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Daily energy expenditure and its main components as measured by whole-body indirect calorimetry in athletic and non-athletic adolescents

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The objectives of the present study were to determine whether differences in usual physical activity affect BMR, sleeping energy expenditure (EE), and EE during seated activities between athletic and non-athletic adolescents, and to establish individual relationships between heart rate and EE. Adolescents (*n* 49, four groups of eleven to fifteen boys or girls aged 16–19 years) participated in the study. Body composition was measured by the skinfold-thickness method and maximum O_2 consumption (VO_{2max}) by a direct method (respiratory gas exchange) on a cyclo-ergometer. The subjects each spent 36 h in one of two large whole-body calorimeters. They followed a standardized activity programme including two periods of exercise simulating their mean weekly physical activities. Fat-free mass (FFM), VO_{2max}, daily EE and EE during sleep and seated activities were significantly higher in athletic than in non-athletic subjects of both sexes. VO_{2max}, daily EE and EE during exercise adjusted for FFM were higher in athletic than in non-athletic adolescents ($P < 0{\cdot}001$), whereas sleeping EE, BMR and EE during seated activities and adjusted for FFM were not significantly different between athletic and non-athletic adolescents. However, sex differences in EE remained significant. Thus, differences in EE between athletic and non-athletic adolescents resulted mainly from differences in FFM and physical exercise. Usual activity did not significantly affect energy utilization of substrates. Finally, individual relationships were computed between heart rate and EE with activity programmes simulating the usual activities of athletic and non-athletic adolescents with the goal of predicting EE of the same subjects in free-living conditions.

Adolescents: Athletes: Body composition: Indirect calorimetry: Energy expenditure

Daily energy expenditure (EE) of humans depends mainly on age, sex, body weight and composition, and physical activity. However, fat-free mass (FFM) and physical activity are the main determinants of daily EE (Goran *et al*. 1994; Bratteby *et al*. 1997; Morio *et al*. 1997*a*). They are influenced by genetic, nutritional and environmental factors. Development of indirect calorimetry, the doubly-labelled water method, the heart-rate (HR) recording method, and the factorial method have enabled major advances in knowledge of daily EE and its main components in adolescents, either in controlled conditions (Rieper *et al*. 1993; Molnar & Schutz, 1997; Bitar *et al*. 1999) or in free-living conditions (Bandini *et al*. 1990; Livingstone *et al*. 1992; Bratteby *et al*. 1997, 1998). However, these studies did not provide any direct comparison of daily EE and its main components between athletic and non-athletic adolescents in the same environmental conditions, or information on EE of athletes in free-living conditions during their various activities.

Therefore, the objectives of the present study were: (1) to determine whether differences in usual physical activity affect BMR, sleeping EE, and EE during seated activities between athletic and non-athletic adolescents, and (2) to establish precise individual relationships between HR and EE to enable evaluation of the EE of the subjects in free-living conditions from HR recordings. EE were measured by whole-body indirect calorimetry over a 24 h period according to a standardized activity programme simulating the mean weekly activities of the subjects.

Abbreviations: EE, energy expenditure; FFM, fat-free mass; HR, heart rate; VO_{2max}, maximum oxygen consumption.
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Subjects and methods

Subjects

Adolescents (*n* 49, four groups of eleven to fifteen boys or girls aged 16–19 years) participated in this study according to a 2 × 2 factorial design with sex (boys or girls) and activity (athletic or non-athletic subjects) as variables. The subjects were recruited from a high school in Clermont-Ferrand either in sports-specialized classes for athletes ('Pôle France Athlétisme') or in ordinary classes of the same study level for non-athletic subjects. Before the study began, the purpose and objectives were carefully explained to each subject and his or her parents. Informed consent was obtained from the adolescents and their parents. The experimental protocol was approved by the National Ethical Committee on Human Research for Medical Sciences. All subjects had a thorough physical examination and a medical history was taken. Only individuals aged 16–19 years, apparently healthy, not suffering from any diagnosed disease, and under no medication known to influence energy metabolism were included. All trained adolescents were non-smokers and only two non-athletic boys and two non-athletic girls were occasional smokers.

