Resting Metabolic Rate and Energy Intake in Female Gymnasts, Figure-Skaters and Soccer Players

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We examined the hypothesis that lean female athletes, as compared to other female athletes and controls, have a greater deficit between reported energy intake (EI) and estimated energy expenditure (EE), and a reduction in resting energy expenditure adjusted to fat free and fat masses (REEadj). The subjects were 12 gymnasts and figure-skaters (lean athletes), 12 soccer players (normal-weight athletes) and 10 normal-weight, untrained controls. Body composition was calculated from a 3-compartment model (underwater weighing and dual energy x-ray absorptiometry). REE was assessed by indirect calorimetry. Physical activity and EI were estimated from 7-day records. EE was calculated using activity records and REE. REEadj was similar in all groups (p > 0.05). EI was 8.29 (SD 1.84), 7.04 (SD 2.23) and 8.95 (SD 1.68) MJ·d⁻¹ in controls, gymnasts and soccer players, respectively (p = 0.06). In gymnasts, reported EI was 3.19 (SD 2.63) MJ·d⁻¹ lower than estimated EE. EI minus EE in controls was -0.18 (SD 1.80; different from gymnasts, p < 0.01) MJ·d⁻¹, and in soccer players -0.47 (SD 1.89; different from gymnasts, p < 0.05) MJ·d⁻¹. Low reported energy intake in gymnasts might reflect their attitudes on diet and body image.

Key words: Athletes, body composition, bone, diet, energy expenditure

Introduction

Several recent studies have found a large difference between estimated energy intake (EI) and expenditure (EE) in lean female athletes (11,23,25,32,37). In these studies, EI, calculated from food records, was 24–44% lower than EE estimated by factorial method (physical activity record) or doubly labelled water. An apparent explanation for the above contradiction is undereating or underreporting during food recording (32). Nevertheless, it has also been suggested that lean female athletes might be energetically more efficient, that is, at least partly adapted to chronic weight control and restricted energy intake (6).

Increased energetic efficiency might be reflected in lowered resting energy expenditure (REE) (6) or lowered diet induced thermogenesis (DIT) (20). While the contribution of DIT to total daily energy expenditure is small, a reduction in REE would be more meaningful. During chronic undernutrition (e.g. anorexia nervosa), REE is lower than in well-nourished controls, even when adjusted to body composition (REEadj) (31).

In disagreement with the above hypothesis of lower REE in lean athletes, two studies showed similar REEadj in female endurance runners and untrained controls (25,37). However, because endurance training might increase REE (27), there is a possibility that this finding cannot be generalized for all types of sports. Therefore, energy intake and expenditure should also be studied in lean athletes with training characteristics different from endurance athletes, e.g. gymnasts and figure-skaters (2).

Because REE is related to body composition, in particular to fat free mass (FFM) (28), accurate assessment of body composition is a critical point in studies on REE in athletes. A major concern related to female athletes is variation in total bone mineral content (TBMC), which affects the density of FFM and might cause errors in the traditional two-compartment model (7). For instance, low TBMC, often associated with menstrual disturbances, would lead to underestimated FFM by the two-compartment model (7).

The objective of the present study was to test the hypotheses that lean female athletes, as compared to other female athletes and untrained controls, have a greater deficit between reported energy intake (EI) and estimated energy expenditure (EE), and a reduction in resting energy expenditure adjusted to body composition (REE).
Table 1  Basic description (mean results, SD in parenthesis) of 11 female controls, 12 gymnasts and figure-skaters and 12 soccer players.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Gymnast</th>
<th>Soccer</th>
<th>ANOVA* Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>16.5 (0.5)</td>
<td>17.1 (1.2)</td>
<td>18.5 (2.3)</td>
<td>0.02 cs</td>
</tr>
<tr>
<td>Age at menarche (yrs)</td>
<td>12.5 (0.8)</td>
<td>14.5 (1.2)</td>
<td>13.1 (1.6)</td>
<td>0.004 CG, GS</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>59.9 (6.7)</td>
<td>51.7 (5.9)</td>
<td>60.8 (5.9)</td>
<td>0.001 CG, GS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168 (6)</td>
<td>163 (6)</td>
<td>167 (5)</td>
<td>0.13</td>
</tr>
<tr>
<td>BMI, kg · m⁻²</td>
<td>21.3 (1.4)</td>
<td>19.6 (1.6)</td>
<td>22.2 (1.8)</td>
<td>0.001 CG, GS</td>
</tr>
</tbody>
</table>

* p-value for ANOVA and significant group differences In Tukey’s test (capital letters: p < 0.01; small letters: 0.01 < p < 0.05). C, G = controls; G, g = gymnasts; S, s = soccer players

Methods

Subjects

Thirty-five young (16–23 years) women volunteered. After being informed about the study, all subjects (if under 18: a parent) signed a written informed consent. The study was approved by the ethical committee of the UKK Institute for Health Promotion Research, Tampere, Finland.

