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

Marcus Smavik Dasa, Oddgeir Friborg, Morten Kristoffersen, Gunn Pettersen, Guy Plasqui, Jorunn Kaiander Sundgot-Borgen, Jan H Rosenvinge

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.

INTRODUCTION

Professional female football players generally cover 9–11 km during a match, with 22%–28% in high-intensity running and sprinting. A typical 7-day in-season period may consist of 1–2 matches plus 4–6 additional training sessions. 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. Correct information about energy expenditure (EE) is essential for quantifying food requirements to sufficiently fuel the energetic demands during matches and training. Although the physiological demands of female football are established in the literature, studies regarding EE are scarce, and most estimates rely on accelerometers or global positioning systems (GPS). 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. Only one study using DLW in female football players exists to date. Yet, this sample of players on international duty limits the findings, as it transfers less well to in-season national-level teams. Hence,
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During a football match, 60%-70% of the total energy requirements are supplied by carbohydrates (CHO), 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 male9 10 and female11 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), 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.30 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>
<thead>
<tr>
<th>Table 1</th>
<th>Participant characteristics</th>
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<tbody>
<tr>
<td></td>
<td>Total (n=51)</td>
</tr>
<tr>
<td>Age</td>
<td>22±4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169±7</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>63.9±6.6</td>
</tr>
<tr>
<td>Free fat mass (kg)</td>
<td>49.3±4.9</td>
</tr>
<tr>
<td>Body fat%</td>
<td>24.6±4.2</td>
</tr>
</tbody>
</table>
TDEE was measured using DLW. The protocol used is developed by Maastricht university and described elsewhere. 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. 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$_2$O and H$_2$O$^{18}$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 2mL 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. 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. Physical activity level (PAL) was calculated from TDEE (DLW) and measured resting metabolic rate (RMR) (Vintus CPX, CareFusion, hoechberg, Germany, Sentsys 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, as part of a larger project. A more thorough methodological description is available elsewhere.

### 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)). The estimation of the average EA during the 14 days was calculated using the method described by Morehen et al. Specifically, the thermic effect of food (TEF) was assumed to be 10% across individuals, 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.

### 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

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

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

Note: **p<0.01. **p<0.001 for all comparisons.
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 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. 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. 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
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. Furthermore, the estimated PAL based on RMR demonstrates that the Harris-Benedict equation is more accurate for female players.

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**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.

**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., 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. These findings confirm that based on EE, nutritional recommendations should not differ between sexes. Nevertheless, several mechanisms may affect substrate metabolism, and more research regarding potential sex differences is needed. 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.

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. Similar studies in elite female football players have reported estimated EI ranging from 1923 to 2387 kcal. Thus, our findings converge with previous studies on the absolute level of EI and previous findings of under-reporting EI. In the most recent UEFA expert group statement on nutrition in elite football, 6–8 g/kg of CHO is recommended on match day. However, in our sample, only 24% of players met these recommendations. The same expert group statement recommends 3–8 g/kg on training days, depending on duration, intensity and player goals. 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. Our findings also provide evidence of minimal periodisation of caloric intake in relation to external work performed, contrary to current guidelines. 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, 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., 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. 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. 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. By applying average weighted EI based on match, training and rest days, similar to previous studies, 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. 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. 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. 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.

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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 Ethics approval from UiT—The Arctic University of Norway.

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