Body Composition, Energy Availability, Training, and Menstrual Status in Female Runners

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Purpose: To determine body composition, energy availability, training load, and menstrual status in young elite endurance running athletes (ATH) over 1 year, and in a secondary analysis, to investigate how these factors differ between nonrunning controls (CON), and amenorrheic (AME) and eumenorrheic (EUM) ATH. Correlations to injury, illness, and performance were also examined. **Methods:** Altogether 13 ATH and 8 CON completed the Low Energy Availability in Females Questionnaire. Anthropometric, energy intake, and peak oxygen uptake assessments were made at 4 time points throughout the year: at baseline post competition season, post general preparation, post specific preparation, and post competition season the following year. Logs of physical activity, menstrual cycle, illness, and injury were kept by all participants. Performance was defined using the highest International Association of Athletics Federations points prior to and after the study. **Results:** ATH had significantly lower body mass ($P = .008$), fat percentage ($P < .001$), and body mass index ($P = .027$) compared with CON, while energy availability did not differ between ATH and CON. The Low Energy Availability in Females Questionnaire score was higher in ATH than in CON ($P = .028$), and 8 ATH (vs zero CON) were AME. The AME had significantly more injury days ($P = .041$) and ran less ($P = .046$) than EUM, while total annual running distance was positively related to changes in performance in ATH ($r = .62$, $P = .043$, $n = 11$). **Conclusions:** More than half of this group of runners was AME, and they were injured more and ran less than their EUM counterparts. Furthermore, only the EUM runners increased their performance over the course of the year.

Keywords: endurance running, injury, RED-S, illness

It is commonly believed by athletes (ATH) and coaches that a reduction in total body or fat mass will improve sports performance, even when body composition measures are well within the normal ranges for elite-level ATH.¹ This is particularly so in endurance sports of a weight-bearing nature, such as distance running.² Indeed, while endurance runners have significantly lower total body and fat masses when compared with healthy controls (CON),³ no significant differences have been identified in body composition between elite and subelite long-distance runners.⁴ Furthermore, there are undesirable consequences when an athlete aims for negative energy balance and weight reduction, which can lead to severely negative effects on health and performance.⁵

Energy availability (EA) is defined as “energy intake minus exercise energy expenditure” and represents the amount of dietary energy remaining for all metabolic processes other than exercise, thereby setting an important foundation for health.⁶ EA is important for maintaining a healthy menstrual status,⁷ reducing injury rates,⁸ and for improving performance⁹ among endurance ATH. Many endurance ATH, including runners, reduce their EA intentionally to modify body size and composition, while aiming to improve performance.¹⁰ Reduced EA may lead to impaired physiological functioning that includes, but is not limited to, impairments of

metabolic rate, menstrual function, bone health, immunity, protein synthesis, and cardiovascular health.¹¹

Numerous research groups have called for a greater focus on the physiology of female ATH,¹² and as a result, female athlete health is a rapidly developing area of interest in sports science research. In particular, the consequences of low EA and menstrual dysfunction in relation to overall health and performance are prevalent contemporary issues in female athlete research. The purpose of the present study was to determine the body composition, EA, training loads, and menstrual status in young elite female endurance runners over a 1-year period. The specific aims were to investigate how these variables differ between ATH and CON and are associated with injury, illness, and performance improvements in ATH. With 8 of the ATH identified as being amenorrheic (AME), an additional outcome of the study was to report the differences between AME and eumenorrheic (EUM) ATH.

Methods

Participants

A total of 22 Finnish elite female endurance runners were invited to join the study (inclusion criteria: age 16–22 y, competing in events from 800 to 5000 m, an International Association of Athletics Federations [IAAF] score within the last 2 y of >800). Of those eligible, a total of 13 ATH voluntarily participated (age 19.6 [2.3] y, body mass 52.8 [7.2] kg, body mass index [BMI] 19.0 [1.8] kg·m⁻², relative fat mass 15.0% [5.2%], peak oxygen uptake [$\dot{V}O_{2peak}$] 59.8 [2.1] mL·kg⁻¹·min⁻¹). All of the participants had placed among the top 5 in their age group at the national championships within the year prior to data collection. Based

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on information from monthly menstrual diaries, 8 runners were identified according to the American College of Obstetricians and Gynecologists¹³ as being AME ($n = 8$) and 5 were EUM ($n = 5$).¹⁴ In addition to ATH, 13 healthy female CON matched by age also voluntarily participated (age 21.4 [1.1] y, body mass 64.1 [8.3] kg, BMI 22.0 [2.4] kg·m⁻², relative fat mass 27.3% [6.6%], $\dot{V}O_{2peak}$ 42.6 [5.4] mL·kg⁻¹·min⁻¹). Five CON participants were not compliant with the study procedures and were therefore excluded from the data analyses. All remaining CON participants ($n = 8$) were EUM. All participants provided written informed consent prior to testing, and all study procedures were approved by the ethical committee of the University of Jyväskylä.

