

Fat Oxidation is Higher in Children than Adults

**John C. Kostyak¹, Penny Kris-Etherton², Deborah Bagshaw²,
James P. DeLany³ and Peter A. Farrell⁴**

**Department of Biology¹, University of Delaware Newark, DE 19716, Department of
Nutritional Sciences², The Pennsylvania State University, University Park, PA 16802,
Department of Medicine³, University of Pittsburgh, Pittsburgh, PA 15261 and Department
of Exercise & Sports Science⁴, East Carolina University, Greenville, NC 27858**

Corresponding Author:

Peter A. Farrell

**176 Minges Academic Wing
Department of Exercise and Sport Science
East Carolina University
Greenville, NC 27858**

Email: farrellp@ecu.edu Phone: 252-328-2634 Fax: 252-328-4654

Word count: 3487

Figures: n=3

Tables: n=2

Abstract

Background: Prepubescent children may oxidize fatty acids more readily than adults.

Therefore, dietary fat needs would be higher for children compared with adults. The dietary fat recommendations are higher for children 4 to 18 yrs (i.e., 25 to 35% of energy) compared with adults (i.e., 20 to 35% of energy). Despite this, many parents and children restrict dietary fat for health reasons. **Materials and Methods:** This study assessed whether rates of fat oxidation are similar between prepubescent children and adults. Ten children (8.7 ± 1.4 yr, 33 ± 13 kg mean \pm SD) in Tanner stage 1 and 10 adults (41.6 ± 8 yr, 74 ± 13 kg) were fed a weight maintenance diet for three days to maintain body weight and to establish a consistent background for metabolic rate measurements (all foods provided). Metabolic rate was measured on three separate occasions before and immediately after breakfast and for 9 hrs using a hood system (twice) or a room calorimeter where continuous metabolic measurements were taken. **Results:** During all three sessions whole body fat oxidation was higher in children (lower RQ) compared to adults (mean RQ = 0.84 ± 0.016 for children and 0.87 ± 0.02 , for adults, $p < 0.02$). Although, total grams of fat oxidized was similar in children (62.7 ± 20 g /24 hrs) compared to adults (51.4 ± 19 g /24 hrs), the grams of fat oxidized relative to calorie expenditure was higher in children ($0.047 \pm .01$ g/kcal, compared to adults ($0.032 \pm .01$ $p < 0.02$) and the grams of fat oxidized per metabolic body size was higher in children (6.12 ± 1.8 grams fat/24 hr/ $\text{kg}^{2/3}$) versus adults (3.01 ± 1.1 , $p < 0.01$).

Conclusions: These data suggest that total relative fat oxidation in prepubescent children is higher than in adults. Consistent with current dietary guidelines, a moderate fat diet is appropriate for children within the context of a diet that meets their energy and nutrient needs.

Background

Progression through puberty includes rapid and major changes in many physiological processes. Several studies have demonstrated a decrease in insulin sensitivity during puberty [1, 2]. Changes in insulin sensitivity or other factors such as the steroidal environment [3] could also alter fuel mobilization and utilization before and during puberty. Jones et al [4] found higher net fat oxidation in children (5-10 yrs), both post-absorptive and postprandial, than in adults. Unfortunately no other direct comparisons of fuel utilization, between pre-pubescent children and adults, seem to exist. If fuel metabolism is altered before or during puberty it is logical that macronutrient requirements also change during this period. However, additional data are needed to establish whether this occurs.

A very low fat diet that also is low in calories and does not meet energy needs will interrupt normal growth and development of young children[5-7]. Until recently, a diet that provides less than 30% of calories from fat was recommended for children over two years of age[8]. This guideline was translated by some in an overzealous, but well-intentioned, manner to provide as little fat as possible in the diet leading to inadequate energy intake and compromised growth. In 2002, the National Academies released “Dietary Reference Intakes for Energy and Macronutrients” for all age groups [9]. For children 1-3 years of age, the Acceptable Macronutrient Distribution Range (AMDR) for total fat is 30 to 40% of energy and 25 to 35% of energy for children 4 to 18 years of age. In adults, the AMDR for fat has been set at 20 to 35% of energy. Collectively, these total fat recommendations represent a “step-wise” reduction in fat intake. The 2005 Dietary Guidelines [10] for total fat are consistent with the AMDR for total fat. The impetus for this guidance was to assure adequate energy and nutrient intake. Demonstrating that fatty acid oxidation rates are higher in children vs. adults would provide additional affirmation for the new total fat guidelines for children. Consequently, we felt it was important

to quantify whole body fatty acid oxidation rates in children versus adults, and determine whether they differed, and if so, by how much.

