et al*. Physiological characteristics of female soccer players and health and performance considerations: a narrative review. *Sports Med* 2021;51:1377–99.
3 Moss SL, Randell RK, Burgess D, *et al*. Assessment of energy availability and associated risk factors in professional female soccer players. *Eur J Sport Sci* 2021;21:861–70.
4 Burke LM, Loucks AB, Broad N. Energy and carbohydrate for training and recovery. *J Sports Sci* 2006;24:675–85.
5 Datson N, Hulton A, Andersson H, *et al*. Applied physiology of female soccer: an update. *Sports Med* 2014;44:1225–40.
6 Magee MK, Lockard BL, Zabriskie HA, *et al*. Prevalence of low energy availability in collegiate women soccer athletes. *J Funct Morphol Kinesiol* 2020;5:96.
7 Reed JL, De Souza MJ, Kindler JM, *et al*. Nutritional practices associated with low energy availability in division I female soccer players. *J Sports Sci* 2014;32:1499–509.
8 Braun H, von Andrian-Werburg J, Schänzer W, *et al*. Nutrition status of young elite female German football players. *Pediatr Exerc Sci* 2018;30:157–67.
9 Anderson L, Orme P, Naughton RJ, *et al*. Energy intake and expenditure of professional soccer players of the English premier League: evidence of carbohydrate periodization. *Int J Sport Nutr Exerc Metab* 2017;27:228–38.
10 Brinkmans NYJ, Iedema N, Plasqui G, *et al*. Energy expenditure and dietary intake in professional football players in the Dutch premier League: implications for nutritional counselling. *J Sports Sci* 2019;37:2759–67.
11 Morehen JC, Rosimus C, Cavanagh BP, *et al*. Energy expenditure of female international standard soccer players: a doubly labeled water investigation. *Med Sci Sports Exerc* 2022;54:769–79.
12 Collins J, Maughan RJ, Gleeson M, *et al*. UEFA expert group statement on nutrition in elite football. current evidence to inform practical recommendations and guide future research. *Br J Sports Med* 2021;55:416:416–16.:.
13 Morton RW, McGlory C, Phillips SM. Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy. *Front Physiol* 2015;6:245:245.:.
14 Areta JL, Elliott-Sale KJ. Nutrition for female athletes: what we know, what we do ''t know, and why. *Eur J Sport Sci* 2022;22:669–71.
15 Mountjoy M, Sundgot-Borgen J, Burke L, *et al*. The IOC consensus statement: beyond the female athlete triad -- relative energy deficiency in sport (RED-S). *Br J Sports Med* 2014;48:491–7.
16 Stand P. The female athlete triad. *Med Sci Sports Exerc* 2007;39:1867–82.
17 Mountjoy M, Sundgot-Borgen JK, Burke LM, *et al*. IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *Br J Sports Med* 2018;52:687–97.
18 Reed JL, De Souza MJ, Williams NI. Changes in energy availability across the season in division I female soccer players. *J Sports Sci* 2013;31:314–24.
19 McKay AKA, Stellingwerff T, Smith ES, *et al*. Defining training and performance caliber: a participant classification framework. *Int J Sports Physiol Perform* 2022;17:317–31.
20 Nana A, Slater GJ, Stewart AD, *et al*. Methodology review: using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. *Int J Sport Nutr Exerc Metab* 2015;25:198–215.
21 Albar SA, Alwan NA, Evans CEL, *et al*. Agreement between an online dietary assessment tool (myfood24) and an interviewer-administered 24-h dietary recall in British adolescents aged 11-18 years. *Br J Nutr* 2016;115:1678–86.
22 Koch SAJ, Conrad J, Cade JE, *et al*. Validation of the web-based self-administered 24-h dietary recall myfood24-germany: comparison with a weighed dietary record and biomarkers. *Eur J Nutr* 2021;60:4069–82.