Anthropometric data and physical fitness

Height was measured to the nearest 1 mm with an anthropometric plane. Weight was measured to the nearest 0·1 kg with a portable digital metric scale, which was calibrated by using standard weights. Body composition was determined using the skinfold-thickness method. Bicipital, tricipital, subscapular and suprailiac skinfolds were measured on each subject with a Harpenden skinfold caliper (Holtain Ltd, Bryberian, UK) by the same investigator. Fat mass (%) was estimated from regression equations that took into account age and sex (Durnin & Rahaman, 1967). FFM was estimated from the difference between measured body weight and estimated body fat mass. Maximum O_2 uptake (VO_{2max}) was measured by direct method (respiratory gas exchange) in all subjects on a cycloergometer. The subjects performed several successive 3 min steps against increasing braking forces until exhaustion. The first step corresponded to 70 W. The exercise intensity was then increased by 35 W steps. The pedalling frequency was 70 rev./min. HR was recorded continuously (Scheller AG, Cardiovit CS-6/12, Baar, Switzerland). O_2 consumption and CO_2 production were measured continuously by open-circuit respirometry and averaged every 30 s using an automated on-line system (Medical Graphics CPX ID, St Paul, MN, USA). The criteria for reaching VO_{2max} were RQ $> 1·1$ and a maximal HR close to the theoretical maximum HR (220 – age (years)).

Timing of measurements and programme of activities in the calorimeters

Subjects were admitted to the Human Nutrition Laboratory at 18.00 hours the evening before their metabolic test. They were fitted with probes for continuous recording of HR by telemetry (Life Scope 6, Nikon Kohden, Tokyo, Japan), then they were fed dinner in the calorimetric chambers and allowed to use the various pieces of equipment to alleviate any concern or apprehension about testing conditions. The subjects spent 36 h in the calorimetric chambers, from 19.00 hours to 07.00 hours 2 d later: one evening and one night for adaptation to the new environment and for adjustment of gas concentrations followed by 24 h of measurements. Smoking was forbidden. During the 24 h measurement period subjects followed a defined activity programme except for exercise, which differed according to sex and activity status (athletic or non-athletic subjects). Subjects awoke at 07.00 hours, BMR was measured from 07.00 hours to 08.00 hours, they got up at 08.00 hours, and they underwent two periods of exercises (at 11.00 hours and 16.00 hours) of different intensities and durations. These two periods of activity were determined with the help of the subjects and their trainer. They consisted of successive periods of walking, running on a treadmill at various intensities, and physical fitness exercises (strengthening, stretching, etc.) reflecting the mean weekly physical activities of the subjects (Table 1). This facilitated establishment of the most precise relationships between EE and HR in order to predict accurately EE from HR recordings in free-living conditions. Between the exercise sessions, activities were unstructured and recorded in a follow-up book by the subjects. They consisted mainly of seated activities (schoolwork, reading and watching television). The subjects were not allowed to do any unplanned exercise. They were offered breakfast at 08.00 hours, lunch at 12.30 hours, snack at 17.40 hours, dinner at 19.30 hours, and they went to bed at 22.00 hours. Supervision was continuous while subjects were in the calorimetric chambers.

Measurement of energy expenditure

EE was determined by whole-body indirect calorimetry, using two large open-circuit calorimetric chambers, comfortably equipped (Morio *et al.* 1997*b*). Air flow, O_2 and CO_2 concentration of air entering and leaving the chambers, as well as ambient temperature, relative humidity and atmospheric pressure were recorded every minute (Vermorel *et al.* 1973). The accuracy of gas exchange measurements was determined gravimetrically by continuous injection of CO_2 and N_2 into the chamber (Vermorel *et al.* 1995). The recovery was 101·2 (SD 1·8) % for O_2 and 101·4 (SD 1·9) % for CO_2 during 6–8 h periods.