The measurement of whole body fat oxidation (under conditions where CO₂ buffering is stable) is straightforward through the use of indirect calorimetry and, with proper scaling for body size, this method is valid for comparisons between children and adults. Identification and partitioning of sources of fatty acids entering beta-oxidation pathways are not as straightforward. One commonly used method is to trace infused or ingested radio or stable isotope labeled fatty acids either in the plasma and/or in breath. Heiling et al.[11] directly compared measures of fat oxidation derived from indirect calorimetry with that derived from ¹⁴C or ³H labeled FA and concluded that the two measures were not comparable. The physiological cause of this discrepancy may be that ingested or infused fatty acids are temporarily sequestered in intracellular pools which are not immediately reflected in either breath or plasma fatty acid specific activities. Because the report that compared fat oxidation in prepubescent children versus adults[4] depended heavily on stable isotopes, we felt it important to directly measure whole body fat oxidation using indirect calorimetry in children and adults. Studying both children and adults under the same experimental conditions permits comparisons to determine whether relative (i.e., on an energy expenditure basis) fat oxidation rates are higher in children than adults.

Materials and Methods

Subjects. Ten adults (5 men, 5 women) aged 27-55 yr and ten children (5 boys, 5 girls) aged 6-10 yr participated in this study after having a routine physical examination and screening for Tanner Stage status. All subjects were healthy and free from diseases known to alter resting metabolism (thyroid disease, diabetes, extreme under or overweight, retarded or excessive

growth rates) and each had a body mass index within the non-obese range (less than 30 kg/m²). Thus excessively obese or lean children and adults were excluded from the study. Subjects were recruited from the general population by use of public advertisements in local newspapers and bulletin board postings. The study was approved by the Institutional Review Board of the Pennsylvania State University and informed written consent was obtained prior to subject involvement in any part of the study.

Cardiovascular fitness test and body composition. All subjects completed a maximal treadmill stress test that required walking until volitional fatigue. Heart rate, respiratory gases and ventilation were measured as previously described [12, 13]. A leveling off of VO₂ with increasing workload was used as the criteria for reaching maximal oxygen consumption (VO₂max). However, three of the children stopped before meeting this criteria. Their VO₂max values were estimated by linear regression (VO₂- HR) analysis and use of the age predicted maximal heart rate. Cardiovascular fitness testing was performed because regular exercise training may result in a greater utilization of fat which could complicate the interpretation of the results although studies exist which both support[14] and refute[15] this concept. Body fat was measured by skin-fold test [17] with the same trained technician making all measurements on all subjects. The validity of his assessments was validated against results obtained from a separate groups of subjects using underwater weighing as the criterion measure[16]. Seven skinfold sites were measured and constants and weighting factors used for children 6-11 yrs were those suggested by Lohman (17).

Diet. The 3-day diet cycle was designed to be child friendly, convenient and easy to prepare using the NUTRITIONIST V database (N-Squared Computing, First Data Bank Division, San Bruno, CA). Subjects were fed the prepared diet for three continuous days and

on the fourth day a metabolic assessment occurred. The identical three-day diet was repeated for each of the three experimental sessions (room calorimeter and two days using a metabolic hood) as described below. Caloric needs were calculated to maintain current body weight using the Harris-Benedict Equation with an activity factor of 1.5. The diet macronutrient targets were: 13-18% protein, 50-55% carbohydrates, and 30-35% fat. All three menus met these requirements. Macronutrient information is provided in Table 1.

Subjects were provided all food for three days prior to the test day and were instructed to consume only foods provided. Portion sizes were adjusted on the basis of each subject's estimated calorie requirements. Beverages were included with the prepared foods (milk and juice) and participants were instructed that they could drink other non-caloric, non-caffeinated beverages as desired. All food was weighed to the nearest tenth of a gram, and packed in a cooler for take out, to be eaten at home. This method of feeding was successful in that no significant weight gain or loss occurred for each individual from the first to the last experiment.

