Relationship between energy deficits and body composition in elite female gymnasts and runners

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ABSTRACT

DEUTZ, R. C., D. BENARDOT, D. E. MARTIN, and M. M. CODY. Relationship between energy deficits and body composition in elite female gymnasts and runners. *Med. Sci. Sports Exerc.,* Vol. 32, No. 3, pp. 659–668, 2000. **Purpose:** The purpose of this study was to evaluate energy balance and body composition in 42 gymnasts ($\bar{X}$ age = 15.5 yr) and 20 runners ($\bar{X}$ age = 26.6 yr), all of whom were on national teams or were nationally ranked. **Methods:** Athletes were assessed for body composition using DEXA and skinfolds, and energy balance was determined with a Computerized Time-Line Energy Analysis (CTLEA) procedure. **Results:** Results from the CTLEA were assessed as the number of within-day energy deficits (largest and frequency) and within-day energy surpluses (largest and frequency). There was a significant difference ($P = 0.000$) in the $\bar{X}$ number of hourly energy deficits > 300 kcal experienced by gymnasts (9.45 ± 6.00) and runners (3.70 ± 5.34). There was also a significant difference ($P = 0.001$) in the $\bar{X}$ number of hourly energy surpluses > 300 kcal experienced by gymnasts (1.40 ± 3.04) and runners (6.20 ± 5.50). The $\bar{X}$ largest daily energy deficit was 743 (± 392) kcal for gymnasts and 435 (± 340) kcal for runners. The $\bar{X}$ largest daily energy surplus was 239 (± 219) kcal for gymnasts, and 536 (± 340) kcal for runners. There was a significant relationship between the number of daily energy deficits > 300 kcal and DEXA-derived body fat percent for gymnasts ($r = 0.508$; $P = 0.001$) and for runners ($r = 0.461$; $P = 0.041$). There was also a negative relationship between the largest daily energy surplus and DEXA-derived body fat percentage for gymnasts ($r = -0.418$; $P = 0.003$). Using the energy balance variables, age, and athlete type (artistic gymnast, rhythmic gymnast, middle-distance runner, long-distance runner) as independent variables in a forward stepwise regression analysis, a small but significant amount of variance was explained in DEXA-derived ($P = 0.000$; $R^2 = 0.309$) and skinfold-derived ($P = 0.000$; $R^2 = 0.298$) body fat percent by the number of energy deficits > 300 kcal and age. **Conclusions:** These data suggest that within-day energy deficits (measured by frequency and/or magnitude of deficit) are associated with higher body fat percentage in both anaerobic and aerobic elite athletes, possibly from an adaptive reduction in the REE. These data should discourage athletes from following restrained or delayed eating patterns to achieve a desired body composition. **Key Words:** ENERGY SURPLUS, BODY FAT PERCENTAGE, DEXA, CTLEA, ATHLETES

Energy balance is an important factor in performance (47), body fat percentage (17,34), menstrual status (12,30,31,44), growth (24,45), and injury rates (13,35,36) among elite athletes. Nevertheless, this is an area of nutrition that is not commonly given the attention it deserves by coaches, health professionals, and the athletes themselves. Athletes who participate in sports in which appearance is an important factor in success (i.e., figure skating, rhythmic and artistic gymnastics, diving, etc.) often purposefully initiate a restrained eating regimen to achieve a desired body fat level or body weight, thereby negatively impacting energy balance (23,24,44). Athletes and coaches commonly believe that a reduction in weight or body fat will improve sports performance, even when weight and body fat are well within the norms for elite level athletes (1,44). However, there is an increasing body of evidence that the energy imbalance created by restrained or poorly timed eating patterns may be associated with lower resting energy expenditure (34,46), higher body fat (4), higher injury rates (30,36), menstrual dysfunction (44), and lower bone density (2,41).

Studies of nonathletes and athletes have demonstrated that the human adaptive response to energy restriction is a reduction in the resting metabolic rate (RMR), with a possible associated increase in fat storage (17,28,34). It is unclear, however, whether regular intensive exercise training blunts or exacerbates the reduction in RMR and the associated increase in body fat storage that is caused by energy restriction (8,22,25,26).

In most studies evaluating the energy balance of athletes, energy intake has been estimated via multiple-day food records, with energy expenditure being estimated by totaling RMR, general daily activity, specific sport activity, and the thermic effect of food. Some recent studies have evaluated

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the energy expense of sport activity via double-labeled water (H_2O^{18}) (7,37,38,43). Regardless of the measurement technique used, athletes who are identified as either energy deficient or energy replete have different resting energy expenditures. Whether they are runners, wrestlers, or gymnasts, those with energy deficits generally have significantly lower resting energy expenditures than those who are energy replete (16,21,27,42,46).

Energy intake and expenditure have typically been evaluated in 24-h time blocks. However, in doing so the periods of energy imbalance that occur within a day cannot be evaluated. To determine whether within-day energy imbalance is an important factor in body fat level, Benardot developed a method for simultaneously estimating energy intake and energy expenditure (4). The energy expenditure procedure for this method follows the procedure described by the National Research Council Subcommittee on the Tenth Edition of the RDA (29). When applied to a small sample of elite female gymnasts, within-day energy imbalance was found to be an important factor in predicting body fat percentage. Using this technique, the present study evaluated the relationship of 24-h energy balance and within-day energy balance with body fat percentage in four groups of elite athletes having different training dynamics: artistic and rhythmic gymnasts and middle- and long-distance runners.

METHODS

Subjects. Subjects for this study consisted of 62 active elite female athletes, including 31 artistic gymnasts, 11 rhythmic gymnasts, 14 long-distance runners, and 6 middle-distance runners. The artistic and rhythmic gymnasts were all members of the United States National teams, and the long- and middle-distance runners were all nationally and/or internationally ranked.

