Energy Expenditure in Low Active Overweight and Obese Children at Varying Treadmill Grades

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Abstract

This study aimed to evaluate differences between low active overweight and obese children in terms of energy expenditure (EE), ventilation (VE), and cardiac response during graded submaximal treadmill testing at constant speed. We categorized 20 children into two weight groups according to the International Obesity Task Force criteria: overweight (n=10; age=9.7 ±1.34 years) and obese (n=10; age=10.4±1.4 years). Children performed treadmill testing at a constant speed (1.53 $m \cdot s^{-1}$) and increasing grade (0%, 4%, and 8%). every 3 min. The EE across all grades was significantly higher ($p<0.001$) in obese than in overweight children. Differences at each grade disappeared when EE was adjusted by body mass; however, several differences remained when the EE was adjusted by fat-free mass or body surface area. The increase in EE with increasing grade was greater in obese children (effect size between 0% and 8% for EE was 1.17). BMI z-score and fat mass (kg) were the main predictors of EE ($Kcal \cdot min^{-1}$) and contributed to explaining 66%, 70% and 83.4% of the variance in EE at 0%, 4% and 8% gradients respectively. We suggest that when assessing EE response to exercise, the degree of obesity should be taken into consideration.

Keywords: Obese, overweight, treatmil test, children, energy expenditure, ventilation

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Introduccion

Research suggests that obesity has become the most prevalent disease in developed countries (38) and that its prevalence continues to rise. Obesity is a chronic disease associated with a significant negative impact on health and quality of life. In general, childhood obesity is associated with a greater risk of obesity in adulthood (36), and with the development of weight-related comorbidity and increased mortality (19). These conditions can be counteracted with regular exercise (20). Indeed, the World Health Organization (WHO) (37) states that there is strong evidence to support regular physical activity as an important modifying factor for obesity-related increased mortality and morbidity.

According to Ravussin and Gautier (26), although the etiology of obesity is complex, the most important factor in childhood is the long-term imbalance between energy intake and energy expenditure (EE). Therefore, the amount of energy expended in physical activity plays a significant role in both the prevention of weight gain and the process of weight reduction (25). A shift in behaviour towards a sedentary lifestyle and decreased physical activity is central to the development of childhood obesity (8, 33). Compared with their normal weight peers, obese children spend less time engaged in moderate physical activity during the day such as walking, and more time in sedentary behaviors (12). An increase in EE through physical activity can lead to a negative energy balance, thus enabling a loss of body mass. Aerobic exercise is a key factor in weight reduction and is widely used to control childhood obesity (21).

Body mass and body composition are major predictors of EE, particularly in weight bearing activities such as walking or running (39). According to Zakeri et al. (39) the relationship between EE and body mass cannot be fully explained by a linear model. They observed that at low levels of exertion (i.e., walking), accounting for body composition did not eliminate the interaction of EE with body mass status. They also noted that, in overweight children, the contribution of body mass to EE was greater than in normal weight children. However, most studies focus on the comparison of EE between obese and lean or normal weight children (25, 35). To our knowledge, few studies have investigated EE at different submaximal aerobic exercise intensities while taking into account the degree of obesity (overweight versus obese) (10). In obese adolescents, even a small weight reduction increases walking economy (i.e., a reduction in EE at different walking speeds) (22). The lack of consistent EE in obese children may be partly explained by the lack of control over factors such as the degree of obesity (1).

It has also been reported that obese children have greater difficulties adapting to physical exercise in absolute terms. This is reflected in higher ventilation parameters (16, 30) and heart rates than in their non-obese peers during exercise of equal intensity. Several studies have also shown that obese children are less fit than their normal weight peers, regardless of sex (5, 9). This difference is probably due to their extra fat mass and the resulting increase in load, thereby preventing physical activity.

