Components and variations in daily energy expenditure of athletic and non-athletic adolescents in free-living conditions

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The objectives of the study were to determine: (1) daily energy expenditure (EE) of athletic and non-athletic adolescents of both sexes in free-living conditions; (2) day-to-day variations in daily EE during 1 week; (3) energy costs of the main activities; and (4) the effect of usual activity on EE during sleep, seated and miscellaneous activities. Fifty adolescents (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 VO_{2max} and external mechanical power (EMP) by a direct method (respiratory gas exchanges) on a cycloergometer. Daily EE and partial EE in free-living conditions were computed from heart-rate (HR) recordings during seven consecutive days using individual prediction equations established from the data obtained during a 24 h period spent in whole-body calorimeters with similar activities. Fat-free mass (FFM), VO_{2max}, EMP, daily EE and EE during sleep were significantly higher in athletic than in non-athletic subjects. After adjustment for FFM, VO_{2max}, EMP, daily EE and EE during exercise were still higher in athletic than in non-athletic adolescents ($P < 0.001$). However, adjusted sleeping EE was not significantly different between athletic and non-athletic adolescents. Increases in exercise EE were partly compensated for by significant reductions in EE during schoolwork and miscellaneous activities. Thus, the differences in daily EE between athletic and non-athletic subjects resulted mainly from increases in FFM and EE during exercise (duration and energy cost).

Adolescents: Athletes: Body composition: Energy expenditure

Mean daily energy expenditure (EE) and consequently energy requirements of man depend greatly on duration of physical activity, and the nature and intensity of the various activities. Thus, in Sweden the physical activity level (PAL = daily EE/BMR) of three subgroups of fifty-seven boys aged 15 years averaged 1·67, 1·90 and 2·23 depending on their usual physical activity (Bratteby *et al.* 1997). Furthermore, PAL as low as 1·45 have been observed in adolescents (M Vermorel, J Vernet, A Bitar, N Fellman, B Beaune, A Chamoux and J Coudert, unpublished results) and PAL greater than 2·4 were obtained in adult athletes in periods of 'rigorous training' (Shetty *et al.* 1996).

In other respects, BMR is closely correlated with fat-free mass (FFM; e.g. Ravussin & Bogardus, 1989) and the latter increases with muscle mass in athletes. Consequently, daily EE increases with FFM and muscle mass for a given PAL.

In addition, daily EE is augmented by physical activity through the direct energy cost of exercise, an elevated postexercise EE (Maelhum *et al.* 1986), possible enhanced resting metabolic rate, and increases or decreases in spontaneous physical activities (stimulating or compensatory effects; Goran & Poehlman, 1992; Morio *et al.* 1998). However, in spite of the copious literature on this topic, results on the effects of physical activity or training on sleeping EE or BMR, spontaneous activity and daily EE are still contradictory and inconclusive (Toth & Poehlman, 1996). Furthermore, information on the effect of physical training on EE in adolescents is very scarce.

Therefore, the objectives of the present study were to determine: (1) daily EE and its main components in athletic and non-athletic adolescents of both sexes in free-living conditions; (2) day-to-day variations in EE over 1 week; (3)

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the energy costs of the main activities; and (4) the effect of usual activity on EE during sleep, seated or miscellaneous activities. EE was assessed over a week by the heart-rate (HR) recording method, using individual prediction equations previously established in the same subjects with the same sedentary and physical activities in whole-body calorimeters over a 24 h period.

Subjects and methods

Subjects

Fifty adolescents (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, France, 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 0·1 cm 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 skinfold thicknesses were measured on each subject with a Harpenden skinfold caliper (Holtain Ltd, Bryberian, Wales, 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. Peak O_2 uptake (VO_{2max}) was measured by direct method (repiratory 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 r.p.m. HR was recorded continuously (Scheller AG, Cardiovit CS-6/12, Baar, Schwitzerland). 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

$RER > 1·1$ and a maximal HR close to the theoretical maximal HR (220 − age (years)).