Assessments. All evaluations took place in the Laboratory for Elite Athlete Performance on the campus of Georgia State University. For most athletes, data collection occurred during a single day, but several athletes had data collected over a 6-month period. The entire data collection took place over a 3-yr period. Appropriate informed consent from all athletes, and from the parent(s) of athletes under age 18 yr, was obtained after the details of procedures were explained. The study protocol was approved by the Institutional Review Board Human Subjects Committee of Georgia State University.

Heights and weights were taken on a standard physician balance-beam scale. Body composition was assessed using full-body scan dual energy x-ray absorptiometry (DEXA) using a LUNAR (Lunar Corporation, Madison, WI) model DPXL and software version 1.34 (32). A quality assurance procedure (QA) was performed at the beginning of each day of assessment. This QA involved scanning an object that contains materials of different known densities, a check of the low and high x-ray peak values, and a check of the DEXA mechanics. The full-body scan induced a radiation exposure of approximately 0.02–0.03 mREM, which can be compared with a nonmedical daily background radiation exposure of 0.50–0.75 mREM. Body composition was also assessed via skinfolds taken at seven sites (biceps, triceps, mid-axillary, subscapular, suprailiac, abdomen, and mid-thigh) using a Harpenden caliper. Body fat percent was estimated using the regression equation of Jackson et al. for athletes (18). In the case of African-American athletes, the equation of Schutte et al. (39) was used. We also assessed four Asian and three Hispanic (of different ethnicity) athletes but, in the absence of prediction equations for these groups, have applied the same equation for these athletes as that used for Caucasian athletes. All pieces of equipment (DEXA, Harpenden calipers, and weight scale) were calibrated before each use. A single trained anthropometrist took the skinfold, height, and weight data from all subjects, and a single certified DEXA technician performed the DEXA scans on all subjects.

On arrival in the laboratory, subjects were asked to describe a recent typical day's schedule to a trained interviewer. This information included time, duration, and intensity of each activity during the day, with a description of foods and beverages that were consumed during each defined activity period of the day. This computerized time-line energy assessment (CTLEA) procedure has been validated as an appropriate means of estimating total energy intake and within-day energy surpluses and deficits for gymnasts but has not been validated for use with runners (4). The energy content of consumed foods was assessed using the USDA nutrient database for standard reference (Release SR11, 1996). Foods that were reported by athletes to be consumed, but that were not part of the nutrient database, were added from information on the food label or data provided by the food producer. Data obtained from each athlete group were summarized to determine group energy balance values.

The CTLEA procedure simultaneously assessed food intake and energy expenditure on a typical training day (4). In this procedure, energy expenditure data were predicted from the method presented by the National Research Council (29) and programmed into the CTLEA. Energy intake data were obtained using a method similar to that of the 24-h recall, except that the activity and food intake information are obtained simultaneously, to account for eating and activity behaviors every minute of the day. In essence, the CTLEA procedure merges two techniques (energy requirement prediction as presented by the Food and Nutrition Board and 24-h recall) that are well-established (3,7,9,10,19,29). The data acquisition sequence for this procedure is as follows: 1) What was your first activity when you woke up? 2) How long did this activity last? 3) Did you consume any food or drink during this time? 4) What was your next activity?, etc. This procedure is followed until every waking minute is accounted for. Activity intensity is also categorized as resting, very light, light, moderate, or heavy.

Data derived from the CTLEA include energy distribution (percent of kilocalories from carbohydrate, protein, and fat), total energy consumed from food, total energy expended, percent of energy requirement achieved over the

TABLE 1. Subject characteristics.

Group	Age x̄ (SD)	Ht (cm) x̄ (SD)	Wt (kg) x̄ (SD)	BMI x̄ (SD)	Race (%) C	AF	A	H
All groups (N = 62)	19.1 (5.9)	158.4 (9.9)	49.9 (7.6)	19.8 (1.9)	88.7	4.8	4.8	1.6
All gymnasts (N = 42)	15.5 (1.8)[a]	154.4 (9.4)[a]	47.7 (7.7)[a]	19.9 (2.1)[a]	85.7	7.1	7.1	0
Artistic gymnasts (N = 31)	15.2 (1.8)[b]	150.9 (8.2)[b]	46.5 (8.3)[b]	20.3 (2.2)[b]	83.9	9.7	6.5	0
Rhythmic gymnasts (N = 11)	16.5 (1.5)[b]	164.3 (3.3)[b]	51.0 (4.3)[b]	18.9 (1.3)[b]	90.9	0	9.1	0
All runners (N = 20)	26.6 (4.5)[a]	166.9 (4.0)[a]	54.7 (5.0)[a]	19.6 (1.3)[a]	95.0	0	0	5.0
Middle-distance runners (N = 6)	23.2 (2.9)[c]	167.0 (3.6)	53.0 (6.2)	18.9 (1.7)	100	0	0	0
Long-distance runners (N = 14)	28.1 (4.2)[c]	166.8 (4.3)	55.4 (4.5)	19.9 (1.1)	92.9	0	0	7.1

C, Caucasian; AF, African-American; A, Asian; H, Hispanic.
[a] Significant difference in age (P = 0.000), height (P = 0.000), and weight (P = 0.000) between all gymnasts and all runners.
[b] Significant difference in age (P = 0.034), height (P = 0.000), weight (P = 0.031), and BMI (P = 0.019) between artistic and rhythmic gymnasts.
[c] Significant difference in age (P = 0.009) between middle- and long-distance runners.

