

Research article

Physical activity patterns and estimated daily energy expenditures in normal and overweight Tunisian schoolchildren

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Abstract

Our aim was to test the normality of physical activity patterns and energy expenditures in normal weight and overweight primary school students. Heart rate estimates of total daily energy expenditure (TEE), active energy expenditure (AEE), and activity patterns were made over 3 consecutive school days in healthy middle-class Tunisian children (46 boys, 44 girls, median age (25th-75th) percentile, 9.2 (8.8-9.9) years. Our cross-section included 52 students with a normal body mass index (BMI) and 38 who exceeded age-specific BMI limits. TEE, AEE and overall physical activity level (PAL) were not different between overweight children and those with a normal BMI [median values (25th-75th) 9.20 (8.20-9.84) vs. 8.88 (7.42-9.76) MJ/d; 3.56 (2.59-4.22) vs. 3.85 (2.77-4.78) MJ/d and 1.74 (1.54-2.04) vs. 1.89 (1.66-2.15) respectively]. Physical activity intensities (PAI) were expressed as percentages of the individual's heart rate reserve (%HRR). The median PAI for the entire day (PAI₂₄) and for the waking part of day (PAI_w) were lower in overweight than in normal weight individuals [16.3 (14.2-18.9) vs. 20.6 (17.9-22.3) %HRR, $p < 0.001$] and 24.8 (21.6-28.9) vs. 26.2 (24.5-30.8) %HRR, $p < 0.01$], respectively. Overweight children allocated more of their day to sedentary pursuits [385 (336-468) vs 297 (235-468) min/d, $p < 0.001$], and less time to moderate physical activity [381(321-457) vs. 460 (380-534) min/d, $p < 0.01$]. Nevertheless, because of the greater energy cost of a given task, total and active daily energy expenditure did not differ from those with a normal BMI.

Key words: Heart rate monitoring, activity patterns, energy expenditure, excess weight, obesity..

Introduction

In most industrialized countries the prevalence of obesity is increasing rapidly (Saris et al., 2003). However, pediatric obesity is less well recognized as one of the fastest growing epidemics among the wealthier urban segments of many developing nations (Gaha et al., 2002). There is considerable controversy concerning possible differences of daily energy expenditure between overweight and normal children. However, both cross-sectional and longitudinal studies generally support the hypothesis that an inadequate amount of physical activity is an independent risk factor for the accumulation of body fat (Maffeis et al., 1995; Saris et al., 2003). A greater understanding of physical activity patterns and energy expenditures in normal and overweight children may thus help efforts to

reduce the prevalence of childhood obesity both in the developed and in the developing world (Molnar and Livingstone, 2000; Peterson et al., 2006, Shephard 2004).

Most studies of childhood physical activities are based on questionnaires, pedometer or accelerometer data (Oppert, 2006, Sallis and Saelens, 2000; Westerterp and Plasqui 2004). However, no one methodology is best for all situations (Welk et al., 2000). Questionnaire data have limited validity in children, particularly in a cross-cultural context, since the test instrument must reflect local language and customs. Accelerometers are frequently used in children (Rowlands, 2007) and can be applied to large samples (Ness et al. 2007). Heart rate (HR) and motion sensors are also promising tools, as each can estimate the time spent at various intensities of activity (Rowlands, 2007; Gavarry et al., 2003) and overall energy expenditures (EE) (Strath et al., 2001). Continuous heart rate monitoring has previously been exploited in a number of studies of developed societies (Armstrong et al., 2000; Ceesay et al., 1989; Maffeis et al., 1995; Molnar and Livingstone, 2000). However, it remains unclear whether differences in activity levels of normal weight and overweight children are related to the duration of moderate or of vigorous physical activity (Sallis and Saelens, 2000). Most children only take high-intensity activity in short-lived bursts (Bailey et al., 1995; Rowlands et al., 2008). Such activity thus has little influence on total daily energy expenditures (Westerterp and Plasqui, 2004). Nevertheless, short bouts of high-intensity activity may stimulate overall metabolism, contributing to an appropriate energy balance (Bailey et al., 1995; Hoos et al., 2004; Westerterp and Plasqui, 2004).