Equations to predict energy expenditure from heart-rate recordings

Daily EE was computed from HR recordings using the individual relationships between EE and HR that had been established with the same subjects during a 36 h stay in two large open-circuit room calorimeters, including the first evening and night for adaptation to this new environment and for adjustment of gas concentrations (Ribeyre *et al.* 2000). Subjects were fitted with probes for continuous recording of HR by telemetry (Life Scope 6; Nikon Kohden, Tokyo, Japan) and were given practice with the various items of equipment to alleviate any apprehension about testing conditions. During the 24 h measurement period subjects followed a definite activity programme simulating their usual activities. They underwent two periods of exercise (at 11.00 and 16.00 hours) of different intensities and durations according to sex and activity status (athletic or non-athletic subjects). These two periods 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. Between the exercise sessions, the seated activities were freely chosen and written down by the subjects. The subjects generally watched television or did their school work (Ribeyre *et al.* 2000). Data collected over this 24 h period were used to compute individual regression equations between HR and EE. The best fit was obtained with polynomial relationships of the third order (EE (kJ/min) = a + b HR + c HR^2 + d HR^3). The correlation coefficients (R^2) averaged 0·91 (SD 0·03) and the differences between predicted daily EE and daily EE determined by whole-body indirect calorimetry during the 24 h period averaged 5 (SD 143) kJ/d (Ribeyre *et al.* 2000). In addition, individual linear regressions were computed between EE and HR during sleep in the room calorimeters. These relationships were used to predict sleeping EE from HR recordings in free-living conditions.

Determination of activities and energy expenditure in free-living conditions

The study was carried out during the months of March, April and May. HR was monitored during seven consecutive days using a cardiofrequency meter (Sport Tester PE 4000; Polar Electro, Kempele, Finland). The system consisted of an electrode-belt transmitter and wrist microcomputer receiver that stored the pulse in a memory. Pulse rate was recorded every min over 24 h periods. Information was then retrieved via an interface unit to a microcomputer and the memory was reprogrammed. EE was then computed from HR recordings and individual prediction equations. Subjects were instructed to complete a daily record of the nature and duration of all activities during the measurement periods. Activities were distributed among five groups: school (class- and homework), meals (breakfast, lunch, snacks and dinner), exercises (physical

Table 1. Physical characteristics, body composition and maximal oxygen uptake of subjects

(Mean values and standard deviations)

| | Boys | | | | Girls | | | | Statistical significance of difference between means (ANOVA): P value | | |
| | Athletic | | Non-athletic | | Athletic | | Non-athletic | | | | |
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Sex	Activity	Sex × Activity
No. of subjects	15		12		11		12				
Age (years)	17.5[a]	1.0	16.9[ab]	0.9	16.4[b]	1.0	17.1[ab]	0.8	0.07	0.91	0.02
Height (cm)	179.7[a]	5.4	178.5[a]	6.2	163.4	4.2	162.5	7.8	0.001	0.60	0.95
Weight (kg)	69.8[a]	6.4	65.0[a]	7.8	55.3	4.1	54.9	8.1	0.001	0.18	0.26
BMI (kg/m²)	21.6	1.6	20.4	2.0	20.7	1.5	20.8	2.9	0.69	0.34	0.25
Fat-free mass (kg)	62.2[a]	5.5	56.2[b]	5.7	44.4	2.5	41.9	4.5	0.001	0.003	0.20
Fat mass (%)	10.6[a]	2.0	12.0[a]	3.5	19.4	3.2	23.0	5.5	0.001	0.02	0.31
VO_{2max} (litre/min)	3.83[a]	0.30	2.89[b]	0.42	2.41[c]	0.16	1.84	0.23	0.001	0.001	0.04
VO_{2max} (ml/min per kg)	55.3[a]	5.16	45.3[b]	4.52	43.9[b]	3.89	33.8	3.32	0.001	0.001	0.94
EMP (W) at VO_{2max}*	292[a]	6	223[b]	7	210[b]	7	162	7	0.001	0.001	0.11
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
Adjusted EMP (W)‡	281[a]	9	218[b]	7	218[b]	9	173	10	0.001	0.001	0.19

VO_{2max}, maximal oxygen uptake; EMP, external mechanical power.
[a,b,c] Mean values within a row with unlike superscript letters were significantly different ($P < 0.05$).
* EMP measured at VO_{2max}.
† VO_{2max} adjusted for fat-free mass.
‡ EMP adjusted for fat-free mass.

training, leisure sports, sports training and competition), sleep (night and siesta), and miscellaneous activities (reading, board games, television video games, transportation, shopping, etc.). Thus, EE associated with these activities and their mean energy costs, as well as their day-to-day variation over 1 week could be determined.

Statistical analysis

Data were analysed by ANOVA using PROC GLM of SAS software (version 6, 1987; Statistical Analysis Systems Institute Inc., Cary, NC, USA) with the following two models: (1) $y = \mu + \alpha$ sex $+ \beta$ activity $+ \gamma$ day $+$ sex × activity × day $+ \varepsilon$ where 'activity' represents the physical activity of subjects (athletic $v.$ non-athletic), and 'day' the day of the week (seven levels), to study the effect of sex, activity, day and the interaction sex × activity × day; (2) $y = \mu + \alpha$ sex $+ \beta$ activity $+ \gamma$ FFM $+ \delta$ day $+$ sex × activity × day $+ \varepsilon$ to study the same effects, using FFM or body weight as covariate. The studied variates (y) were the duration of activities (min), the energy cost of activities, and EE during sleep, school, meals, exercises, miscellaneous activities, and 24 h EE. For both models adjusted means were computed and compared using 'LSMEANS' and 'TDIFF' options of PROC GLM. Differences were considered as significant for $P < 0.05$.