24-h period of analysis, and the kilocalorie level of energy surplus and energy deficit periods during this 24-h period. For the purpose of this study, energy surplus and energy deficit data were converted to 24 hourly energy balance values (1 value for each hour of the day). For instance, an athlete consuming 1,000 kcal and burning 800 kcal before initiating exercise would begin the exercise bout with a 200-kcal surplus (the difference between energy consumed and energy expended up to that point in the day). If that exercise bout caused an energy expenditure of 600 kcal and lasted 2 h (300 kcal·h^{-1}), hour 1 of the exercise bout would have a predicted −100 kcal energy balance (expressed in this paper as a 100-kcal deficit). Hour 2 of the exercise bout would have a predicted −400 kcal energy balance (300-kcal additional energy expenditure added to the 100-kcal energy deficit from the previous hour).

Statistical analysis. Data were analyzed statistically using SPSS for Windows 95, version 7.0 (Chicago, IL). Descriptive statistics, Pearson Correlations, *t*-tests, and regression analyses were performed to evaluate the relationship between within-day energy balance and body composition. Several variables were used as determinants of energy balance, including the largest energy surplus and deficit, the number of energy surpluses and deficits greater than 300 kcal (a level selected because it is the predicted amount of liver glycogen storage for small subjects), total energy intake and total energy expenditure, and the largest single-hour energy surplus and deficit. Body composition was measured via both DEXA and skinfold prediction equation. The decision to use both DEXA and skinfolds was made because DEXA is increasingly used to determine body composition (and is approved by the FDA to do so), but much of the athletic literature has reported body composition as determined via skinfold regression equation. Pearson product-moment correlation coefficients were used to determine whether there was consistent movement between the DEXA and skinfold methods, and paired *t*-tests were used to determine whether the results were of the same magnitude.

It was determined that Pearson product-moment correlation coefficients were an appropriate means of evaluating whether a relationship between the "energy balance" and body composition variables existed. Correlations were obtained on these variables for all athletes in the subject pool. To determine whether there were differences between athlete groups (determined by sport) on the "energy balance" variables, a one-way ANOVA with a Bonferroni *post-hoc* test was run.

It was believed that the answer to the research question might also be addressed by performing a linear regression analysis (forward stepwise) using body fat percent as the dependent variable, and the energy balance variables as the independent variables. Athlete age and "athlete group" (four separate groups) were included as independent variables in this analysis because there were age and group differences in both body composition and energy balance. This linear regression analysis was performed twice, once using DEXA-derived body fat percent and once using skinfold-derived body fat percent, because of the significant differences found in these methods.

RESULTS

Subject characteristics. The mean age of the athletes assessed was 19.11 yr (± 5.99), with the youngest athletes coming from the artistic gymnastics group ($\bar{x}$ = 15.19 yr) and the oldest athletes coming from the long-distance running group ($\bar{x}$ = 28.14 yr). A statistically significant difference in age was found between all four athlete groups. The athletes were predominantly Caucasian (88.7%), with three African-Americans (4.8%), three Asians (4.8%), and one of Hispanic origin (1.6%). The mean height and weight of the assessed athletes was 158.42 cm (± 9.92) and 49.95 kg (± 7.61), respectively. Runners were significantly taller and heavier than gymnasts (P = 0.000 and P = 0.000, respectively), and rhythmic gymnasts were significantly taller and heavier than artistic gymnasts (P = 0.000 and P = 0.031, respectively). Body mass index was 20.29 (± 2.20) for all groups assessed. Artistic gymnasts had a higher BMI than rhythmic gymnasts (P = 0.019). See Table 1 for subject characteristics by group.

Body fat percentage. In the total athlete population studied, there is a strong positive relationship between body fat percentage derived from DEXA and body fat percentage derived from skinfolds (r = 0.855; P = 0.000). A positive relationship also exists within each group assessed, but is notably lowest (yet still statistically significant) in the long-distance runners (Table 2). While there was a statistically significant relationship between DEXA and skinfold methods, we also found, except in middle-distance runners, a

TABLE 2. The relationships (correlations) and differences (t-tests) between body fat percentage derived from DEXA and body fat percentage derived from skinfold equation for all groups assessed.

	DEXA Body Fat % $\bar{x}$ (SD)	Skinfold Body Fat % $\bar{x}$ (SD)	Pearson Correlations R (P)	Paired t-Tests t-score (P)
All groups (N = 62)	13.72 (4.02)	12.25 (2.31)	0.855 (0.000)	4.892 (0.000)
All gymnasts (N = 42)	13.47 (4.17)	11.94 (2.48)	0.909 (0.000)	4.560 (0.000)
Artistic gymnasts (N = 31)	12.36 (3.96)	11.31 (2.45)	0.908 (0.000)	2.883 (0.007)
Rhythmic gymnasts (N = 11)	16.60 (3.10)	13.69 (1.62)	0.778 (0.005)	4.583 (0.001)
All runners (N = 20)	14.25 (3.73)	12.91 (1.78)	0.703 (0.001)	2.159 (0.044)
Middle-distance runners (N = 6)	12.18 (4.33)	12.22 (2.18)	0.836 (0.038)	−0.029 (0.978)
Long-distance runners (N = 14)	15.14 (3.21)	13.20 (1.58)	0.562 (0.037)	2.713 (0.018)

statistically significant difference in the mean body fat percent values produced by these methods. Higher body fat percentages were observed with DEXA than with skinfold equation in 61.3% of the artistic gymnasts, 90.9% of the rhythmic gymnasts, 33.3% of the middle-distance runners, and 60% of the long-distance runners. Because of these findings, it was determined that the results of both methods should be reported. See Table 2 for the body fat percentages (determined by both DEXA and skinfold equation) of the groups assessed.