We have now used continuous heart rate monitoring to assess the physical activity patterns and energy expenditures in normal and overweight Tunisian primary school children. Our working hypotheses were (1) that children of normal weight would be more active than those who were overweight, but (2) differences in physical activity patterns would lead to similar total energy expenditures in the two groups of children.

Methods

Subject

Our subjects were North African 8-11 year-old children recruited from a primary school in Tunis. They may be

considered typical of middle-income urban students in that country. Tunisian schools are attended between the hours of 8 a.m. and 4 p.m.; thereafter, students are free to engage in activities chosen by themselves or their parents. Signed informed consent was obtained from the children's parents under conditions approved by the committee on the ethics of human research of the Faculty of Sciences, University of Tunis. All potential subjects underwent a medical examination. We excluded 26 children because of acute or chronic illness, medication, or incomplete heart rate monitoring, leaving 46 boys and 44 girls. Overweight individuals were distinguished by appropriate international criteria (Cole et al., 2000) [overweight $\geq 85^{\text{th}}$ percentile of BMI for age and sex]; 24 boys and 28 girls were of normal weight [median BMI, range = 16.5 (15.7 - 18.1)] and 22 boys and 16 girls were overweight [BMI = 21.4 (20.6 - 22.8)], with 3 boys and 4 girls from this group being obese [BMI = 24.3 (23.4 - 27.4)].

Protocol

Simple techniques appropriate to a developing society included anthropometric measurements, and field estimates of resting energy expenditure (REE), total daily energy expenditure (TEE), physical activity level (PAL), physical activity intensities (PAI), and maximal oxygen intake ($\text{VO}_2 \text{ max}$). Data were collected in March, when typical ambient conditions were a temperature of 8-18°C, and a relative humidity of 75 %.

At the first visit to the school, the protocol was explained, consent to participate was obtained, and anthropometric measurements were completed. Following the technique of Armstrong et al. (2000), heart rates (HR) were then monitored continuously over 3 consecutive schooldays (Monday to Wednesday) during the month of March, using the Sport-Tester monitor (Polar Instruments, S610i, Kempele, Finland). HR measurements were averaged every 60 s. Time intervals were verified by keeping an activity notebook throughout the three days. Subjects were visited each morning and evening to check on functioning of the monitors. Recordings with more than 3 cuts of 30 min duration during a day, or cumulative cuts of more than 2 h a night were rejected. Individuals with periods of unusable data recording were among the 26 excluded from our original sample. Data were analyzed using "Polar Precision Performance software" (3.03.011 version, Electro Oy, Kempele, Finland). We accepted as the resting heart rate (RHR) 10 minutes of stable readings taken while the individual was sleeping. Maximal oxygen intake ($\text{VO}_2 \text{ max}$) and maximal heart rate (MHR) were estimated using a children's multistage 20 metre shuttle-run (Léger et al., 1984). The run was halted when the subject could no longer maintain the required velocity, and tests were rejected if the HRmax did not reach the criteria proposed by Rowland (1993).

Physical characteristics and body composition

Body mass was measured to the nearest 0.1 kg, using a portable digito-metric scale, calibrated by standard weights. Standing height was measured to the nearest 5 mm, using a wall-mounted height board. The body mass

index (BMI) was then calculated as body mass / height² ($\text{kg}\cdot\text{m}^{-2}$). The fat-free mass (FFM), fat mass (FM) and percentage of body fat (BF %), were derived from measurements by a 50 Hz bio-impedance system (BIA 101; RJL Systems, Detroit, MI), without specific control of hydration. Total body water (TBW) was calculated as:

$$\text{TBW} = (a * \text{Ht}^2) / Z + b * M + c$$

where *Ht* and *M* are height and body mass respectively, *Z* is the electrical impedance, *a* and *c* are age and sex-related constants. The manufacturers claim a standard error of about 4% for this equation.

Estimations of energy expenditure and physical activity patterns

The resting energy expenditure (REE) was estimated from body mass, height, age and sex according to Molnar's equations (1995) for both obese and non-obese children:

REE for boys = 50.9 body mass (kg) + 2530 Height (m) - 50.3 Age (yr) + 26.9 (kJ/24 hr) and REE for girls = 51.2 body mass (kg) + 2450 Height (m) - 207.5 Age (yr) + 1629.8 (kJ/24 hr).