Results

Physical characteristics and body composition of subjects

Age, body composition, physical characteristics, VO_{2max} and external mechanical power at VO_{2max} of the subjects are presented in Table 1. There were no significant differences in age, height, body weight and BMI between athletic and non-athletic subjects. However, FFM was significantly affected by sex ($P < 0.001$) and usual physical activity ($P < 0.003$) but the interaction was not

significant. FFM was 6.0 and 2.5 kg greater in athletic than in non-athletic boys and girls respectively. In addition, fat mass (%) was significantly lower in athletic than in non-athletic subjects ($P = 0.02$).

Physical capacities

Athletes performed 8–11 h physical training (including competition) per week (9.8 h on average). Athletic boys trained on Monday, Tuesday, Wednesday, Friday and Saturday, and athletic girls on Monday, Tuesday, Wednesday, Thursday and Friday. Non-athletic subjects performed 1–4 h physical activity per week (2.8 h on average) on Wednesday and Friday for boys, and only on Wednesday for girls. Their physical activity consisted of 2 h of physical training in the high school and 1 or 2 h of sport leisure (mainly football, basketball, tennis, etc.)

VO_{2max} was 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 ($P = 0.04$; Table 1). The differences were on average 0.94 litre/min and 0.57 litre/min in boys and girls respectively ($P < 0.001$). VO_{2max} expressed per kg body weight was also significantly affected by sex ($P < 0.001$), and usual physical activity ($P < 0.001$) 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. In other respects, adjusted VO_{2max} was 23 % higher in boys than in girls ($P < 0.001$). External mechanical power corresponding to VO_{2max} was significantly affected by usual physical activity and sex ($P < 0.001$). It was 30.5 % higher in athletic than in non-athletic adolescents, and 38.4 % higher in boys than in girls. Furthermore, external mechanical power at VO_{2max} adjusted for FFM was also significantly affected by usual physical activity and sex ($P < 0.001$, Table 1).
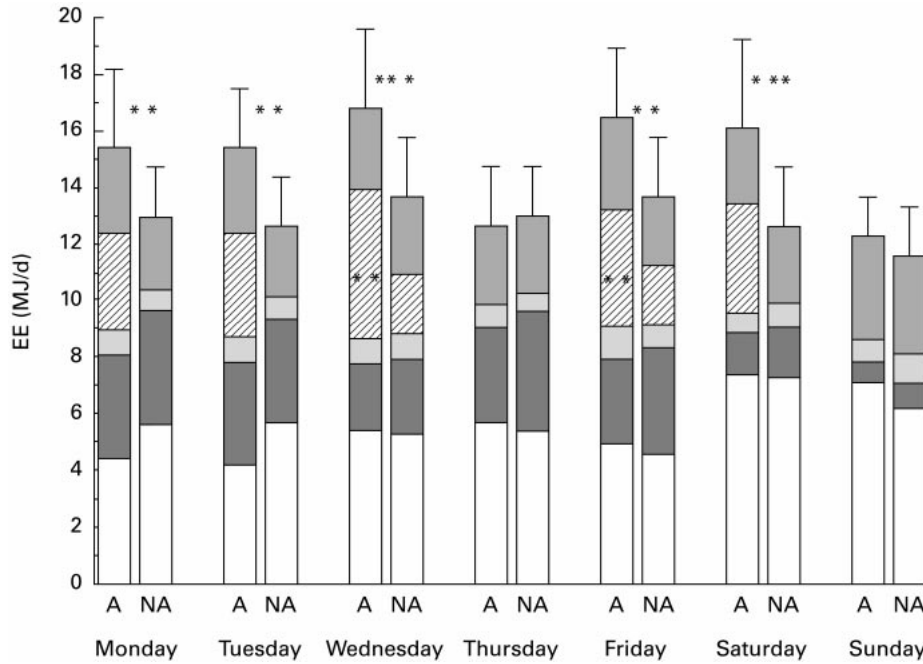
Fig. 1. Variations of daily energy expenditure (EE) and EE during miscellaneous activities (□), school- and homework (▦), meals (▦), exercise (▨) and sleep (▨) in athletic (A) and non-athletic (NA) boys during 1 week. Values are means with standard deviations represented by vertical bars. Mean values were significantly different between athletes and non-athletes: **$P < 0.01$, ***$P < 0.001$.

