Assigning Energy Costs to Activities in Children: A Review and Synthesis

KATE RIDLEY[1] and TIM S. OLDS[2]

[1]Centre for the Analysis of Educational Futures, School of Education, Flinders University; adelaide, AUSTRALIA; and [2]Nutritional Physiology Research Centre, School of Health Sciences, University of South Australia, Adelaide, AUSTRALIA

ABSTRACT

RIDLEY, K., and T. S. OLDS. Assigning Energy Costs to Activities in Children: A Review and Synthesis. *Med. Sci. Sports Exerc.*, Vol. 40, No. 8, pp. 000–000, 2008. **Purpose:** Compendia of energy costs are often used to assign energy expenditures (EE) to self-reported and observed activity. As there is a lack of data on the energy cost of children's everyday activities, adult values are often used as surrogates. However, the best way to adjust adult values for use with children remains unclear. Various strategies have been used to estimate rates of EE in children. **Methods:** To evaluate these existing methods for assigning EE to children, a literature search reviewed all English-language studies that measured energy costs in healthy 6.0–17.9 yr olds using criterion EE measures. Data were combined using the Monte Carlo simulation procedure, with walking and running forming separate data sets. **Results:** The resultant data set (excluding walking and running) contained 5592 data points encompassing 51 activities. Analyses revealed using adults METs, combined with child resting metabolic rates, as the best existing technique to assign EE to children when measured values are not available. Prediction equations for the energy cost of walking and running were calculated using multiple regression. **Conclusion:** This study has provided a literature base and analytical support for a compendium of energy costs for use with children with energy costs expressed as METs. **Key Words:** ENERGY EXPENDITURE, ADOLESCENTS, YOUTH, METS

The mounting evidence associating physical activity (PA) and various dimensions of health (5,50) coupled with increasing prevalence of childhood overweight and obesity (17,20) have led to a greater interest in measuring children's activity levels. In addition to measuring the number of minutes children devote to different types of activities, it is often desirable to be able to estimate rates of energy expenditure (EE; or energy cost) in those activities. This permits an overall estimate of daily EE and hence allows comparison with, and recommendations for, energy intake. It also allows for estimation of how much time children spend in sedentary, moderate, and vigorous PA (MVPA), as these constructs are defined relative to rates of EE, for example, MVPA Œ 3 METs (26).

Unfortunately, there are relatively few data on the energy cost of everyday activities in children and adolescents. As a result, adult data are often used as surrogates (1). However, evidence suggests that when performing the same or similar activities, in particular walking and running, adults have lower rates of EE when expressed as oxygen consumption ($\dot{V}O_2$) or caloric cost per unit body mass (2,33,37,46). This increased energy cost is likely to be due to size- and physiology-related mechanisms, such as immature motor patterns and increased breathing rates (36). Disparities may also be due to children living in an adult-sized world. For example, children need to reach higher and further to manipulate everyday objects that are proportionally larger and heavier for children compared to adults.

The most desirable solution would be to use a compendium compiled from EE measured in children. However, such a compendium will always be a work in progress because of the methodological difficulties associated with such measurements, differences across age groups, and the wide and evolving range of activities that need to be examined. Although there are still gaps in child-measured data, we need strategies for assigning energy costs on the basis of adult values.

Existing techniques used to assign energy costs to children. Various strategies have been used to estimate rates of EE in children on the basis of adult values. These include the following:

1. *Using Metabolic Units (METs)*. Many compendia express rates of EE in METs, which are multiples of resting metabolic rate (RMR), either measured or estimated (8). For adults, RMR (i.e., 1 MET) is usually taken to be 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ or 4.2 $kJ \cdot kg^{-1} \cdot h^{-1}$ (=1 $kcal \cdot kg^{-1} \cdot h^{-1}$). Mass-specific child RMR is considerably higher and vary with sex, age,

Address for correspondence: Kate Ridley, Ph.D., School of Education, Flinders University, GPO Box 2100, Adelaide SA 5001, Australia; E-mail: Kate.Ridley@flinders.edu.au.
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body mass, pubertal status, and body composition (13,23,38). It has been suggested that using METs may assist in equalizing differences in adult/child energy costs (13). For example, a value of 2 METs for a given activity may then equate to 7 $mL \cdot kg^{-1} \cdot min^{-1}$ for adults but 9 $mL \cdot kg^{-1} \cdot min^{-1}$ for children, given the difference in RMR.

