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Nutrient Oxidation during Moderately Intense Exercise in Obese Prepubertal Boys

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The aim of this study was to measure the nutrient oxidation rate during walking at different speeds and to identify the walking speed associated with the highest fat oxidation rate in a group of prepubertal boys with different levels of adiposity. Twenty-four prepubertal boys (age, 10 ± 1 yr) with different levels of overweight (body mass index, 25.5 ± 3.5 kg/m^2; SD score of body mass index, 3.4 ± 1.1) performed a treadmill test. We measured by indirect calorimetry their respiratory exchange while they walked at speeds of 4, 5, and 6 km/h as well as their maximal oxygen uptake. The fat oxidation rate did not change significantly when the speed of walking was increased, whereas carbohydrate oxidation increased significantly ($P < 0.001$). A significant ($P < 0.05$) association was found between adiposity (percent fat mass) and the fat to carbohydrate oxidation ratio during walking at 4, 5, and 6 km/h (r = 0.37, r = 0.37, and r = 0.36, respectively), adjusting for exercise intensity (maximal oxygen uptake, percentage). The lowest fat to carbohydrate oxidation ratio, *i.e.* the highest fat oxidation/carbohydrate oxidation rate, was found at a walking speed of 4 km/h. Moderately intense exercise promoted the highest fat to carbohydrate oxidation ratio. Increasing the exercise intensity did not promote fat oxidation. Therefore, walking at a speed of 4 km/h is recommended as practicable exercise for obese boys and, consequently, for the treatment of childhood obesity. (*J Clin Endocrinol Metab* 90: 231–236, 2005)

OBESITY IS THE result of a prolonged positive energy balance, the development of which involves several factors, genetic and environmental, involved in the development of a positive fat balance (1). Environmental factors include intake behavior as well as sedentary behavior and little participation in sports and organized physical activity (2). Skeletal muscle activity in the regulation of fat balance is important because of the impact of fat oxidation during exercise on the total daily fat oxidation rate of the body. In normal conditions, skeletal muscles are responsible for the greatest amount of oxidized fat. Muscular activity is discretionary and may be subjectively modulated; therefore, an increase in the amount of daily physical activity and a wiser choice of exercises with the best combination of highest fat oxidation and lowest intensity may be helpful in the prevention and treatment of obesity.

Studies of adults have shown a distinct relationship between the intensity of common activities, such as walking, running or biking, and fat oxidation (3–5). In fact, most programs for the treatment of childhood obesity include reducing sedentary behavior and increasing nonorganized physical activity, especially walking (6–9). To optimize fat oxidation during walking, it could be helpful to regulate the speed of walking to obtain maximal fat oxidation.

At present, no data are available on the relationship between the absolute (milligrams per minute) and relative (percent energy expenditure) fat oxidation rates during walking and the intensity of the exercise; for example, the walking speed of prepubertal children with different levels of overweight. Therefore, the aims of this study were 1) to measure the nutrient oxidation rate during walking at different speeds, and 2) to identify the walking speed associated with the highest fat oxidation rate in a group of prepubertal boys with different levels of adiposity.

Subjects and Methods

Subjects

Twenty-four prepubertal Caucasian boys, aged 10 ± 1 yr, were recruited among the overweight children who attended the out-patient clinic of the Department of Pediatrics at University Hospital (Verona, Italy). Each child underwent a physical examination and anthropometry. Puberty development was clinically assessed on the basis of Tanner stages (10). Height and weight were measured in postabsorptive conditions and with an empty bladder. Height was measured to the nearest 0.5 cm on a standardized height board. Weight was determined to the nearest 0.1 kg on a standard physician's beam scale, with the subject dressed only in light underwear and no shoes. The body mass index (BMI) was calculated as weight (kilograms) divided by height (meters) squared. Boys with a BMI above the 85th percentile were defined as overweight, and boys with a BMI above the 95th percentile were defined as obese. National BMI tables were used as a reference (11). None of the boys had any overt disease other than obesity, none was dieting at the time of the study, and none was taking medication. The boys arrived at the Department of Pediatrics at 0800 h, accompanied by their parents. Informed consent was obtained before taking part in the study. The protocol was in accordance with the 1975 Declaration of Helsinki as revised in 1983.

