Energy expenditure during walking and running in obese and nonobese prepubertal children

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We measured body composition and energy expenditure during walking and running on a treadmill in 40 prepubertal children: 23 obese children (9.3 ± 1.1 years of age; 46 ± 10 kg (mean ± SD)) and 17 nonobese matched control children (9.2 ± 0.6 years of age; 30 ± 5 kg). Energy expenditure was assessed by indirect calorimetry with a standard open-circuit method. At the same speed of exercise, the energy expenditure was significantly ($p < 0.01$) greater in obese than in control children, in both boys and girls. Expressed per kilogram of body weight or per kilogram of fat-free mass, the energy expenditure was comparable in the two groups. Obese children had a significantly ($p < 0.01$) larger pulmonary ventilatory response to exercise than did control children. Heart rate was comparable in boys and girls combined but significantly higher ($p < 0.05$) in obese subjects, if boys and girls were analyzed separately. These data indicate that walking and running are energetically more expensive for obese children than for children of normal body weight. The knowledge of these energy costs could be useful in devising a physical activity program to be used in the treatment of obese children. (J PEDIATR 1993;123:193-9)

In industrialized countries the prevalence of obesity in children is increasing,[1] and obesity during childhood is strongly associated with obesity in adulthood.[2] Both the environmental conditions and the typical life-style of Western countries, in particular the reduction of physical activity, favor the development of obesity.[3] Moreover, the efficacy of therapy is frequently disappointing.[4] Therefore the addition of a physical exercise program to a hypocaloric diet has been suggested.[5] For this purpose, it might be useful to know,

more precisely, the energy expenditure during certain commonly performed physical exercises.

At the present time, few data are available on the energy cost of specific physical exercise in prepubertal obese children. We assessed the rate of energy expenditure in a group of sedentary obese and nonobese children, during both walking and running. In addition, we explored the relationship between the rate of energy expenditure and the speed of locomotion during these exercises.

FFM	Fat-free mass
HR	Heart rate
RMR	Resting metabolic rate
$\dot{V}_{CO_2}$	Carbon dioxide output
$\dot{V}_{O_2}$	Oxygen uptake

METHODS

Subjects. Investigations were carried out in 40 prepubertal (mean [± SD] age, 9.3 ± 0.9 years) healthy children: 23

Table I. Physical characteristics and body composition of obese and nonobese children

	Obese children (n = 23)	Nonobese children (n = 17)	p
Male/female ratio	16:7	7:10	
Age (yr)	9.3 ± 1.1	9.2 ± 0.6	NS
Weight (kg)	46.2 ± 9.6	30.3 ± 5.3	<0.01
Height (cm)	137.8 ± 7.4	136.7 ± 7.7	NS
BMI (kg · m^2)	24.6 ± 4.1	16.3 ± 1.5	<0.01
Weight/height (%)	138.3 ± 15.5	95.5 ± 7.9	<0.01
% FM	31.3 ± 6.9	16.5 ± 5.4	<0.01
FM (kg)	14.7 ± 5.1	5.1 ± 2.4	<0.01
FFM (kg)	31.4 ± 6.0	25.2 ± 3.8	<0.01

NS, Not significant; *BMI*, body mass index; *FM*, fat mass.

Table II. Heart rate during walking and running at different speeds in obese and control children, grouped by sex

	Heart rate (beats/min)			
	Boys		Girls	
Steps	Obese (n = 15)	Nonobese (n = 8)	Obese (n = 8)	Nonobese (n = 9)
Walking				
2 km/hr	112 ± 7	95 ± 5	121 ± 13	115 ± 8
3 km/hr	114 ± 8	105 ± 5	129 ± 11	122 ± 7
4 km/hr	123 ± 8	115 ± 4	134 ± 10	128 ± 9
5 km/hr	134 ± 10	123 ± 6	147 ± 10	136 ± 11
6 km/hr	151 ± 13	132 ± 7	164 ± 14	151 ± 10
7 km/hr	168 ± 15	148 ± 7	177 ± 11	169 ± 11
Running				
7 km/hr	180 ± 20	155 ± 9	187 ± 10	181 ± 11
8 km/hr	183 ± 10	165 ± 5	198 ± 3	190 ± 6
9 km/hr	187 ± 13 (n = 5)	174 ± 8 (n = 6)	199 ± 4 (n = 2)	191 ± 6 (n = 4)
10 km/hr	188 ± 3 (n = 3)	179 ± 9 (n = 4)	200 (n = 1)	
11 km/hr	200 (n = 1)	191 ± 9 (n = 3)		