Calculation of energy expenditure

EE was calculated from O_2 consumption and CO_2 production by using the equation of Weir (1949). EE was calculated over periods of 5 min during exercise and 30 min for the rest of the day. Data collected over the last 24 h were used to compute individual polynomial relationships of the third order (EE (kJ/min) $= a + b \times HR + c \times HR^2 + d \times HR^3$) which gave the best fit in a previous study (Bitar *et al.* 1996). To compare EE of athletic and non-athletic subjects, EE was pooled into five main periods: actual sleep (from 22.00 hours to 07.00 hours), BMR (from 07.00 hours to 08.00 hours), meals (lunch and dinner: 1 h 55 min including two 30–45 min periods of eating and two 15–30 min postprandial periods of resting), seated activities (9 h 20 min), and

Table 1. Nature, duration and intensity (% VO_{2max}) of exercise during the morning and the evening sessions in the whole-body calorimeters (Mean values and standard deviations)

	Boys						Girls					
	Athletic			Non-athletic			Athletic			Non-athletic		
		% VO_{2max}			% VO_{2max}			% VO_{2max}			% VO_{2max}	
Activity	Duration (min)	Mean	SD	Duration (min)	Mean	SD	Duration (min)	Mean	SD	Duration (min)	Mean	SD
Morning session												
Walking (6 km/h)	15	32	3	20	41	5	15	34	2	20	54	8
Jogging*	20	73	6	0			20	77	2	0		
Strengthening	15	38	6	0			15	40	2	0		
Stretching	5	21	3	10	32	4	5	22	2	10	30	3
Recovery periods	20			35			20			35		
Total	75			65			75			65		
Evening session												
Jogging*†	10	73	6	15	78	8	10	77	2	15	86	7
Strengthening	20	38	6	15	44	7	20	40	2	15	46	8
Running‡	15	96–74	7	0			15	102–77	5	0		
Walking (5 km/h)	15	27	3	30	36	4	15	29	2	30	45	7
Stretching	10	21	3	5	32	4	10	22	2	5	30	3
Recovery periods	20			35			20			35		
Total	90			100			90			100		
Total daily activity	165			165			165			165		

* Speed: 11–13 km/h and 9–11 km/h in athletic boys and girls respectively.
† Speed: 9–10 km/h and 8–9 km/h in non-athletic boys and girls respectively.
‡ Speed: successive bouts at 18–12 km/h in athletic boys and 15–10 km/h in athletic girls.

exercise plus recovery periods (2 h 45 min) (Table 1). During the recovery periods the subjects freshened themselves up for about 5 min and had seated activities, generally watching television.

Mean RQ were computed to examine possible differences in substrate oxidation between athletic and non-athletic subjects during sleep, seated activities (including meals), and exercise plus recovery periods.

Statistical analysis

Data were analysed by ANOVA using PROC GLM of SAS software (version 6, 1987; Statistical Analysis Systems Institute Inc., Cary, NC, USA) according to the following model: $y = \mu + \alpha$ gender $+ \beta$ activity $+ \chi$ gender $\times$ activity $+ \varepsilon$. The 'LS MEANS' statement was used to calculate the adjusted means. The latter were compared using the 'TDIFF' option, differences being considered significant at $P < 0{\cdot}05$.

Results

Physical characteristics and body composition of subjects

Age and physical characteristics of subjects are presented in Table 2. There were no significant differences between athletic and non-athletic subjects for the various criteria considered: age, height, body weight, BMI. However,

Table 2. Physical characteristics, body composition and maximal oxygen uptake (VO_{2max}) of subjects (Lean square means (LS means) with standard errors of LS means)