2. *The FAO/WHO/UNU Method* (12). The FAO/WHO/UNU (12) recommendations involve multiplying either measured or estimated child RMR by factors for different types of activities. *Going to school and other light activities* are classified as 1.5 METs, *moderate activity* = 2.2 METs, and *high activity* = 6.0 METs.
3. *The Method of Torun* (47). The Torun (47) recommendation involves using prescribed MET values (for children aged 1–15 yr) or multiplying adult MET values by an age-correction factor, depending on the activity being performed. *Sedentary activities* are classified as follows: lying down = 1.1 METs, sitting = 1.2 METs, and standing = 1.4 METs. *Non-walking light activities* are assigned 2.0 METs for 1.5–6.9 yr olds or 2.2 METs for 6.0–14.9 yr olds. *Walking at normal pace on level ground OR moderate activities* are assigned 2.2 METs for 1.5–6.9 yr olds or 2.9 METs for 6.0–14.9 yr olds. Assigning MET costs for *heavier* activities involves multiplying adult MET values by age-correction factors of 0.50 for 1.5–6.9 yr olds, 0.65 for 6.0–12.9 yr olds, and 0.80 for 13.0–14.9 yr olds.
4. *The Method of Sallis et al.* (37). In contrast, the Sallis et al. (37) recommendation involves applying an age-correction factor to adult $\dot{V}O_2$ data. The correction factors are on the basis of five large (n > 100) treadmill studies and decrease with age from 1.37 at age 5 yr to 1.03 at age 17 yr.

The assignment techniques yield different energy cost values for individual activities. There has been little research comparing these methods, and there is currently no consensus on which energy cost assignment technique is best. Most raw data sets are too small to make definitive decisions. Spadano et al. (39) compared the age adjustments recommended by Torun (47), the FAO/WHO/UNU (12), and the adult METs from the adult compendium compiled by Ainsworth et al. (1) to measure METs in a sample of seventeen 12-yr-old girls while sitting, standing, and walking at three intensities. It was concluded that adult METs provided the best overall approximation of the energy cost across the five activities. A large study by Harrell et al. (13) compared children's energy costs measured in 18 activities and converted to METs using measured child RMR, with estimations from the compendium-derived adult METs (1). The use of child RMR resulted in a more accurate estimation of the energy cost of activities than the standard adult RMR. The authors therefore recommended the use of MET values derived from published adult compendia combined with age- and/or and pubertal status-adjusted RMR predictions when child-measured values are not available.

This review will add to the work undertaken by Spadano et al. (39) and Harrell et al. (13) by collating and combining all existing energy cost data collected on children. The aims of the study are to

a) review current data of energy costs of everyday activities in children, and
b) compare four existing techniques for assigning energy costs to children.

METHODS

Search criteria. An extensive literature search was conducted for studies that report the energy cost of children and adolescents performing everyday activities. The literature search involved searching both online and CD-ROM bibliographic databases (MEDLINE, Sport Discus, Educational Resources Information Centre, Current Contents, Academic Search Elite, Australian Digital Theses Program, Digital Dissertations) using the following keywords: energy cost, energy expenditure, caloric expenditure, oxygen consumption, aerobic demands, and MET. The following modifiers were used in conjunction with the keywords: child/children, adolescent/adolescence, youth, boy, and girl. As many studies use criterion energy cost measures to validate accelerometry, pedometry, and HR measures, the keywords, namely, accelerometry/accelerometer, pedometer/pedometry, and heart rate, were also used with the following modifiers: valid/validity/validation. The reference lists of all published studies that were obtained through the computer searches were also examined and cross-referenced. All studies that involved measuring EE in healthy 6.0- to 17.9-yr-old children and adolescents using criterion methods (i.e., oxygen consumption or CO_2 breath tests) were included. Only those studies that were published in English were used (n = 54).

Data treatment. As studies report rates of EE in different metrics, these were initially standardized to $mL\ O_2 \cdot kg^{-1} \cdot min^{-1}$. Studies that reported data in calories or joules were converted to $\dot{V}O_2$ using a standard energy equivalent for oxygen uptake: 21 $kJ \cdot L^{-1} \cdot O_2$ (27). Child METs for each of the activities were calculated by dividing mean oxygen consumption by mean predicted child-specific RMR for each sample. The Schofield equations (38) were used to estimate RMR. These equations have been validated against indirect calorimetry (34,52). Although some studies measured the RMR of their subjects, details were rarely provided. The measurement of RMR in children is extremely difficult, and studies vary in their methodologies (38). Therefore, standard RMR equations (38) were used to predict METs across all studies to reduce methodological variability.