Values are expressed as mean ± SD.
Significance:
   Obese versus nonobese boys: *p* <0.05.
   Obese versus nonobese girls: *p* <0.05.
   Obese boys versus obese girls: *p* = not significant.
   Nonobese boys versus nonobese girls: *p* <0.05.

obese (15 boys) and 17 nonobese (9 girls). The physical characteristics of both groups of children are shown in Table I. Body weight and other measurements related to body composition were significantly higher (*p* <0.01) in the obese children than in the control subjects with normal body weight; age and height were comparable in the two groups. Physical examination and routine laboratory tests documented the absence of any disease. None of the children was taking any medication. The pubertal stage was assessed according to Tanner.[6] None of the subjects reported significant changes in body weight during the month preceding the study.

The protocol was approved by the ethics committee of the university hospital of Verona. Informed consent was obtained from the parents of each child.

Body composition. Anthropometric measurements (i.e., weight, height, and skin-fold thicknesses) were done by the same investigator. Body weight was determined to the nearest 0.5 kg on a standard physician's beam scale with the child dressed in light underwear and wearing no shoes. Height was measured to the nearest 0.5 cm on a standardized wall-mounted height board.

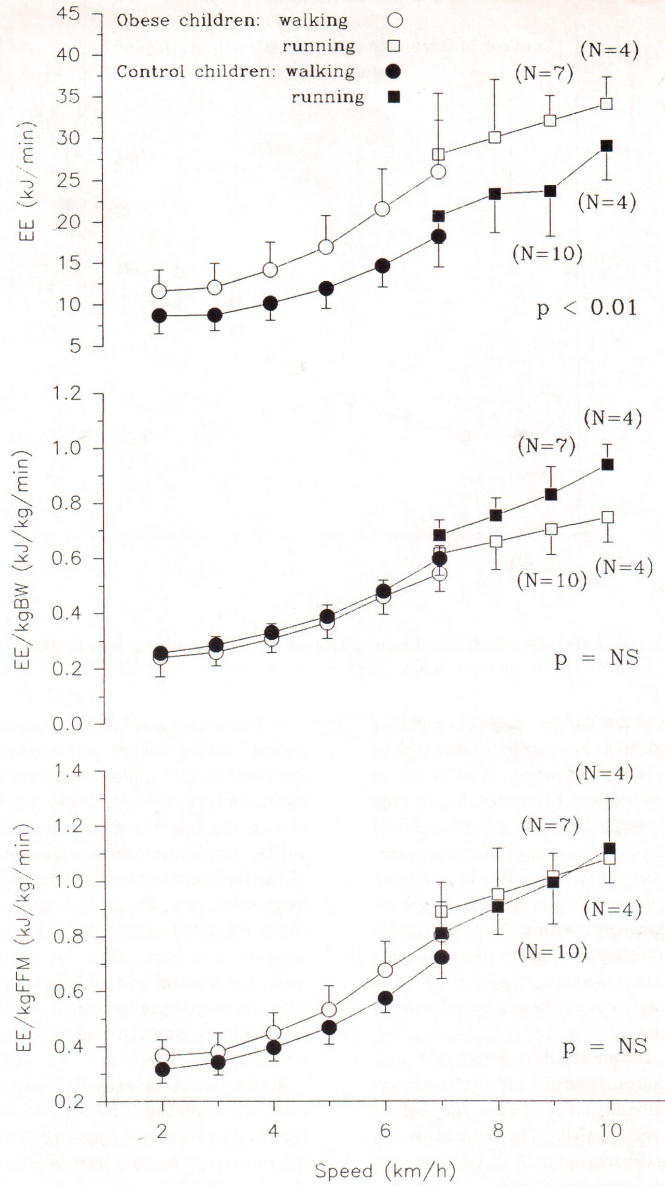Obesity was defined as weight >20% of predicted weight for height; weight was considered as normal when it was in