The total daily energy expenditure (TEE) was estimated from continuous heart rate (HR) measurements. The average waking heart rate during the day was converted to the corresponding percentage of heart rate reserve (HRR), using the formula of Hiilloscorpi et al (2003):

$$\% \text{ HRR} = 100 \times [(\text{waking HR} - \text{resting HR}) / (\text{maximal HR} - \text{resting HR})].$$

Accepting the approximate equivalence of %HR reserve and % $\text{VO}_2 \text{ max}$, the TEE (MJ/day) was then estimated as:

$$\text{TEE} = \text{AEE} + \text{REE}$$

where AEE is the active energy expenditure = duration of waking heart rate recording (min) $\times \text{VO}_2 \text{ max}$ ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) \times body mass (kg) \times %HRR \times energy equivalent, and REE is given by predicted resting energy expenditure \times (S/1440), where S is the number of minutes of sleep per day.

The average daily level of physical activity (PAL, dimensionless) was calculated from the ratio TEE / RMR, as suggested by FAO/WHO/UNU (James & Schofield 1992). The relative intensities of activity adopted at various points during the day were classified based on usage of the individual's heart rate reserve (Maffei et al. 1996): sedentary (< 30%HRR), moderate (30-50%HRR), vigorous (50-70%HRR) and high intensity (> 70%HRR).

Statistical analysis

Statistical analyses were completed using SPSS version 13.0 for Windows (SPSS Inc, Chicago). Statistical significance was set at $p < 0.05$. Normality of data distribution was checked, using Kolmogorov-Smirnov tests. A nonparametric (Mann-Whitney U) test was adopted to compare normal and overweight children, since body mass values were skewed. Data are presented as median (25th-75th percentiles). Associations between body composition and other variables were calculated using non-parametric (Kendall) correlation tests.

Table 1. Physical characteristics of subjects [Median (25th-75th)].

	Total group (n=90)	Normal BMI (n = 52)	Exceeded BMI limits for age (n = 38)
Age (y)	9.20 (8.80-9.90)	9.30 (8.80-9.90)	9.20 (8.8-9.9)
Height (m)	1.38 (1.32-1.42)	1.37 (1.32-1.41)	1.39 (1.34-1.43)
Body mass (BM) (kg)	35.0 (29.8-40.3)	30.5 (28.0-35.0)	42.0(37.8-46.0) ***
Body mass index (BMI) (kg·m ⁻²)	18.5 (16.3-21.0)	16.5(15.7-18.1)	21.4 (20.6-22.8) ***
Body Fat (BF) (%)	20.4 (17.6-26.4)	18.2 (16.5-19.9)	27.3 (23.2-30.6) ***
Fat Free Mass (FFM) (kg)	27.0 (24.4-30.7)	25.3(23.1-28.3) ± 3.1	30.8 (27.8-33.8) ***
Fat Mass (FM) (kg)	7.8 (5.2-10.3)	5.5(4.7-6.6)	11.7 (8.8-13.4) ***
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	47.0 (44 .5-48.7)	47.6 (46.1-49.9) ± 2.8	46.1 (43.4-47.2) ***
HRmax (bpm)	204 (198-211)	205(198-211)	203 (199-210)

VO₂ max = shuttle-run estimate of maximal oxygen intake. *** denotes p < 0.001 compared with Normal BMI.

Results

Physical characteristics are summarized in Table 1. As expected, children who exceeded BMI limits on average had not only more body fat, but also more lean tissue than children of normal body mass (p < 0.001).

Absolute values for total energy expenditure (TEE, MJ/day) and energy expenditures during the waking part of the day (AEE, MJ/day) did not differ between normal and overweight children (Table 2). However, when TEE was expressed per kg of body mass or per kg of fat-free mass, values were significantly higher in normal children than in those exceeding age-specific BMI limits (p < 0.001, Table 2).