Protocol. Prior to testing, subjects were familiarized with metabolic testing in both a room calorimeter and a flow-through hood system. Once adapted to the testing environment, each subject's experimental sessions were scheduled at least one week apart (1-3 wks range). In a random order, subjects completed metabolic measurement (RMR) using a hood calorimeter on two occasions and they lived in a room calorimeter for the other session. Subjects rested supine for 30 minutes under a ventilated clear plexiglass hood every hour for eight hours. On another day subjects stayed for 9 hours in a room calorimeter. Subjects were fasted overnight prior to all metabolic testing. Both systems, hood and room calorimeter, used Hartmann Braun oxygen (Magnos 4G) and carbon dioxide (Uras 4) analyzers. Calibration gases were analyzed using both mass spectrometry (supplier analysis) and the Scholander micro technique [19] in our

laboratory. The room calorimeter was tested using several controlled alcohol burns to measure CO₂. This calibration revealed that CO₂ production could be measured with an accuracy of 96%. Analyzers were calibrated immediately before use in the morning, periodically throughout the day (for the first few subjects, until we became confident in the consistency of the analyzers) and immediately after the last gas collection.

Upon arrival at the laboratory the subjects voided and were weighed. Ensure®, a supplement meal replacement drink, was provided as a standard means to deliver all meals of known macronutrient composition. The meal was heated to a desired temperature (85°F) [20]. Ensure contains 14.1% of calories from protein, 22% of calories from fat (1.9% saturated, 6.7% polyunsaturated, 11.8% monounsaturated) and 63.9% of calories from carbohydrate. Both children and adults consumed the Ensure without incident and this was the only calorie containing beverage or food allowed during the experiment. Subjects were given 15 minutes to consume all of the Ensure. Each meal comprised 30% of the subjects estimated daily caloric needs (RMR X 1.2 for activity levels). This activity constant was reduced from the value usually assigned for free living conditions because during the experimental day subjects were instructed to maintain low levels of spontaneous physical activity in the laboratory.

For the hood measurement day, subjects rested in bed for 20 minutes in the semi-recumbent position prior to the first metabolic measurement. Upon completion of this first metabolic measurement subjects ingested breakfast as described above. During the room calorimeter experiments, the subject entered the room after voiding and was served breakfast (Ensure) 15 minutes later. The reason for the slight difference in protocols between room and hood experiments was that it takes about 25 minutes for the room calorimeter to reach

equilibrium after the doors are sealed. Subjects were inactive for the duration of the tests and were constantly supervised. No planned or spontaneous physical exercise was allowed. Children and adults watched movies, read books or played games. Physical exertion was limited to slow walking in the building. During each test day, only bottled water was permitted in addition to the test meal. Lunch was identical to breakfast and was served 4 hrs after breakfast. All urine produced during each test day was collected, pooled, and a small sample was assayed for urea nitrogen.

Heart rate (HR) and blood pressure (BP) were monitored every other hour during the hood collections days and before and after the room calorimeter days. The child's size blood pressure cuff of the Dynamap instrument (HR and BP) was used for children. Subjects were weighed (after emptying the bladder and in the same clothes) to the nearest 100g before and after the experiments.

Calculations and Statistical Analyses. Total fat grams oxidized were calculated from the equation, $\text{g fat/min} = 1.67 \text{ VO}_2 - 1.67 \text{ VCO}_2 - 1.92 \text{ N}$, where VO_2 and VCO_2 are in L/min and N is the rate of excretion of urinary UREA nitrogen in g/min[21]. The grams of fat oxidized using this equation were extrapolated to 24hrs. We realize that this extrapolation probably underestimates values for fat oxidation which would be found under free living conditions where activity is not restricted. Statistical analysis included tests for normalcy of the data and then parametric tests such as paired t-test for two group comparisons (children vs adults) and ANOVA for four group comparisons (boys, girls, men, women). When significant F ratios were found through ANOVA, a Student- Newman- Keuls multiple comparison post hoc test was used

to locate means which differed significantly. A 0.05 level of confidence was chosen a priori as being significant.

Results

Subject characteristics are presented in Table 2. These data suggest that we studied a subject group that was representative of the region. Body weight of the adults and children remained stable, 0.25 ± 0.26 and 0.13 ± 0.13 kg, respectively, for the room calorimeter day and similar non-significant changes occurred on the hood days. Values for VO_2 and VCO_2 obtained for the two hood experiment days were statistically identical as were average heart rate and blood pressure recordings. Heart rate averaged between 80-85 bpm for individual children and between 62- 74 bpm for adults on both hood days. Mean arterial pressures also were within normal ranges with no marked elevations or declines during the testing period.