Knowing the EE for physical activity according to weight will allow a better estimation of daily EE, thereby facilitating the development of more accurate recommendations for caloric ingestion. In addition, it will help physical activity instructors to design workouts adapted to planned EE goals. EE data have been established for physical activity in adults, but only minimal data are available for children; what is more, most of these data were obtained from normal weight children (28). EE has been evaluated in obese youngsters while performing different physical exercise activities, including walking outdoors at 4-5 $km \cdot h^{-1}$ (34), but neither the effect of a vertical component (grade) nor the impact of the degree of adiposity on walking EE have been examined.

The present study aimed to assess the differences in EE, pulmonary response, and cardiac response between overweight and obese children with low levels of activity. The research comprised submaximal treadmill testing at constant speed and different inclines. Differences at each treadmill inclination were considered in terms of both the absolute values and the values relative to body mass.

Methods

This is a cross-sectional study where overweight and obese children with low levels of activity performed a walking treadmill test at a constant speed with increasing grades.

Participants

Twenty white European children (mean age 10.1 ± 1.4 years; overweight, n = 10; obese, n = 10) from the Paediatric Health Services took part in the study. Participants were aged between 8 and 12 and were overweight or obese. Overweight and obese groups were determined according to the body mass index (BMI) standard deviation (SD) score (the BMI z-score) following the LMS method (22) based on the International Obesity Task Force (IOTF) criteria defined by Cole et al (3). Children were also required to report low levels of activity (less than 3 hours per week of physical activity outside school hours), as established in the questionnaire by Serra-Majem and Aranceta (32), which is specific for Spanish children between the ages of 4 and 14 years. Patients with comorbidities or diseases that contraindicated physical exertion, patients with obesity related to endocrine or genetic disease, comorbid cardiac or neurological disorders, and those receiving any medication that could interfere with physical performance were excluded.

Prior to definitive inclusion, the children and their families were informed about the nature of the study, and written informed consent was obtained from the parents. The hospital ethics committee and institutional review board approved the study and procedures.

Procedure and Instruments

The treadmill test was performed at a constant speed of 1.53 $m \cdot s^{-1}$ (5.5 $km \cdot h^{-1}$) with an increasing incline. The grade increased every 3 minutes and was established at 0%, 4%, and 8% inclines. The test was initiated after a standardized period of habituation to the treadmill and a warm-up of 3 minutes. The speed and these grades were chosen because they represent moderate to vigorous intensity for the majority of children and, in theory, they were achievable for participants with low levels of activity.

During the test, the heart rate was measured using a chest heart rate monitor (Polar 610s; Polar electro YO, Kempele, Finland). The oxygen uptake (VO_2), carbon dioxide output (VCO_2), respiratory exchange ratio (RER), and ventilation (VE) were measured by means of breath-by-breath gas exchange using an indirect calorimetry system (VO2000; Medical Graphics Corporation, St. Paul's, Minnesota); the mean values from the last 30 seconds of each stage were used for the analysis. The VO2000 has demonstrated reliability and validity during rest periods and sub-maximal exercise intensities (4). For further analysis, the EE and its ventilatory equivalents were calculated. The EE was calculated using the following equation (29): EE (kcal·min^{-1}) = VO_2 (L·min^{-1}) × (RER × 1.232 + 3.815). The ventilatory equivalents were calculated from the relationship between the VE and VO_2 (VE/VO_2) and the VE and VCO_2 (VE/VCO_2). The tests were conducted by the same researchers under identical conditions for each child. Before each test, the gas analyzers were calibrated using gases of known concentration, while the flow meter was calibrated using a 3 L syringe. Body mass was measured with a weighing scale (Seca model 755, Hamburg, Germany; accuracy 0.05 g) and height was measured with a stadiometer (Añó Sayol, Barcelona, Spain). Participants were lightly dressed and barefoot. The body surface area (BSA) was calculated using the Gehan and George formula (7): BSA (m^2) = 0.02350 × Ht$^{0.42246}$ × Wt$^{0.51456}$, where Ht is height (cm) and Wt is weight (kg). Waist circumference was measured following the International Society for the Advancement of Kinanthropometry protocol (15). Body composition was estimated by multichannel bioelectrical impedance analysis (BIA); total body resistance and reactance were measured with a multisegmental and multifrequency bioelectrical impedance analyzer (Promis Body Composition; Promis Corp, Puerto de Santa Maria, Spain), where fat free mass (FFM) and fat mass (FM) are calculated using the Cole–Cole equation (2). The BIA has been shown to be valid and reliable for the assessment of body composition in children (11). Blood pressure was recorded on the right arm in the recumbent position using an automated digital sphygmomanometer. The children had rested for 5 minutes before measurement.