	Boys				Girls				Statistical significance of difference between means (ANOVA): *P* value		
	Athletic		Non-athletic		Athletic		Non-athletic				
	LS mean	SE	LS mean	SE	LS mean	SE	LS mean	SE	Sex	Activity	S×A
No. of subjects	15		12		11		11				
Age (years)	17·5[a]	0·2	16·9[ab]	0·3	16·4[b]	0·3	17·1[ab]	0·3	0·08	0·89	0·02
Height (m)	179·8[a]	1·6	178·8[a]	1·8	163·5	1·8	163·1	1·8	0·001	0·66	0·87
Weight (kg)	69·8[a]	1·7	65·0[a]	1·9	55·3	2·0	53·9	2·0	0·001	0·11	0·37
BMI (kg/m^2)	21·6	0·5	20·4	0·5	20·7	0·6	20·3	0·6	0·39	0·14	0·43
Fat-free mass (kg)	62·3[a]	1·3	56·2[b]	1·4	44·4	1·5	41·9	1·5	0·001	0·004	0·22
Fat mass (%)	10·6[a]	0·8	12·0[a]	0·9	19·4	1·0	21·9	1·0	0·001	0·04	0·59
VO_{2max} (litre/min)	3·83[a]	0·08	2·91[b]	0·09	2·40[c]	0·09	1·83	0·09	0·001	0·001	0·05
VO_{2max} (ml/min per kg)	55·3[a]	1·12	45·0[b]	1·25	43·9[b]	1·31	34·1	1·31	0·001	0·001	0·83
Adjusted VO_{2max} (litre/min)*	3·45[a]	0·10	2·76[b]	0·08	2·69[b]	0·10	2·22	0·11	0·001	0·001	0·14

[a,b,c] Mean values within a row not sharing a common superscript letter were significantly different, $P < 0{\cdot}05$.
* Adjusted VO_{2max} (litre/min), VO_{2max} adjusted for fat-free mass.

height and body weight were significantly higher in boys than in girls. FFM was significantly affected by usual physical activity ($P < 0·004$) and sex ($P < 0·001$) but the interaction was not significant. The differences were 6·1 kg in boys and 2·5 kg in girls. In addition, percentage of fat mass was significantly lower in athletic than in non-athletic subjects ($P = 0·04$).

Physical capacities

Athletes performed 8–11 h physical training (including competition) per week (9·8 h on average) while non-athletic subjects performed 1–4 h physical activity per week (2·8 h on average). VO_{2max} was significantly higher in athletes than in non-athletic subjects ($P < 0·001$) and in boys than in girls ($P < 0·001$), and the interaction was significant ($P < 0·05$; Table 2). The differences were on average 0·9 litre/min and 0·6 litre/min in boys and girls respectively ($P < 0·001$). VO_{2max} expressed per kg body weight was also significantly affected by usual physical activity ($P < 0·001$) and sex ($P < 0·001$) but the interaction was not significant. Similarly, VO_{2max} adjusted for FFM was significantly higher in athletic than in non-athletic subjects ($P < 0·001$) by 25 % and 21% in boys and girls respectively, and in boys than in girls ($P < 0·001$).

Daily energy expenditure

Daily EE exhibited great variations in each group (Fig. 1). Daily EE were significantly higher in athletic than in non-athletic subjects ($P < 0·001$), and in boys than in girls ($P < 0·001$), and the interaction was significant ($P < 0·02$). The differences were 3·63 MJ in boys and 1·95 MJ in girls ($P < 0·001$). However, because of the great differences in body size and composition in each group, daily EE was adjusted for differences in FFM. Adjusted daily EE was significantly affected by usual physical activity and sex ($P < 0·001$) and the interaction was significant ($P < 0·04$). The differences were 2·91 MJ in boys ($P < 0·001$) and 1·66 MJ in girls ($P < 0·01$).

Daily energy expenditure – energy expenditure of exercise

Because intensity and duration of exercise were different between athletic and non-athletic subjects, and between boys and girls, EE during the periods of exercise were subtracted from daily EE to compare EE of the four groups of subjects in the same conditions and with the same activity programme (Fig. 1). Over more than 21 h/d, daily EE – EE exercise were significantly higher in athletic than in non-athletic subjects (+ 0·67 MJ; $P < 0·01$), and in boys than in girls (+ 2·53 MJ; $P < 0·001$). However, daily EE – EE exercise adjusted for FFM was not significantly affected by usual physical activity, but was significantly higher in boys than in girls ($P = 0·04$, Table 3).