Experimental Overview

This study was a prospective observational study performed over 1 year. The Low Energy Availability in Females Questionnaire (LEAF-Q) was completed at the start of the study period, while anthropometric and $\dot{V}O_{2peak}$ measurements were made at 4 time points throughout the year: at baseline post competition season (T1, September); post general preparation (T2, November); post specific preparation (T3, May); and post competition season the following year (T4, September). In addition, daily logs of training and physical activity, menstrual cycle, illness, and injury were completed by all participants. Competition performance, season best (SB) and personal best (PB), were determined based on IAAF points.

Measurements

Participants recorded all training data in diaries designed by the principal investigators, including total training distance (in kilometers) for running and total training time for other training forms. Illness, injury, and rest days were also reported within the training logs, as was information relating to the menstrual cycle, which was subsequently used to assess self-reported amenorrhea.¹³ All results from running competitions (800–10,000 m) during the investigated period were collected for ATH ($n = 13$). ATH PB, SB1 (season prior to T1), and SB2 (season prior to T4) results, as well as highest corresponding IAAF points, were collected from the Internet.¹⁵

Body composition was measured following an overnight fast using dual-energy X-ray absorptiometry and Encore software (version 9.3, LUNAR Prodigy Advance; GE Medical Systems, Chicago, IL) as described previously.¹⁶

One to 3 days after the measurement of body composition, all participants performed an incremental treadmill test at an incline of 0.5°, starting at 10 km·h⁻¹ and followed by an increase of 1 km·h⁻¹ every minute until volitional exhaustion. The time of day of testing was standardized throughout the study and was chosen by the participants. Heart rate was recorded continuously using a heart rate monitor (Polar V800; Polar Electro Oy, Kempele, Finland). Oxygen uptake was measured breath-by-breath throughout the test using a portable spiroergometer (OxyconPro; Jaeger, Hoechberg, Germany). The highest 60-second oxygen uptake value during the treadmill test was defined as the $\dot{V}O_{2peak}$.

Food diaries were recorded at the 4 time points (T1–T4) for a 7-day period before the laboratory tests and were analyzed for macro- and micro-nutrient intake using Aivodiet-software (Aivo Finland Oy, Turku, Finland). The same person analyzed all dietary records. Energy intake (EI), exercise-induced energy expenditure (EEE), total energy expenditure, and EA were calculated as described previously,⁸ using fat-free mass (FFM) assessed by dual-energy X-ray absorptiometry. Briefly, EA was estimated

from food and training diaries as EI minus EEE and expressed as kilocalorie per kilogram per fat-free mass per day of dietary energy. EA was classified as low (<30 kcal·kg⁻¹ FFM⁻¹·d⁻¹), moderate (30–45 kcal·kg⁻¹ FFM⁻¹·d⁻¹), or optimal (>45 kcal·kg⁻¹ FFM⁻¹·d⁻¹).¹⁷

Statistical Analyses

Statistical analyses were conducted using SPSS Statistics (version 24; IBM Corp, Armonk, NY). Results are reported as mean (SD). Data were assessed using a Shapiro–Wilk goodness-of-fit test and nonparametric tests were used with nonnormally distributed data. Within-group changes during the study for normally distributed variables were assessed using a repeated-measures analysis of variance, followed by a Bonferroni post hoc test to determine the P value in the pairwise comparisons. Between-group differences were analyzed using independent t tests. Significance level was set at $P < .05$. For not normally distributed data and comparisons between AME and EUM, within-group differences were assessed using the Wilcoxon signed-rank test and between-group comparisons were analyzed by the Mann–Whitney U test. Spearman correlation coefficients (R_s) were used to examine the associations between body composition, EA, performance, and injury and illness days. Effect size (ES) was estimated using corrected Hedge g with values of <0.2, 0.2 to 0.5, 0.5 to 0.8, and >0.8 reflective of trivial, small, moderate, and large ESs, respectively, for normally distributed data. Test statistics from nonparametric tests were used to calculate ES for not normally distributed data.¹⁸