Daily energy expenditure

Daily EE was significantly higher in athletic than in non-athletic subjects ($P < 0.001$) and in boys than in girls ($P < 0.001$). Variation in daily EE in boys over 1 week is presented on Fig. 1. Daily EE of athletic boys ranged from 12·32 (SD 1·54) MJ on Sunday to 17·05 (SD 3·96) MJ on Wednesday, and averaged 15·12 (SD 1·58) MJ over 1 week. They were on average 16·5 % higher than those of non-athletic boys ($P < 0.02$). In addition, daily EE on Thursday and Sunday (no physical training) were 3·23 and 3·81 MJ lower than the mean value for the five other days, and not significantly different from daily EE of non-athletic boys. Daily EE of the latter ranged from 11·49 (SD 1·87) MJ on Sunday to 14·48 (SD 2·91) MJ on Friday, and averaged 12·98 (SD 1·82) MJ. There were, on average, only small day-to-day variations in daily EE except on Sunday, when daily EE was 1·65 MJ lower than the mean value of the six other days. However, the CV of daily EE within athletic boys averaged 17 (SD 6) % over 1 week, 14 (SD 5) % for the 5 d with physical training, and 9 (SD 8) % for the 2 d without physical training. The corresponding figures for non-athletic boys were 12 (SD 5) % over 1 week, 9 (SD 8) % for the 2 d with physical training, and 9 (SD 5) % for the 5 d without physical training.

Variation in daily EE in girls over 1 week is presented on Fig. 2. Daily EE of athletic girls ranged from 8·60 (SD 1·69) MJ on Sunday to 11·50 (SD 2·40) MJ on Wednesday, and averaged 10·40 (SD 1·28) MJ over 1 week. Similarly, daily EE of non-athletic girls ranged from 8·09 (SD 2·04) MJ on Sunday to 10·36 (SD 2·79) MJ on Wednesday (the day with physical training), and averaged 9·10 (SD 1·99) MJ over 1 week. Thus, daily EE of athletic girls was on average

1·99 MJ/d higher than those of non-athletic girls on Monday, Tuesday and Friday ($P < 0.02$, $P < 0.05$ and $P < 0.02$ respectively). They tended to be higher on Thursday ($P < 0.08$), but were similar during the weekend. As a whole, they were not significantly higher than those of non-athletic girls over 1 week ($P < 0.17$).

Day-to-day variation in daily EE of athletic and non-athletic girls was similar to that described for boys, except on Saturday because athletic girls did not perform physical training. The CV of daily EE within athletic girls were of the same order as for athletic boys: 18 (SD 6) % over 1 week, 14 (SD 6) % for the 5 d with physical training, and 11 (SD 11) % for the weekend. They averaged 14 (SD 4) % in non-athletic girls during the 6 d without physical training.

Finally, daily EE adjusted for FFM was significantly affected by usual physical activity and sex ($P < 0.001$; Table 2). It was 11·4 % higher in athletic than in non-athletic adolescents and 25·3 % higher in boys than in girls.

Energy expenditure during sleep

Time spent sleeping did not vary significantly with usual physical activity and sex and averaged 518 (SD 95) min/d (Fig. 5). However, adolescents slept longer on Sunday than during the six other days: 603 (SD 115) *v.* 496 (SD 115) min/d ($P < 0.01$). In each group, mean HR, energy cost of sleeping and sleeping EE were equal in free-living conditions and in the calorimeters. Nevertheless, sleeping EE and energy cost of sleeping were significantly higher in athletic than in non-athletic adolescents, and in boys than in girls ($P < 0.001$, Figs. 1–4). However, after adjustment for

Table 2. Mean energy expenditures and energy costs of activities, adjusted for fat-free mass or body weight in athletic and non-athletic boys and girls

(Least square means (LS means) and standard errors of LS means)

| | Boys | | | | Girls | | | | Statistical significance of difference between mean (ANOVA): P value | |
| | Athletic | | Non-athletic | | Athletic | | Non-athletic | | | |
	LS mean	SE	LS mean	SE	LS mean	SE	LS mean	SE	Sex	Activity
Daily EE (MJ)	14.10[a]	0.62	12.56[ab]	0.65	11.16[bc]	0.69	10.10[c]	0.68	0.001	0.001
Sleeping EE (MJ)	2.52[ab]	0.13	2.59[ab]	0.13	2.33[ab]	0.14	2.15[a]	0.14	0.001	0.26
EE school work (MJ)	2.46[ab]	0.26	2.90[ab]	0.27	2.00[a]	0.29	2.07[a]	0.29	0.001	0.01
EE meals (MJ)	0.83	0.08	0.81	0.08	0.59	0.09	0.60	0.09	0.001	0.94
EE exercise (MJ)*	4.40[a]	0.31	3.19	0.48	2.38	0.39	2.32	0.73	0.02	0.17
EE miscellaneous activities (MJ)	4.62	0.51	5.33	0.54	4.80	0.57	5.32	0.57	0.79	0.01
Sleeping EE (kJ/min)	5.00[a]	0.14	5.01[a]	0.15	4.46	0.16	4.34	0.16	0.001	0.29
EE school work (kJ/min)	7.01	0.60	8.24	0.63	6.81	0.67	6.73	0.66	0.04	0.02
EE meals (kJ/min)	9.43[bc]	0.56	9.89[b]	0.58	8.53[bc]	0.62	7.93[c]	0.61	0.001	0.77
EE exercise (kJ/min)*	34.76[a]	1.35	29.22[b]	2.06	19.60	1.69	15.06	3.15	0.001	0.01
EE miscellaneous activities (kJ/min)	11.03	0.62	11.07	0.64	9.92	0.69	9.35	0.68	0.001	0.28