Seven rhythmic gymnasts, two artistic gymnasts and three figure-skaters represented lean females engaged in sports emphasizing skills and artistic appearance (Table 1). They all competed at Finnish elite level in sports, in which a lean body is favoured for both physiological and aesthetic reasons. Training characteristics and physiological demands in gymnastics and figure-skating are also rather similar (2). This group is referred to as “gymnasts”. Twelve soccer players from a team in the Finnish national league were chosen as physically active females with normal body weight and without a significant emphasis on leanness. A control group consisted of eleven females, who did not participate in competitive sports.

Two controls and three gymnasts were oligomenorrheic (4–9 menstrual cycles during the past year) and two gymnasts (both aged 16) had primary amenorrhea. As a group, these seven participants with menstrual disorders were not evidently different from the rest of the subjects. Contraceptive pills were used by two controls and two soccer players. One control and six soccer players smoked.

All laboratory measurements (REE, body composition, bone density) were done before ovulation of the menstruating subjects. Physical activity and dietary intake records were kept within a month before the laboratory measurements.

Body composition assessment

Body density was assessed by underwater weighing (UWW) and total bone mineral content (TBMC) by dual energy X-ray absorptiometry (DXA). Body density by UWW was not obtained for one control subject. Percentage of body fat (BF%) was calculated from a three-compartment equation (22), assuming that TBMC represents 82.4% of the body’s total minerals:

$$BF\% = \frac{D_s \cdot D_w \cdot 3.961 \cdot W_T - 6.090}{100},$$

where $D_s$ = body density from UWW (g · cm⁻³), $BTM$ = body’s total minerals (kg), $WT$ = body weight (kg).

Before UWW, the subject was weighed in a swimming-suit on a high-precision scale (Sartorius F150S-D2, Goettingen, Germany). Then the subject was submerged to her neck and the residual volume (RV) was determined by helium-dilution method, using a wet spirometer (Pulmonet III, Sensormedics BV, Bilthoven, The Netherlands). Two to four trials were performed to obtain two readings with less than 0.1 L difference. RV was the mean of these two values.

The scale for UWW (Tamron Inc., Tampere, Finland) was connected via a 12-bit A/D converter (DT2801, Data Translation Inc., Marlborough, MA, USA) to a microcomputer which continuously acquired weight values at 20 samples per second. A dedicated software was used to record the underwater trials and to calculate the average weight for each trial detected. All weight measurements were visually verified. The subject performed eight successive underwater trials after full exhalation (at RV) and the average of the three trials giving the highest results were used in further calculations. Air volume in the gastrointestinal tract was assumed to be 0.1 L.

BMC was determined using a total-body scanner (XR-26, Norland Corp, Fort Atkinson, WI, USA). The scan speed was 80 mm · s⁻¹ and resolution (pixel size) 6.5 · 13 mm². Duration of the scan was about 20 minutes. BMC was calculated from the scan data by the Norland total body composition software (version 2.2.2/11.4). The scanner was calibrated daily using a dedicated calibration standard. According to the manufacturer, the imprecision in vivo of the BMC measurements is 0.8%, which is similar to site-specific quality control results (imprecision 0.5–0.7%) in our laboratory (34).

Energy expenditure assessments

Only light physical exercise was allowed during the day before REE measurements. All subjects were either transported from their homes in the morning, or they spent the preceding night at the institute. Smoking was prohibited in the morning before measurements. The effects of smoking on REE, measured after a 10–12 h abstinence, is insignificant (24).

REE was assessed in the morning, after a 12 h fast, using a Sensormedics 3000Z energy measurement system (Sensormedics Corp., Anaheim, CA, USA) in a dilution mode. The subject was in supine position with constantly ventilated canopy over her head. The oxygen and carbon dioxide concentrations in the diluted gas were measured for 40 minutes. The data from the last 15 minutes were used to determine REE. The measurement system was calibrated prior to each measurement. REE was not obtained from one control person.