The Schofield equations require body mass as an input, which was not always reported in the studies located. If body weight was not reported, mean age-specific values were calculated using a regression equation on the basis of the masses of 70216 Australian children aged between 5 and 18 yr measured between 1937 and 2000: *male* mass (kilograms) = 0.104 (year of measurement) + 4.02 (age) − 210.5, $r = 0.81$, SEE = 8.1 kg; *female* mass (kilograms) = 0.058 (year of measurement) + 3.7 (age) − 115.9, $r = 0.82$, SEE = 7.7 kg [on the basis of the data from Ref. (25)]. Where studies combined male and female values, weighted means were used applying the RMR and estimated mass formulae for both sexes. Less than 1% of the total number of studies did not report body mass.

Creation of a comparative adult–child data set. Activities with comparable adult MET values listed in the adult compendium (1) were included in the data set, except continuous running and walking at various speeds that formed separate data sets. Cycling was excluded because of complexities such as speed, type of bicycle, gears, and cycling surface, all of which affect EE. To calculate a sample-weighted mean child MET score across all studies, the Monte Carlo data simulation procedure was used. This procedure involves using a random generator to create "pseudo data" in a normal distribution, matching the original data set in summary characteristics where only means and SD were available (45). The simulation procedure was applied iteratively until the mean of the generated data was within 0.5% and the SD was within 2.5% of those of the original data set. Subsequently, four existing assignment techniques were used for comparison: adult METs, FAO/WHO/UNU (12), Torun (47), and a modified version of the Sallis et al. (37) technique. The adult METS were derived from the adult compendium (1). The mean ages of the children from each energy cost study were then used to assign MET estimations on the basis of the age-specific recommendations of the FAO/WHO/UNU (12), Torun (47), and Sallis et al. (37). Some subjective decisions were made to assign the FAO/WHO/UNU and Torun energy costs, for example, is "hanging out the washing" considered "standing—little or no movement" or "walking at normal pace OR moderate activity?" To calculate METs using the Sallis et al. technique, age-correction factors were applied to adult METs, not $\dot{V}O_2$ values. However, it is acknowledged that Sallis et al. (37) did not investigate the MET technique as a means of assigning energy costs to children. Therefore, by converting $\dot{V}O_2$ values to METs, the Sallis technique referred to in subsequent analyses is not an exact application of the recommended technique and will be referred to hereafter as the modified Sallis technique.

Creation of a comparative adult–child data set for continuous walking and running. For the continuous locomotor activities of running and walking, energy cost measurements had been made at a range of intensities. Grade running and walking were not included because of lack of data. To combine these data, a Monte Carlo procedure was used at each intensity. As the FAO/WHO/UNU (12) and Torun (47) techniques are not designed to assign energy costs to running and walking at different speeds (each speed is likely to be assigned the same MET value), only adult METs were compared to predicted child METs for running and walking. The running and walking pseudo data sets were converted into METs by dividing by Schofield-predicted RMR (38).

Comparative analyses. Paired *t*-tests were performed to determine whether there were any significant differences between the estimated child METs, calculated from the energy cost review on the basis of measured $\dot{V}O_2$ values, and the four energy cost assignment techniques. The assignment techniques were also compared using Bland–Altman analyses and intraclass coefficients (ICC). Multiple regression was used to create predictive equations for the MET cost of walking and running on the basis of age and speed.

BASIC SCIENCES

RESULTS

Energy cost data in children and adolescents. Data from 54 studies were combined with walking and running forming separate data sets. The resultant data set (excluding walking and running) contained 5592 data points encompassing 51 activities. Table 1 summarizes the data obtained via the literature review and lists the adult compendium codes, compendium descriptions, FAO/WHO/UNU classifications, and Torun classifications used to assign MET classifications for each of the 51 activities. The majority of studies measured EE by indirect calorimetry using respiration chambers, Douglas bags, metabolic carts, or portable oxygen consumption systems. Two studies (16,30) measured energy costs using CO_2 breath tests. The mean ± SD predicted RMR across all studies was 4.59 ± 1.07 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$. T1