EE, energy expenditure.
[a,b,c] Mean values within a row with unlike superscript letters were significantly different (P < 0.05).
* Adjusted for differences in body weight; mean values for the days of physical training.

FFM, the energy cost of sleeping and sleeping EE were not significantly higher in athletic than in non-athletic subjects, but significantly higher in boys than in girls ($P < 0.001$; Table 2).

Energy expenditure during school work and during meals

Time devoted to school work (class- and homework) tended to be shorter in athletic than in non-athletic adolescents: 296 (SD 153) v. 317 (SD 164) min/d on average ($P = 0.07$; Fig. 5). Similarly, EE during school work was significantly lower in athletic than in non-athletic adolescents ($P = 0.03$; Figs. 1 and 2), but the energy costs of school work were not significantly different (Figs. 3 and 4). However, after adjustment for FFM, the energy cost of school work and EE during school work were significantly lower in athletic than in non-athletic adolescents ($P < 0.02$ and $P < 0.01$ respectively), and significantly lower in girls than in boys ($P < 0.04$ and $P < 0.001$ respectively; Table 2). Differences according to usual activity were greater in boys than in girls. In other respects, time spent, energy cost and EE
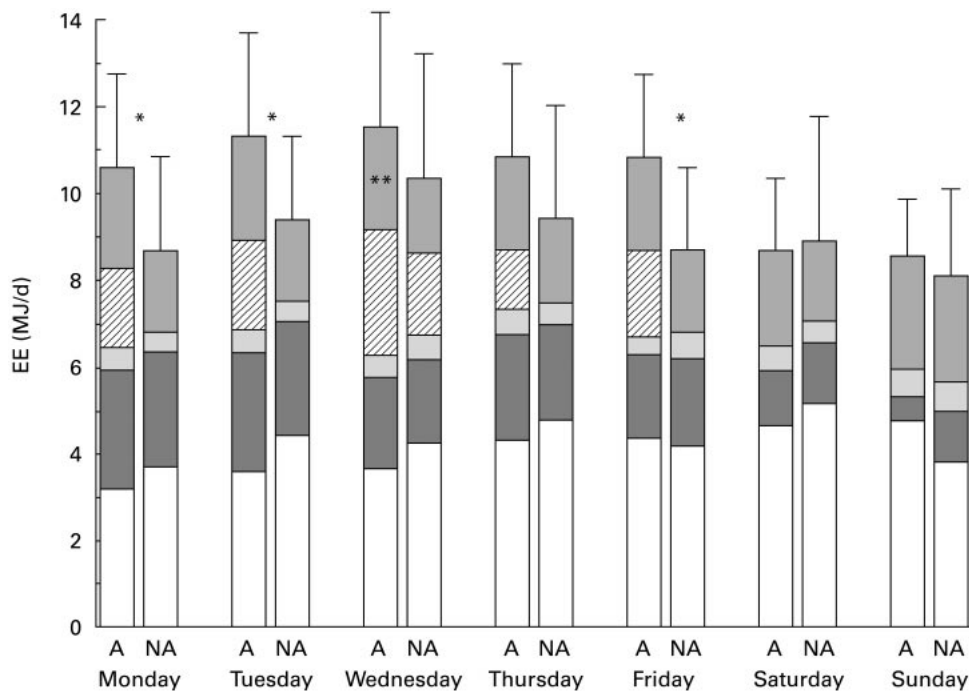