Sleeping energy expenditure, BMR, energy expenditure during meals and energy expenditure during seated activities

Sleeping EE and BMR were significantly higher in boys than in girls ($P < 0·001$, Figs. 2 and 3). Sleeping EE was significantly influenced by usual physical activity ($P < 0·01$) but not BMR, and the interaction was not significant. Sleeping EE adjusted for FFM was significantly higher in boys than in girls ($P < 0·002$), and slightly but not significantly

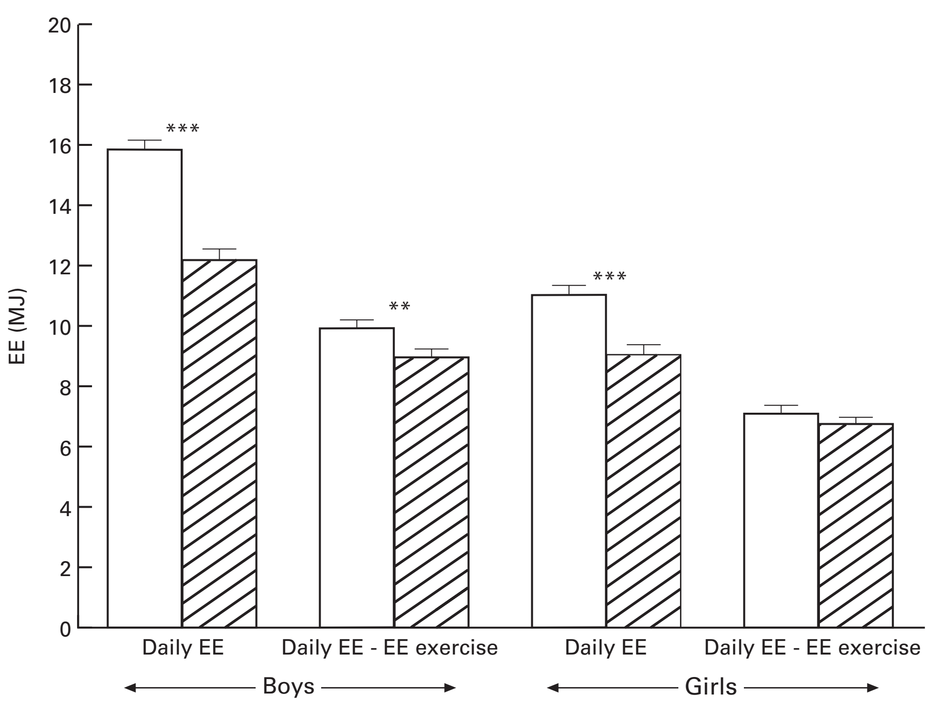

Fig. 1. Daily energy expenditure (EE) and daily EE – EE during exercise in adolescent athletes (□) and non-athletes (▨) of both sexes (*n* 49). EE was measured in the final 24 h of a 36 h stay in a whole-body calorimeter. Subjects followed a standardized activity programme simulating their mean weekly physical activities. Mean values were significantly different between athletes and non-athletes: **$P < 0·01$, ***$P < 0·001$ (ANOVA).

Table 3. Energy expenditure (EE) adjusted for fat-free mass and body weight in adolescents as measured by whole-body indirect calorimetry (Lean square means (LS means) with standard errors of LS means)

	Boys				Girls				Statistical significance of difference between means (ANOVA): *P* value		
	Athletic		Non-athletic		Athletic		Non-athletic				
	LS mean	SE	LS mean	SE	LS mean	SE	LS mean	SE	Sex	Activity	S×A
Daily EE (MJ)	14·62[a]	0·42	11·71[b]	0·33	11·98[b]	0·40	10·32	0·45	0·001	0·001	0·04
Daily EE – EE exercise (MJ)	8·90[a]	0·28	8·55[ab]	0·21	7·94[b]	0·26	7·85[b]	0·30	0·04	0·32	0·54
BMR (kJ/min)	5·24	0·27	5·72	0·21	5·18	0·26	4·94	0·29	0·27	0·57	0·07
Sleeping EE (kJ/min)	5·26[a]	0·15	4·99[a]	0·12	4·41	0·14	4·40	0·16	0·002	0·26	0·24
EE meals (kJ/min)	8·33	0·37	8·53	0·29	8·61	0·36	8·35	0·40	0·93	0·91	0·40
EE seated activities (kJ/min)	8·70[a]	0·29	8·17[ab]	0·23	7·50[bc]	0·28	7·25[c]	0·32	0·01	0·10	0·52
EE exercise (kJ/min)*	34·5[a]	0·98	19·1[b]	0·92	24·6[c]	1·04	15·7	1·08	0·001	0·001	0·001