Comparing existing techniques to assign energy costs to children. The 51 nonlocomotor activities, weighted mean METs calculated from the pseudo data set, weighted mean ages, and METs assigned by the four techniques are displayed in Table 2. Table 3 compares the biases, SEM, upper and lower limits of agreement (LoA), and ICC for the METs assignment techniques. Figure 1 shows the Bland–Altman plot comparing the estimated child METs, on the basis of measured $\dot{V}O_2$ values, and adult METs. Paired *t*-tests found significant differences between the measured child METs and both the FAO/WHO/UNU METs ($t = 4.96$, $P < 0.0001$) and the Torun METs ($t = 2.78$, $P = 0.008$). T2 T3 F1

Comparing existing techniques to assign running and walking energy costs to children. Paired *t*-tests revealed significant differences between child and adult MET values for running ($t = -11.35$, $P < 0.0001$) and walking ($t = 8.004$, $P < 0.0001$). The best prediction equations for METs during running and walking use both age (in years) and speed (v, in meters per second). The running MET prediction equation was on the basis of 1974 data points: 0.27 age + 1.91 speed (meters per second)

TABLE 1. Summary of data collected from the literature review, adult compendium codes, descriptions, and FAO/WHO/UNU and Torun classifications used to assign MET classifications for each of the 51 activities.