BMI, body fat (whether expressed as a percentage of body mass or as kg of fat) and fat-free mass (FFM) all showed weak but statistically significant positive correlations with TEE (Table 3). In contrast, when the intensity of activity was expressed as a percentage of HRR, values for both the entire day (PAI₂₄) and for the waking part of the day (PAI_w) showed stronger inverse correlations with body mass, BMI, body fat (%), FM, and FFM (Table 3).

The percentages of time allocated to the most waking parts of the day (vigorous and high intensity activities) did not differ significantly between normal and overweight children, but overweight children allocated more time to sedentary activities, and less time to moderate intensities of physical activity (p < 0.01) (Table 4).

Discussion

This study confirms our initial hypotheses, in that normal children spend more time in moderate activity and less

time in sedentary pursuits than those who are overweight, but the greater energy cost of any type of activity in those who are overweight leads to similar levels of total energy expenditure in the two groups.

Inter-group differences in physical activity patterns and energy expenditures

Relative to those who were overweight, individuals with a normal BMI had a greater PAI over the entire day (PAI₂₄) and over the waking part of the day (PAI_w), spending a greater proportion of their day in moderate physical activity. In agreement with our findings, the heart rate recordings of Maffei et al. (1996) found overweight children allocating a larger amount of their day to sedentary and low intensity activities (PAI < 30%HRR). On the other hand, we found no significant inter-group differences in the amounts of vigorous and high intensity physical activity; however, such activities occupied only a small part of the day in either group, and thus made only a small contribution to overall energy expenditures (Molnar and Livingstone, 2000).

Our total energy expenditures did not differ significantly between normal and overweight children. Bailey et al. (1995) argued that very short bursts of intense physical activity interspersed with bouts of low and moderate intensity could have an impact on TEE. The lack of a difference in TEE that we measured was explained by Bailey's argument. Studies of European and North American children have found similar overall energy expenditures to those of our Tunisian students; using the heart rate method, Maffei et al (1996) found a trend to higher EE in obese Italian children (9.46 ± 1.40 vs. 7.51 ± 1.67 MJ), whereas DeLany et al. (1995), using the DLW

Table 2. Energy expenditure and physical activity of subjects [Median (25th-75th)].

	Total group (n=90)	Normal BMI (n = 52)	Exceeded BMI limits for age (n = 38)
TEE (MJ)	9.16 (7.92-9.79)	8.88(7.41-9.76)	9.20 (8.20-9.84)
TEE/kg of BM (kJ·kg ⁻¹)	258 (221-298)	277 (248.08-310.69)	222 (187.6-258.9) ***
TEE/kg of FFM (kJ·kg ⁻¹)	328 (282-369)	343 (301-385)	296 (251-353) ***
AEE (MJ)	3.73 (2.75-4.68)	3.85 (2.77-4.78)	3.56 (2.56-4.21)
AEE (%TEE)	41.9 (34.1-48.1)	44.1 (35.5-49.9)	38.4 (30.8-44.9) *
AEE / kg of BM (kJ·kg ⁻¹)	103 (76-143)	123 (91.9-155.26)	84(56.7-114.7) ***
AEE /kg of FFM (kJ·kg ⁻¹)	138 (95-178)	155 (107.3-191.7)	112 (74.9-157.8) **
PAL	1.81 (1.60-2.11)	1.89 (1.66-2.14)	1.73 (1.53-2.03) 0.29
PAI ₂₄ (%HRR)	18.6 (16.2-21.4)	20.6 (17.8-22.3)	16.3 (14.1-18.9) ***
PAI _w (%HRR)	25.8 (23.4-29.6)	26.2 (24.5-30.7)	24.8 (21.5-28.9) **

TEE = total energy expenditure, AEE = active energy expenditure, PAL = ratio of total energy expenditure to resting energy expenditure for entire day. PAI₂₄ = physical activity averaged over entire day, PAI_w = physical activity intensity averaged over waking part of day, BM = body mass; HRR= heart rate reserve. *, ** and *** denote p < 0.05, 0.01 and 0.001 respectively compared with Normal BMI.

Table 3. Correlations (r) between total energy expenditure (TEE), physical activity intensities for 24 hours (PAI₂₄) and the waking part of the day (PAI_w) and anthropometric variables; combined data for normal and overweight subjects.

