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**Review**

# Contributing factors and variability of energy expenditure in non-obese, obese, and post-obese adolescents

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**Abstract** – Energy expenditure (EE) is a major determinant of energy balance and body composition. The objectives of this paper were to review the contributing factors of the main components of daily EE (DEE) and the inter-individual variability in these components in non-obese (NOb), obese (Ob), and post-obese (POb) adolescents. Body composition especially fat-free mass (FFM), is the major determinant of the basal metabolic rate which contributes 50–70% of DEE, whereas fat mass (FM) is a significant factor only in obese subjects. Physical activity is the second main variation factor of DEE, whereas growth, the thermic effect of food, and thermoregulation are generally of marginal importance. The energy costs and EE associated with various sedentary and physical activities were assessed in NOb, Ob and POb subjects both in standardised and in free-living conditions. The inter-individual variability of DEE is high, even after adjustment for body composition, mainly because of great differences in time devoted to the various physical activities. DEE and EE associated with sleep and sedentary activities are significantly higher in Ob than in NOb, but not after adjustment for FFM. On the contrary, EE associated with physical activities is not significantly different between Ob and NOb adolescents, but 61% lower in Ob subjects after adjustment for body composition. Multidisciplinary weight-reduction programmes including moderate energy restriction and physical training result in great FM loss, maintenance of FFM, improvement of physical capacities, but reductions in organ and tissue metabolic rate and in EE associated with the various sedentary and physical activities, which may favour body weight regain in the less active POb subjects.

**body composition / basal metabolic rate / physical activity / thermoregulation**

## 1. INTRODUCTION

The prevalence of overweight and obesity has been increasing dramatically in industrialised and many developing countries during the last decades [1]. The trends particularly affect children and adolescents [2–4] who are then at risk of developing a

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number of medical morbidities [5]. Obesity generally arises from a mismatch between energy intake and energy expenditure (EE). The imbalance results from both a progressive reduction in physical activity, mainly in adolescents [6, 7], and an increase in energy intake [8, 9]. Therefore, EE is a major determinant of energy balance and body composition. Knowledge of its contributing factors enables a better understanding of some drifts in body weight (BW) and body composition, as well as in blood metabolic and hormonal profiles, and offers possibilities to correct the drifts.

According to a usual scheme in human nutrition, daily EE (DEE) can be distributed between basal metabolic rate (BMR) extrapolated to 24 h, and the increases in EE associated with thermoregulation, alimentation (thermic effect of food, TEF), and physical activity, although these factors are interdependent. In addition, for practical purposes, the increase in EE associated with physical activities must be partitioned between sedentary (seated) activities and real physical activities. The objectives of this paper were (1) to review the variation factors of the main components of DEE, and (2) the inter-individual variability in basal metabolic rate, physical activity EE, and DEE in non-obese (NOb), obese (Ob), and post-obese (POb) children and adolescents.

## 2. MAIN COMPONENTS OF ENERGY EXPENDITURE IN NON-OBESE CHILDREN AND ADOLESCENTS

### 2.1. Basal metabolic rate

BMR is a major determinant of DEE since it contributes, on average, 60% to DEE. However, it ranges from 45–50% in very active subjects to about 70% in sedentary subjects. BMR can be considered as the sum of the EE of tissues and organs at fast and rest and in thermoneutral conditions. Therefore, it depends on mass and metabolic rate (EE·g tissue$^{-1}$·min$^{-1}$) of tissues and organs, and broadly speaking from body composition as expressed as fat-free mass (FFM) and fat mass (FM), sex, age, physical and nutritional status.