Daily EE was estimated from a 7-day activity record, modified from an interview method (30). The recording was divided into three and four day periods, separated by one week. The subjects recorded the time (to the nearest half hour) spent daily...
in four types of activities: 1) rest: sleep and lying in bed; 2) moderate activities: gymnastics and figure-skating training, leisure walking, cycling <20 km h⁻¹, downhill skiing; 3) strenuous activities: gym and weight training, low impact aerobics, jogging, slow cross-country skiing, cycling 20–25 km h⁻¹, moderate soccer training, dancing; 4) very strenuous activities: running, cross-country skiing, soccer game, high impact aerobics. The activity classes corresponded to metabolic equivalents (MET-values, defined as EE: REE⁻¹) 1, 4, 7 and 10, respectively (1).

Time spent in daily sedentary activities (MET-value: 1.5) was obtained by subtracting the sum of hours in classified activities from 24. To get the individual daily activity factor, the products of daily hours and the corresponding MET values were totalled, and divided by 24. Daily EE was calculated as measured REE multiplied by the activity factor.

Dietary intake assessment

All subjects kept a 7-day diet record on the same days as the physical activity record. Participants were given written instructions on how to fill in records with exact descriptions and amounts of all foods and drinks consumed. Amounts were measured using household measures (glasses, cups, tablespoons, slices, etc.). All records were checked by one of the authors. Daily energy intake was calculated by a computer program developed in the Division of Nutrition, University of Helsinki, Finland. The main part of the food composition data was obtained from Finnish food analyses, and completed from international food composition tables.

Statistical analyses

Differences between the groups were tested by 1-way analysis of variance (ANOVA, BMDP 7D) and p < 0.05 was chosen as indication of a statistically significant difference between any of the groups. Because REE is affected by body composition (28), and possibly also by menstrual status (26) and smoking (24), an analysis of covariance (ANCOVA, BMDP 1V) was also carried out with REE as the dependent variable and FFM, fat mass (FM), menstrual status (0 = primary amenorrhea or oligomenorrhea; 1 = regular cycles) and smoking (0 = no, 1 = yes) as covariates. FFM was the most significant covariate (p = 0.008), followed by FM (p = 0.03). In contrast, the regression coefficients for menstrual status (p = 0.28) or smoking (p = 0.59) were not significant. If ANOVA or ANCOVA indicated significant differences between any of the groups, the Tukey Studentized Range post hoc test (BMDP 7D) was used to identify the differences at 1 or 5% level (p < 0.01 and p < 0.05, respectively).

The association of BF% with the difference between EI and EE was tested by Spearman correlation (BMDP 3D). All statistical procedures were carried out by BMDP statistical software (1990 version). The results are presented as mean and standard deviation (SD).

Results

The soccer players were slightly, but significantly older than the controls (Table 1). The gymnasts had the highest menarcheal age, and the lowest weight and body mass index. The gymnasts had also significantly less body fat (both in kg and in percentage of body weight) than the two other groups (Table 2). TBMC in gymnasts was lower than in soccer players. REE, unadjusted or adjusted to body composition, menstrual status and smoking, was not significantly different between the groups.

The estimated daily EE was higher in gymnasts than in controls, but the soccer players were not significantly different from either group. The gymnasts tended to have lower reported EI than the other groups, but the differences were not significant. In contrast, the difference between reported EI and estimated EE was larger in gymnasts than in the two other groups (Table 3 and Fig. 1). Moreover, gymnasts were the only group with 95% confidence interval for the mean difference (lower limit: -4.85, upper limit: -1.53) of less than zero. Only two from the gymnast group (both were figure-skaters) reported

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**Table 2** Body composition (mean results, SD in parenthesis) of 10 female controls, 12 gymnasts and figure-skaters and 12 soccer players.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Gymnast</th>
<th>Soccer</th>
<th>ANOVA* Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body density (g cm⁻³)</td>
<td>1.041 (0.011)</td>
<td>1.058 (0.006)</td>
<td>1.044 (0.006)</td>
<td>0.0001 CG, GS</td>
</tr>
<tr>
<td>TBMC (g)</td>
<td>2715 (332)</td>
<td>2486 (341)</td>
<td>2916 (201)</td>
<td>0.005 GS</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>26.4 (6.2)</td>
<td>17.5 (3.1)</td>
<td>25.8 (3.0)</td>
<td>0.0001 CG, GS</td>
</tr>
<tr>
<td>FM (kg)</td>
<td>15.9 (5.3)</td>
<td>9.1 (2.3)</td>
<td>15.8 (2.6)</td>
<td>0.0001 CG, GS</td>
</tr>
<tr>
<td>FFM (%)</td>
<td>43.2 (3.2)</td>
<td>42.6 (4.2)</td>
<td>45.1 (3.5)</td>
<td>0.26</td>
</tr>
</tbody>
</table>

* p-value for ANOVA and significant group differences in Tukey's test (capital letters: p < 0.01; small letters: 0.01 < p < 0.05). C.C = controls; C,g = gymnasts; S.s = soccer players.