Activity	Total Number of Data Points	Reference Numbers	Adult Compendium Code	Adult Compendium Description	FAO/WHO/UNU Description	Torun Description
Art and craft	110	(6,48)	09075	Sitting—arts and crafts, light effort	Moderate activity	Nonwalking light
Basketball game	11	(10)	15040	Basketball game	Heavy activity	Heavier activity
Basketball—shooting hoops	74	(28,49)	15050	Basketball, nongame	Heavy activity	Heavier activity
Bed making	78	(6,31)	05100	Making bed	Moderate activity	Walking at normal pace OR moderate activity
Bowling	11	(10)	15090	Bowling	Moderate activity	Walking at normal pace OR moderate activity
Caring for animals	14	(6)	05053	Feeding animals	Moderate activity	Walking at normal pace OR moderate activity
Catching ball	49	(11,21)	15235	Football or baseball, playing catch	Moderate activity	Nonwalking light
Climbing stairs	325	(13,28,49)	17130/17070	Mean of walking upstairs and walking downstairs	Heavy activity	Heavier activity
Crayoning	49	(11,21)	09075	Sitting—arts and crafts, light effort	Light activity	Sitting—little or no movement
Cricket	31	(6)	15150	Cricket (batting and bowling)	Heavy activity	Heavier activity
Dancing	32	(6)	03025	General, Greek, Middle Eastern, hula, flamenco, duplicating machine	Heavy activity	Heavier activity
Drawing—standing	17	(43)	09020	Standing—drawing (writing), casino gambling, duplicating machine	Moderate activity	Standing—little or no movement
Dressing and undressing	78	(6,43)	13020	Dressing, undressing (standing or sitting)	Moderate activity	Nonwalking light
Dusting	24	(14)	05040	Cleaning light (e.g., dusting)	Moderate activity	Nonwalking light
Gardening	48	(6)	08245	Gardening, general	Moderate activity	Walking at normal pace OR moderate activity
Gymnastics	61	(6)	15300	Gymnastics, general	Heavy activity	Heavier activity
Hanging out washing	14	(31)	05090	Laundry, or hang clothes	Moderate activity	Walking at normal pace OR moderate activity
Hopscotch	49	(11,21)	15135	Children's games (hopscotch, etc.)—adults playing	Heavy activity	Heavier activity
Lacrosse	34	(6)	15460	Lacrosse	Heavy activity	Heavier activity
Listening to music	20	(44)	07021	Sitting quietly, listening to music (not talking or reading)	Light activity	Sitting—little or no movement
Lying at rest	126	(3,4,19,28,49,51)	07011	Lying quietly, doing nothing	Light activity	Lying down—little or no movement
Outdoor work/heavy	26	(6)	08020	Chopping wood, splitting logs	Heavy activity	Heavier activity
Outdoor work/light	25	(6)	08240	Weeding, cultivating garden	Moderate activity	Walking at normal pace OR moderate activity
Outdoor work/summer	34	(6)	08210	Trimming shrubs or trees, manual cutter	Heavy activity	Heavier activity
Playground games	24	(6)	15135	Children's games (hopscotch, 4-square, dodge ball, etc.)	Heavy activity	Heavier activity
Playing piano	26	(6)	10070	Playing piano	Light activity	Sitting—little or no movement
Playing violin or cello	15	(6,15)	10100/10020	Mean of playing violin (10100) and playing cello (10020)	Light activity	Standing—little or no movement
Playing with puzzles and board games	314	(13,14,42)	09010	Sitting—card playing, playing board games	Light activity	Sitting—little or no movement
Reading sitting	28	(3,4)	07070	Reclining—reading	Light activity	Sitting—little or no movement
Rollerblading	26	(31)	15591	Rollerblading	Heavy activity	Heavier activity
Rope jumping (skipping)	262	(13)	15552	Rope jumping (slow)	Heavy activity	Heavier activity
Schoolwork sitting	713	(13,32,48)	09060	Sitting—studying, general, including reading and/or writing	Light activity	Sitting—little or no movement
Setting table	20	(31)	05051	Setting table, implied walking or standing	Moderate activity	Walking at normal pace OR moderate activity
Shoveling	285	(13)	08050	Digging, spading	Heavy activity	Heavier activity
Singing sitting	13	(44)	20005	Sitting in church, sitting or singing	Light activity	Sitting—little or no movement
Singing standing	15	(44)	20020	Standing, singing in church, attending a ceremony, active participation	Light activity	Standing—little or no movement
Sitting quietly	176	(3,4,6,22,32,39–41,51)	07021	Sitting quietly, listening to music (not talking or reading)	Light activity	Sitting—little or no movement
Soccer	22	(6)	15610	Soccer, casual, general	Heavy activity	Heavier activity
Standing quietly	195	(6,24,39)	07040	Standing quietly (standing in a line)	Light activity	Standing—little or no movement
Step aerobics	74	(28,49)	03016	Aerobic, step with 6- to 8-inch step	Heavy activity	Heavier activity
Stretching	264	(13)	20100	Stretching, hatha yoga	Light activity	Nonwalking light
Sweeping	378	(10,13,14,49)	05010	Carpet sweeping, sweeping floors	Moderate activity	Walking at normal pace OR moderate activity
Swimming front crawl 0.9 $m \cdot s^{-1}$	11	(29)	18290	Calculated from regression equation on the basis of all swimming data in adult compendium (1)	Heavy activity	Heavier activity
Swimming front crawl 1.0 $m \cdot s^{-1}$	21	(18,29)	18230	Calculated from regression equation on the basis of all swimming data in adult compendium (1)	Heavy activity	Heavier activity
Swimming front crawl 1.1 $m \cdot s^{-1}$	11	(29)	18280	Calculated from regression equation on the basis of all swimming data in adult compendium (1)	Heavy activity	Heavier activity
Television watching, lying down	31	(19)	07010	Lying quietly and watching TV	Light activity	Lying down—little or no movement
Television watching, sitting	470	(7,13,15,28,48,49)	07020	Sitting quietly and watching TV	Light activity	Sitting—little or no movement
Vacuuming	299	(13,14,32)	05043	Vacuuming	Moderate activity	Walking at normal pace OR moderate activity
Washing the dishes	32	(31,32)	05041	Wash dishes—standing or in general	Moderate activity	Nonwalking light
Weaving	17	(6)	05080	Sitting—knitting, sewing	Light activity	Sitting—little or no movement
Weightlifting	510	(13)	02130	Weightlifting, light or moderate effort	Moderate activity	Walking at normal pace R moderate activity

TABLE 2. Energy cost values for the 51 activities estimated as child METs on the basis of measured $\dot{V}O_2$ values and assigned by adult METs, FAO/WHO/UNU METs, Torun METs, and Sallis METs.