The body fat percentage of artistic gymnasts is significantly lower than that for rhythmic gymnasts when either DEXA-derived (P = 0.002) or skinfold-derived (P = 0.001) estimations are made. The differences in body fat percentage between long-distance and middle-distance runners are not statistically significant. Artistic gymnasts have a significantly lower body fat percentage than long-distance runners (P = 0.018 using DEXA; P = 0.004 using skinfolds) but not middle-distance runners.

Energy balance. The average energy intake for all athletes was 1,600 kcal (± 657), and the average predicted energy usage was 2,384 kcal (± 258), resulting in an average energy deficit of 784 kcal over 24 h. The average largest within-day energy deficit was −644 kcal (± 400), and the average largest within-day energy surplus was 335 kcal (± 296). The average number of hours in which the within-day energy deficits were greater than 300 kcal was 7.60 (± 6.36), while the average number of hours where the within-day energy surpluses were greater than 300 kcal was 2.95 (± 4.56). In general, there is a tendency for these athletes to be in a state of energy balance (approximately ± 100 kcal) for the first 10 h of the day (hour 1 begins at time of wake-up, so the clock hour may be different for each athlete). However, by hours 13 and 14, the average energy deficit exceeds 300 kcal. The mean energy balance profile for all athlete groups assessed is represented in Figure 1. In addition, Table 3 provides a breakdown of relevant energy balance variables for each athlete group.

As compared with the other athlete groups assessed, the middle-distance runners came closest to consuming a level of energy that approached their predicted requirement. The gymnasts had the largest energy inadequacies, both for 24 h and within 24 h. Rhythmic gymnasts had the largest daily energy deficit (−865; ± 282 kcal) and the largest single-hour kcal deficit (−749 ± 367 kcal). The largest energy deficits occurred, regardless of athlete group, immediately following the afternoon training session.

Using ANOVA (with the Bonferroni *post-hoc* test), there was a statistically significant difference between the groups on the "energy balance" variables. Because of these differences, we determined that it would be appropriate to evaluate the relationship between the "energy balance" variables and body composition for each athlete group.

Relationship between energy balance and body composition. In these athletes, energy deficits are positively associated with body fat percentage, whereas energy surpluses are negatively associated with body fat percentage. The number of hours with energy deficits greater than 300 kcal is positively associated with body fat percentage derived from DEXA (r = 0.407; P = 0.001) and skinfolds (r = 0.293; P = 0.021). Similar correlations are seen with the largest daily energy deficits, which are positively associated with DEXA derived body fat (r = 0.378; P = 0.002) and skinfold derived body fat (r = 0.305; P = 0.016). The total hours with deficit kilocalories are positively associated with DEXA-derived body fat percentage (r = 0.285; P = 0.025), while the total hours with surplus kilocalories are negatively associated with DEXA-derived body fat percentage (r = −0.284; P = 0.025). Other variables positively associated with DEXA-derived body fat percentage include age (r = 0.267; P = 0.036), height (r = 0.375; P = 0.003), and weight (r = 0.425; P = 0.001). (See Table 4.)

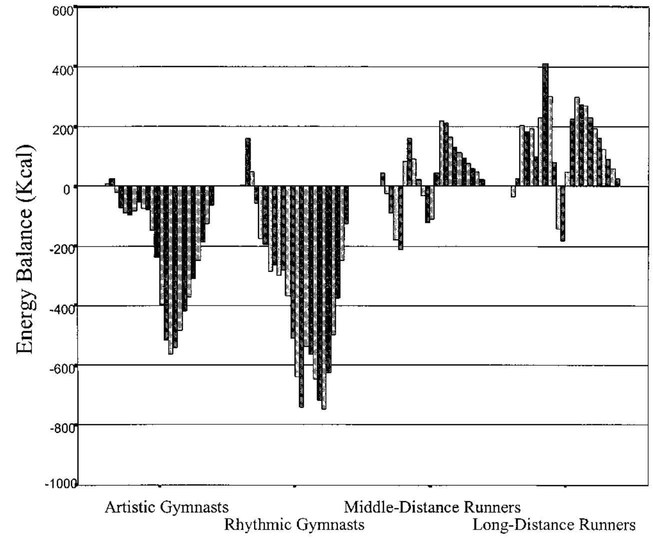

Figure 1—Comparison of within-day energy balance in four groups of elite athletes. Each group has 24 bars, beginning with wake-up and ending 24 h later. The bars represent 1 h for each hour in the day. Energy surpluses and deficits are represented, respectively, by variations above and below the zero (0) energy-balance line.

TABLE 3. Mean energy balance factors of assessed athlete groups.