The VO_2 and VCO_2 data show similar patterns for both the children and the adults, Figure 1. However, as expected, children had significantly, $p < 0.05$, higher values for both VO_2 and VCO_2 when expressed relative to body weight ($ml/kg \cdot min^{-1}$). Calculated kcals expended on a 24 hr basis were within expected ranges, taking into account the restricted physical activity. Men showed the highest value at 2072, then boys 1496, women at 1329 and finally girls at 1194 kcals/day. When energy expenditure was normalized to lean body mass (LBM), no significant difference was found between men (29.7 ± 1.49) and women (29.48 ± 2.7 kcal/d/kg LBM). However, values for children were higher (50.4 ± 6.9 for boys and 52.4 ± 5.3 for girls), $p < 0.05$ compared to adults.

A consistent age effect for RQ was observed on all collection days (Figures 2 and 3).

This difference is mostly accounted for by the male adults who had higher RQ values relative to children of both genders and women. However, on the hood day and room calorimeter day, the RQ values for women were statistically higher ($p < 0.05$) than those of children. Using only the data collected for the hood measurement days, we calculated the total fat grams oxidized for each sub-group for 24 hours using standard equations that included correction for urea nitrogen excretion. Total grams of fat oxidized were somewhat but not significantly higher in children (62.7 ± 20 g /24 hrs) compared to adults (51.4 ± 19 g /24 hrs). In an attempt to determine the contribution of fat oxidation to daily calorie expenditure, we calculated the grams of fat oxidized per kcal of energy expenditure. This value was higher in children (0.047 ± 0.01 g/kcal) compared to adults (0.032 ± 0.01 , $p < 0.02$). In addition, grams of fat oxidized per metabolic body size ($\text{kg}^{2/3}$) was higher in children (6.12 ± 1.8 grams fat/24 hr/ $\text{kg}^{2/3}$) than in adults (3.01 ± 1.1 , $p < 0.01$). The adult men oxidized the least amount of fat per hour relative to metabolic body size, while the other three groups (adult females, young females and young males) were similar.

Discussion

The results of this study, based on indirect calorimetry on three separate days, suggest that pre-pubertal children have a higher rate of relative whole body fat oxidation than adults. By the term relative we mean that of the total food which was provided on a body weight basis, children oxidize a greater percentage of fat from that meal than do adults. The absolute amount (g/hr) of fat oxidized by adults was not statistically different between adults and children probably due to age dependent differences in body size and LBM in children and adults. Prepubescent children may oxidize more fat relative to total energy expenditure than adults, for the purpose of supporting normal growth processes such as higher rates of protein synthesis, lipid storage and bone growth.

The average RQ values shown in Figures 2 and 3 are within the range found in normal weight children by Riddell[22] (10-14 yr) and McCann[23] (6-13 yr) and are slightly lower than those reported by Molnar et al.[24] (9-16 yr), Maffei et al.[25], and Goran and Nagy[26] (4-9 yr). Postprandial RMR values found in this study are similar to those of Ventham and Reilly[27] (using laboratory measures) as well as those of free-living children of similar age using $^2\text{H}_2^{18}\text{O}$ methodology[28]. In addition, the calculated grams of fat oxidized per day in our study is almost identical to that reported by Jones et al.[4] and Salbe et al.[29] and only slightly higher than those reported by Maffei et al.[25]. Thus, the RQ and RMR data are quantitatively similar to those reported for children of similar age in the literature.

It is possible that there were differences in the psychological response to the test protocols between adults and children that accounted for the different fat oxidation rates. Heightened arousal could alter fuel selectivity; however, we are not aware of studies in this area. We were especially cognizant of the fact that isolation while in the room calorimeter might be more stressful for children. Both adults and children spent time in the room calorimeter on a familiarization day prior to actual testing. The children involved in this study tolerated the time in the calorimeter room very well by engaging in quiet play, games and other relaxing activities. The door of the calorimeter has a window so that subjects can interact with experimenters, if needed, and one wall of the calorimeter had a window view to the outside. While not quantified, our subjective impression was that children were comfortable in the room calorimeter in a manner similar to the adults.

The number of subjects in each group is small and this limits the ability to generalize to the overall population. However, we made three independent and repeated measures of this difference using two different measurement systems (hood and room). With such a small

number of subjects it is possible that gender could influence our findings. Adult males oxidized significantly less fat relative to metabolic body size than young males and adult females also oxidized less fat than young females however, that difference was not statistically significant. We speculate that due to earlier maturation in females, metabolic pathways in the girls resembled those of women more closely than those found between men and boys. We suggest that an investigation using a greater number of subjects be performed to verify our results. It would also be valuable to know whether ethnicity influences our findings.