The major components of cellular metabolic rate are nucleic acid and protein turnover (20–25% [10], phospholipid and tryglicerides turnover (5%) [11], active transports ($NA^+$, $K^+$, 20–30%; $Ca^{2+}$, 5%, [12–14] and substrate cycles (10%, on average) [15]), as well as anabolic pathways. The intensity of these phenomena depends on metabolic functions of tissues and organs, and is subject to hormonal regulation (catecholamines, thyroid hormones [16, 17], insulin, glucocorticoids, growth hormone [18], IGF1, testosterone [19], etc.), and nutritional regulation, especially energy intake [20, 21]. Therefore, the metabolic rate of tissues and organs is highly variable. For instance, it is about 10, 15, 20, 35, and 35 times higher in the digestive tract, liver, brain, heart, and kidney than in resting muscle, whereas it is only about 1/3 in white adipose tissues [22]. Consequently, while organs account for about 7% of BW, they contribute about 60% to BMR, whereas skeletal tissues and adipose tissues account for 35–40% and 15–30% of BW and contribute only 18–22% and 3–4% to BMR, respectively [23]. In addition, organ mass increases relatively less than skeleton and muscle mass during childhood and adolescence. Consequently, the contribution of organs to BW decreases from about 10% to 6% between 10 and 20 years of age [22].

The main significant determinant of BMR is FFM ($R^2$ = 0.65–0.80 [24, 25]), whereas FM is significant only in obese subjects ($R^2 < 0.04$, [24, 26]). Sex is also a significant determinant of BMR ($0.02 < R^2 < 0.04$, [24]): after adjustment for body composition, BMR is significantly higher in boys than in girls, by 3% and 6% in prepubertal and pubertal subjects, respectively [24, 27, 28], because of (1) higher proportions of skeletal glycolytic fibres [29], and higher $Na^+$-$K^+$ ATPase activity [30], and (2) changes in hormonal status [19].

BMR is higher in trained than in untrained adolescents, because of their higher FFM [31]. However, after adjustment for body composition BMR is not significantly different between trained and untrained subjects [32–34].

Finally genetic factors influence BMR, probably through differences in organ mass and metabolic rate, and hormonal status [35], since the residual standard deviation of BMR adjusted for the previous determinants averages 7% [36].

## 2.2. Growth

During the growth period, energy is stored in the body as protein and lipids (23.4 and 39.7 kJ·g$^{-1}$, respectively). Body weight gain averages 10 g·d$^{-1}$ before the onset of puberty, and increases to 25–30 g·d$^{-1}$ at peak of growth (at 12 years of age in girls and 14 years in boys) while lipid gain is very low in boys. Consequently, energy stored in the body ranges from 85 to 125 kJ·d$^{-1}$ in boys between 10 and 15 years of age, then decrease to less than 40 kJ·d$^{-1}$ in boys. On the contrary, the fat mass increases continuously in girls, and energy stored in the body increases from 125–165 kJ·d$^{-1}$ in prepubertal girls to 290–335 kJ·d$^{-1}$ at peak of growth, then declines rapidly. Consequently, assuming a 50–70% efficiency of energy utilisation for growth, depending on the proportion of energy stored as lipids, growth would contribute 2 to 4% of daily energy requirements in adolescents [37].

## 2.3. Thermic effect of food (TEF)

TEF includes increases in EE during ingestion and digestion of food, and metabolism of nutrients instead of body reserves. It averages 12% of energy intake (EI), which is generally close to DEE, over a 24-h-measurement period [38]. It is lower for lipids and carbohydrates (3 and 5% of EI, respectively, over 3–4 h periods) than for protein (20–25%) because of the energy cost of urea synthesis, the likely effect on protein turnover, and the stimulating effect on the sympathetic nervous system [39, 40]. However, the small variations in TEF with usual diets hardly affect DEE of NOb subjects.

## 2.4. Thermoregulation

The increase in EE of subjects exposed to cold depends on the extent and duration of cold exposure and clothing and on their current EE which is closely linked to physical activity intensity. In developed countries, the effects of cold are minimised by adjustment of clothing, housing and heating [41]. However, people can be exposed to cold during short periods of time because of inadequate clothing or rapid changes in environmental conditions. In mild cold conditions, heat loss is decreased by peripheral vasoconstriction, whereas EE is first increased by spontaneous alteration of activity pattern and increases in muscular tone and metabolic rate, resulting in 5–7% increases in resting EE in normally clothed women exposed to 22 °C compared to 28 °C [42].

In more severe environmental conditions, especially with wind and humidity, the EE of naked or lightly clothed resting people could be increased up to 5 times, on average, by shivering [43, 44]. However, the shivering peak of EE corresponds to only 42 ± 5% of $VO_2$max, that is to the increase in EE during physical activities such as walking at 6 km·h$^{-1}$, sport training or hard manual work.