	All Athletes (N = 62) x̄ (SD)	All Gymnasts (N = 42) x̄ (SD)	Artistic Gymnasts (N = 31) x̄ (SD)	Rhythmic Gymnasts (N = 11) x̄ (SD)	All Runners (N = 20) x̄ (SD)	Middle-Distance Runners (N = 6) x̄ (SD)	Long-Distance Runners (N = 14) x̄ (SD)
Total hours with surplus kcal	8.34 (7.95)	5.81 (6.29)	6.65 (7.04)	3.45 (2.34)	13.65 (8.59)	15.50 (6.75)	12.86 (9.39)
Total hours with deficit kcal	15.47 (7.92)	17.98 (6.25)	17.16 (7.00)	20.27 (2.28)	10.20 (8.61)	8.33 (6.77)	11.00 (9.41)
No. hours with surplus > 300 kcal	2.95 (4.56)	1.40 (3.04)	1.81 (3.46)	0.27 (0.47)	6.20 (5.50)	7.00 (5.66)	5.86 (5.61)
No. hours with deficit > −300 kcal	7.60 (6.36)	9.45 (6.00)	8.32 (6.07)	20.27 (2.28)	3.70 (5.34)	1.67 (1.86)	4.57 (6.14)
Largest daily kcal surplus[a]	335 (296)	239 (219)	244 (245)	224 (130)	536 (340)	548 (219)	531 (388)
Largest daily kcal deficit[b]	−644 (400)	−743 (392)	−700 (419)	−865 (282)	−435 (340)	−336 (249)	−478 (373)
Largest single-hour kcal surplus[c]	55 (179)	62 (146)	28 (132)	159 (146)	242 (531)	411 (198)	219 (586)
Largest single-hour kcal deficit[c]	−358 (557)	−576 (424)	−565 (463)	−749 (367)	−142 (480)	−185 (204)	−214 (317)
kcal consumed in 24 h	1600 (657)	1326 (498)	1317 (559)	1353 (285)	2175 (581)	2431 (363)	2065 (632)
kcal expended in 24 h	2384 (258)	2328 (231)	2263 (199)	2513 (223)	2500 (277)	2635 (291)	2442 (260)

[a] The mean of the largest kcal surplus of all hours for each subject.
[b] The mean of the largest kcal deficit of all hours for each subject.
[c] Refer to Figures 1–7 for all single-hour surplus and deficit values.

In artistic gymnasts, the energy balance factor most strongly associated with body fat percentage is the largest daily kilocalorie deficit. With either skinfold-derived or DEXA-derived body fat percentage, the more pronounced the daily energy deficit the higher the body fat percentage. The number of energy deficits greater than 300 kcal is also significantly associated with both DEXA-derived body fat percentage (r = 0.487; P = 0.005) and skinfold-derived body fat percentage (r = 0.510; P = 0.003). A statistically significant inverse relationship between within-day energy surpluses greater than 300-kcal and DEXA-derived body fat percent and skinfold-derived body fat percent also exists. Similar relationships exist in rhythmic gymnasts, in which the total number of hours with surplus energy is inversely associated with skinfold-derived body fat percentage (r = −0.648; P = 0.03), and total hours with deficit energy is positively associated with skinfold-derived body fat percentage (r = 0.598; P = 0.05). The rhythmic gymnasts had the highest energy deficits of all the athlete groups assessed and also had the highest body fat percentages, regardless of the method (DEXA or skinfolds) used in making the body composition determination. In rhythmic gymnasts weight (r = 0.723; P = 0.012) and kilocalories expended in 24 h (r = 0.707; P = 0.015) were also strongly associated with skinfold-derived body fat percentage.

DEXA-derived body fat percentage was significantly related to the number of hours with energy deficits greater than 300 kcal (r = 0.461; P = 0.041) and weight (r = 0.530; P = 0.016) in runners (both middle- and long-distance runners combined). In this group weight was most strongly associated with skinfold-derived body fat percentage (r = 0.459; P = 0.042). Assessing the middle- and long-distance runners separately determined that weight was the only variable significantly associated body fat percentage (DEXA-derived).

In comparing athlete groups on energy balance variables, it was found that gymnasts are significantly different than runners on all measured factors (Table 5). Artistic gymnasts have significantly more hours with within-day energy surpluses and significantly fewer hours with within-day energy deficits than rhythmic gymnasts. In addition, artistic gymnasts experience more hours with energy surpluses greater than 300 kcal and fewer energy deficits greater than 300 kcal than rhythmic gymnasts. The total (24-h) energy expenditure of rhythmic gymnasts is significantly higher than that of artistic gymnasts. There are no statistically significant differences in the energy balance variables between middle- and long-distance runners.

Using a forward stepwise linear regression analysis with body fat percentage as the dependent variable and the "energy balance" variables plus age and athlete group (four separate groups) as the independent variables, we determined that we could predict both skinfold-derived and DEXA-derived body fat percentage in the assessed populations (Table 6). Using DEXA- or skinfold-derived body fat percentage as the dependent variable, age and energy deficits > 300 kcal explained a significant amount of variance (R^2 = 0.309; SEE = 3.399; P = 0.000 and R^2 = 0.298; SEE = 1.966; P = 0.000 respectively).

DISCUSSION

The typical time frame for assessment of nutrient and energy intake is 24 h or multiples of 24-h units. Since the various available population recommendations (i.e., Recommended Dietary Allowances, World Health Organization Standards, etc.) for determining dietary adequacy are also based on 24-h intakes, there is logic in using this time frame. However, basing energy assessment on 24-h units causes an important loss of data that limits valuable insights on how within-day variations in energy balance affect body composition, mood states, energy metabolism, strength, and probably other factors that may be important variables in athletic performance. The purpose of this study was to evaluate how within-day energy balance impacts on one of these factors, namely, body composition, in four groups of elite athletes.

The validity of the CTLEA procedure for determining energy intake has been previously evaluated with gymnasts

TABLE 4. Relationships (Pearson correlations) between energy balance factors, age, height, and weight, and body fat percentage in all athletes, gymnasts, and runners.