Anthropometry and body composition

Anthropometric measurements (height and weight) as well as total body densitometry [dual energy x-ray absorptiometry (DXA)] were recorded for each child, to assess body size (BMI) and body composition. Fat mass (FM) and fat-free mass (FFM) were measured by DXA using

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Abbreviations: BMI, Body mass index; DXA, dual energy x-ray absorptiometry; FFM, fat-free mass; FM, fat mass; RQ, respiratory quotient; SDS, SD score; VCO_2, carbon dioxide output; VO_2, oxygen uptake; VO_2max, maximal oxygen uptake.

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a DPX-L densitometer (Lunar Corp., Madison, WI). Subjects were scanned in light clothing while lying flat on their backs. On the day of each test, the DPX-L was calibrated according to the procedures described by the manufacturer. Body fat mass (FM) was calculated by multiplying the percentage of body fat by body weight.

Experimental design

The study was designed as a cross-sectional study and lasted 5 consecutive hours, during which the boys were under constant medical supervision. During the days preceding the test, no attempt was made to influence the usual diet of the boys (who had access to a free diet), but none of them was on a low calorie diet. On the day before the test, they did not participate in any sports or perform moderate to intense physical activity. Each boy arrived at the Department of Pediatrics at 0800 h on the day of the exercise test. Tanner's criteria were used to estimate sexual maturation on the scale of 1–5, with stage 1 being prepubertal, and 5 being adult. The same qualified pediatrician assessed the Tanner stage for all of the boys. Before their measurements were taken, the protocol was explained to the children, and they were allowed to familiarize themselves with the exercise apparatus, in particular breathing through the mouthpiece and running on the treadmill (PV rolling belt, Beta, Reggio Emilia, Italy). After the physical examination, anthropometry, and a DXA scan, they had a light drink (200 ml skim milk, no sugar added). The effects of milk intake on substrate oxidation and energy expenditure are no more detectable 2 h after ingestion (12). A questionnaire on usual physical activity and sports performed by the boys was filled out by the pediatrician together with the mother after the physical examination of each subject. The questionnaire provided information on time devoted to light (sedentary activities: sitting, reading, watching TV, *etc.*), moderate (walking, biking at a low speed, free play, *etc.*), or intense (running, sports, very active play, *etc.*) physical activity during the week. Two hours after drinking the milk, the boys performed a walking/running treadmill exercise, appropriately designed for children.

Starting at 3 km/h at a 0% treadmill grade, the speed was increased by 1 km/h in separate stages, lasting 8–10 min each, until the speed reached 6 km/h. The children were allowed an 8-min recovery interval between speed sessions. The treadmill grade was maintained at 0% grade until the speed of 6 km/h. When the exercise of walking at the speed of 6 km/h at a treadmill grade of 0% was finished, and the 10-min recovery period was over, an incremental progressive exercise was performed. The relatively small interval between two different workloads, *i.e.* 4 *vs.* 5 km/h, did not permit a complete return of heart rate to preexercise baseline levels; however, the difference between the two values was minimal (<5%). Moreover, the brief duration of the exercise at this low intensity did not cause subjective fatiguing of the boys, as confirmed by fat to carbohydrate oxidation ratio [respiratory quotient (RQ)] values, which were not suggestive of anaerobic workouts. The treadmill grade was raised to 10% and then increased by 2.5% every 2 min. The speed remained constant until a 22.5% grade was reached, at which time the speed was increased by 0.6 km/h until the maximal individual workload was attained or a heart rate of 195 beats/min was reached. We measured the boys' maximal oxygen uptake (VO_2max) to calculate the workload as a percentage of the VO_2max and to explore the relationship between workload and body size and composition in the total group.

Oxygen consumption and carbon dioxide production were measured continuously and analyzed using a metabolic cart (model 2900, Sensormedics, Yorba Linda, CA). Heart rate was monitored by a Vantage XL heart rate monitor (model 61204, Polar Electro, Inc., Woodbury, NY). Three criteria were used to determine a successful maximal test: 1) a leveling or stabling of O_2 (defined as an increase in oxygen uptake <2 ml/kg·min), 2) a heart rate greater than 195 beats/min, and 3) a respiratory exchange ratio greater than 1.0. VO_2max (which was defined as satisfying two of three criteria).