**Table 3** Assessments of energy expenditure and intake (mean results, SD in parenthesis) of 11 female controls, 12 gymnasts and figure-skaters and 12 soccer players.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Gymnast</th>
<th>Soccer</th>
<th>ANOVA* Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE (MJ d⁻¹)</td>
<td>5.66 (0.54)</td>
<td>5.33 (0.55)</td>
<td>5.79 (0.32)</td>
<td>0.07</td>
</tr>
<tr>
<td>REE₄ (MJ d⁻¹)</td>
<td>5.55 (0.44)</td>
<td>5.59 (0.53)</td>
<td>5.58 (0.48)</td>
<td>0.97 **</td>
</tr>
<tr>
<td>EE₅ (MJ d⁻¹)</td>
<td>8.48 (0.87)</td>
<td>10.23 (1.48)</td>
<td>9.42 (0.90)</td>
<td>0.004 CG</td>
</tr>
<tr>
<td>EE₆ (MJ d⁻¹)</td>
<td>8.29 (1.84)</td>
<td>7.04 (2.23)</td>
<td>8.97 (1.68)</td>
<td>0.06</td>
</tr>
<tr>
<td>El minus EE (MJ d⁻¹)</td>
<td>-0.18 (1.80)</td>
<td>-3.19 (2.63)</td>
<td>-0.47 (1.89)</td>
<td>0.003 CG, GS</td>
</tr>
</tbody>
</table>

* p-value for ANOVA and significant group differences in Tukey's test (capital letters: p < 0.01; small letters: 0.01 < p < 0.05). C.C = controls; C,g = gymnasts; S.s = soccer players.

** Analysis of covariance (ANCOVA)

### EE = estimated energy expenditure

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EI higher than their estimated EE. There was a moderate correlation between BP% and the difference EI minus EE (Spearman’s r = 0.53, p = 0.001). Hence, reported EI lower than estimated EE was more typical for those with lower BP%.

Discussion

Compared with 165 female participants in the 1987 World Championships in artistic gymnastics (9), our gymnasts were at the 80th percentile for weight and at the 90th percentile for height. Our gymnasts’ menarcheal age was higher than in the general white female population, but similar to elite gymnasts reported by Claessens et al. (9). Higher menarcheal age of the present gymnasts, compared to the two other groups, was also expected.

In a recent review, Davies and Brewer (12) summarized six studies with anthropometric data for elite female soccer players. The mean weight and height of 77 players were 59.7 kg and 165 cm, respectively. The ratio weight/height (0.36) was similar to ours. The present soccer players were younger than those reviewed by Davies and Brewer (12), but yet significantly older than the present control group. Nevertheless, only three soccer players were between 21 and 23 years old, and the mean difference between the soccer players' and the controls' age was only two years. Hence, the possibility that the observed group difference could have affected our results was considered minimal.

The present control subjects’ weight and height were close to those found in slightly older (mean: 24 years), inactive or moderately active students in Finland (17,18). Therefore, the controls’ weight, height and BMI were quite representative for young Finnish women.

As anticipated (2,9,12), the gymnasts had significantly lower BP% than the two other groups. Nevertheless, the gymnasts and figure skaters did not show a significant energy conservation by decreased REExad. A similar finding has been made earlier from endurance runners (25,37). Hence, it appears that neither low body fat nor training characteristics of lean female athletes are associated with REE. Differences in menstrual status and smoking were controlled for by statistical means (ANCOVA), as well as by prohibiting smoking before REE measurements. Therefore, it is unlikely that the apparently higher prevalence of menstrual disorders and smaller number of smokers in the gymnasts group, compared to the soccer players, biased our finding.

In the control group, the estimated daily EE was comparable to that of moderately active Finnish female university students (8.5 MJ·d⁻¹) (17). The EE in soccer players was slightly higher than that of university students (8.9 MJ·d⁻¹) during a fitness training program (17). Nevertheless, it was unexpected that soccer players’ EE was not different from the controls. Apparently the timing of our study (after the competitive soccer season) affected EE estimations, and the soccer players' results might have been slightly higher some months earlier. Nevertheless, because the aim was to compare reported EI with EE, we consider seasonal variations at most a minor source of potential bias.