	All Athletes (N = 62)		Artistic Gymnasts (N = 31)		Rhythmic Gymnasts (N = 11)		Middle-Distance Runners (N = 6)		Long-Distance Runners (N = 14)	
	DEXA BF% r(*P*)	Skinfold BF% r(*P*)	DEXA BF% r(*P*)	Skinfold BF% r(*P*)	DEXA BF% r(*P*)	Skinfold BF% r(*P*)	DEXA BF% r(*P*)	Skinfold BF% r(*P*)	DEXA BF% r(*P*)	Skinfold BF% r(*P*)
Total hours with surplus Kcal	−0.284 (0.03)	−0.170 (0.19)	−0.371 (0.04)	−0.395 (0.03)	−0.428 (0.19)	−0.648 (0.03)	−0.551 (0.26)	−0.566 (0.24)	−0.187 (0.52)	0.258 (0.37)
Total hours with deficit Kcal	0.285 (0.03)	−0.168 (0.19)	0.380 (0.04)	0.398 (0.03)	0.389 (0.24)	0.598 (0.05)	0.540 (0.27)	0.586 (0.22)	0.185 (0.53)	−0.264 (0.36)
No. hours with Kcal surplus > 300	−0.190 (0.14)	−0.056 (0.66)	−0.294 (0.11)	−0.318 (0.08)	−0.034 (0.92)	0.156 (0.65)	−0.383 (0.45)	−0.092 (0.86)	−0.121 (0.68)	0.176 (0.55)
No. hours with Kcal deficit > −300	0.407 (0.00)	0.293 (0.02)	0.484 (0.01)	0.508 (0.00)	0.161 (0.64)	0.278 (0.41)	0.488 (0.33)	0.369 (0.47)	0.464 (0.10)	−0.098 (0.74)
Largest daily kcal surplus[a]	−0.096 (0.46)	−0.022 (0.86)	−0.289 (0.12)	−0.324 (0.08)	−0.161 (0.64)	−0.219 (0.52)	−0.172 (0.75)	0.124 (0.82)	0.042 (0.89)	0.434 (0.12)
Largest daily kcal deficit[b]	−0.378 (0.00)	−0.305 (0.02)	−0.465 (0.01)	−0.518 (0.00)	−0.129 (0.71)	−0.207 (0.54)	−0.661 (0.15)	−0.570 (0.24)	−0.321 (0.26)	0.126 (0.67)
kcal consumed in 24 hr.	−0.158 (0.22)	−0.021 (0.87)	−0.332 (0.07)	−0.358 (0.05)	0.122 (0.72)	0.289 (0.39)	−0.372 (0.47)	−0.441 (0.38)	−0.273 (0.34)	0.220 (0.45)
kcal expended in 24 hr.	0.141 (0.28)	0.214 (0.10)	−0.022 (0.91)	0.017 (0.93)	0.298 (0.37)	0.707 (0.02)	−0.226 (0.67)	−0.401 (0.43)	0.068 (0.82)	−0.010 (0.97)
Age (yr)	0.267 (0.04)	0.374 (0.00)	0.445 (0.01)	0.519 (0.00)	0.105 (0.76)	0.480 (0.14)	0.556 (0.25)	0.432 (0.39)	0.197 (0.50)	0.353 (0.22)
Height (cm)	0.375 (0.00)	0.473 (0.00)	0.304 (0.10)	0.360 (0.05)	0.165 (0.63)	0.169 (0.62)	0.715 (0.11)	0.773 (0.07)	−0.254 (0.38)	−0.193 (0.51)
Weight (kg)	0.425 (0.00)	0.494 (0.00)	0.309 (0.09)	0.367 (0.04)	0.554 (0.08)	0.723 (0.01)	0.815 (0.05)	0.652 (0.16)	0.268 (0.35)	0.263 (0.36)

[a] Values recorded as positive numbers.
[b] Values recorded as negative numbers.

but not with runners (4). However, the recall technique used for obtaining information in this procedure is similar to the 24-h recall, a well-established research procedure for predicting the nutrient/energy intakes of groups (3,6,7,9,10,19). With the CTLEA, the 24-h recall technique is followed, but additional activity information is acquired to better understand within-day energy intake and expenditure. With both the activity and food intake information available in each discrete time period, a comparison between predicted energy intake and energy expenditure for each activity period throughout the day is possible and is the basis for the energy deficit/surplus values obtained. Since individuals have schedules that differ in activity duration and intensity, the activity periods were converted into 1-h units to permit an hourly comparison of energy balance data in the assessed subjects. While this procedure has not been fully validated, the total energy intakes were the same before and after the hourly data conversion. Most importantly, this hourly conversion procedure was necessary to enable a statistical comparison of within-day energy balance for the assessed subjects.

Virtually all techniques for predicting energy/nutrient intakes (24-h recalls, single and multi-day food records, food frequencies, phone interviews, etc.) have the problem of underreporting food intake (3,7,9,10,19). We expect, therefore, that this would also be a problem with the CTLEA. However, since the average amount of under-reporting among athlete groups in this study is likely to be similar, we believe the relative accuracy of the data between athlete groups is satisfactory. It is possible that the day of the week may impact on the 24-h energy balance. In this study, we asked athletes to provide information on a *typical training day* (as opposed to the previous day) because we were most interested in predicting within-day energy balance in groups of people with large training loads. To some extent, evaluating the intake on a typical training day may serve to minimize variability within these athlete groups since elite athletes tend to have similar, regular, and predictable training life-styles that enable them to accurately remember both activity and food intake patterns.

The basis of the energy expenditure data is the predicted REE, which is adjusted for age, weight, and gender, using the method described in the 10th edition of the Recommended Dietary Allowances (29). The issue of whether the growth requirement is satisfactorily addressed in these equations is important, since most of the gymnasts assessed in this study are of an age when growth is a normal expectation. The equations used do produce a higher REE for same-weight females between 10–18 yr than for those between 19–30 yr. This difference amounts to approximately 137 kcal for a person weighing 45 kg, and since this difference is magnified for high activity individuals, it is likely that the higher energy requirement for growth is appropriately accounted for in these young subjects. For instance, using these REE equations with an activity factor of 1.6 (for moderate activity), a 15-yr old would have a predicted energy requirement of 2,072 kcal and a 20-yr old of the same weight would have a predicted energy requirement of

TABLE 5. Comparison of means (*t*-tests) of energy balance factors in gymnasts and runners.