Macronutrient oxidation rate

The macronutrient oxidation rate was calculated by oxygen uptake (VO_2) and carbon dioxide output (VCO_2) from the last 5 min of each speed session using the following formulas (13): Fox (g/min) = 1.67 × VO_2 (liters/min) − 1.67 × VCO_2 (liters/min) − 0.307 Pox, and Cox (g/min) = 4.55 × VCO_2 (liters/min) − 3.21 VO_2 (liters/min) − 0.459 Pox, where Fox is the fat oxidation rate, Cox is the glucose oxidation rate, and Pox is the protein oxidation rate.

The protein oxidation rate was estimated as follows: Pox (g/min) = [energy expenditure (kJ/min) × 0.12 (g)]/16.74 (kJ). We assumed that protein oxidation covered approximately 12% of resting energy expenditure in both obese and nonobese girls.

Energy expenditure (kilojoules per minute) during each stage was calculated as the sum of each macronutrient oxidation rate (grams per minute) multiplied by the conversion factor (carbohydrate and protein = 16.74; fat = 37.66).

Statistical analysis

All results are shown as mean and SD. ANOVA for repeated measures was used to compare energy expenditure and nutrient oxidation rates during walking at speeds of 4, 5, and 6 km/h. ANOVA was also used to compare energy expenditure and the nutrient oxidation rate among the children, who were divided into tertiles on the basis of the SD score (SDS) of their BMI. *Post hoc* analysis by Tukey's test was also run for comparison between groups.

A partial regression analysis was run to assess the relationship between adiposity (FM, percentage) and nutrient oxidation (RQ), adjusting for exercise intensity (VO_2max, percentage). Another partial regression analysis, for each workload, was run between energy expenditure during walking and FM (kilograms), adjusting for FFM (kilograms).

A probability level of $P < 0.05$ was used to indicate statistical significance. The SPSS 10.0 for Windows (SPSS, Inc., Chicago, IL) package for personal computers was used for all statistical analyses.

Results

Table 1 shows the physical parameters, body composition, and VO_2max of the boys categorized by tertiles of the SDS of BMI. The ages of the boys in the three groups were not statistically different, but physical parameters and body

TABLE 1. Physical parameters and body composition

	I tertile	II tertile	III tertile	Total	*P*
No.	8	8	8	24	
Age (yr)	9.77 (1.96)	10.08 (1.58)	11.05 (1.40)	10.30 (1.90)	0.57
Weight (kg)	44.94 (8.31)	51.56 (4.70)	71.56 (7.93)	56.02 (13.44)	<0.001
Height (cm)	143.3 (12.5)	142.6 (6.3)	155.9 (8.0)	147.3 (10.9)	<0.001
BMI (kg/m^2)	21.8 (1.2)	25.4 (2.0)	29.3 (1.7)	25.5 (3.5)	<0.001
SDS BMI	2.25 (0.52)	3.38 (0.41)	4.59 (0.42)	3.41 (1.07)	<0.001
FM (%)	28.7 (11.2)	40.3 (3.5)	43.5 (3.0)	37.5 (9.3)	<0.001
FM (kg)	13.1 (5.7)	20.8 (3.0)	31.0 (3.6)	21.6 (8.5)	<0.001
FFM (kg)	32.8 (5.5)	30.4 (2.5)	41.4 (6.2)	34.9 (6.8)	<0.001
VO_2max (liters/min)	1.60 (0.48)	1.64 (0.27)	1.94 (0.30)	1.73 (0.38)	0.14
VO_2max/body weight (ml/kg·min)	35 (7)	32 (6)	27 (4)	32 (6)	0.037
VO_2max/FFM (ml/kg·min)	48 (10)	54 (10)	48 (11)	50 (10)	0.40

Data represent mean (SD).

composition were statistically different among the groups. Heavier children had higher body weight, height, BMI, FM, and FFM. VO_2max, expressed as an absolute value as well as per kilogram of FFM, was not statistically different among the groups. VO_2max, expressed per kilogram of body weight, showed a progressive reduction from the first (least obese) to the third (most obese) tertile of the SDS of BMI.