Participants were referred to the Functional Assessment Laboratory between 6:00 pm and 7:00 pm for their anthropometric assessment and for the subsequent exercise tests. They had been instructed to attend without having eaten during the previous four hours, and without having drunk or performed any physical exertion during the previous two hours. All participants confirmed their adherence to these requirements.

Statistical Analysis

The outcome variables EE and VE were expressed in both absolute values (Kcal·min-1; L·min-1) and values relative to body mass (Kcal·kg·min^{-1}; mL·kg·min^{-1}), fat free mass (Kcal·kgFFM^{-1}·min^{-1}; mL·kgFFM·min^{-1}), and body surface area (Kcal·min^{-1}·m^{-2}; mL·min-1·m^{-2}). Descriptive data are presented as mean and SD. An independent sample *t*-test was used to examine the differences between overweight and obese children in anthropometric and exercise test variables.

Stability of VO_2 during the last 30 s of each stage was evaluated by subjective assessment of the graphic representation of VO_2 (ml·min^{-1}) versus time during the treadmill test and by the coefficient of variation (CV) analysis of the data obtained during the last minute of the 8% gradient. To evaluate the interactions between the overweight and obese groups and the differences across intensity grades, we performed a mixed effects model with the random effects as the grades (0%, 4% and 8%) and the fixed effect as the adiposity group (overweight versus obese). Changes in outcome variables between different treadmill grades (0% versus 8%) were tested using the *t*-test for paired samples. Pearson correlations and linear regression models were used to test the relationships between parameters across the varying grades. The normality of residual distribution was checked using the Kolmogorov–Smirnov test. A p-value < 0.05 was considered significant. Data analysis was performed using SPSS statistical software (version 17.0, SPSS Institute Inc, Chicago, Illinois).

Results

The participant characteristics are shown in Table 1. The overweight group comprised 5 boys and 5 girls, and the obese group comprised 6 boys and 4 girls; the groups did not differ in mean age, sex distribution, and resting heart rate. Height and resting systolic and diastolic blood pressures were significantly higher in the obese group. As expected, all adiposity parameters were also significantly greater in the obese group. The FM/FFM ratio indicated that obese children carried 240 ± 83 g of extra FM per kg of FFM in comparison to the overweight children, but the difference was not statistically significant (p = 0.8).

Table 1. Anthropometric characteristics of participants.

Variable	Overweight (n=10) Mean ± SD	Obese (n=10) Mean ± SD	Group effect p-value
Age (years)	9.7±1.3	10.4±1.4	0.273
Height (cm)	142.1±7.9	152.9±7.7	0.006
Body mass (kg)	44.3±8.1	67.1±9.9	<0.001
BMI (kg/m^2)	21.8±1.7	28.5±2.3	na
BMI z-score (Units)	1.76±0.35	2.81±0.33	na
Waist Circumference (cm)	74.5±15.7	96.0±7.9	<0.001
FM (kg)[a]	14.2±5.5	27.6±7.9	<0.001
FFM (kg) [a]	31.1±3.9	39.6±4.2	<0.001
Body Fat (%)[a]	30.6±7.8	40.4±6.8	0.006
Central Fat (%)[a]	31.0±9.5	46.6±4.5	<0.001
BSA (m^2)	1.49±0.16	1.84±0.16	<0.001
HR rest (bpm)[a]	71±10.3	75±9.52	0.440
SBP rest (mmHg)	99.6±11.8	114.4±8.1	0.004
DBP rest (mmHg)	57.9±4.7	71.8±4.9	<0.001