A mathematical model for predicting human thermal and regulatory responses in cold, cool, neutral, warm, and hot environments has been developed from the results of 26 independent experiments. The model was validated using experimental data obtained from 90 exposures covering a range of steady and transient ambient temperatures and exercise intensities [45]. This model enabled the prediction of heat loss and EE of an average person (body weight: 73.5 kg; FM content: 14%, BMR: 5.23 kJ·min$^{-1}$) depending on environmental temperature (Ta), air velocity, and clothing ensemble.

After 30 min exposure to Ta ranging from 20 to 0 °C in calm air (0.1 m·s$^{-1}$), heat loss increases from 9 to 15, 17, and 22 kJ·min$^{-1}$ in the average person wearing an appropriate casual clothing ensemble, a soccer dress plus a tracksuit, or only a soccer dress, respectively. The effects of Ta and clothing on heat loss are much more important with an air velocity of 5 m·s$^{-1}$ (20, 24, and 35 kJ·min$^{-1}$ at 0 °C, respectively). The physical activity ratios (PAR = EE/BMR) necessary to increase EE for balancing heat loss, and the corresponding usual physical activities were calculated. The PAR average 2.8, 3.2, and 4.2, respectively, at 0 °C and calm air, and 3.9, 4.7, and 6.7, respectively, at 0 °C and 5 m·s$^{-1}$ air velocity. Such PAR correspond to walking at various speeds ($3 \leq PAR \leq 4.5$) or physical training ($5 \leq PAR \leq 7$), and can easily be reached by moderately active adolescents. In sedentary subjects the energy deficit is only partially compensated for by non-shivering and shivering thermogenesis.

Thus, in industrialised countries with temperate climatic conditions, the effects of thermoregulation on EE are usually negligible for most children and adolescents who spend most of the time indoors, except in the winter during recreations, and at the beginning of the physical education lessons or training sessions performed outdoors if children and adolescents are not adequately clothed.

## 2.5. Physical activity EE in non-obese children and adolescents

Physical activity EE (AEE) is a major component of DEE. The latter has been determined in children and adolescents over a period of 10–15 days using the doubly labelled water (DLW) method [46–50] or the heart-rate recording method [31, 51, 52]. AEE was estimated as DEE minus BMR × 1440 or DEE minus TEF and BMR × 1440, assuming that TEF averaged 0.1 DEE [46, 53]. AEE averaged 33–39% and 42–47% of DEE in 15-y-old girls and boys, respectively [46, 47, 50–52, 54]. However, AEE overestimates the EE associated with real physical activities because it includes increases in EE above BMR during sedentary activities [7].

EE associated with real physical activity was assessed in 110 NOb children and adolescents aged 10–18 years in standardised and in free-living conditions. EE was determined by whole-body indirect calorimetry with a standardised activity programme simulating their usual activities, to determine changes in EE with sex, age or pubertal stage and body composition [36, 55, 56]. EE and heart rate (HR) were continuously recorded. Mean EE (kJ·min$^{-1}$) during sleep, various sedentary activities, walking at several speeds and recovery periods were determined. In addition, individual polynomial relationships between heart rate (HR) and EE recorded over a 24-h-period were computed. Then, DEE and the circadian variations of EE were determined in free-living conditions during 5 or 7 consecutive days using the HR recording method and an activity diary. EE associated with light physical activities (slow walking, shopping, recreation, playing quietly), moderate physical activities (fast walking, recreation sport, dancing) and team sport (physical education lessons, training and competition) averaged 8.5, 7.2, and 8.3% of DEE, respectively. They were lower in girls than in boys, and decreased between 12.5 and 15.0 years of age [52].