Activity	Mean Age (yr)	Mean Child METs	Mean Adult METs	Mean Torun METs	FAO/WHO/UNU METs	Mean Sallis METs
Art and craft	8.9	1.6	1.5	2.2	2.2	1.8
Basketball game	11.4	8.2	8.0	5.2	6.0	9.1
Basketball—shooting hoops	14.1	7.2	6.0	4.8	6.0	6.5
Bed making	14.3	3.4	2.0	2.9	2.2	2.1
Bowling	11.4	4.9	3.0	2.9	2.2	3.4
Caring for animals	9.5	2.5	2.5	2.9	2.2	2.9
Catching ball	9.4	2.6	2.5	2.2	2.2	3.0
Climbing stairs	13.2	7.0	5.5	4.4	6	6.1
Crayoning	9.4	1.4	1.5	1.2	1.5	1.8
Cricket	13.3	3.5	5.0	3.6	6.0	5.4
Dancing	16.2	5.5	4.5	4.2	6.0	4.6
Drawing—standing	10.2	1.9	2.3	1.4	1.5	2.7
Dressing and undressing	13.9	2.7	2.0	2.2	2.2	2.2
Dusting	12.5	4.2	2.5	2.2	2.2	2.8
Gardening	12.9	3.7	4.0	2.6	2.2	4.4
Gymnastics	14.9	4.0	4.0	2.9	6.0	4.2
Hanging out washing	11.6	2.6	2.0	2.6	2.2	2.2
Hopscotch	9.4	5.9	5.0	3.3	6.0	6.0
Lacrosse	14.9	6.4	8.0	6.0	6.0	8.4
Listening to music	10.6	1.3	1.0	1.2	1.5	1.1
Lying at rest	13.0	1.2	1.0	1.1	1.5	1.1
Outdoor work/heavy	15.7	6.8	6.0	4.8	6.0	6.3
Outdoor work/light	15.8	4.1	4.5	2.9	2.2	4.7
Outdoor work/summer	14.4	5.0	4.5	3.6	6.0	4.8
Playground games	13.9	4.9	5.0	3.7	6.0	5.4
Playing piano	14.1	1.7	2.5	1.2	1.5	2.7
Playing violin or cello	14.8	1.7	2.4	1.4	1.5	2.5
Playing with puzzles and board games	12.7	1.6	1.5	1.2	1.5	1.7
Reading sitting	13.2	1.0	1.0	1.2	1.5	1.1
Rollerblading	11.0	6.5	12.5	8.2	6.0	9.2
Rope jumping (skipping)	12.9	8.3	8.0	6.4	6.0	8.9
Schoolwork sitting	12.2	1.4	1.8	1.2	1.5	2.0
Setting table	11.9	2.6	2.5	2.9	2.2	2.8
Shoveling	12.8	4.3	5.0	4.0	6.0	5.5
Singing sitting	10.2	1.4	1.5	1.2	1.5	1.7
Singing standing	10.2	1.6	2.0	1.4	1.5	2.3
Sitting quietly	14.0	1.4	1.0	1.2	1.5	1.1
Soccer	15.6	8.8	7.0	5.6	6.0	7.7
Standing quietly	13.5	1.5	1.2	1.4	1.5	1.3
Step aerobics	14.1	6.2	8.5	6.8	6.0	9.2
Stretching	12.9	2.5	2.5	2.2	1.5	2.8
Sweeping	13.0	3.6	3.3	2.9	2.2	3.6
Swimming front crawl 0.9 $m \cdot s^{-1}$	12.4	8.4	9.1	5.9	6.0	10.1
Swimming front crawl 1.0 $m \cdot s^{-1}$	12.1	9.9	9.8	6.4	6.0	10.9
Swimming front crawl 1.1 $m \cdot s^{-1}$	12.4	11.6	10.7	7.0	6.0	11.9
Television watching, lying down	10.0	1.1	1.0	1.1	1.5	1.2
Television watching, sitting	12.1	1.2	1.0	1.2	1.5	1.1
Vacuuming	12.9	4.2	3.5	2.9	2.2	3.9
Washing the dishes	12.8	1.9	2.3	2.2	2.2	2.5
Weaving	9.5	1.8	1.5	1.2	1.5	1.8
Weightlifting	13.8	2.7	3.0	2.9	2.2	3.3

Sallis METs were calculated using a modification of the technique recommended by Sallis et al. (37).

+ 0.46; r = 0.61, SEE = 1.38 METs. The walking MET prediction equation was on the basis of 1187 data points: 0.07 age − 1.21 speed (meters per second) + 1.65 speed^2 (meters per second) + 1.72; r = 0.65, SEE = 1.0 MET. The studies used to collect the data for the running and walking analyses are available by request to the authors.

TABLE 3. Results of Bland–Altman analyses comparing techniques for assigning energy costs to children as METs.

Technique	Bias	SEM	Upper LoA	Lower LoA	ICC
Adult vs child METs	−0.03	1.19	−2.36	+2.30	0.91
Torun vs child METs	−0.85*	1.23	−3.26	+1.56	0.80
FAO vs child METs	−0.56*	1.43	−3.36	+2.24	0.80
Modified Sallis technique vs child METs	+0.37	1.36	−2.30	+3.04	0.89

−, estimated child values higher than assigned values; +, estimated child values lower than assigned values.
* Significant difference as determined by paired t-test, $P < 0.05$.