SD (Standard Deviation) – BMI (Body Mass Index) – FM (Fat Mass) – FFM (Free Fat Mass) – BSA (Body surface area) **-** HR (Heart Rate) – SBP and DBP (Systolic and Diastolic Blood pressure).
na (Not applicable)
[a] n=9, in the overweight group

Stability of VO_2 was confirmed by visual inspection and the CV analysis (mean CV 3.0% ± 5.4%). Furthermore, the variability was lower than the differences noted between gradients (19% between the 4% and 8% gradients for absolute VO_2) or between adiposity groups (52% between overweight and obese groups for VO_2 at the 8% gradient) (Table 2).

Absolute VO_2, EE, and VE values were significantly higher in obese than in overweight children at each grade. Additionally, obese children had significantly higher HR levels at the 0% and 4% gradients, but not at 8%. In contrast, when RER and ventilatory equivalents were assessed, no differences were observed between groups (Table 2).

The EE relative to body mass ($Kcal \cdot kg^{-1} \cdot min^{-1}$) did not differ between obese and overweight children at any grade (Table 2). However, despite adjustment of the EE by FFM ($Kcal \cdot kg^{-1} FFM \cdot min^{-1}$) and BSA ($Kcal \cdot min^{-1} \cdot m^{-2}$), differences were still observed between obese and overweight children at each grade (Table 2). In contrast, when VE was normalized for total body mass ($ml \cdot kg^{-1} \cdot min^{-1}$), FFM ($ml \cdot kg^{-1} FFM \cdot min^{-1}$), or BSA ($ml \cdot min^{-1} \cdot m^{-2}$), differences between groups were only significant for VE/FFM and VE/BSA at the 8% grade, as shown in Table 2.

Table 2. Physiological and cardiorespiratory variables in children during treadmill testing.

Variable/Grade	Overweight (n=10)	Obese (n=10)	Group effect P value [a]	Grade x Adiposity P value [b]
	Mean ± SD	Mean ± SD		
VO_2 ($ml \cdot min^{-1}$)				
0 %	690±171	1110±161	<0.001	
4 %	877±157	1340±173	<0.001	<0.033
8 %	1049±183	1601±188	<0.001	
RER				
0%	0.81±0.06	0.80±0.10	0.756	
4%	0.86±0.06	0.86±0.07	0.896	0.710
8%	0.9±0.06	0.90±0.05	1	
EE ($Kcal \cdot min^{-1}$)				
0 %	3.32±0.80	5.33±0.77	<0.001	
4 %	4.28±0.76	6.54±0.88	<0.001	0.019
8 %	5.16±0.86	7.89±0.95	<0.001	
EE/kg ($Kcal \cdot kg^{-1} \cdot min^{-1}$)				
0 %	0.07±0.02	0.08±0.01	0.442	
4 %	0.1±0.01	0.1±0.01	0.791	0.709
8 %	0.12±0.01	0.12±0.01	0.504	
EE/FFM ($Kcal \cdot kgFFM^{-1} \cdot min^{-1}$)				
0 %	0.11±0.02	0.13±0.02	0.027	
4 %	0.14±0.02	0.17±0.03	0.045	0.292
8 %	0.17±0.02	0.20±0.02	0.008	