In addition, the mean energy EE of adolescents during 19 usual activities were assessed and are expressed as multiples of sleeping or basal metabolic rate (physical activity ratio, PAR). The PARs did not vary significantly with sex and age between 12 and 18 years of age. They averaged 1.3 and 1.4 during TV watching in the lying and sitting position, respectively; 1.5–1.8 during sedentary activities including meals; 2.5 during light activities; 3.5 during moderate activities, and 4–6 during sports [52] (Fig. 1). The PAR of training and competition in adolescent athletes were also assessed for several sports. They averaged 5–7 at light

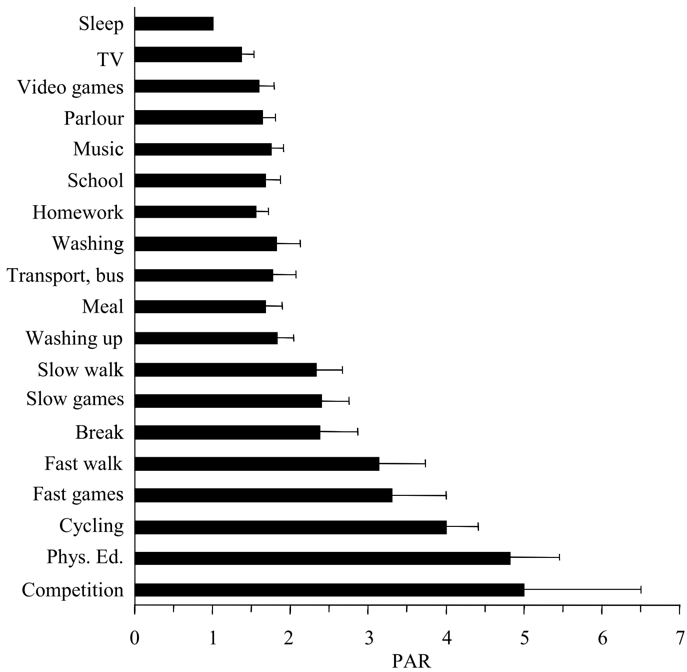


**Figure 1.** Energy cost (physical activity ratio, PAR) of activities in non-obese adolescents in free-living conditions (mean and standard deviation).

intensity, 6–10 at moderate intensity, and 9–15 at high intensity [57] (Fig. 2).

### 2.6. Variability of energy expenditure in non-obese adolescents

Changes in the EE of boys and girls (13–16 subjects per group) with age (10–18 y) were determined both in standardised and in free-living conditions [52, 55, 56]. With the same activity programme in the calorimeters, sleeping and daily EE were 9.8, 23.0, and 34.1% higher in boys than in girls at 12.5, 15.0 and 18 years of age, respectively ($P < 0.001$), but not at 10 years of age. They increased with age, and interestingly plateaued at 13 and 16 years of age in boys and girls, respectively, and tended to decrease in 18-year-old girls (Fig. 3), in spite of significant increases in BW and FFM [52].

In free-living conditions, changes in DEE with age and sex were similar to changes in standardised conditions (Fig. 4). In addition, the inter-individual variability of DEE in each age-class was high since the standard deviation and the range averaged 1.7 and 5.8 MJ·d$^{-1}$, respectively. The inter-individual variability of DEE resulted not only from differences in BW and FFM, but mainly from the variability in the energy cost of the various activities and in physical activity EE. The coefficients of variation of PAR averaged 11% for sedentary activities, 16% for washing, dressing, and travelling by bus, and 20% for physical activities including training and competition. The time devoted to moderate and sport activities ranged from 40 to 160 min·d$^{-1}$ on average, over a week in boys and girls both at 12.5 and 15.0 years of age. The intensity of these activities also differed among subjects so that the increases in EE above sedentary activity EE ranged from 0.16 to 2.70 MJ·d$^{-1}$ (Fig. 5). Consequently, the physical activity