	TEE (MJ)	PAI ₂₄ (%HRR)	PAI _w (%HRR)
Body mass index (BMI) (kg·m ⁻²)	.198 *	-.386 ***	-.263 **
Body Fat (BF) (%)	.179 *	-.313 ***	-.191 **
Body Mass (BM) (kg)	.208 **	-.451 ***	-.276 **
Fat Mass (FM) (kg)	.193 *	-.391 ***	-.235 **
Fat Free Mass (FFM) (kg)	.198 **	-.415 ***	-.265 **

*, ** and *** denote $p < 0.05$, 0.01 and 0.001 respectively. HRR = heart rate reserve.

method, reported a higher average EE in lean than in obese American children (9.29 ± 1.39 vs 7.96 ± 1.28 MJ).

The paradox of equal absolute energy expenditures

Despite the differences in physical activity that we observed, absolute values for total and active energy expenditures were similar in normal and overweight children. Our results agree closely with those of Maffei et al. (1996) (PAL of 1.72 ± 0.25 vs 1.61 ± 0.28). Such findings seem due largely to the impact of a greater body mass upon the absolute energy cost of any type of activity (Hoos et al., 2004; Maffei et al., 1993). Grund et al. (2000) emphasized that body size and physical activity are both important determinants of daily energy expenditure. If our energy expenditures are expressed per kg of body mass or fat-free mass (Table 2), the effects of body size are largely eliminated, and the energy costs of walking and running become comparable in normal and overweight groups (DeLany et al., 1995; Garby and Lammert 1994). The normal weight children then show a 9.3 per cent greater unit energy expenditure than those who are overweight; this is a somewhat larger difference than that noted by Garby and Lammert (1994), possibly reflecting the greater average physical activity of normal children in a developing society. According to Welsman and Armstrong (2000), when the ratio standards are not corrected for body size, they give artificially high values to smaller individuals and low values to larger individuals. This is highly relevant when comparing lean and normal weight.

Importance of physical activity to the control of obesity.

Our data demonstrate the ability of simple field methods to bring out differences of energy expenditure related to an individual's body composition. They also support the view that the accumulation of body fat by children in a developing society is associated with a low level of habitual physical activity, much as in industrialized nations. By implication, an excessive body mass for age should be prevented by encouraging children to reduce sedentary activities, and by facilitating an increase of physical activity. Further, it appears that at least in Tunisian society moderate physical activity makes a greater contribution to

the prevention of obesity than does intense activity, presumably because it occupies a larger fraction of the child's day, and thus contributes more to the total daily energy expenditure.

Because the cost of body movement is increased, overweight individuals may match the total daily energy expenditures of their leaner peers once obesity has developed. However, they must develop a larger energy expenditures than normal children (or at least develop an energy deficit) if their body fat content is to be normalized.

Caveats and limitations of study

How far does the apparent equality of total energy expenditure in normal and overweight children reflect problems of the heart rate method in children who are obese? Using the FLEX HR method, Ceesay et al. (1989) found a systematic error of only $1.2 \pm 6.2\%$ relative to whole body calorimetry. However, using the doubly labelled water method (DLW) on a small group of very obese children, Maffei et al. (1995) found a 6.2 per cent over-estimate of energy expenditures by the HR method; this discrepancy needs confirming on a larger subject group. The heart rate monitoring method is cheap relative to doubly labelled water, and it seems a useful technique for evaluating TEE and PAL in resource-poor situations (Kurpad et al., 2006). Advantages include its social acceptability, and the ability to examine time spent in specific activities and at specific intensities of exercise (Beghin et al., 2000; Ceesay et al., 1989). Treuth et al. (1998) underlined that the combination of HR recording and activity diaries allows the determination of EE not only for groups, but also for individuals. Hiilloscorpi et al., (2003) have argued that inter-individual errors in EE estimates are minimized if HRR or HR net is used, as in our study. However, few studies investigated the physiological significance of HR reserve in obese children.