Results

The LEAF-Q score was significantly higher in ATH than CON (12.4 [5.2] vs 6.4 [4.3], $P = .028$, $g = 1.12$) and in AME than EUM (15.2 [3.6] vs 8.0 [4.3], $P = .038$, $g = 2.32$). Furthermore, at baseline, ATH had a lower body mass (52.8 [7.2] vs 62.1 [6.3] kg, $P = .008$, $g = 0.656$); relative fat mass (15.0% [5.2%] vs 27.2% [6.0%], $P < .001$, $g = 2.215$); and BMI (19.0 [1.8] vs 21.5 [3.0] kg·m⁻², $P = .027$, $g = 1.08$) than CON, while AME had lower body mass (49.1 [4.7] vs 58.7 [4.4] kg, $P = .048$, $g = 2.09$); relative fat mass (12.5% [4.7%] vs 18.9% [2.5%], $P = .030$, $g = 1.584$); and BMI (17.9 [1.0] vs 20.8 [1.5] kg·m⁻², $P = .003$, $g = 2.41$) than EUM. There was substantial interindividual variation in relative fat mass within groups, ranging from 4.8% to 19.6% in AME, 16.7% to 22.9% in EUM, and 15.6% to 34.0% in CON. The $\dot{V}O_{2peak}$ was significantly higher in ATH (59.8 [2.1] mL·kg⁻¹·min⁻¹) than in CON (42.6 [5.4] mL·kg⁻¹·min⁻¹, $P < .001$, $g = 4.68$). $\dot{V}O_{2peak}$ and PB IAAF scores (965 [92] vs 924 [82]) did not differ between AME and EUM.

The mean EI, EEE, and total energy expenditure were all higher in ATH than in CON (2640 [490] vs 2330 [300] kcal, $P = .043$, $g = 0.712$; 900 [290] vs 440 [170] kcal, $P < .001$, $g = 1.92$; and 2980 [410] vs 2500 [300] kcal, $P = .001$, $g = 1.29$, respectively), but there were no differences between groups for EA (neither for ATH vs CON nor for AME vs EUM; 39.0 [8.3] vs 40.0 [5.2] kcal·kg⁻¹ FFM⁻¹·d⁻¹ and 40.2 [11.0] vs 38.4 [3.0] kcal·kg⁻¹ FFM⁻¹·d⁻¹, respectively) on average or at any time point. Two runners had optimal EA, 10 runners had moderate EA, and 1 runner had low EA, while all participants in CON had moderate EA.

Changes in body composition are presented in Figure 1. Body mass and fat mass increased in ATH by 1.5 (0.5) and 1.4 (0.5) kg, respectively, between T1 and T4 ($P = .028$, $g = 0.197$; $P = .028$, $g = 0.361$, respectively), and these changes differed between AME

Figure 1 — Changes in body mass (A), fat-free mass (B), fat mass (C), and relative fat mass (D) from T1 to T4. Each participant (within each group) is represented by a Δ . The horizontal short line represents the group mean *significant within group difference, #significant between AME and EUM difference, $P < .05$. AME indicates amenorrheic athletes; CON, controls; EUM, eumonnorrheic athletes.

and EUM ($P = 0.036$, $g = 1.40$ and $P = .048$, $g = 1.42$, respectively). In AME, body mass increased from T1 to T4 (2.2 [0.5] kg, $P = .002$, $g = 1.64$), as did fat mass (1.6 [0.5] kg, $P = .012$, $g = 1.24$). No significant changes were observed between any time points in EUM or in CON.

There were no differences in EI, EEE, EA, total energy expenditure, or energy balance between the measurement points for ATH or CON. Average EA in ATH and CON and individual profiles of EA in ATH are presented in Figure 2. In ATH, EI, energy balance, and EA correlated negatively with the number of self-reported infection days ($R_s = -.59$, $P = .048$; $R_s = -.58$, $P = .048$; $R_s = .69$, $P = .020$, respectively). The EI did not differ between AME and EUM (2740 [560] vs 2500 [430] kcal, respectively).

The $\dot{V}O_{2peak}$ was lower at T2 (57.2 [4.6] mL·kg⁻¹·min⁻¹, $P = .048$, $g = 0.725$, $n = 11$) and T3 (57.1 [4.0] mL·kg⁻¹·min⁻¹, $P = .036$, $g = 0.568$, $n = 11$) compared with T1 (59.8 [2.1] mL·kg⁻¹·min⁻¹) in ATH, whereas no seasonal variations were observed in CON. Two ATH in AME were unable to compete because of injuries during the competition season, thus were excluded from the performance results. During the competition season (between T3 and T4), 5 runners (4 EUM and 1 AME) achieved a PB. All the ATH in EUM increased their SB IAAF score compared with the season prior to T1, whereas only one athlete in AME increased her SB IAAF score. The EUM group increased their SB IAAF score (20.8 [14.8], $P = .013$, $g = 1.78$), whereas no difference was observed in AME (9.0 [25.4], $P = .502$).