[a,b,c] Mean values within a row not sharing a common superscript letter were significantly different, $P < 0·05$.
* Adjusted for differences in body weight.

higher in athletic than in non-athletic subjects (Table 3). On the contrary, EE corresponding to seated activities or meals were significantly higher in athletic than in non-athletic subjects ($P < 0·002$), and in boys than in girls ($P < 0·001$). Similarly, after adjustment for differences in FFM, EE during seated activities remained higher in boys than in girls (+1·07 kJ/min, i.e. +14 %, $P < 0·01$) and tended to be higher in athletic than in non-athletic subjects ($P < 0·10$), especially for boys (Fig. 2).

Energy expenditure during physical exercise

The duration of actual physical exercise (i.e. without the stretching and recovery periods) was 110 and 85 min in athletic and non-athletic adolescents respectively. The intensities of exercise, expressed as % VO_{2max}, are presented in Table 1. EE during physical exercise and recovery periods was on average 3·6-fold higher than for seated activities in athletic boys and girls. It was significantly higher in athletic than in non-athletic subjects ($P < 0·001$, Figs. 2 and 3). EE during exercise and recovery periods amounted to 5·88 and 3·92 MJ in athletic boys and girls respectively, i.e. 37·2 and 35·5 % of daily EE. The corresponding values were 3·22 and 2·46 MJ, i.e. 26·2 and 26·5 % in non-athletic boys and girls respectively. EE during physical exercise adjusted for body weight was also significantly higher in athletic than in non-athletic subjects ($P < 0·001$) and in boys than in girls ($P < 0·001$). Furthermore, the

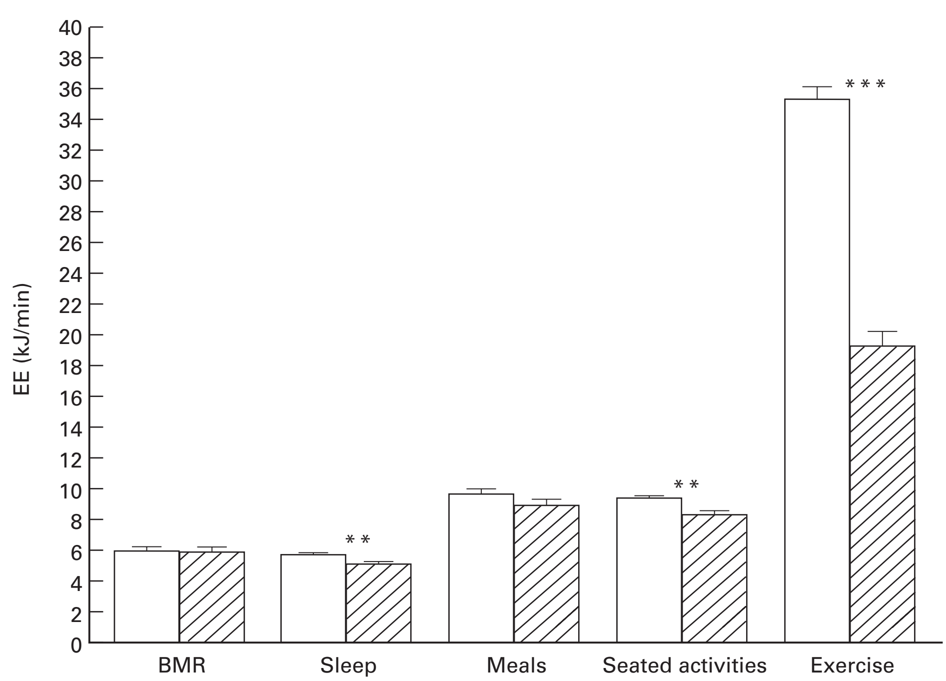

Fig. 2. Energy expenditure (EE) of adolescent athletic (□) and non-athletic (▨) boys during the various daily activities, measured during the final 24 h of a 36 h stay in a whole-body calorimeter. Subjects followed a standardized activity programme simulating their mean weekly physical activities. Mean values were significantly different between athletes and non-athletes: ** $P < 0·01$, *** $P < 0·001$ (ANOVA).