Fig. 1. Effect of speed of locomotion on the rate of energy expenditure *(EE)* during walking *(circle)* and running *(square)* on the treadmill in obese and control children, expressed in absolute value *(upper panel)*, per kilogram per body weight per day *(middle panel)*, and per kilogram FFM per day *(lower panel)*. Data are mean ± SD.
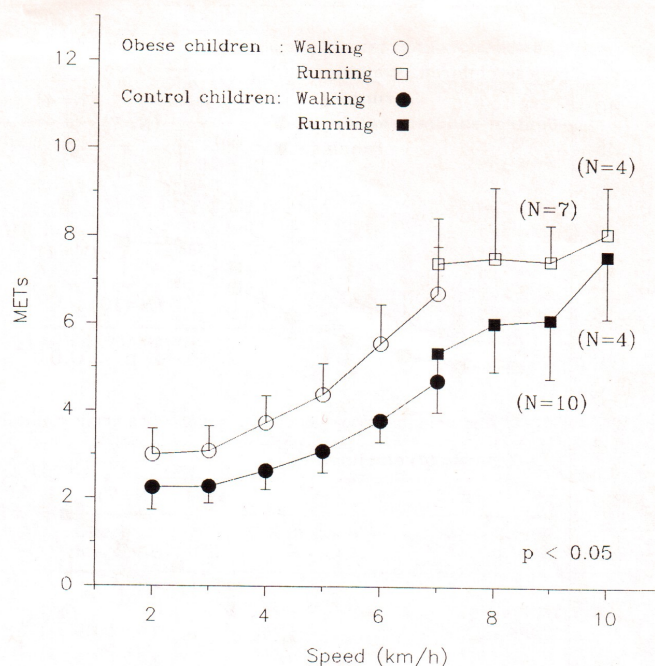
Fig. 2. Changes in multiples of RMR *(METs)* during walking *(circles)* and running *(squares)* in obese and control children (1 MET = 1 × RMR). Data are mean ± SD.

the −10% to 10% range of the 50th percentile of weight for actual height, calculated on the basis of the Tanner tables,[7] as recommended by the National Consensus Conference on Obesity.[8] Body mass index was calculated by dividing weight (in kilograms) by height in square meters. Skin-fold thicknesses were measured in triplicate to the nearest millimeter at the triceps and subscapular sites by means of Harpenden skin-fold calipers (CMS Weighing Equipment Ltd., London, United Kingdom), with the Lohman formulas[9] to calculate the percentage of body fat. Body fat mass was obtained by multiplying the percentage of body fat by body weight. Fat-free mass was calculated by subtracting body fat from body weight.

Experimental design. During the days before each test, the children were on an unrestricted diet and no attempt was made to influence it. On the day before the test, they did not perform any intense physical activity. The children arrived by car at the pediatrics department at 7:30 AM, in fasting condition, the last meal having been taken at 8:00 PM on the preceding day. When the child was admitted, the first thing he or she did was to lie down on a hospital bed in a temperature-(∼24° C) and humidity-controlled environment. Af-

ter 30 minutes of absolute rest (considered as an adaptation period), during which the procedure to be used was explained to each child, continuous respiratory exchange measurements were performed by indirect calorimetry. During the calorimetric measurement, the child rested quietly, watching videotapes appropriate for children.

The treadmill test was performed in the exercise physiology laboratory, about 2½ hours after a light breakfast consisting of 200 ml of milk and 30 gm of bread. Before the measurements were taken, the children were instructed about the protocol and allowed to familiarize themselves with the exercise experimental apparatus—in particular, breathing through the mouthpiece and running on the treadmill.