DISCUSSION

The Bland–Altman analyses revealed that using adult METs would have been the most accurate technique to assign energy costs to children in the 51 selected non-locomotor activities if measured values had not been available. Overall, published adult METs were slightly lower than the estimated child METs calculated using measured $\dot{V}O_2$ data (bias = −0.03 METs). The adult METs technique produced the lowest bias and the tightest limits of agreement compared to the other techniques. Energy costs were also underestimated using the Torun

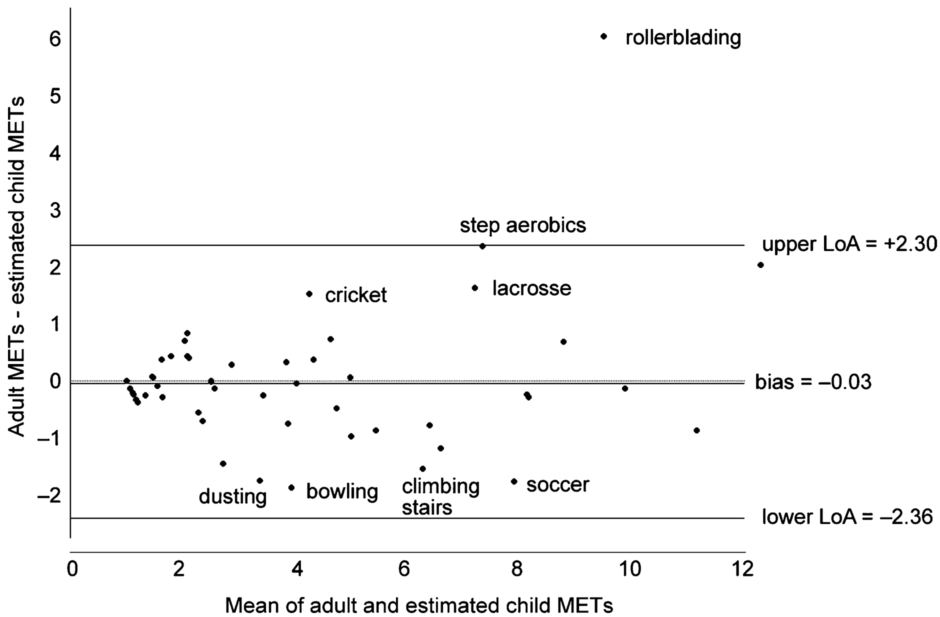

FIGURE 1—Bland–Altman plot (bias and limits of agreement) for the energy cost of children's activities estimated in child METs (on the basis of measured $\dot{V}O_2$ values) and predicted by adult METs. Selected activities with the greatest discrepancies in MET costs are labeled.

METs and FAO/WHO/UNU METs techniques. Although the METs calculated using the modified Sallis correction factors overestimated the child METs, the values were not significantly different statistically. It is important to note that these comparisons were on the basis of only 51 activities, so the results should be interpreted with caution.

Using adult values to predict child energy costs of continuous running and walking has been shown to produce significant biases (37). Previous research suggests that the $\dot{V}O_2$ of walking and running increases with speed but decreases with age (2,37). However, within this data set, the MET cost of walking and running (as opposed to the $\dot{V}O_2$) was found to generally increase with speed and increase with age. This finding is consistent with Torun's findings that the MET cost of walking and moving around increases with age from preschool years to adolescence (47). Hence, Torun's recommendation for assigning METs to heavy activities involves applying correction factors that get progressively closer to 1.0 with increasing age, this is, 0.65 for 6.0 to 12.9 yr olds and 0.80 for 13.0 to 14.9 yr olds. These findings suggest that although both RMR and oxygen cost of locomotion decrease with age, the declines do not occur at a proportional rate. It may be that the oxygen cost of locomotor activities remains elevated compared to changes in RMR because of the inefficiency in gait in children (9,35,36). Alternatively, the oxygen cost of running and walking may remain relatively stable, in comparison to other activities, as children may be *relatively* more efficient at running and walking than at other tasks (such as household chores), as running and walking are more practiced activities. In addition, the environmental factors related to a child living in an adult's world (e.g., table heights, size of equipment, etc.) are not as influential during running and walking as children are usually able to self-select their gait pattern without having to maneuver around or use adult-sized paraphernalia. Hence, changes in the oxygen cost of running and walking may be less evident than in other activities. As the MET cost of walking and running is significantly influenced by age, adult MET values should not be used to assign energy costs to children for these activities.