Fig. 2. Variations of daily energy expenditure (EE) and EE during miscellaneous activities (□), school- and homework (▦), meals (▦), exercise (▨) and sleep (▨) in athletic (A) and non-athletic (NA) girls during 1 week. Values are means with standard deviations represented by vertical bars. Mean values were significantly different between athletes and non-athletes; *P < 0.05, **P < 0.01.
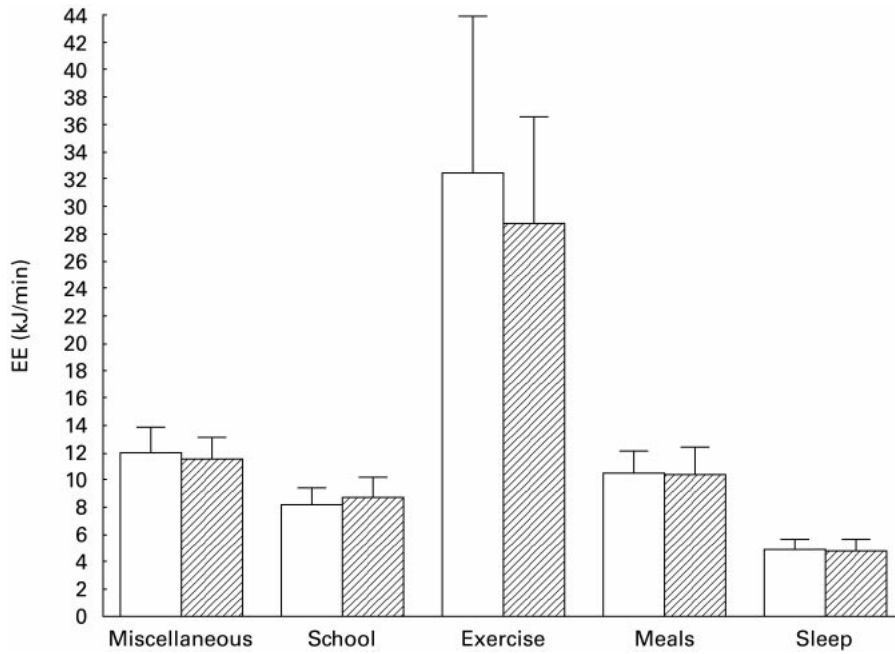
Fig. 3. Mean energy costs (kJ/min) of miscellaneous activities, school- and homework, meals, exercise and sleep in athletic (□) and non-athletic boys (▨) (mean energy cost is the energy expenditure (kJ)/duration of activity (min)). Values are means with standard deviations represented by vertical bars.

during meals were similar in athletic and in non-athletic subjects (Figs. 1–5; Table 2).

Energy expenditure during exercise

Mean value for time devoted to physical exercise was significantly higher in athletic than in non-athletic adolescents: 92 (SD 44) *v.* 26 (SD 12) min/d in boys ($P < 0.001$), and 72 (SD 30) *v.* 16 (SD 9) min/d in girls ($P < 0.001$) respectively (Fig. 5). EE during exercise ranged from 3·48 (SD 2·32) MJ on Monday to 5·32 (SD 3·64) MJ on Wednesday in athletic boys. It averaged 4·08 (SD 0·25) MJ/d for the 5 d training, and 2·38 (SD 0·47) MJ/d for the 2 d training in athletic and non-athletic boys respectively. As a
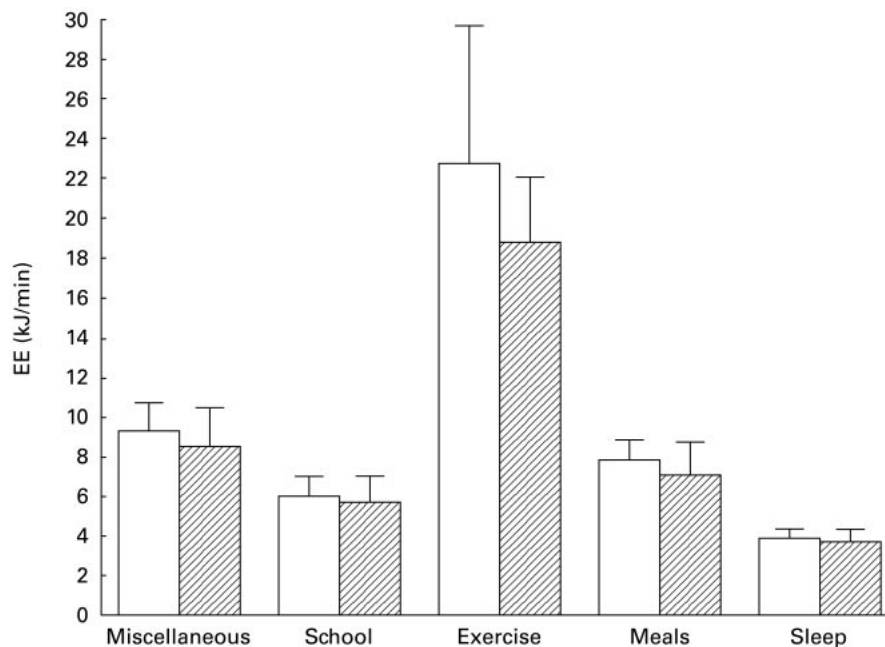