The present study has shown that children oxidize greater amounts of fat per calorie expended each day compared to adults. This is supportive of a higher total fat dietary recommendation for children versus adults. However, this interpretation needs to be framed in the context of energy balance and nutrient adequacy. This is particularly important given the increasing incidence of overweight/obesity in children in the U.S.[30]. Nonetheless, as is apparent, sufficient fat must be included in the diet for children to support normal growth and development. Because there is a recommended fat range for children of different ages it is important to provide flexibility in diet planning, and to facilitate adherence to the fat recommendations that have been made.

Table 1
Diet Analysis (example for ~ 2000 kcal menu) *

	Day 1	Day 2	Day 3	3- Day Average
Kcal	1987	1972	2008	1989
Carbohydrates (% en)	51	53	50	51
Protein (% en)	16	13	16	15
Total Fat (% en)	35	35	36	34
SFA (% en)	14	13	12	13
MUFA (% en)	13	12	9	11
PUFA (% en)	3	7	7	6
Cholesterol (mg)	163	264	100	176
Fiber (g)	20	12	22	18

* analysis from Nutr V database

Table 2
Characteristics of Subjects by Group

	Age (yrs)	Height (cm)	Weight (kg)	% Body Fat	BMI (kg/m ²)	VO2 Max (ml/kg/min)	Urinary N ₂ (total g/24 hr)
Adults (n=10)	41.6 ± 8.5	170.6 ± 10.9	73.6 ± 13.2	27.08 ± 5.43	25.1 ± 2.8	36.7 ± 10.7	12.7 ± 3.5
Children (n=10)	8.7 ± 1.4	136.4 ± 13.6	33.9 ± 13.9	17.35 ± 11.09	17.7 ± 3.9	42.7 ± 9.2	7.5 ± 2.4

BMI: body mass index

VO₂

VO₂

VCO₂

VCO₂

Acknowledgements: We thank the subjects who participated in this study. The study was supported by the National Dairy Council and the General Clinical Research Center, at Penn State, MO1 RR 10732 from NIH. We also thank Fritz Kramer and Brian Krawiec for help in collecting data and supervising subjects.

Competing Interest

The authors declare that there are no competing interests associated with the preparation or publication of this article.

Author Contributions: JCK (jck@udel.edu) conducted all data collection using the room calorimeter and hood systems, recruited subjects, analyzed the data and wrote the manuscript. PKE (pmk3@psu.edu) helped design the experiments, obtain IRB approval, helped write the manuscript, coordinated meal development. DB (ddm108@psu.edu) supervised all aspects of meal preparation and delivery. JPD (delanyj@dom.pitt.edu) helped design the experiment, data analysis, writing the manuscript and interpretation of results. PAF (farrellp@ecu.edu) helped design the experiment, obtain IRB approval, collect data, recruit subjects and write the manuscript.

References

1. Arslanian SA, Kalhan, S: **Correlations between fatty acid and glucose metabolism. Potential explanation of insulin resistance of puberty.** Diabetes 1994, **43**:908-914.
2. Bloch CA, Clemons P, Sperling MA: **Puberty decreases insulin sensitivity.** J Pediatr 1987, **110**:481-487.
3. Arslanian S, Suprasongsin C: **Testosterone treatment in adolescents with delayed puberty: changes in body composition, protein, fat, and glucose metabolism.** J Clin Endocrinol Metab 1997, **82**:3213-3220.
4. Jones AE, Murphy JL, Stolinski M, Wootton SA: **The effect of age and gender on the metabolic disposal of [1-13C] palmitic acid.** Eur J Clin Nutr 1998, **52**:22-28.
5. Pugliese MT, Weyman-Daum M, Moses N, Lifshitz F: **Parental health beliefs as a cause of nonorganic failure to thrive.** Pediatrics 1987, **80**:175-182.
6. Lifshitz F, Moses N: **Growth failure. A complication of dietary treatment of hypercholesterolemia.** Am J Dis Child 1989, **143**:537-542.
7. Lifshitz F, Tarim O: **Considerations about dietary fat restrictions for children.** J Nutr 1996, **126**:1031S-1041S.
8. U.S. Department of Health and Human Services USDA: **Dietary Guidelines for Americans 2000.** January.