23 Westerterp KR, Wouters L, van Marken Lichtenbelt WD. The Maastricht protocol for the measurement of body composition and energy expenditure with labeled water. *Obes Res* 1995;3 Suppl 1:49–57.
24 Speakman JR, YamadaY, Sagayama H. A standard calculation methodology for human doubly labeled water studies. *Cell Rep* 2021;2:100203.
25 Osgnach C, Poser S, Bernardini R, *et al*. Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sports Exerc* 2010;42:170–8.
26 Compher C, Frankenfield D, Keim N, *et al*. Best practice methods to apply to measurement of resting metabolic rate in adults: a systematic review. *J Am Diet Assoc* 2006;106:881–903.
27 Rosenvinge JH, Dasa MS, Kristoffersen M, *et al*. Study protocol: prevalence of low energy availability and its relation to health and performance among female football players. *BMJ Open Sport Exerc Med* 2022;8:e001219.
28 Stenqvist TB, Melin AK, Garthe I, *et al*. Prevalence of surrogate markers of relative energy deficiency in male Norwegian olympic-level athletes. *Int J Sport Nutr Exerc Metab* 2021;31:ijsnem.2020-0368:497–506.:.
29 Loucks AB, Kiens B, Wright HH. Energy availability in athletes. *J Sports Sci* 2011;29 Suppl 1:S7–15.
30 Westerterp KR. Diet induced thermogenesis. *Nutr Metab (Lond)* 2004;1:5.
31 Mansournia MA, Collins GS, Nielsen RO, *et al*. A checklist for statistical assessment of medical papers (the CHAMP statement): explanation and elaboration. *Br J Sports Med* 2021;55:1009–17.
32 Sjödin AM, Andersson AB, Högberg JM, *et al*. Energy balance in cross-country skiers: a study using doubly labeled water. *Med Sci Sports Exerc* 1994;26:720–4.

33 Boisseau N, Isacco L. Substrate metabolism during exercise: sexual dimorphism and women's specificities. *Eur J Sport Sci* 2022;22:672–83.
34 Mohr M, Vigh-Larsen JF, Krustrup P. Muscle glycogen in elite soccer-a perspective on the implication for performance, fatigue, and recovery. *Front Sports Act Living* 2022;4:876534.
35 Krustrup P, Mohr M, Nybo L, *et al*. Muscle metabolism and impaired sprint performance in an elite women's football game. *Scand J Med Sci Sports* 2022;32 Suppl 1:27–38.
36 Capling L, Beck KL, Gifford JA, *et al*. Validity of dietary assessment in athletes: a systematic review. *Nutrients* 2017;9:1313.
37 de Sousa MV, Lundsgaard A-M, Christensen PM, *et al*. Nutritional optimization for female elite football players-topical review. *Scand J Med Sci Sports* 2022;32 Suppl 1:81–104.
38 McHaffie SJ, Langan-Evans C, Morehen JC, *et al*. Carbohydrate fear, skinfold targets and body image issues: a qualitative analysis of player and stakeholder perceptions of the nutrition culture within elite female soccer. *Sci Med Footb* 2022;6:675–85.
39 Dobrowolski H, Włodarek D. Low energy availability in group of Polish female soccer players. *Rocz Panstw Zakl Hig* 2020;71:89–96.
40 Burrows TL, Ho YY, Rollo ME, *et al*. Validity of dietary assessment methods when compared to the method of doubly labeled water: a systematic review in adults. *Front Endocrinol (Lausanne)* 2019;10:850:850.:.
41 Dasa MS, Friborg O, Kristoffersen M, *et al*. Accuracy of tracking devices' ability to assess exercise energy expenditure in professional female soccer players: implications for quantifying energy availability. *Int J Environ Res Public Health* 2022;19:4770.
42 Taylor HL, Garabello G, Pugh J, *et al*. Patterns of energy availability of free-living athletes display day-to-day variability that is not reflected in laboratory-based protocols: insights from elite male road cyclists. *Journal of Sports Sciences* 2022;40:1849–56.