Fig. 4. Mean energy costs (kJ/min) of miscellaneous activities, school- and homework, meals, exercise and sleep in athletic (□) and non-athletic (▨) girls (mean energy cost is the energy expenditure (kJ)/duration of activity (min)). Values are means with standard deviations represented by vertical bars.
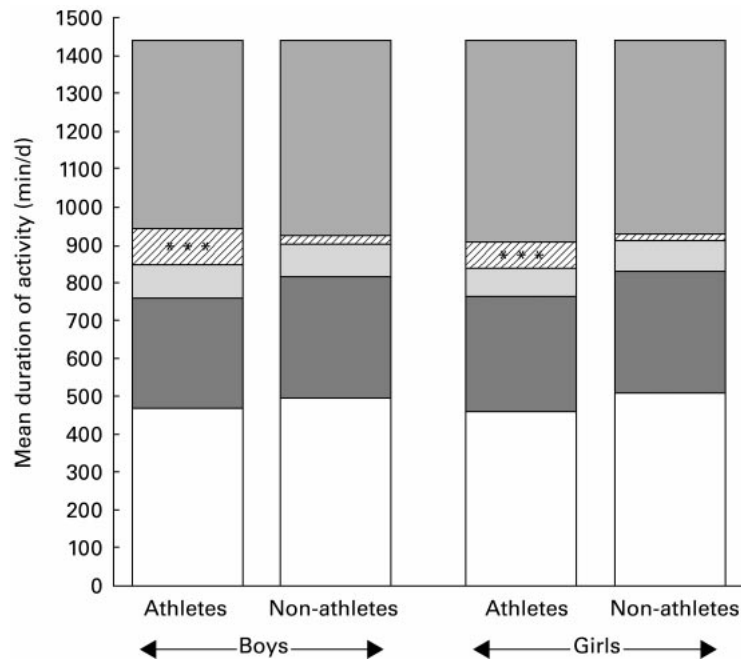
Fig. 5. Mean duration (min/d) of miscellaneous activities (□), school- and homework (▦), meals (▦), exercise (▨) and sleep (▧) in athletic and non-athletic boys and girls over 1 week. Values are means with standard deviations represented by vertical bars. Means values were significantly different between athletes and non-athletes: ***$P < 0.001$.

whole, EE during exercise averaged 2·92 (SD 1·28) MJ/d and 0·68 (SD 0·45) MJ/d in athletic and non-athletic boys respectively ($P < 0.001$) over 1 week.

EE of athletic girls during exercise ranged from 1·39 (SD 1·04) MJ on Thursday to 2·90 (SD 2·45) MJ on Wednesday, and averaged 2·14 (SD 0·55) MJ/d for the 5 d training. Interestingly, EE during exercise was similar (1·85 (SD 1·49) MJ) in non-athletic girls on Wednesday, the day with 2 h physical training. As a whole, EE during exercise averaged 1·53 (SD 0·57) MJ/d, and 0·26 (SD 0·21) MJ/d in athletic and non-athletic girls respectively ($P < 0.04$) over 1 week.

The mean energy cost of exercise tended to be significantly higher in athletic than in non-athletic subjects ($P < 0.06$) : 32·4 (SD 11·5) v. 28·6 (SD 7·9) kJ/min in boys and 22·7 (SD 6·9) v. 18·7 (SD 3·2) kJ/min in girls (Figs. 3 and 4). Energy cost of exercise adjusted for body weight was also significantly higher in athletic than in non-athletic subjects ($P < 0.01$) and in boys than in girls ($P < 0.001$; Table 2). The differences averaged 5·54 kJ/min and 4·54 kJ/min in boys and girls respectively ($P < 0.02$ and $P < 0.16$; Table 2). Consequently, differences in EE during exercise resulted mainly from differences in the duration of exercise and slightly from differences in the mean energy costs of exercise.

Energy expenditure during miscellaneous activities

Time devoted to miscellaneous activities varied greatly during the week, depending on time spent on school work and physical exercise. Nevertheless, it was, on average,

significantly shorter in athletic than in non-athletic adolescents: 468 (SD 178) v. 508 (SD 146) min/d respectively ($P = 0.002$; Fig. 5). Mean EE during miscellaneous activities was slightly, but not significantly lower in athletic than in non-athletic adolescents. However, it averaged 5·65 and 4·25 MJ/d in boys and girls respectively over 1 week ($P < 0.001$; Figs. 1 and 2). Consequently, the energy cost of miscellaneous activities was 6·6 % higher in athletic than in non-athletic subjects ($P < 0.01$) and 31 % higher in boys than in girls ($P < 0.001$; Figs. 3 and 4). However, after adjustment for FFM, energy cost of miscellaneous activities was not significantly affected by usual physical activity ($P = 0.28$), whereas mean EE corresponding to miscellaneous activities was significantly lower in athletic than in non-athletic subjects ($P < 0.01$) mainly due to differences in time devoted to these activities. Finally, there were no significant sex differences in adjusted EE for miscellaneous activities (Table 2).