Resting metabolic rate. Respiratory gas exchange was measured continuously for 30 to 45 minutes in a basal resting state by means of open-circuit computerized indirect calorimetry (Deltatrac; Instrumentarium Oy, Datex Division, Helsinki, Finland), with the use of a transparent ventilated hood system, as previously described.[10] The system was calibrated before each test with a reference gas mixture (O_2 95.2%; CO_2 4.8%).
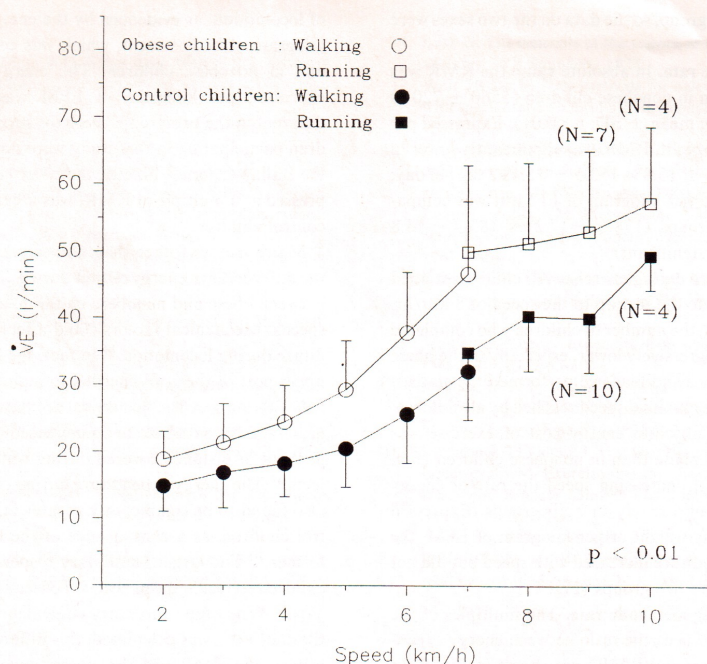
Fig. 3. Effect of speed of locomotion on the rate of pulmonary ventilation *(V̇E)* during walking *(circles)* and running *(squares)* in obese and control children. Values are mean ± SD.

Oxygen uptake and carbon dioxide output were printed out at 1-minute intervals, and the mean of the resting metabolic rate was calculated as the average value of the 30 to 45 minutes measurement period. The energy expenditure was calculated according to the Lusk formula.[11]

Energy expenditure during exercise. Steady-state oxygen consumption and carbon dioxide production were determined during walking and running on a treadmill at 0% grade (PV Rolling belt; Beta, Reggio Emilia, Italy). Starting from 2 km/hr, the speed was increased by 1 km/hr in separate steps lasting 6 minutes each, until the maximal individual work load was attained or a heart rate of 200 beats/min was reached. An 8- to 10-minute recovery interval was observed before each successive work load was started, so that HR and $\dot{V}O_2$ could return nearly to baseline values.

Expired air was collected in a Douglas bag during the last 2 minutes of each work load, and $\dot{V}O_2$ and $\dot{V}CO_2$ were calculated by measuring oxygen and carbon dioxide concentrations (Oxinos 100 and Binos C gas analyzers; Leybold Heraeus Gmbh, Hanau, Germany), as well as volume (Gas Meter MCG; SIM, Rome, Italy). Energy expenditure was calculated by using the simplified Weir formula,[12] which assigns 20.5 kJ per liter of oxygen consumed. Heart rate was measured by a cardiotachometer (Polar Sport Tester; Polar Electro Ky, Kempele, Finland) consisting of an electrode-belt transmitter and a wrist microcomputer receiver.

Statistical analysis. Results are expressed as mean ± SD. The comparisons between obese and control children were made by using the unpaired two-tailed Student t test. To evaluate the differences between obese and control children of energy expenditure during walking and running, we carried out analysis of variance with a split-plot design, considering each subject as a whole plot allocated to one of the two categories (obese or nonobese) of the main treatment. Seven subtreatments (subplot or split plot), corresponding to the seven speeds reached by all the children (2 to 8 km/hr), were considered for each child. The effects of the main subplot treatment were considered fixed. A statistical significance level of 0.05 was used.

RESULTS

Our findings were first analyzed separately in boys and girls. No significant differences were found in either the

obese or the control group, so the data on the two sexes were pooled.

Resting metabolic rate. In absolute value the RMR was higher in obese than in nonobese children (5560 ± 720 vs 4602 ± 602 kJ/day; mean $\pm$ SD; $p < 0.01$). Expressed per kilograms of body weight, RMR was significantly lower in obese children (84.1 ± 13.8 vs 153.5 ± 15.1 kJ/kg per day; $p < 0.01$). Expressed per kilogram of FFM, it was comparable in the two groups (178.6 ± 17.2 vs 183.7 ± 13.8 kJ/kg per day; not significant).