The boys had a sedentary lifestyle, as previously reported in an independent sample of children in the same geographical area (14). None of the boys reported performing strenuous exercise or competitive activities. All children spent 2 h/wk participating in recreational organized physical activity (football or swimming) in the afternoon after school. Therefore, the potential acute or chronic conditioning of the children before the exercise test was likely to be minimal.

Energy expenditure and macronutrient oxidation rates during walking at speeds of 4, 5, and 6 km/h are shown in Table 2. Energy expenditure, expressed as an absolute value as well as per kilogram of body weight or kilogram of FFM, increased as walking speed increased (Fig. 1). Accordingly, carbohydrate oxidation increased progressively as speed increased. On the contrary, the fat oxidation rate did not change significantly when the speed of walking increased. The RQ, which is an index of fat to carbohydrate oxidation ratio, significantly increased with the speed of walking. As expected, the energy cost of the exercise, expressed as a percentage of the VO_2max, grew as the workload (speed of walking) increased.

Table 3 and Fig. 2 show the energy expenditure, macronutrient oxidation rate, and VO_2max for the three groups of boys during walking at speeds of 4, 5, and 6 km/h, respectively. Energy expenditure and carbohydrate oxidation increased from the first to the third tertile of the SDS of BMI. As expected, a significant increase in heart rate was found whenever the speed of walking increased. However, no significant differences were found among tertiles at walking speeds of 4, 5, and 6 km/h, respectively. *Post hoc* analysis by Tukey's test revealed that there was a significant difference in the energy expenditure expressed as an absolute value and carbohydrate oxidation (grams per minute) between the first and third tertiles as well as between the second and third tertiles. These results were found at 4, 5, and 6 km/h of speed, respectively. No other significant differences were found for the other variables. On the contrary, energy expenditure, expressed per kilogram of body weight and per kilogram of FFM, well as the fat oxidation rate were not significantly different among tertiles of overweight (Fig. 3).

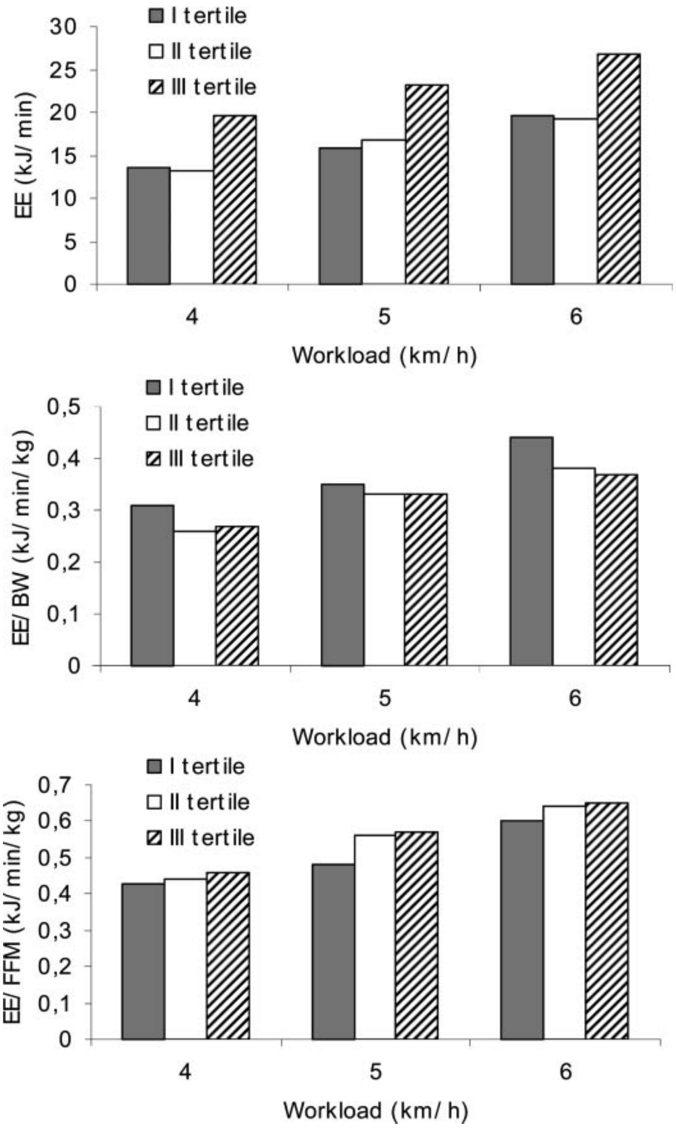

FIG. 1. Energy expenditure (absolute value, kilograms of body weight, and kilograms of FFM) at different walking speeds (4, 5, and 6 km/h) for different grades of overweight.