9. IOM. National Academies - **Dietary Reference Intakes: Energy, Carbohydrates, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids**. Washington, DC: National Academies Press, 2002.
10. USDA. DHHS - **Dietary Guidelines for Americans, 2005**. 6th Edition. Washington, DC: U.S.: Government Printing Office, January.
11. Heiling VJ, Miles JM, Jensen MD: **How valid are isotopic measurements of fatty acid oxidation?** *Am J Physiol* 1991, **261**:E572-E577.
12. Farrell PA, Gustafson AB, Kalkhoff RK: **Assessment of methods for assigning treadmill exercise workloads for lean and obese women**. *Int J Obes* 1985, **9**:49-58.
13. Farrell PA, Gustafson AB, Garthwaite TL, Kalkhoff RK, Cowley AW, Jr., Morgan WP: **Influence of endogenous opioids on the response of selected hormones to exercise in humans**. *J Appl Physiol* 1986,**61**:1051-1057.
14. Mikines KJ, Sonne B, Farrell PA, Tronier B, Galbo H: **Effect of training on the dose-response relationship for insulin action in men**. *J Appl Physiol* 1989, **66**:695-703.
15. Schulz LO, Nyomba BL, Alger S, Anderson TE, Ravussin E: **Effect of endurance training on sedentary energy expenditure measured in a respiratory chamber**. *Am J Physiol* 1991, **260**:E257-E261.
16. Akers R, Buskirk ER: **An underwater weighing system utilizing "force cube" transducers**. *J Appl Physiol* 1969, **26**:649-652.
17. Lohman TG: **Applicability of body composition techniques and constants for children and youths**. *Exerc Sport Sci Rev* 1986, **14**:325-357.
18. Siri WE. **Body Composition from fluid spaces and density**. In: **Brozek, A., ed. Techniques for Measuring Body Composition**: National Academy of Sciences, National Research Council, 1961:223-244.
19. Scholander PF: **Analyzer for accurate estimation of respiratory gases in one-half cubic centimeter samples**. *J. Biol. Chem.* 1947,**1**:235-250.
20. DeLany JP, Windhauser MM, Champagne CM, Bray GA: **Differential oxidation of individual dietary fatty acids in humans**. *Am J Clin Nutr* 2000, **72**:905-911.
21. Frayn KN: **Calculation of substrate oxidation rates in vivo from gaseous exchange**. *J Appl Physiol* 1983, **55**:628-634.
22. Riddell MC, Bar-Or O, Wilk B, Parolin ML, Heigenhauser GJ: **Substrate utilization during exercise with glucose and glucose plus fructose ingestion in boys ages 10--14 yr**. *J Appl Physiol* 2001, **90**:903-911.
23. McCann DJ, Adams WC: **A theory for normalizing resting .VO(2) for differences in body size**. *Med Sci Sports Exerc* 2002, **34**:1382-1390.
24. Molnar D, Schutz Y: **Fat oxidation in nonobese and obese adolescents: effect of body composition and pubertal development**. *J Pediatr* 1998, **132**:98-104.
25. Maffeis C, Pinelli L, Schutz Y: **Increased fat oxidation in prepubertal obese children: a metabolic defense against further weight gain?** *J Pediatr* 1995, **126**:15-20.
26. Goran MI, Nagy TR: **Effect of the pre-testing environment on measurement of metabolic rate in children**. *Int J Obes Relat Metab Disord* 1996, **20**:83-87.
27. Ventham JC, Reilly JJ: **Reproducibility of resting metabolic rate measurement in children**. *Br J Nutr* 1999, **81**:435-437.
28. Livingstone MB, Coward WA, Prentice AM, Davies PS, Strain JJ, McKenna PG, Mahoney CA, White JA, Stewart CM, Kerr MJ: **Daily energy expenditure in free-living**

- children: comparison of heart-rate monitoring with the doubly labeled water (2H₂(18)O) method.** Am J Clin Nutr 1992, **56**:343-352.
29. Salbe AD, Weyer C, Harper I, Lindsay RS, Ravussin E, Tataranni PA: **Assessing risk factors for obesity between childhood and adolescence: II. Energy metabolism and physical activity.** Pediatrics 2002, **110**:307-314.
30. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM: **Prevalence of overweight and obesity in the United States, 1999-2004.** JAMA 2006, **295**:1549-1555.