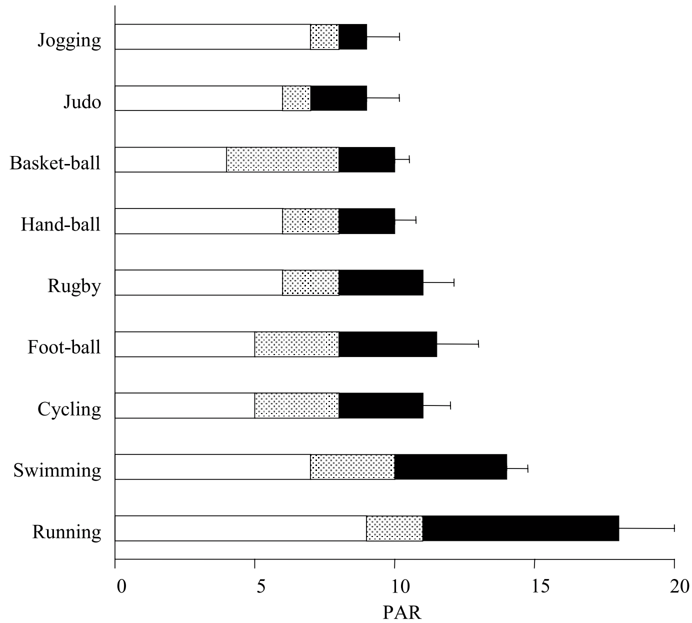


**Figure 2.** Energy cost (physical activity ratio, PAR) of sport activities at light (□), moderate (▨), and high intensity (■) (mean and standard deviation).

level (PAL = DEE/BMR) ranged from 1.4 to 2.0, and averaged 1.75 in boys between 12 and 18 years of age, and in the 12.5-year-old girls in agreement with the literature [43, 51, 58]. However, PAL was lower (1.65) in the 15-and 18-y-old girls in agreement with the literature [51]. These results agreed with the changes in activity patterns of girls after puberty [59].

However, EE associated with physical activity is higher in active adolescents. PAL averaged 1.93 and 1.89 in 17-y-old athletes, boys and girls, respectively, who devoted, on average, 0.85 $h \cdot d^{-1}$ to moderate intensity physical activities, and 1.70 $h \cdot d^{-1}$ to sport activities [56]. PAL was still higher (2.23 in boys and 1.98 in girls) in very active Swedish adolescents who practiced, on average, 1.57 and 1.36 $h \cdot d^{-1}$ of sport activities, and 2.15 $h \cdot d^{-1}$ of moderate intensity activities such as walking or riding a bicycle to school, 2.09 and 2.75 $h \cdot d^{-1}$ of light intensity physical activities such as walking indoors [50].

## 3. ENERGY EXPENDITURE IN OBESE ADOLESCENTS

Because of their higher body weight and greater FFM, obese children and adolescents have higher DEE, BMR and AEE than do non-obese subjects [46, 60, 61]. However, obese children are known to spend less time in physical activities and more time in sedentary activities than do their age-matched counterparts [60, 62–64]. This observation raises the question of metabolic rate and energy cost of activities in obese children and adolescents.

DEE and EE associated with usual sedentary and physical activities were assessed in 60 NOb adolescents (23 boys and 27 girls), and 27 Ob adolescents (13 boys and 14 girls) of similar age (14.0 ± 0.3 y) and height (163.4 ± 2.2 cm) [7]. BW, BMI, FFM and FM were significantly higher in Ob than in NOb subjects: 92.1 vs. 49.7 kg; 34.1 vs. 18.8 $kg \cdot m^{-2}$, 52.4 vs. 39.9 kg, and 43.1 vs.

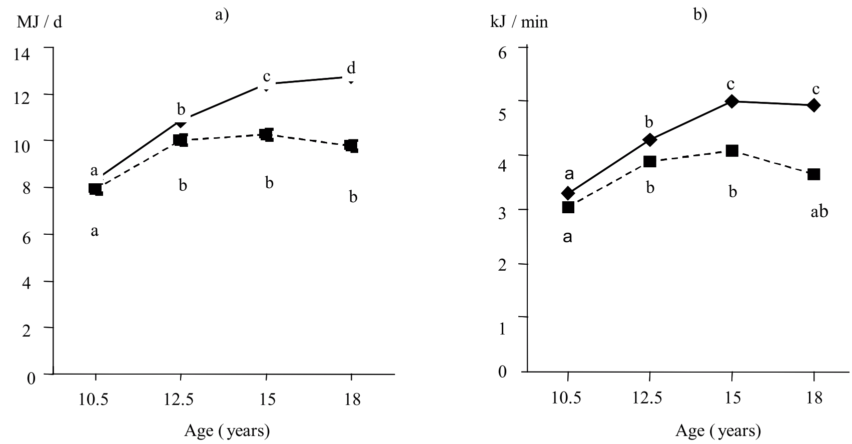


**Figure 3.** Changes in daily energy expenditure (a) and sleeping energy expenditure (b) in boys (——) and girls (- - -) with a standardised activity programme in the whole-body calorimeters, between 10 and 18 years of age (values with different superscripts are significantly different between age groups and genders).