EE/BSA (Kcal·min^{-1}·m^{-2})				
0 %	2.23±0.55	2.89±0.39	0.006	
4 %	2.86±0.37	3.56±0.51	0.002	0.941
8 %	3.46±0.40	4.28±0.35	<0.001	
VE (L·min^{-1})				
0%	16.31±3.84	24.16±5.20	<0.001	
4 %	21.82±4.04	31.36±6.52	<0.001	0.968
8 %	26.43±4.25	39.35±6.33	<0.001	
VE/kg (L· kg^{-1}·min^{-1})				
0 %	0.37±0.09	0.36±0.08	0.834	
4 %	0.5±0.09	0.47±0.10	0.571	0.807
8 %	0.6±0.07	0.59±0.72	0.709	
VE/FFM (ml·kgFFM^{-1}·min^{-1})				
0 %	0.57±0.08	0.62±0.14	0.300	
4 %	0.74±0.14	0.80±0.19	0.438	0.172
8 %	0.86±0.10	1±0.17	0.051	
VE/BSA (ml·min^{-1}·m^{-2})				
0 %	10.96±2.54	13.12±2.69	0.081	
4 %	14.65±2.50	17.02±3.29	0.086	0.882
8 %	17.71±1.97	21.30±2.54	0.002	
VE/VO$_2$				
0%	23.76±1.62	21.69±3.07	0.075	
4%	24.99±3.21	23.28±2.77	0.220	0.258
8%	25.35±2.20	24.52±1.83	0.371	
VE/VCO$_2$				
0%	27.90±4.36	27.23±2.40	0.676	
4%	28.01±2.36	26.93±2.30	0.313	0.636
8%	28.07±1.37	27.16±1.81	0.220	
HR (beats/min)				
0 %	119±10.15	131±9.90	0.017	
4 %	124±11.02	145±13.92	0.002	0.009
8 %	152±17.61	161±10.37	0.160	

[a] P value Significance by Independent T-Student Sample

[b] P value Significance by mixed effects model analysis of the main effects of grade and adiposity groups.

SD (Standard Deviation) - HR (heart rate) - VO$_2$ (oxygen consumption) - FFM (Free Fat Mass) - BSA (Body surface area) - VE (ventilation) – EE (energy expenditure) – RER (respiratory exchange ratio), VE/VO$_2$ and VE/VCO$_2$ (ventilatory equivalents for VO$_2$ and VCO$_2$, respectively).

As expected, nearly all outcome variables increased significantly in both groups as the treadmill grade increased (Table 2). The increases in absolute VO$_2$, EE and HR differed between overweight and obese children as shown by the significance of the interaction between the grade effect and adiposity effect (Table 2). This increase was more pronounced in obese children with a relatively large effect size, in particular for EE and VE (Table 3).

Conversely, when EE and VE were adjusted by body mass, FFM, or BSA the increase with increasing grade did not differ between the obese and overweight groups, as suggested by the lack of interaction between the grade effect and the adiposity effect (Table 2), as well as by the non-significant effect size (Table 3). For ventilatory equivalents and HR, the magnitude of increase was also similar in the two groups, as shown in Table 3.

Table 3. Changes in energy expenditure and cardiorespiratory variables across the grades for overweigh and obese children.

Difference between 0% and 8%	Overweight (n=10) Mean ± SD	Obese (n=10) Mean ± SD	Effect size[a]	P value[b] Group effect
VO2 (ml·min^{-1})	358.91±151.03	491.90±100.96	1.06	0.033
EE (Kcal·min^{-1})	1.9±0.73	2.56±0.51	1.17	0.019
EE/kg (Kcal·kg^{-1}·min^{-1})	0.04±0.01	0.04±0.007	-0.18	0.709
EE/FFM (Kcal·kgFFM^{-1}·min^{-1})	0.06±0.02	0.06±0.01	0.50	0.292
EE/BSA (Kcal·min^{-1}·m^{-2})	1.22±0.43	1.38±0.21	0.50	0.304
VE (L·min^{-1})	10.1±3.74	15.19±3.66	1.37	0.007
VE/kg (L· kg^{-1}·min^{-1})	0.23±0.09	0.22±0.0.39	-0.07	0.891
VE/FFM (ml·kgFFM^{-1}·min^{-1})	0.31±0.10	0.38±0.09	0.84	0.083
VE/BSA (ml·min^{-1}·m^{-2})	6.8±2.39	8.18±1.62	0.71	0.135
VE/VO_2	1.58±2.20	2.80±2.55	0.52	0.258
VE/VCO_2	0.17±4.99	0.07±1.03	-0.03	0.880
HR (beats·min^{-1})	32±20	30±4.5	-0.20	0.704

[a] Standardized effect size was computed as the mean difference between overweight and obese groups divided by the pooled standard deviation. Values 0.2-0.5 represent small changes; 0.5-0.8 moderate changes and >0.8 large changes.