Energy expenditure during exercise. All children studied were able to complete the test up to the speed of 8 km/hr. At the higher speeds, the number of children who completed the exercise was progressively lower, especially in the obese group. Therefore, to avoid bias, we performed the statistical analysis up to the maximal speed reached by all children. At each speed the absolute energy cost of exercise was higher ($p < 0.01$) in obese than in nonobese children (Fig. 1). As expected, with increasing speed the rate of energy expenditure rose progressively in both groups. Expressed per kilogram of body weight or per kilogram of FFM, the rate of energy expenditure increased with speed but did not differ in either of the two groups (Fig. 1).

Multiple of resting metabolic rate. The multiples of the RMR for each speed (i.e., the ratio between energy expenditure during exercise and RMR) are shown in Fig. 2. In both groups, the multiples of the RMR rose progressively with speed. Overweight children had significantly ($p < 0.05$) higher METs than the control group had.

Heart rate and pulmonary ventilation. The HR was progressively increased at different speeds of locomotion; HR was higher in girls than in boys ($p < 0.05$; Table II). The HR was not significantly higher in obese children. However, if the boys and girls were analyzed separately, the obese children had a significant higher HR ($p < 0.05$) than the control subjects had. A significantly larger ventilatory response during exercise ($p < 0.01$) was observed in obese children (Fig. 3). Pulmonary ventilation increased with speed, progressively more in obese than in control children.

DISCUSSION

The results of this study show that the obese children expended more energy in moving their bodies than nonobese children did. For example, while walking at a speed of 5 km/hr, the obese children expended approximately 50% more energy than the control children. This additional cost was progressively higher with increased walking speed. Thus the overweight state, rather than a metabolic defect, may explain the greater rate of energy expenditure in obese children.[13] Excessive body weight induces an excess load that increases the energy needed to maintain the same speed

of locomotion, as evidenced by the energy expenditure per kilogram of body weight, which was comparable in obese and in nonobese children. The energy cost of exercise expressed per kilogram of FFM was not significantly different in the two groups, perhaps because the obese children participating in this study were not severely obese by the Italian criteria.[8] Finally, the energy cost of exercise, expressed as a multiple of RMR, was greater in obese than in control children.

Many factors (other than adiposity) may contribute to the differences in energy output during walking and running between obese and nonobese children, especially at higher speeds. Mechanical factors could affect the energy expenditure during locomotion.[14] In fact, the forward lean of the upper part of the body, needed to maintain equilibrium at fast walking speeds, and vertical oscillations of the center of gravity may contribute to an increased energy expenditure per unit of distance covered during walking by obese subjects.[14] The energy expenditure during the resting state was also found to be significantly greater in obese than in control children, as a consequence of the larger FFM of the former.[10] The larger ventilatory response shown by obese children at each speed was a consequence of the higher $\dot{V}_{O_2}$.[15] When the ventilatory equivalence (pulmonary ventilation/$\dot{V}_{O_2}$) was calculated, this difference vanished. The sum of the RMR and the energy expenditure devoted to physical activity cover approximately 90% of daily energy output (the remaining 10% constitutes postprandial thermogenesis)[16]; thus an increase in the duration and intensity of physical exercise could produce an increase in both components, and hence in the total daily energy output. In fact, the practice of physical exercise produces, in addition to the energy expenditure directly resulting from the exercise, a residual increase of resting energy output after exercise—the so-called excess postexercise $\dot{V}_{O_2}$.[17]

The evidence of greater energy expenditure in obese than in nonobese prepubertal children supports the hypothesis that an exercise program, combined with dietary restriction, should help the obese subject to lose fat tissue, as suggested by other investigators.[5, 18, 19] However, specific recommendations for intensity and duration of exercise in the obese are not available. Further studies are needed to explore daily energy expenditure during a physical exercise program in overweight and in normal-weight children.

We conclude that there is a greater absolute energy expenditure in obese than in nonobese prepubertal children at the same walking and running speeds. Therefore the prescription of light physical exercise that is simple to perform and has a high gravitational component, such as walking and running, could constitute a useful tool, in addition to dieting, to achieve fat loss in obese children.

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