The analysis of everyday nonlocomotor activities found that eight activities resulted in mean differences of Œ1.5 METs. The energy costs of rollerblading (+6.0 METs), step aerobics (+2.3), lacrosse (+1.6), and cricket (+1.5) were overestimated using adult METs, whereas bowling (−1.8 METs), soccer (−1.7), dusting the table (−1.7), and climbing stairs (−1.5) were underestimated. As the walking and running analyses revealed inaccuracies when using adult METs to assign costs to children, these sporting and household chore activities that involve interspersed periods of walking and running at various intensities may be more poorly estimated using adult METs. Another likely explanation for the increased mean error in these activities is the variation in speed and intensity possible within many of these activities. In particular, the rollerblading METs in the adult compendium may be on the basis of a faster speed than the child study (i.e., 1.4–3.6 $m \cdot s^{-1}$). It is important to note that complications arising from individual variations in intensity, and so on, are not limited to energy cost assignments in children. Researchers working with adult data are also conscious of the limitations of using compendia-derived EE. Ainsworth et al. (1) warn that: "It (the compendium) does not take into account individual differences when estimating the energy cost of physical activity in individuals."

The modified Sallis technique was relatively successful at predicting the MET cost of the 51 measured activities.

However, because the technique involves applying correction factors >1.0 to adult values, large errors occurred when the estimated child METs, on the basis of measured $\dot{V}O_2$ values, were lower than the published adult METs (e.g., rollerblading and step aerobics). It seems that the adjustments recommended by Torun (47) were inaccurate in heavy activities where the adult MET cost was less than the measured child MET cost, for example, swimming, basketball, and soccer. In these activities, the Torun-recommended adjustment factors of 0.65 or 0.80 widen the gap between child and adult values and subsequently underestimate the energy cost in children. The FAO/WHO/UNU recommendations were limited by a maximum MET allocation of 6.0, as many of the activities reviewed had measured energy costs >6.0 METs.

Limitations. There are some limitations in this study that should be acknowledged. Although the analyses incorporated all published energy cost data available at the time the study was undertaken, the combined data set contains a limited range of activities. Predicted, rather than measured, RMR was used to calculate METs. As the RMR equations use age as a predictor variable, differences in RMR between similarly aged children may not have been accounted for. In addition, the range of subjects studied was relatively narrow. The energy cost studies typically involved normal-weight white children. Therefore, further research is required to confirm whether using adult METs to assign energy costs to children is effective across a wide range of activities and across diverse populations of children. The method of data generation should also be considered. Raw data from each study were not used in the analyses. The data generated using the Monte Carlo technique assume the data sets were normally distributed, and this may not have been the case in all studies. Although this is likely to have marginal effect on the sample-weighted mean MET scores for each activity and the walking and running regression equations, the estimations may be less accurate than if raw data were used. Finally, as acknowledged previously, the Sallis technique was modified to report energy costs as METs rather than oxygen consumption in units of milliliters per kilogram per minute.

CONCLUSION AND RECOMMENDATIONS

In conclusion, although compendia of EE exist for adults (1), there is a lack of data on the energy cost of everyday activities in children. Nevertheless, this study provides evidence that adult METs are the best existing technique to assign energy costs to children in most activities when measured values are not available. However, as adult METs are inaccurate in assigning energy costs to children in continuous running and walking activities, predictive equations on the basis of age and speed should be used. This study provides support for the recommendations of Harrell et al. (13), that is, when research designs require calculation of gross EE expressed as joules, calories, or oxygen cost per unit body mass, adult METs should be multiplied by a child-specific RMR either measured or estimated.

Clearly, there is a need for more studies investigating the energy cost of activities in a wide range of groups, varying in age, ethnicity, and body composition, to allow for comparison. In addition, the breadth of measured activities needs to be widened. For example, there are very few data regarding sports and playground games undertaken by children. As many of these activities are also missing from adult compendia (1), it is even more imperative that energy cost data in these activities be collected. The extensive literature search undertaken in this article provides energy cost data that can serve as a basis for the development of a compendium of physical activities for children.

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