[b] P value by independent T-student test;

SD (Standard Deviation) - HR (heart rate) - VO2 (oxygen consumption) - FFM (Free Fat Mass) - BSA (Body surface area) - VE (ventilation) – EE (energy expenditure) - VE/VO_2 and VE/VCO_2 (ventilatory equivalents for VO2 and VCO2. respectively).

For all children, the increase of EE at each grade was influenced by their degree of obesity, as shown in Figure 1. In general, EE was greater with higher BMI z-scores. This finding was consistent for each grade. However, changes in EE with increases in the BMI z-score appeared to be less prominent at 0% and 4% grades than at 8%. Beta-coefficients for BMI z-score were 1.68, 1.82 and 2.20 at 0%, 4% and 8% treadmill inclines respectively (Figure 1). Nevertheless, the value of BMI z-score as a predictor of EE did not differ substantially across gradients.

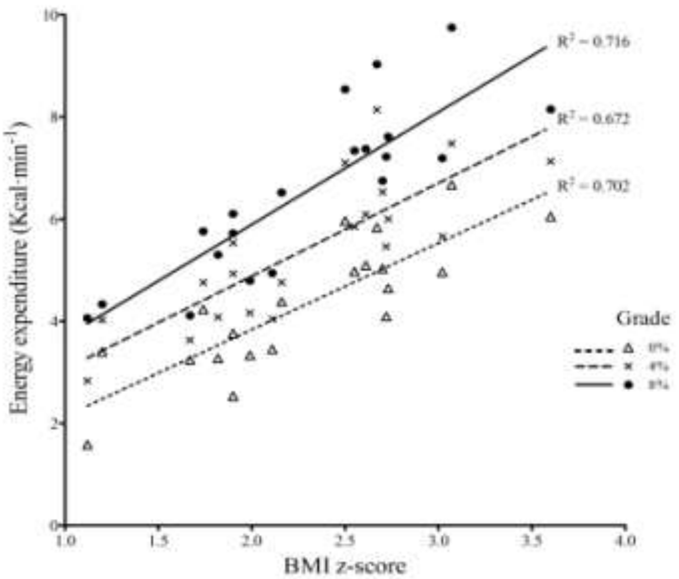

Figure 1. The relationship between EE (Kcal·min^{-1}) and BMI z-score at the three grades.

BMI z-score (Body Mass Index z score) - EE (Energy expenditure)

Beta- coefficients for BMI z-score were 1.69 (IC95%: 1,15 to 2,24); 1.82 (IC95%:1,19 to 2,45); 2.20 (IC95%: 1,52 to 2,89) at 0%, 4% and 8% treadmill grades, respectively.

Multiple regression models confirm the influence of the extra body mass (degree of obesity) on EE (Kcal·min^{-1}). BMI z-score contributed strongly to explaining EE across all gradients; however its contribution fell slightly at 4% and 8% inclines, due to a greater influence of FM. The contribution of the models to explaining the variance in EE (Kcal·min^{-1}) was greater at the 8% incline than at 0%.

Table 4. Multiple regression models that during treadmill testing in overweight and obese children.