Legends to Figures

Figure 1. Oxygen consumption and carbon dioxide production for each group during the background hood day. Symbols (▲ = child VO₂, ◆ = child VCO₂, ■ = adult VO₂, ● = adult VCO₂). N= 10 per group. Values are means + or - SE.

Figure 2. RQ values for each of the groups on the hood day. (□ = Adult male, n=5), (+ = Adult female, n=5), (* = Children male, n=5), (x = Children female, n=5). Values are means ± SEM.

Figure 3. Average RQ values for children (n=10) and adults (n=10) for the room calorimeter day. For graphical clarity, indicators of variability around the mean are not presented. Each line represents a tracing of the average value for all ten subjects in each age group.

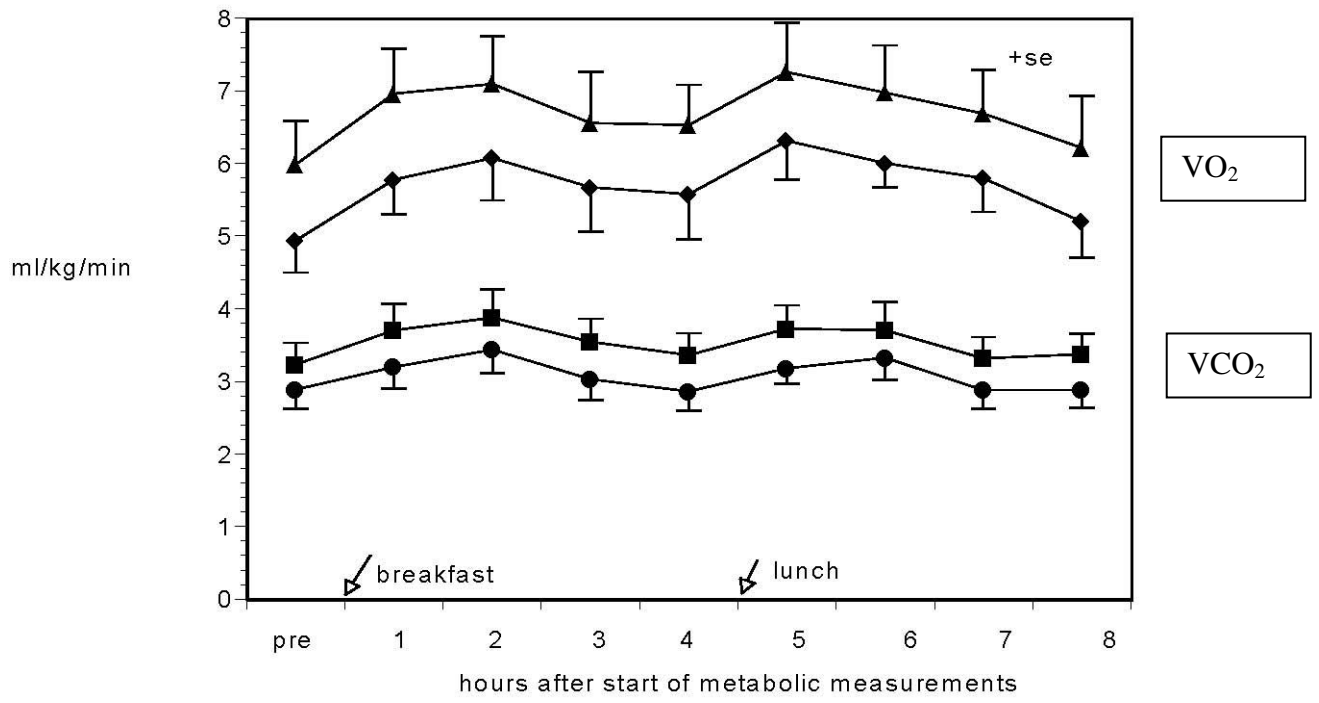


Figure 1

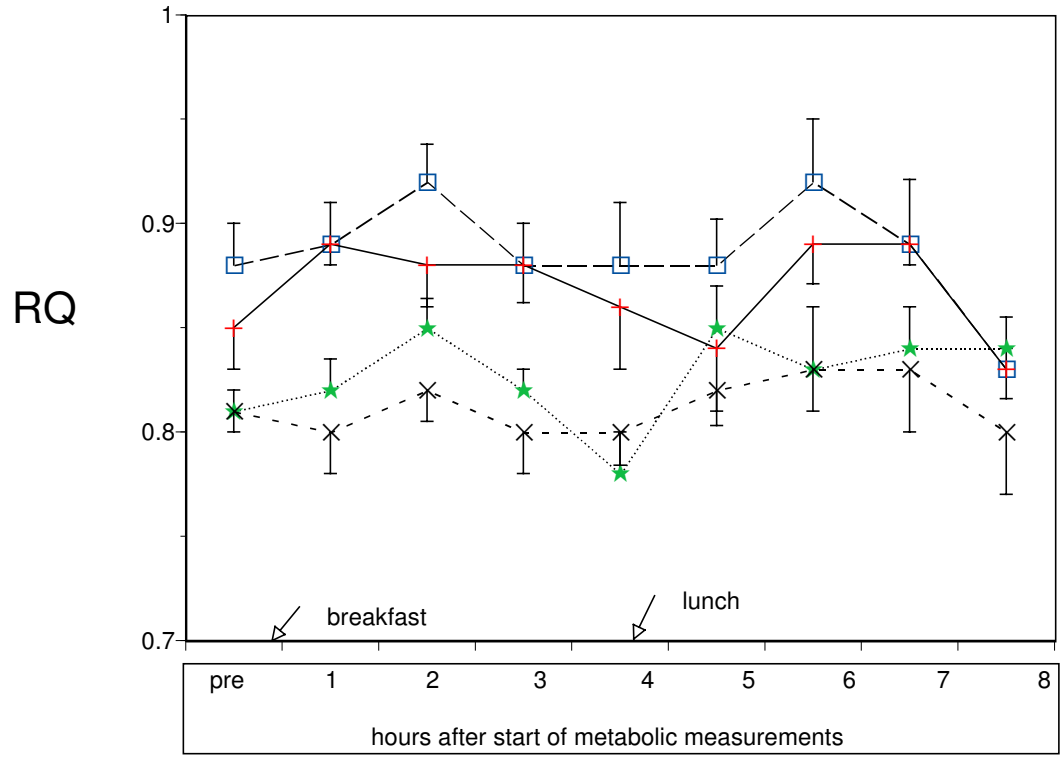


Figure 2

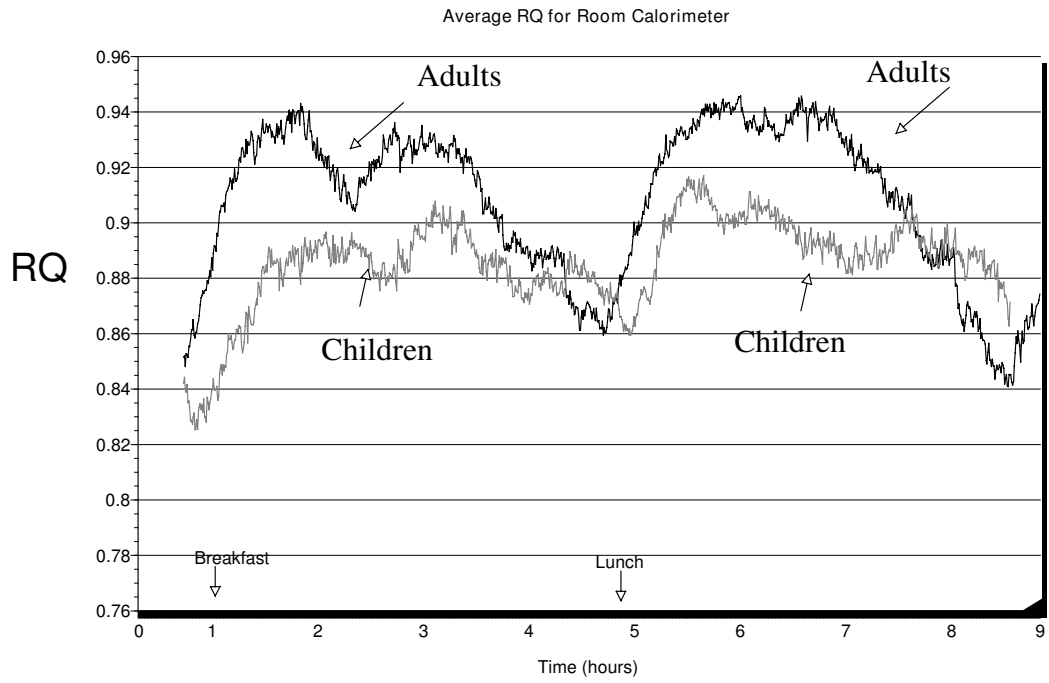


Figure 3