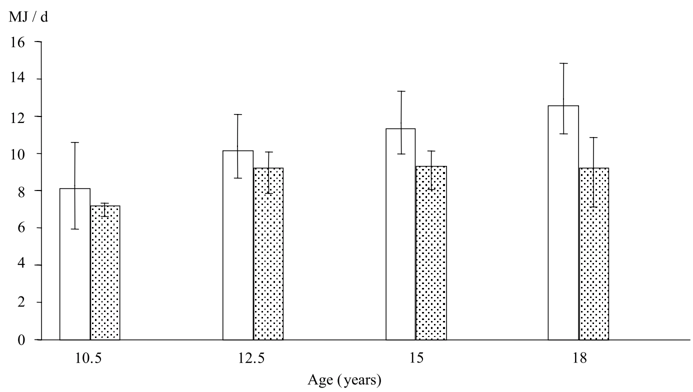


**Figure 4.** Changes and variability in daily energy expenditure in boys (□) and girls (▨) between 10 and 18 years of age in free-living conditions (mean and standard deviation)

19.7 kg, respectively. Excess weight was composed of 27% FFM and 73% FM, on average.

Sleeping EE and sedentary activities EE, as determined in standardised conditions during a 36 h-stay in two whole-body calorimeters, were 19% higher in Ob than in NOb subjects (2.92 vs. 2.46, and 6.75 vs. 5.67 MJ·d$^{-1}$, respectively). However, after adjustment for body composition, sleeping EE and sedentary activities EE were not significantly different between Ob and NOb subjects. These results agreed with previous results showing that BMR, sleeping and sedentary EE are closely correlated to FFM [46, 53]. In addition, these results suggest that tissue and organ metabolic rates are not significantly different between Ob and NOb subjects.

TEF could not be determined accurately in this study, but previous studies showed that TEF is about 25% lower in Ob than in

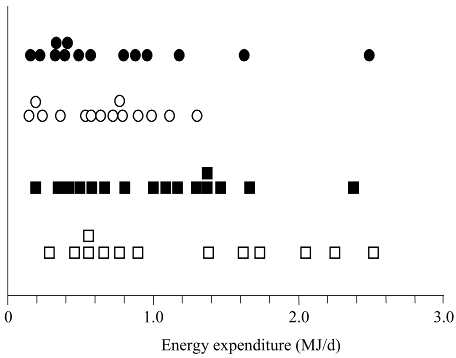


**Figure 5.** Inter-individual variability in the increase in energy expenditure due to physical activities in boys aged 12 years (□) or 15 years (■), and in girls aged 12 years (O) or 15 years (●) in free-living conditions (mean values over a week).

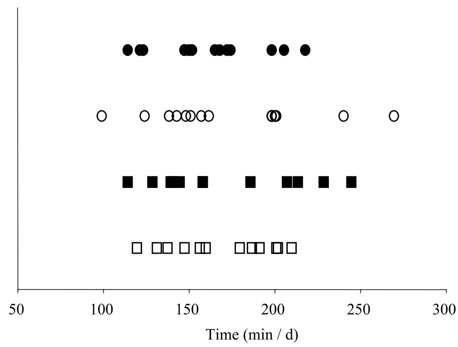


**Figure 6.** Inter-individual variability in time devoted to physical activities in obese (□) or post-obese (■) boys, and in obese (O) or post-obese (●) girls in free living conditions.

NOb children [65, 66]. However, the corresponding decrease in DEE was small (1.5%).

The metabolic response to cold in obese adult subjects is inversely related to body fatness but may vary with the type of obesity [67]. The increase in EE of normally clothed obese women exposed to a mild cold (23.3 °C) was lower than that of non-obese women [68], whereas other authors did not observe significant differences [41]. At low environmental temperature, skin temperature decreases less in obese than in lean subjects [69] partly because of a higher peripheral thermal insulation. In addition, fatter subjects respond to cold air exposure with a later onset and a lower intensity of shivering than do lean subjects [43]. Consequently, subjects with higher body weight and greater body fatness can face more severe cold and for longer periods than can lean subjects [44].