	All Gymnasts vs All Runners		Artistic Gymnasts vs Rhythmic Gymnasts		Middle-Distance vs Long-Distance Runners	
	Mean (SD)[a]	*P*	Mean (SD)[a]	*P*	Mean (SD)[a]	*P*
Hours with surplus kcal	5.81 (8.61)		6.65 (7.04)		8.33 (6.77)	
	13.65 (6.25)	0.001	3.45 (2.34)	0.033	11.00 (9.41)	0.490
Hours with deficit kcal	17.98 (8.59)		17.16 (7.00)		15.50 (6.75)	
	10.20 (6.29)	0.001	20.27 (2.28)	0.036	12.86 (9.39)	0.488
Hours with surplus > 300 kcal	1.40 (3.04)		1.81 (3.46)		7.00 (5.66)	
	6.20 (5.50)	0.001	0.24 (0.47)	0.022	5.86 (5.61)	0.687
Hours with deficit > −300 kcal	9.45 (6.00)		8.32 (6.07)		1.67 (1.86)	
	3.70 (5.34)	0.000	12.64 (4.70)	0.024	4.57 (6.14)	0.126
Largest kcal surplus	239 (219)		244 (245)		548 (219)	
	536 (340)	0.001	224 (130)	0.736	531 (388)	0.900
Largest kcal deficit	−743 (392)		−700 (419)		−336 (249)	
	−435 (340)	0.003	−865 (282)	0.157	−478 (373)	0.337
Total kcal consumed in 24 hr	1326 (499)		1317 (559)		2430 (363)	
	2175 (581)	0.000	1353 (285)	0.785	2065 (632)	0.124
Total kcal expended in 24 hr	2328 (231)		2263 (199)		2635 (291)	
	2500 (277)	0.023	2514 (223)	0.005	2442 (260)	0.196

[a] For each pair of values within each variable, the first value represents the top listed group.

1,853 kcal. This 219-kcal daily difference in requirement translates into an additional 3,500 kcal (the theoretical amount of excess kcal to add 1 pound of body weight) every 16 d.

The energy intake of the gymnasts in this study can be compared with previously published data on age and achievement-equivalent gymnasts. While the energy intakes of less competitive young gymnasts are in the range of 1,568 to 1,744 kcal (11,15,33), surveys of more competitive gymnasts have found intakes ranging from 1,381 to 1,496 kcal (4,20). In this study, the mean energy intakes (1,326 kcal) are similar to other published data on the highest competitive level artistic gymnasts. The difference in energy intakes between highly competitive and less competitive gymnasts may help to explain the greater heights and weights commonly seen in the less competitive gymnasts.

This study finds that athletes with higher average within-day energy deficits have higher body fat percentages, regardless of age or whether they are gymnasts or runners. The magnitude of the deficits is also related to the degree of difference in body fat percentages. Whether the assessment is for all athletes combined or for the specific athlete groups combined, body fat percentage was inversely correlated with the largest within-day calorie deficits, with the number of energy deficits > 300 kcal, and with the total number of hours an athlete experiences an energy deficit. Artistic gymnasts, who had fewer hours with deficits exceeding 300 kcal and lower peak within-day deficits than rhythmic gymnasts, also had significantly lower body fat percentages whether measured by DEXA ($P = 0.002$) or the skinfold equation ($P = 0.001$). Although there are no significant differences in within-day energy balance factors in runners and no significant differences in body fat percentage between middle- and long-distance runners, even within these running groups there are trends suggesting a relationship between within-day energy deficits and body fat percentage. Thus, while the middle-distance runners have a somewhat more mesomorphic appearance than the more ectomorphic long-distance runners, they have a lower body fat percentage than the long-distance runners (whether assessed by DEXA or skinfold equation). They also have a lower number of within-day deficits greater than 300 kcal and lower within-day peak deficits than the long-distance runners.

It is important to note that the proportion of total 24-h energy consumed relative to the predicted 24-h energy requirement is also important in the assessed body fat percentage of these athlete groups. Those consuming a higher proportion of the 24-h energy requirement had lower

TABLE 6. Multiple regression analysis (forward stepwise) to predict body fat percentage from energy balance variables[a] and athlete group.

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	*t*	Sig.
DEXA-derived body fat percentage					
(Constant)	6.245	1.710		3.652	0.001
No. deficits > 300 kcal	0.327	0.073	0.501	4.500	0.000
Age (yr)	0.257	0.075	0.383	3.444	0.001
Equation: Body fat $\%_{DEXA}$ = Age in years (0.257) + No. Deficits > 300 kcal (0.327) + 6.245 [$R^2 = 0.309$; SEE = 3.399; Sig. = 0.000]					
Skinfold-derived body fat percentage					
(Constant)	7.595	0.989		7.680	0.000
No. deficits > 300 kcal	0.153	0.042	0.409	3.644	0.001
Age (yr)	0.181	0.043	0.469	4.184	0.000
Equation: Body fat $\%_{SKINFOLDS}$ = Age in years (0.181) + No. Deficits > 300 kcal (0.153) + 7.595 [$R^2 = 0.298$; SEE = 1.966; Sig. = 0.000]					

[a] Energy balance variables included in analysis: Age; Number of within-day deficits > 300 kcal; number of within-day surpluses > 300 kcal; number of within-day kcal deficits; number of within-day kcal surpluses; total daily kcal consumed; total daily kcal expended; athlete group (1, artistic gymnasts; 2, rhythmic gymnasts; 3, middle-distance runners; and 4, long-distance runners).

body fat percentages. Artistic gymnasts, with significantly lower body fat percentages than rhythmic gymnasts, consumed approximately 58% of their predicted energy requirement, while rhythmic gymnasts consumed 54% of their predicted requirement, a nonsignificant difference in the proportion of total energy requirement consumed. Despite the similarity in total energy intake, the rhythmic gymnasts had significantly greater within-day energy deficits and a significantly greater body fat percent. It is also interesting to note that having an energy surplus, which does not occur with the same frequency or magnitude as energy deficits in these groups, is inversely associated with body fat percentage.