A partial regression analysis showed that the energy expenditure during walking, adjusting for FFM, correlated with adiposity in boys (4 km/h: r = 0.45; $P < 0.04$; 5 km/h: r = 0.35; $P = 0.09$; 6 km/h: r = 0.37; $P = 0.07$). Furthermore, another partial regression analysis showed a significant ($P <$

TABLE 2. Energy expenditure (EE), RQ, nutrient oxidation rate, and exercise intensity (expressed as a percent of VO_2max) measured during walking at speeds of 4, 5, and 6 km/h, respectively

	4 km/h	5 km/h	6 km/h	*P*
EE (kJ/min)	15.40 (4.64)	18.63 (5.78)	21.84 (6.12)	0.001
EE/body weight (kJ/min·kg)	0.28 (0.08)	0.34 (0.10)	0.40 (0.11)	<0.001
EE/FFM (kJ/min·kg)	0.44 (0.12)	0.54 (0.16)	0.63 (0.16)	<0.001
RQ	0.85 (0.05)	0.87 (0.05)	0.90 (0.06)	0.015
CHO (g/min)	0.45 (0.23)	0.64 (0.32)	0.88 (0.42)	<0.001
Fat (g/min)	0.15 (0.08)	0.15 (0.08)	0.12 (0.10)	0.40
CHO/fat	4.18 (3.47)	6.70 (6.90)	18.2 (20.8)	<0.001
VO_2max (%)	45 (11)	53 (13)	62 (13)	<0.001

Data represent mean (SD). CHO, Carbohydrates.

TABLE 3. Energy expenditure (EE), heart rate (HR), RQ, nutrient oxidation rate, and exercise intensity (expressed as a percentage of VO_2max) measured during walking at speeds of 4, 5, and 6 km/h, respectively. Data are shown separately at speeds of 4, 5, and 6 km/h. Subjects are divided into tertiles, on the basis of their SDS of BMI

4 km/h	I tertile	II tertile	III tertile	P
EE (kJ/min)	13.5 (4.2)	13.3 (3.2)	19.7 (3.7)	<0.01[a]
EE/BW (kJ/min·kg)	0.31 (0.09)	0.26 (0.08)	0.27 (0.05)	0.42
EE/FFM (kJ/min·kg)	0.43 (0.13)	0.44 (0.13)	0.46 (0.11)	0.88
HR (beats/min)	138 (17)	125 (24)	129 (22)	0.53
RQ	0.83 (0.05)	0.84 (0.05)	0.88 (0.03)	0.15
Carbohydrates (g/min)	0.31 (0.12)	0.36 (0.18)	0.70 (0.15)	<0.001[b]
Fat (g/min)	0.17 (0.10)	0.14 (0.07)	0.15 (0.06)	0.80
VO_2max (%)	44 (9)	40 (6)	52 (15)	0.125

[a] I *vs.* III, $P = 0.14$; II *vs.* III, $P = 0.008$.
[b] I *vs.* III, $P < 0.001$; II *vs.* III, $P = 0.001$.

5 km/h	I tertile	II tertile	III tertile	P
EE (kJ/min)	15.9 (4.7)	16.7 (6.0)	23.3 (3.8)	0.012[a]
EE/BW (kJ/min·kg)	0.35 (0.10)	0.33 (0.14)	0.33 (0.05)	0.87
EE/FFM (kJ/min·kg)	0.48 (0.13)	0.56 (0.23)	0.57 (0.10)	0.52
HR (beats/min)	147 (18)	134 (24)	142 (18)	0.50
RQ	0.86 (0.06)	0.86 (0.04)	0.90 (0.04)	0.19
Carbohydrates (g/min)	0.45 (0.20)	0.54 (0.26)	0.93 (0.28)	0.002[b]
Fat (g/min)	0.16 (0.10)	0.15 (0.06)	0.14 (0.08)	0.82
VO_2max (%)	49 (8)	49 (14)	60 (15)	0.19

[a] I *vs.* III, $P = 0.17$; II *vs.* III, $P = 0.035$.
[b] I *vs.* III, $P = 0.003$; II *vs.* III, $P = 0.012$.