Running training volumes (in kilometers) across different exercise intensities and individual injury days are presented in Figure 3. Notably, running volume correlated positively with the

change in SB IAAF score ($R_s = .62$, $P = .043$). In addition, EUM ran more than AME (3550 [660] vs 2400 [1100] km, respectively, $P = .043$, $g = 0.801$), and the range in total running distance varied between 500 and 3211 km in AME and 2660 and 4150 km in EUM. CON reported no injuries during the 1-year follow-up, whereas ATH reported 40 (58) missed training days because of injury. AME had a higher number of injury days (63 [23]) than EUM (4 [5], $P = .046$, $g = 1.243$). The range in injury days, in which the ATH were unable to run, varied from 0 to 42 in EUM and from 0 to 200 in AME. Finally, EUM reported a higher number of illness days due to infection than AME (12 [11] vs 27 [11] d, $P = .041$, $g = 0.833$).

One individual in AME (body mass 48.8 kg, BMI 17.4, and relative fat mass 19.3% at baseline) had 3 irregular sessions of bleeding between T2 and T4. Increase in body mass was 1.6 kg, whereas relative fat mass decreased by 0.6%. The EA for this athlete was 45, 31, 44, and 51 kcal·kg⁻¹ FFM·d⁻¹ (ie, moderate to optimal). This athlete did not have any injuries during the study.

Discussion

The main findings of this study were that the female runners had a lower body mass and less body fat than the control group, while there were no differences in EI or EA between ATH and CON. In total, 8 of the 13 ATH were found to be AME, whereas all participants in CON were EUM. Analyses based on the menstrual status of the ATH revealed that AME had lower BMI values and total running distances and higher LEAF-Q scores and injury rates than EUM, while only EUM increased their season best

Figure 2 — Mean (SD) energy availability in AME (A), EUM (B), and CON (C) and individual energy availability profiles at the 4 seasonal time points. AME indicates amenorrheic athletes; CON, controls; EUM, eumonnorrheic athletes.

performance. Body mass and fat mass increased in AME during the 1-year follow-up, but whether these increases were due to injuries and the inability to train, or altered nutritional strategies, is unknown.

Higher LEAF-Q scores in ATH versus CON and in AME versus EUM are consistent with the findings of Heikura et al⁸ and further support the use of the LEAF-Q to assess increased risk of the negative effects of low EA. The prevalence of AME ATH in the present study (62%) was slightly higher than in previous cross-sectional studies (33%–50%) of similar populations.^{8,19,20} It should be noted that the sample sizes in all previous studies, including this one, have been small, which potentially distorts percentages. The different results might be due to younger and lower caliber ATH involved in the present study, which is consistent with Dusek et al,²¹ who reported a 75% prevalence of amenorrhea in young long-distance runners. As amenorrhea is an important marker for relative energy deficiency in sport, a syndrome affecting many aspects of physiological functioning, health, and athletic performance, the

prevention of relative energy deficiency in sport should be emphasized when working with young female ATH.

The reported prevalence of low EA ($<30 \text{ kcal} \cdot \text{kg}^{-1} \text{ FFM}^{-1} \cdot \text{d}^{-1}$) in female and male track-and-field ATH is between 18% and 58%, with the highest prevalence among ATH practicing endurance and jumping events.²² In the present study, only one athlete had low EA ($<30 \text{ kcal} \cdot \text{kg}^{-1} \text{ FFM}^{-1} \cdot \text{d}^{-1}$), and 2 had optimal EA according to previously defined thresholds.¹⁰ Similarly to Muia et al,²⁰ we found that most of the ATH and all CON had moderate EA ($30\text{--}45 \text{ kcal} \cdot \text{kg}^{-1} \text{ FFM}^{-1} \cdot \text{d}^{-1}$). Consistent with previous studies, our findings suggest that assessing the physiological consequences of low EA, such as menstrual function, provides a better assessment of the overall health status of endurance ATH than assessing EA using nutritional diaries only.²³