Heart rate estimates are vulnerable to effects of environmental temperature. Kriemler et al. (2002) found that the increase of HR in a warm summer climate could explain 8.8 (3.5) % of apparent EE during outdoor activities, leading to an overall 2.9 (2.7)% overestimate of EE during daily waking hours and a 1.9 (1.8)%

Table 4. Time (min/day) allocated to different intensities of physical activity [PAI, Median (25th-75th)].

	Sleep	Sedentary activity (PAI<30)	Moderate activity (PAI30-50)	Vigorous activity (PAI50-70)	High activity (PAI>70)
Total group (n = 90)	588 (539-629)	329 (261-378)	416 (336-490)	71 (37-113)	21 (14-27)
Normal BMI (n =52)	577 (533-613)	297 (226-374)	460 (388-574)	89 (57-125)	15 (11-23)
Excess BMI for age (n = 38)	591 (557-618)	385 (328-456)	381 (328-436)	66 (49-88)	20 (12-26)
Percentage of spontaneous physical activity (%)					
Normal BMI (n=52)		34.1	54.4	9.4	2.1
Exceeded BMI limits for age (n = 38)		45.7 ***	43.8 ***	8.1	2.4

*** $p < 0.001$ compared with Normal BMI.

overestimate of the 24-h EE. Such temperature effects could have been slightly greater in those who were overweight. However, our observations were made in the temperate season, and our comparisons are based on grouped statistics, so we have reasonable confidence in our estimates of both total energy expenditure and its distribution throughout the day.

The calculation of HRR depends on our estimate of VO_2 max by the shuttle run procedure. The validity of this method has been questioned in the obese. However, we rejected tests that did not reach the anticipated maximal heart rate, and our method of expressing VO_2 max takes into account the body mass of the subject.

A second major factor in our calculations was the estimation of resting metabolic rate. We used Molnar's equations (Molnar et al., 1995). Ethnic differences in body composition between Tunisian children and those tested by Molnar et al. (1995) might bias estimates in populations from developing societies. However, there seems no a priori reason why any such errors should affect normal and overweight children differentially. There is also a 6-7 per cent inter-subject variation in resting metabolic rate (Garby and Lammert, 1994), possibly due to inter-individual differences in muscle mass and the size of internal organs such as the brain, liver, kidneys, heart and spleen (Delany et al., 1995; Garby and Lammert, 1994; Molnar and Shutz, 1997). However, DeLany and associates (1995) found no systematic differences in resting metabolism between lean and obese children; accepting their conclusions, estimates based on age, sex, height and body mass should not have biased our inter-group comparisons.

Finally, our observations were made only on school days. This procedure could be criticised due a lack of a weekend day. Future studies are required to compare weekend patterns of activity in overweight and normal weight children.

The correlations between our estimates of energy expenditure and body composition support the construct validity of our data (Grund et al., 2000). Like us, Grund, et al. (2000) found a substantial correlation between AEE and fat free mass ($r = 0.81$). The negative correlation between the percentage of body fat and habitual physical activity has also been reported previously (Abbott and Davies, 2004).

Conclusion

Our Tunisian sample demonstrates that helpful metabolic data can be collected by simple field techniques. The study confirms our hypothesis that relative to normal weight children, those who are overweight have a lower PAI over both the entire day (PAI_{24}) and the waking part of the day (PAI_w). However, because the energy cost of activity is greater in those who are overweight, they do not differ in absolute TEE or AEE. Relative to those who are overweight, normal children spend more time in moderate intensity activity and less in sedentary pursuits. A larger scale longitudinal experiment seems possible, applying the personalized heart rate techniques that we have adopted at various points in the year on both weekdays

and weekend days; this would test for possible circadian, circaseptan and seasonal effects in Tunisian society, and would help to establish causality in the relationships that we have observed. Nevertheless, our preliminary findings suggest that the best tactics to counter an accumulation of fat may be to commend moderate rather than high intensity physical activity and to reduce sedentary behaviour.

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Key points

- The physical activity intensity for the entire day (PAI₂₄) and for the waking part of day (PAI_w) were lower in overweight than in normal weight individuals.
- However, because the energy cost of activity is greater in those who are overweight, they do not differ in total energy expenditure or in active energy expenditure.
- Normal children spend more time in moderate activity and less time in sedentary pursuits than overweight children.

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