6 km/h	I tertile	II tertile	III tertile	P
EE (kJ/min)	19.6 (4.6)	19.2 (6.7)	26.8 (3.8)	0.013[a]
EE/BW (kJ/min·kg)	0.44 (0.08)	0.38 (0.26)	0.37 (0.04)	0.44
EE/FFM (kJ/min·kg)	0.60 (0.14)	0.64 (0.25)	0.65 (0.07)	0.84
HR (beats/min)	159 (18)	142 (26)	153 (16)	0.29
RQ	0.88 (0.07)	0.89 (0.05)	0.93 (0.04)	0.21
Carbohydrates (g/min)	0.65 (0.28)	0.76 (0.40)	1.24 (0.35)	0.007[b]
Fat (g/min)	0.17 (0.14)	0.11 (0.06)	0.09 (0.07)	0.28
VO_2max (%)	61 (11)	56 (14)	68 (13)	0.20

[a] I *vs.* III, $P = 0.030$; II *vs.* III, $P = 0.021$.
[b] I *vs.* III, $P = 0.008$; II *vs.* III, $P = 0.030$.

0.05) association between adiposity (percent FM) and the fat to carbohydrate oxidation rate (RQ) during walking at 4, 5, and 6 km/h ($r = 0.37$, $r = 0.37$, and $r = 0.36$, respectively), adjusting for exercise intensity (percent VO_2max). Therefore, at similar exercise intensities, the greater the adiposity of the body, the higher the energy expenditure and the proportion of carbohydrate in the fuel mix that oxidized during walking.

Discussion

Obesity is associated with an impaired utilization of fat as a fuel. In Pima Indians, low rates of fat oxidation have been associated with accelerated weight gain (15). In Caucasians, low fat oxidation has been associated with weight regain in postobese women (16). Moreover, the skeletal muscles of obese individuals are impaired to use plasma free fatty acids in postabsorptive conditions and β-adrenergic stimulation (17, 18). Finally, free fatty acid utilization is impaired in obese subjects after weight loss, which suggests that the defects could be related primarily to the obese state (19). Based on the above-reported evidence, the effect on fat utilization is one of the factors that justifies the importance of exercise for the obese. Exercise has been shown to stimulate fat oxidation in both postabsorptive conditions and during exercise (or catecholamine) stimulation in lean subjects (20, 21). Similar effects may occur in obese subjects; exercise may be able to compensate for the impaired ability to oxidize fat, thereby promoting a negative fat balance and weight reduction in obese subjects and the maintenance of fat balance and body weight in obesity-reduced subjects. A recent preliminary study of obese adolescents reported that an individualized exercise program (plus diet) performed at an intensity corresponding to maximal lipid oxidation was able to increase the ability to oxidize lipids during exercise (22). Similar results were obtained in studies of obese adults (5).

To our knowledge, ours is the first study to measure nutrient oxidation rates during moderately intense exercise in obese prepubertal children, specifically boys. The most interesting finding of our study was that the carbohydrate oxidation rate increased with the workload (speed of walking as well as percent VO_2max) and level of overweight, whereas fat oxidation was not changed significantly by increasing the workload or the level of overweight. This find-

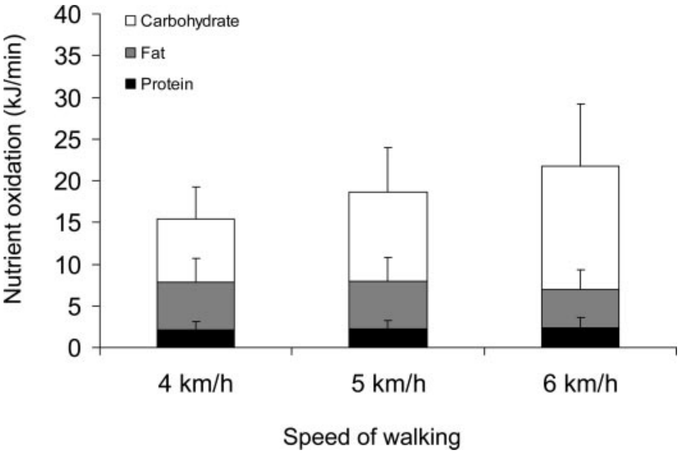

FIG. 2. Nutrient oxidation (protein, carbohydrate, and fat), expressed as kilojoules per minute, measured during walking at speeds of 4, 5, and 6 km/h, respectively.