EE during walking at the same speeds on a treadmill in the whole-body calorimeters was 81% higher in Ob than in NOb subjects (3.8 vs. 2.1 MJ) ($P < 0.001$). After adjustment for BW, it was still 25% higher in Ob than in NOb subjects ($P < 0.001$), probably because of greater difficulty of walking in severely obese subjects [7]. In free-living conditions, sleeping EE, sedentary activities EE and DEE were 16%, 42% and 22% higher, respectively, in Ob than in NOb adolescents ($P < 0.001$), whereas EE associated with physical activities were not significantly different. After adjustment for body composition, sleeping EE, sedentary activities EE and DEE were not significantly different between Ob and NOb subjects. On the contrary, EE associated with physical activities were 61% lower (1.4 vs. 3.6 $MJ \cdot d^{-1}$) in Ob adolescents ($P < 0.001$) in spite of the higher energy cost of physical activities. In fact, the Ob adolescents spent 47 $min \cdot d^{-1}$ more at light physical activities (slow walking, housework, etc.) and 53 $min \cdot d^{-1}$ less at moderate physical activities (walking at a normal speed, recreational activities, etc.) than the NOb subjects. Time devoted to physical activities was equivalent to 69 and 122 $min \cdot d^{-1}$ walking at 5 $km \cdot h^{-1}$ in Ob and NOb adolescents, respectively [7].

The inter-individual variability in EE was also high and gender dependent in obese adolescents. After adjustment for differences in FFM, it averaged ± 10.1% in boys and ± 12.4% in girls for EE during sedentary activities in standardised conditions (whole-body calorimeter). Similarly, after adjustment for BW, the inter-individual variability in EE during walking at 5 $km \cdot h^{-1}$ on

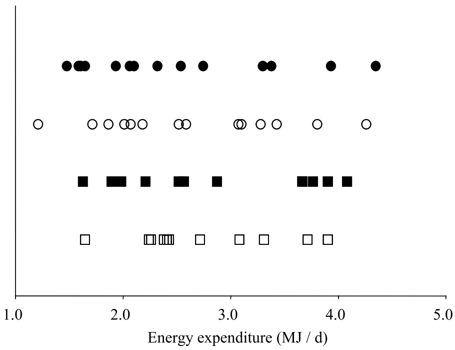


**Figure 7.** Inter-individual variability in energy expenditure associated with physical activities in obese (□) or post-obese (■) boys, and in obese (O) or post-obese (●) girls in free-living conditions (mean values over a week).

a treadmill was ± 21.3% in boys and ± 12.9% in girls [7], which suggests differences in walking efficiency.

In free-living conditions the time devoted by obese adolescents to physical activities ranged from 99 to 270 min·d$^{-1}$ (mean: 171 ± 39) min·d$^{-1}$ [7] (Fig. 6). In addition, after adjustment for BW the inter-individual variability in EE (kJ·min$^{-1}$) during physical activities averaged ± 11.9% depending on the respective contribution of very light, light and moderate intensity activities. Consequently, after adjustment for BW, the inter-individual variability in EE associated with physical activities was 24.7% in obese boys and 32.7% in obese girls (Fig. 7). These results support the opinion that the energy imbalance responsible for overweight and obesity may result either from low physical activity and a small excess of energy intake, or from adequate physical activity but a large excess of energy intake.

## 4. ENERGY EXPENDITURE IN POST-OBESE ADOLESCENTS

Energy restriction, a common treatment of obesity, is usually effective in achieving short-term BW and FM loss, but it is associated with FFM reduction, which could explain the usual decrease in BMR [17, 70, 71], and a further BW regain. On the contrary, TEF is significantly higher in POb than in Ob children, and not significantly different between POb and NOb children [72]. However, significant decreases in BW and FM, without significant reductions in FFM and BMR, have been reported in children when physical activity is associated with a hypocaloric diet [73]. Thus, a combination of energy restriction and regular physical activity may provide a fruitful strategy to preserve FFM and maintain DEE during a weight-reduction program.