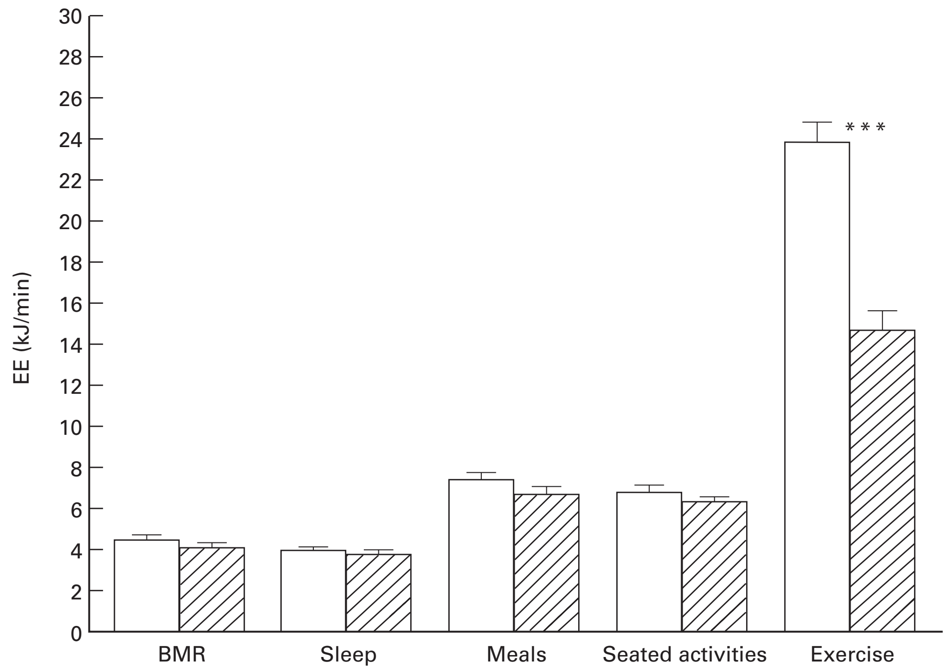

Fig. 3. Energy expenditure (EE) of adolescent athletic (□) and non-athletic (▨) girls during the various daily activities, measured during the final 24 h of a 36 h stay in a whole-body calorimeter. Subjects followed a standardized activity programme simulating their mean weekly physical activities. Mean values were significantly different between athletes and non-athletes: ***$P < 0.001$.

interaction was significant ($P < 0.001$). The differences amounted to 15·4 kJ/min and 8·6 kJ/min on average, in boys and girls respectively ($P < 0.001$, Table 3).

Substrate utilization

Substrate utilization was not significantly affected by usual physical activities or sex. The RQ corrected for zero energy balance averaged 0·850 (SD 0·037), 0·861 (SD 0·029), 0·942 (SD 0·036) during sleep, seated activities (including meals), and exercise plus recovery periods respectively.

Relationship between heart rate and energy expenditure

The correlations coefficients (R^2) of the regressions of EE over HR averaged 0·91 (SD 0·03). The differences between daily EE calculated and daily EE determined by whole-body indirect calorimetry during the same period averaged 5 (SD 143) kJ/d.

Discussion

The athletic adolescents exhibited higher EE during sleep, BMR, seated activities and meals, that is to say daily EE – EE exercise, than non-athletic subjects, but the differences were explained mainly by differences in FFM. Furthermore, substrate utilization was not significantly altered by differences in usual physical activities. The activity programmes in the whole-body calorimeters were suitable for the subjects and well adapted to their habits since their daily EE were similar to those measured in free-living conditions using the HR-recording method: 15·82 *v.* 16·13 MJ and 11·04 *v.* 11·07 MJ in athletic boys and girls respectively, during the 5 d/week with physical training, and 12·19 *v.* 12·98 MJ and 9·09 *v.* 9·10 MJ in non-athletic boys and girls respectively (J Ribeyre, N Fellmann, J Vernet, M Delaître, A Chamoux, J Coudert and M Vermorel, unpublished results).