ing may be important for the treatment of obesity. Indeed, it seems more reasonable to prescribe and encourage low intensity exercise, which is more feasible and acceptable to obese children, than to insist on more intense exercises that do not have any advantage in terms of fat oxidation. Walking at a speed of 6 km/h is not comfortable for an obese youngster, and it is unlikely that he/she could maintain that speed for long. On the contrary, the moderate speed of 4 km/h is quite acceptable and, theoretically, would facilitate the duration of the exercise. Moreover, less intense exercise is unlikely to be followed by compensatory sedentary behavior, as would be the case for more strenuous exercise.

On the basis of our results, we estimate that a boy with a body weight of 70 kg, a BMI of 29 kg/m^2, and an SDS of BMI of 4.6 who walks for 40 min at the speed of 4 km/h burns approximately 600 kJ. Fat oxidation during this amount of exercise is about 6 g, whereas carbohydrate oxidation is approximately 18 g. To exert the same amount of energy, this boy would have to walk at a speed of 6 km/h for 27.5 min. During this more intense exercise, fat oxidation is approximately 3.2 g, and carbohydrate oxidation about 24 g. Therefore, when walking at 6 km/h, the boy oxidizes more carbohydrate (+33%) and less fat (−47%). Therefore, in terms of fat balance, more intense exercise is less favorable than less intense exercise. Moreover, higher carbohydrate oxidation could contribute to earlier exhaustion, increased appetite, and compensatory food consumption.

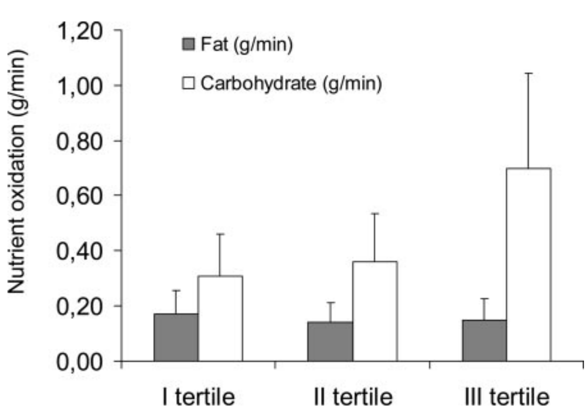

FIG. 3. Fat and carbohydrate oxidation, expressed as grams per minute, measured in boys with different grades of overweight while walking at 4 km/h.

The maximal fat oxidation rate was found at a moderate walking speed (4 km/h), which corresponds to an exercise intensity of about 50% VO_2max. This value is similar to that reported in animals (23) and sedentary obese adults (24, 25). Steffen *et al.* (24) found a higher absolute fat oxidation rate at 50% than at 75% VO_2max. Deriaz *et al.* (25) found the maximal fat oxidation rate in obese men to be 42% VO_2max during a treadmill exercise. Endurance training has been shown to increase the capacity to oxidize fatty acids (3, 26). However, most studies that investigated the effect of endurance training on the capacity to oxidize fat have implicated high intensity exercise (>60%VO_2max) for many hours per week, but these training programs are not easily compatible with the daily lives of most people. Comparisons between very intense and low intensity exercise programs for obese children have shown that compliance with the programs was much higher in the latter than in the former case (27). Recent results of a study of nonobese sedentary men showed that a low intensity (40% VO_2max) endurance training program (12 wk) was effective in increasing fat oxidation during exercise (26). The results of our study also contribute to support the rationale of promoting low intensity exercise that is easily incorporated into daily life activities, such as walking at a moderate speed, as an effective way to treat obesity in children.

In conclusion, moderately intense exercise promotes higher fat oxidation rates, expressed as a percentage of total energy expenditure, than more strenuous exercise. Walking at a speed of 4 km/h is a feasible exercise, and we recommend that it be used in the treatment of childhood obesity.

Acknowledgments

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