The relationships between energy deficits and body fat percentage are not unexpected, although athletes commonly use energy restriction as a primary means of achieving desirable body composition. Past studies have indicated that the human adaptive response to energy deficits is well developed (27,34,42). Studies indicate that starvation, famine, or energy restriction may cause a reduction in energy metabolic rate and a relative increase in fat storage from the limited energy consumed (34,46). The data presented in this paper are consistent with these findings. Although exercise is thought to maintain or increase metabolic rate, these data suggest that, when coupled with an energy deficit state, metabolic rate is reduced. This apparent reduction is evidenced even in the highly active runners or gymnasts, who have increased body fat percentage when within-day and overall energy deficits are present.

Energy intake data of the younger subjects (the gymnasts) can be compared with published data on age and achievement-equivalent gymnasts. These comparisons demonstrate that the gymnast energy intake data in this study are of the same magnitude for previous studies that have assessed the most accomplished elite-level gymnasts (4,20). Studies of less competitive gymnasts (i.e., high school and club gymnasts) tend to show that a higher proportion of predicted energy requirement is consumed (5,11,15,33). This may help to explain the greater heights and weights in the less competitive gymnasts as compared with age-equivalent more competitive gymnasts. The magnitude of differences in energy consumption versus energy usage for gymnasts in this study show that only 16% ($N = 5$) of the artistic gymnasts had energy intakes of $\geq$ 2,000 kcal, while none ($N = 0$) of the rhythmic gymnasts had energy intakes $\geq$ 2,000 kcal. This is found despite the fact that the rhythmic gymnasts are significantly taller and heavier than the artistic gymnasts.

Although runners clearly expend more energy than nonrunners, past studies have shown that runners were capable of maintaining weight despite energy intakes equivalent to that of the nonrunners and calculated to be well below the predicted energy requirement (14,27). These past findings of lower than expected energy intakes are consistent with those of the present study, which found daily predicted energy deficits of approximately 200–400 kcal for the assessed runners.

The basis of the energy expenditure data is the predicted REE, which is adjusted for age, height, weight, and gender. The additional energy requirements of growth are, therefore, considered in the calculations. It is clear, however, that measuring RMR would have been useful in refining the energy balance data and the interaction between energy deficits, REE, and body composition.

The athletes evaluated were unquestionably elite level and represent the extreme in successful athletic performance. The gymnasts were the best in the United States, as determined through national competitions. Some of the artistic gymnasts assessed were members of the 1996 Centennial Olympic Games gold medal winning team. The majority of rhythmic gymnasts assessed were on the United States Group rhythmic team at the 1996 Games, and the sole individual rhythmic competitor representing the United States during the 1996 Olympics was also in the pool of rhythmic gymnasts assessed. Similarly with the runners, all athletes qualified for the 1996 United States Olympic Team selection trials, and several earned berths on the 1996 Olympic Team or the 1995 and 1997 World Championship teams.

Importantly, these athletes represent sports that have distinctly different training regimens and competition requirements. Based on training and competition, the gymnasts can generally be considered primarily anaerobic athletes, while the runners can be considered primarily aerobic athletes. However, there are differences between artistic and rhythmic gymnasts and between middle-distance and long-distance runners. For our purpose, the athletes can be differentiated by placing them on an anaerobic-to-aerobic continuum. The artistic gymnasts are the most anaerobic group, followed by the rhythmic gymnasts (who also do predominantly anaerobic work, but less intensive and longer in duration than the artistic gymnasts). They are followed by the middle-distance runners whose training and racing includes a sizable anaerobic component superimposed on aerobic training (30%:70%). In turn, they are followed by the long-distance runners, who do mainly aerobic work in training and racing, with a considerably smaller anaerobic component (10%: 90%).

The gymnasts and runners were significantly different in age, height, weight, and the energy balance factors assessed. However, the within-gymnast differences (i.e., differences between artistic and rhythmic gymnasts) are more pronounced than the within-runner differences (i.e., differences between middle- and long-distance runners). In fact, only age is significantly different between the running groups, while the artistic and rhythmic gymnasts are significantly different in age, height, weight, the number of hours with energy surpluses greater than 300 kcal, the number of hours with energy deficits greater than 300 kcal, the total predicted energy expended over 24 h, total hours with surplus energy, and total hours with deficit energy. These findings suggest that artistic and rhythmic gymnasts are entirely different disciplines that attract different types of individuals to each sport and that describing both groups simply as "gymnasts" is inadequate.

As a practical conclusion, athletes and coaches should become more aware of these relationships so that both athlete appearance and performance can be best developed in an environment of optimum energy balance. Thus, dietary restriction resulting in energy intake below estimated energy needs should be avoided, not only because inadequate energy impairs performance, but also because the increased stored body fat affects appearance. It appears clear from these data that consuming sufficient energy is better than not getting enough, and getting energy on time to prevent an energy deficit state during the day is better than getting it late.

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