Grade (%)	Variables in the model	2	B-Coefficient		
			B-Coefficient	95% CI	P-value
0	**BMI z-score**	,665	1,22	0,41 to 2,04	0,006
	FM (kg)		0,03	-0,02 to 0,08	0,236
4	**BMI z-score**	,705	1,08	0,21 to 1,96	0,019
	FM (kg)		0,06	0,005 to 0,11	0,034
8	**BMI z-score**	,834	1,23	0,43 to 2,02	0,005
	FM (kg)		0,09	0,04 to 0,13	0,001

BMI z-score (Body Mass Index z score) - FM (Fat Mass) - FFM (Free Fat Mass)

CI (confidence interval)

Discussion

This study demonstrates that EE, VE, and HR increased significantly in both overweight and obese children with increasing treadmill gradients, and that EE and VE were significantly higher in obese children than overweight children at each grade. These differences declined (or disappeared) when the respective variables were adjusted for total body mass. However, several differences persisted between overweight and obese children when these variables were adjusted for FFM and BSA.

This study is the first to compare the physiological responses of overweight and obese children during treadmill walking at different grades. Importantly, it demonstrates that both groups differed in their response to low and vigorous intensity exercise, which is consistent with our understanding of the difference between obese and normal-weight children in other locomotion activities (1, 14, 16, 25). To our knowledge, only one study (10) has considered overweight and obese children separately during a cycling exercise. Even though cycling is not a weight-bearing activity, obese children presented greater VO_2 and EE in absolute terms than overweight children. Jabbour et al (10) attributed this supplementary energy cost to the greater VO_2 and EE recorded at rest in obese children rather than to differences in the energy cost of the activity.

Data from the present study indicate that the greater the excess body mass (BMI z-score), the higher the EE, which is consistent with previous studies (1, 12, 14, 25, 35). Results also suggest that fat mass (kg) has a greater impact on EE with increasing workload. To a certain extent, our results support those of Volpe Ayub and Bar-Or (35), who reported that weight was the main determinant of EE at each intensity, but that when adjusting EE to body mass, the EE was similar between groups. This finding has already been reported by other researchers when comparing obese and non-obese children (14, 35), but is at odds with the results of Peyrot et al. (25), who found that differences between obese and non-obese children persisted at different walking speeds. Those authors attributed the higher metabolic cost observed in obese participants to mechanical parameters such as the need for isometric muscular contraction in order to maintain balance during walking (24). Moreover, it should be borne in mind that fat mass does not participate in the transfer of energy to movement during exercise, but represents an extra burden; therefore, when expressing EE in relation to FFM, obese children again present higher energy costs than overweight children.

In addition, EE at each grade was greater in obese children even when adjusted to BSA, which reflects weight and height factors. The question remains: Why is there a difference between groups across each grade? Although obese children might be expected to expend more energy because of their greater height, being taller should also be associated with a longer, more efficient, stride length. However, higher EE could be caused by the greater circumference of the thigh (25), which causes chafing between the thighs with each stride, or because obese children are biomechanically less efficient in transferring energy through to their hips (27).

Increases in adiposity may also induce changes in the cardiopulmonary response to exercise. As already mentioned, body fat constitutes an additional load during activity, particularly during weight-bearing activities. Obesity has also been reported to impair ventilatory function by reducing pulmonary compliance and increasing the cost of breathing due to the extrinsic compression of the fat mass on the chest wall (23).

VE increased significantly with the exercise load in both groups. Nevertheless, obese children at each grade had significantly greater ventilation values than their overweight peers. The pattern of increase in these values along the treadmill test was also significantly steeper in the obese group. This may suggest that obese children are more burdened by their excess mass than overweight children, a finding that would corroborate previous reports (17, 35) comparing obese children with their normal weight peers during treadmill tests at different intensities (speed/grade). Nonetheless, Marinov (16) also observed that the influence of adiposity diminishes when the VE is adjusted by body mass, FFM, or BSA at moderate loads, but persists for vigorous exercise loads. This may be the consequence of a greater VE cost, as Volpe and Bar-Or suggest (35).