Discussion

The present study showed that mean daily EE of adolescents in free-living conditions was significantly higher than those of non-athletic adolescents of the same age in the same environmental conditions, even after adjustment for differences in FFM. Differences in adjusted daily EE resulted mainly from the higher exercise EE of athletic subjects, which were only partly compensated for by reductions in school work and miscellaneous EE. However, the higher usual physical activity of athletes did not significantly alter the adjusted energy costs of

sleeping, meals, and miscellaneous activities, but it significantly reduced the adjusted energy cost of school work.

Daily EE was predicted from 7 d HR recordings using individual relationships. The latter had been established from the data obtained during a 36 h period in large whole-body calorimeters with activity programmes simulating their usual activities, including sleep, school work, walking, jogging, running etc., and the recovery periods. This approach overcame many of the disadvantages of the classical HR-recording method (Ribeyre *et al.* 2000). In addition, specific individual relationships between EE and HR during sleep were computed to assess precise sleeping EE in free-living conditions. The prediction error could not be quantified through cross-validation measurements. However, it should be lower than with relationships established from measurements of EE and HR during BMR and VO_{2max} tests without recovery periods.

Adjusted sleeping EE and EE during meals, as well as the adjusted energy cost of miscellaneous activities, were not significantly affected by training. These results confirmed those obtained with the same subjects in standardized conditions by indirect calorimetry (Ribeyre *et al.* 2000). They agree with the results obtained for sleeping EE in athletes by Horton & Geissler (1994) and Van Etten *et al.* (1997), for resting metabolic rate in adults exhibiting a wide range of aerobic fitness levels (Broeder *et al.* 1992), and for daily EE without exercise in trained and untrained men (Schultz *et al.* 1991), suggesting that: 'RMR adjusted for FFM was independent of both the subject current aerobic level and training status' (Broeder *et al.* 1992). However, these results disagree with those reviewed by Toth & Poehlman (1996) and Ribeyre *et al.* (2000), showing that BMR and sleeping EE were higher in resistance-trained or endurance-trained subjects, indicating that excess postexercise O_2 consumption may persist for more than 12 h. However, in the present study athletic and non-athletic subjects did not perform unusual and intense exercise which could be expected to enhance metabolic rate through an increase in noradrenaline secretion (Poehlman & Danforth, 1991) or muscle sympathetic nervous system activity (Ng *et al.* 1994).

Exercise EE of athletes did not vary greatly during the five training days. Increases in duration and adjusted energy cost of exercise in athletes accounted for 73 % and 27 % respectively of the differences in exercise EE between athletic and non-athletic boys. Thus, differences in daily EE resulted mainly from differences in duration of physical activities.

The mean PAL averaged 1·86 (SD 0·39) in athletic boys and girls, and 1·72 (SD 0·24) and 1·67 (SD 0·36) in non-athletic boys and girls respectively. These values seem relatively low for athletes, compared with mean PAL values obtained in 15-year-old adolescents (1·94 and 1·89 in boys and 1·79 in girls; Bratteby *et al.* 1997, 1998). This could be explained by the fact that athletes performed, on average, only 9·8 h physical training per week and had little other physical activity, since most of them lived in a boarding school, prepared for an examination and had little free time. It may also result from the rather high values of sleeping EE of our athletes compared with the values

obtained by Bratteby *et al.* (1998). As a matter of fact, if BMR of our subjects was assessed from body weight and height using the FAO's prediction equations (Food and Agriculture Organization/World Health Organization/United Nations University, 1985), which do not take into account body composition, the estimated PAL would be 1·94 and 1·76 in athletic boys and girls respectively, and 1·74 and 1·55 in non-athletic boys and girls respectively.

In conclusion, the results of the present study show that the higher daily EE of athletes results partly from their greater FFM but mainly from differences in duration and intensity of physical exercise. However, usual physical activity did not significantly affect sleeping EE or energy cost of miscellaneous activities. Nevertheless, increases in exercise EE were partly compensated for by reductions in EE during school work and miscellaneous activities. Consequently, the recommended energy allowances of adolescents must take into account FFM and detailed usual activities (nature, duration and intensity), especially in athletes.

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