Body composition of the subjects was assessed by the skinfold-thickness method. Its limitations are well known, especially in children and obese people (Deurenberg *et al.* 1990), who were not the subjects of the present study. Measurements were made by the same investigator and with a high methodological discipline, to minimize errors between groups. Determination of body composition by the bioimpedance analysis method failed for technical reasons. However, a previous study in our laboratory showed that there was a good agreement between the skinfold-thickness and the bioimpedance analysis methods in 12–16-year-old adolescents (Bitar *et al.* 1999).

Regular intensive physical training induced significant alterations of body composition, in agreement with the results of Broeder *et al.* (1992) and Horton & Geissler (1994) in young adults. FFM of athletes was 11 % and 6 % higher than those of non-athletes in boys and girls respectively, whereas fat mass was 10 % lower in athletic than in non-athletic subjects. Interestingly, the higher body weight of athletes was only due to their greater FFM. VO_{2max} was also 32 % higher in athletic than in non-athletic subjects of both sexes in agreement with the results of Broeder *et al.* (1992) and Horton & Geissler (1994) in young adults.

Sleeping EE adjusted for differences in FFM was not significantly affected by usual training. This result agrees with those obtained for resting metabolic rate by Broeder *et al.* (1992), for sleeping EE by Van Etten *et al.* (1997), for daily EE and sleeping EE by Horton & Geissler (1994) in athletes, and for daily EE without exercise in trained and untrained men by Schultz *et al*. (1991), suggesting that resting metabolic rate adjusted for FFM was independent of both the subject's current aerobic level and training status (Broeder *et al*. 1992). BMR adjusted for FFM was, however, 5 % and 10 % higher in resistance-trained and endurance-trained young men respectively, than in untrained subjects (Poehlman *et al.* 1992). In addition, four × 30 min cycling periods on five separate days with workloads ranging from 0 to 100 W in men and 0 to 75 W in women induced significant increases in sleeping and BMR (Goldberg *et al*. 1989). This result confirmed those obtained by Maelhum *et al*. (1986) in subjects exercising for 80 min at 70 % VO_{2max}, showing that excess postexercise O_2 consumption may persist for at least 12 h and possibly for 24 h. Results by Goldberg *et al*. (1989) demonstrated that excess postexercise O_2 consumption was induced at even low levels of exercise intensity. Performing usual exercise might be responsible for persistant excess postexercise O_2 consumption in untrained subjects.

Precise individual relationships between HR and EE were established from the data obtained over 24 h with activity programmes simulating the usual activities of athletic and non-athletic adolescents, such as sleep, schoolwork, meals, miscellaneous activities and the various types of exercise, including walking, jogging, running at several speeds, strengthening, etc., and the recovery periods. This approach overcame many of the disadvantages of the classical HR-recording method in which HR and EE are recorded over short periods of time during lying, sitting, standing, walking on a treadmill or working at increasing intensities on a cycloergometer, without consideration of HR and EE during the recovery periods. As a matter of fact, HR and EE are affected differently by the type of muscular activity (Dauncey & James, 1979), and HR decreases more slowly than EE during the recovery periods (Saris, 1982). This could partly explain why EE is generally overestimated by the HR-recording method (Spurr *et al*. 1988; Ceesay *et al*. 1989; Livingstone *et al*. 1990; Emons *et al*. 1992). Therefore, the individual relationships established between HR and EE in the present study could be used to predict accurately EE of the same subjects in free-living conditions from HR recordings during a week (J Ribeyre, N Fellmann, J Vernet, M Delaître, A Chamoux, J Coudert and M Vermorel, unpublished results).

In conclusion, differences in EE between athletic and non-athletic adolescents resulted mainly from differences in FFM and physical activity. Usual training of athletic adolescents, including high-intensity exercise, did not affect significantly sleeping EE, BMR and EE during seated activities, i.e. did not induce persistent excess postexercise O_2 consumption, and did not alter significantly substrate utilization. In addition, precise individual relationships between HR and EE were computed over periods of 24 h to predict EE of the same subjects from HR recordings in free-living conditions with similar activity programmes.

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