It has been suggested that resumption of menstrual function can be obtained when fat mass reaches a specific threshold.²⁴ While fat mass was lower in AME in the present study, we did not observe a specific “cut-off” limit as there were some EUM ATH with lower absolute and relative fat masses than some of the AME ATH. Interestingly, however, body mass and fat mass increased in the AME group during the follow-up period. This might be due to the ATH in AME trying to gain fat mass in order to normalize their menstrual cycle. Another explanation could be that their injuries prevented them from training and that they subsequently gained weight due to a lower energy expenditure. However, it has to be noted here that there were no differences in exercise-induced energy expenditure between EUM and AME at any measurement point in the present study. Interestingly, one of the ATH in AME (body mass 48.8 kg, BMI 17.4, and relative fat mass 19.3% at baseline) had 3 irregular sessions of bleeding between T2 and T4. Similar to previous case reports,^{25–27} the AME athlete in the present study reported irregular bleedings (oligomenorrhea) while starting to recover from amenorrhea. Furthermore, this individual increased her body mass by 1.6 kg, whereas relative fat mass decreased by 0.6%, in line with an increase in EA. By the end of the study, her EA was optimal, supporting previous studies that have reported nutritional interventions to be effective in restoring menses in ATH.²⁴ Longer periods of time may be required to fully restore regular bleedings. Previous interventions, in which EA has been increased, have shown that the restoration of menses may take 23 days to 16 months.^{24,25,28}

Altogether 5 and 6 ATH were able to enhance their PB and SB IAAF score, respectively. All of these ATH except for one were in the EUM group. However, it should be noted that differences in the change in SB IAAF points between EUM and AME did not reach statistical significance. More injury days were observed in AME, as well as a lower running volume, which would have affected performance developments. In addition, 2 ATH in the AME group were unable to compete during the observed competition season due to injuries. This study highlights not only the high prevalence of menstrual disturbances in female runners, but also the likelihood of amenorrhea status as a risk factor for impaired athletic performance. This is consistent with Vanheest et al,⁹ who observed improved performance in EUM swimmers after a 12-week training intervention, whereas the same training intervention led to decreased performance in ovarian-suppressed AME swimmers.

The current study had several major limitations, including self-reporting of menstrual status, dietary and training information, and the limited number of participants, especially when splitting the group for AME and EUM ATH. The self-reported nature of reproductive function means that women with subclinical menstrual issues, such as anovulatory cycles and/or a shortened luteal phase, may have been

Figure 3 — Running volume (in kilometers) in different intensities and individual injury days per month for each athlete (EUM and AME). One athlete (AME6) was unable to train for 200 days because of a strain injury and has been excluded from the training data in this figure. AME indicates amenorrheic athletes; EUM, eumonnorrheic athletes; HIT, high-intensity training; LIT, low-intensity training; MIT, moderate-intensity training; SE, speed endurance; S, speed.

overlooked in the present study population. We recognize that self-reported diet and training information also has limitations, such as response bias and misreading of the record. However, all studies using questionnaires suffer from such constraints to some degree. In addition, in the present study we were unable to control the menstrual cycle phase for testing. We acknowledge these shortcomings, but also emphasize the strengths of the present study. All participants were highly motivated to participate, and the research team took great care to continually interact throughout the study with the participants, encouraging their full and complete compliance with the protocol. In addition, the participating ATH represented the best young female runners in Finland. The association between menstrual status and performance in the present population is an important and novel finding, which needs to be further investigated through longitudinal research with higher sample sizes.

Conclusions

Although no difference in EI or EA was observed, female elite runners had lower body and fat masses than nonathletic CON. In contrast to CON, a high proportion of the runners were AME. It is important to acknowledge that even if low body mass, low relative fat mass, and low BMI may be advantageous in weight-sensitive sports, this is not always the case. Amenorrhea should be considered as a warning flag for reduced performance. The EUM ATH had lower injury rates and performed higher running volumes than the AME runners. Interestingly, only EUM ATH increased their performance over the observed competition season. Furthermore, both body and fat masses increased in the amenorrhoeic ATH, possibly due to reduced training volumes caused by injuries.

Practical Applications

1. Physiological consequences of low EA are meaningful to endurance runners, whereby increased injury prevalence and impaired performance were associated with being AME.

2. Using questionnaires, in this case the LEAF-Q, for screening ATH that might be at risk for injuries and suboptimal performance are simple to administer and can easily be used with young endurance runners.
3. It is essential that ATH and coaches are educated on ATH energy needs including health and performance consequences of an energy deficiency.
4. The menstrual cycle is part of a much bigger health issue for female ATH as it is an important warning flag when preventing negative outcomes of high training loads and intensities of training.

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