The ventilatory equivalents for oxygen and carbon dioxide, as indicators of ventilatory efficiency, were not altered by the elevation gradient of the test or by the extra fat mass of obese children. This may reflect the fact that during moderate–vigorous submaximal walking, both overweight and obese children compensate for the additional metabolic requirements during exercise (O_2 uptake and CO_2 output) regardless of the degree of adiposity. These results are consistent with previous studies showing that obese children and adolescents have similar ventilatory equivalents (VE/VO_2, VE/VCO_2) to leaner peers when performing maximal (16), or submaximal treadmill walking tests at different intensities (speed/grade) (17). However, Prado et al. (23) reported that ventilatory efficiency at the ventilatory threshold load (VE/VCO_2 at VT) was lower in obese children.

As expected, HR increased between the grades of the test. At lower inclines, overweight children had lower HRs than obese children, possibly reflecting the effect of extra fat mass. However, as reported by Rowland (30), it could reflect an association in which moderate adiposity increases cardiac functional capacity, while morbid obesity lowers cardiovascular fitness. Higher HRs are also reported in obese children compared with lean children during submaximal treadmill tests (35, 17). In this study, vigorous exercise resulted in similar elevations in HR in the two groups.

Several potential limitations of this study deserve attention. First, normal developmental differences may have influenced the outcomes, and the degree of maturity should have been recorded. In future studies we recommend examining and adjusting for pubertal stage and anthropometric measurements, such as waist-size index. Second, all comparisons were made at absolute levels of exercise; for safety reasons, peak values were not obtained. We established that the exercise testing should be submaximal because only overweight and obese children with low levels of activity were enrolled. Therefore, it was not possible to analyse data relative to maximal exertion levels. Nonetheless, the lack of maximal data does not preclude the study of EE at different absolute testing intensities (grades) in relation to the degree of adiposity. Third, because ventilation parameters were below the range of detection of the flow pneumotach used, VO_2 could not be recorded at rest in the majority of participants. Consequently, we were unable to calculate the net VO_2 during exertion (VO_2 of the stage minus VO_2 at rest), or the ensuing net EE parameters. For this reason, it is not possible to attribute the differences observed in EE between the obese and overweight groups to a deficient mechanical transference of energy during walking, because we cannot rule out the possibility that their energy consumption at rest was dissimilar. As reported by Jabbour (10) recently, obese children consume more energy at rest than their overweight and normal weight peers, even though they do not differ in the net mechanical efficiency during cycling. Another concern that should be mentioned is that BIA values are affected by several variables, including age, sex, level of body fat and fluid (6). Although standardized guidelines were followed, no specific measurements for body water balance were performed and we assumed that all the children presented a dynamic hypohydrated-euhydrated state. BIA prediction equations have been developed for children (13). However, both children (18) and adults (31) showed dissimilar results in BIA. The criteria used (dual-energy X-ray absorptiometry) reported increasing levels of fat. Thus, data derived from BIA (FFM and FM) should be interpreted with caution.

Finally, the small sample size may have affected the statistical power of several parameters and the error estimation of the variables. For this reason, we should be cautious when extrapolating the data. However, this caveat does not apply to our main hypothesis.

Conclusion

The study shows that overweight and obese children have different physiological adaptations to exercise. Indeed, for the same absolute effort, the EE, VE, and HR demands increased with the degree of obesity. Although extra body mass, as well as fat mass (kg), appear to have an important influence on the increase in EE, other variables, such as thigh thickness, may also contribute to the increase. Further research is necessary and should consider other contributing factors such as the kinetic or kinematic aspects of walking. In addition, differences in EE and VE persisted between overweight and obese children when the variables were adjusted to FFM or BSA, which may reflect a greater cost of physical activity due to the excess fat mass and its impact on walking balance. However, ventilatory efficiency was not affected by the degree of adiposity. In future studies, we propose that the degree of obesity should be considered when assessing either the EE or the ventilatory response to exercise. For this reason, overweight and obese children should be considered separately.

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