To the best of our knowledge, only Erp-Baart et al. (15) have estimated EE in elite gymnasts. The mean EE using factorial method was 8.5 MJ·d⁻¹. However, Erp-Baart et al. (15) calculated EE as the sum of REE and EE during daily training. Therefore, they might have overlooked some daily non-training activities. Dahlström et al. (11) estimated female dancers’ daily EE to be 10.3 MJ, that is, very similar to ours. Values ranging from 10.2 to 12.3 MJ·d⁻¹ have been reported for endurance runners (23,25,32,37).

The reported EI in the control group was very similar to Finnish female university students (7.9–8.5 MJ·d⁻¹) (17,18). EI in our gymnasts and figure-skaters was comparable to the range (6.5–8.0 MJ·d⁻¹) reported for gymnasts (3,4,15,19) and dancers (5,10,11,16,33). Only some studies with figure-skaters have shown either clearly lower (28) or higher EI (13) than the above studies.

In the present gymnasts and figure-skaters, the difference between reported EI and estimated EE (EI 45% lower than EE) was of similar magnitude as published for endurance runners by Wilmore et al. (37), but larger than others have found in gymnasts (15), dancers (11) or endurance runners (23,25,32). The difference EI minus EE in soccer players (−5%) and controls (−3%) was not different from zero at 5% level.

There are two possible interpretations for the large difference between EI and EE in gymnasts and figure-skaters. First, unintentional underreporting of EI (or undereating) may be typical for athletes in sports emphasizing leanness. The apparent underreporting might be connected with disordered body image, eating attitudes and eating habits (14), found especially among athletes competing in “aesthetic” sports, such as gymnastics and figure skating (35). Indeed, Rucinski (29) found lower reported EI to be associated with higher total score in the Eating Attitude Test (a measure of symptoms in anorexia nervosa). During dietary recording, these athletes might unconsciously change their diet or reports quantitatively (and perhaps also qualitatively) to something they consider “ideal”. If this explanation is true, results from dietary intake assessments of athletes from sports emphasizing thinness should be interpreted with great caution.
Like lean female athletes, also obese people with a strong drive for lower body weight show undereported EI, but no abnormalities in energy metabolism (21, 36). It is interesting to note that Westerterp et al. (36) found a significant association between body weight (in their study: BMI) and the difference EI minus EE among normal weight and obese people ($r = -0.55$, $p < 0.01$). The association was negative, that is, a larger underreporting of EI was associated with increasing BMI.

A second explanation for lower EI than EE is that EE in gymnasts might have been overestimated (15). An evident pitfall in the factorial method (record) is that the chosen MET-values affect the outcome. However, it is very unlikely that the factorial method alone would have caused such a large error in only one group.

MET-values published in a recent compendium (1) were used in the present study. Erp-Baart et al. (15), using a time-and-motion method, calculated the mean EE during elite gymnasts’ training to be 4.1 times REE, that is, similar to the MET-value we used for gymnastic training. Nevertheless, if the mean training intensity or EE of gymnasts and figure-skaters was lower and that of soccer players higher than the chosen MET-values indicated, the real difference between these groups would obviously be smaller than was found. To test this hypothesis, EE in gymnasts and ball game athletes should be measured simultaneously by the doubly-labelled water and factorial methods. Another point of concern in the factorial method was the rough estimation of sedentary activities, such as cleaning, cooking, washing, etc. Nevertheless, although the participants’ involvement in sports training was different, the subjects were rather homogeneous regarding age (16–23 years), education (high-school or college) and place of residence (urban). Therefore, a significant group-difference regarding activities classified as sedentary was not very probable.

The inclusion of three figure-skaters in the gymnasts’ group might also be a source of bias. As mentioned earlier, the only two lean athletes reporting higher EI than estimated EE were figure-skaters. Therefore, they tended to weaken the main conclusion, i.e., that lean female athletes, compared to other female athletes and controls, had the greatest reported energy deficit. Because of similar body composition and training characteristics, and of strong aesthetic demands in both gymnastics and figure-skating, there were no a priori reasons for excluding the skaters from the study.

Recognizing the limitations of factorial EE assessment, we conclude that 1) reported EI was lower than estimated EE in gymnasts and figure-skaters, but not in soccer players or controls with normal body weight; 2) gymnasts and figure-skaters did not show energy conservation by lowered REEadj; 3) the apparent underreporting of EI might reflect lean athletes’ attitudes on diet and body image.

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References