Ob adolescents in a specialised institution followed a 9-month weight-reduction programme including moderate energy restriction (energy intake 15 to 20% less than the initial DEE), dietetic education, regular physical activity, and progressive physical training [74]. BW decreased, on average, by 18.0 and 15.8 kg, and FM by 18.0 and 12.5 kg in boys and girls, respectively, whereas FFM did not vary significantly in boys, mainly because of height gain, but decreased by 3.3 kg in girls ($P < 0.001$). Physical capacities and cardio-vascular fitness were also significantly improved [74].

In standardised conditions (whole-body calorimetry) BMR, sleeping EE and sedentary activity EE were 8.3, 14.0 and 14.0% lower, respectively, at the end than at the beginning of the weight-reduction period ($P < 0.001$). The differences were still significant (–6.8, –12.6, and –11.7%, respectively, $P < 0.001$) after adjustment for body composition [74]. This phenomenon could result from reductions in organ (stomach, intestines liver, pancreas, kidneys, etc.) mass and metabolic rate due to energy restriction, as shown in farm animals [75–77]. In addition, EE during walking at the same speeds decreased significantly (–23%) even after adjustment for BW (–17.6%, $P = 0.004$). This phenomenon may result from easier walking and improved work efficiency after weight loss [78, 79]. Consequently, with the same activity programme, DEE was significantly lower after than before the weight-reduction programme, both in absolute value (–16.4%, $P < 0.001$) and after adjustment for FFM (–14.0%, $P < 0.001$). The decrease in metabolic rate and EE for all types of activities may favour BW regain in less active adolescents.

In free-living conditions, DEE, sleeping EE and sedentary EE were 8%, 14% and 22% lower than before the weight-reduction programme, respectively ($P < 0.001$). On the contrary, EE associated with real physical activities (kJ·min$^{-1}$ and kJ·d$^{-1}$) were not significantly different before and after the weight reduction programme in spite of BW loss, indicating an increase in type or intensity of physical activities. In fact, time and EE corresponding to moderate physical activities increased from 21 to 49 min·d$^{-1}$ ($P < 0.03$), and from 0.13 to 0.49 MJ·d$^{-1}$ ($P < 0.025$), respectively, at the expense of sedentary activities during the weight reduction programme [80].

The inter-individual variability in EE (kJ·min$^{-1}$) remained high after the weight-reduction programme. After adjustment for FFM it averaged ± 10.5% in boys, but it was reduced to ± 6.9% in girls during sedentary activities in standardised conditions. The phenomenon was similar for EE during walking at 5 km·h$^{-1}$ on a treadmill: the inter-individual variability in EE averaged ± 21.6% in boys and ± 9.9% in girls [74]. In free-living conditions, the inter-individual variability in EE and time devoted to physical activities increased in boys, but decreased in girls, mainly due to great changes in 3 and 2 subjects in each group [80] (Figs. 6 and 7).

Thus, in spite of life-style education, physical training and regular physical activity, body weight loss and improvement of physical capacities during a 9-month-weight-reduction programme, the inter-individual variability in physical activity (time and intensity) remains high among post-obese adolescents, which may favour BW regain in the less active subjects.

## 5. CONCLUSION

Body composition, especially FFM, physical activity (nature, duration and intensity) and, to a lesser extent, sex are the major variation factors of DEE in NOb, Ob and POb adolescents, whereas FM, growth, TEF and thermoregulation are generally of marginal importance. Nevertheless, after adjustment for the main variation factors, the inter-individual variability in BMR, sleeping EE, and sedentary activity EE remains high, which suggests that other factors of genetic, hormonal or nervous origin affect the tissue metabolic rate of individuals. In addition, the inter-individual variability in DEE and physical activity EE among NOb adolescents in free-living conditions is considerable mainly because of the very little time devoted to moderate and medium intensity physical activities by many adolescents. This suggest that a sedentary lifestyle may have played a major role in the increase in the prevalence of overweight and obesity in children and adolescents during the last decades.

Multidisciplinary weight-reduction programmes including energy restriction, physical training and regular physical activity result in great FM loss, maintenance of FFM, improvement of physical capacities, and increases in time devoted to moderate physical activities in most subjects. However, the reduction in metabolic rate and in EE associated with sleep, sedentary and physical activities favours BW regain in the less active NOb subjects. Therefore, moderate and high intensity physical activities have to be performed regularly after the end of the weight-reduction programme to preserve its beneficial effects.

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