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Comparison of the TriTrac-R3D accelerometer and a self-report activity diary with heart-rate monitoring for the assessment of energy expenditure in children

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Determining total energy expenditure (EE) in children under free-living conditions has become of increasingly clinical interest. The aim of this study was to compare three different methods to assess EE triaxial accelerometry (TriTrac-R3D; Professional Products, Division of Reining International, Madison, WI, USA), activity diary and heart-rate (HR) monitoring combined with indirect calorimetry (IC). Twenty non-obese children and adolescents, aged 5.5 to 16.0 years, participated in this study. Results from the three methods were collected simultaneously under free-living conditions during the same 24 h schoolday period. Neither activity diary (5904 (SD 1756) kJ) nor the TriTrac-R3D (6389 (SD 979) kJ) showed statistical differences in 24 h total EE compared with HR monitoring (5965 (SD 1911) kJ). When considering different physical activity (PA) periods, compared with HR monitoring, activity diary underestimates total EE during sedentary periods ($P<0{\cdot}001$) and overestimates total EE and PA-EE during PA periods ($P<0{\cdot}001$) because of the high energy cost equivalence of activity levels. The TriTrac-R3D, compared with HR monitoring, shows good agreement for assessing PA-EE during PA periods (mean difference +0·25 (SD 1·9) kJ/min; 95 % CI for the bias −0·08, 0·58), but underestimates PA-EE and it does not show good precision during sedentary periods (−0·87 (SD 1·4) kJ/min, $P<0{\cdot}001$). Correlation between the vector magnitude generated by the TriTrac-R3D accelerometer and EE of activities derived from HR monitoring is high. When compared with the HR method, the TriTrac-R3D and activity diary are not systematically accurate and must be carefully used for the assessment of children's EE depending on the purpose of each study.

Energy expenditure: Accelerometry: Activity diary: Heart-rate monitoring: Physical activity

Energy balance problems occur frequently in patients referred to a children's hospital. Failure to thrive, undernutrition and obesity are pathologies which need a correct evaluation at diagnosis and posterior controls. Theoretically, under free-living conditions, a combination of energy intake and energy expenditure (EE) could allow an estimate of energy balance in each subject. Total daily EE in children and adolescents is made up of resting (EE), diet-induced thermogenesis, physical activity (PA) and growth (Durnin, 1991). Resting EE is 60–70 % total daily except in those children who are involved in high-energy aerobic competitive sports (World Health Organization, 1985) or, in contrast, in children with a disease which increases resting EE such as cystic fibrosis (Turck & Michaud, 1998). Diet-induced thermogenesis constitutes 5–10 % total daily EE, PA is 25–30 % total daily EE, and growth on a daily basis is too small to measure except in rapidly growing infants.

The measurement of total EE has been a research procedure under laboratory conditions involving the use of cumulative heart-rate (HR) monitoring and indirect calorimetry (IC; ventilated hood system or whole-body method

Abbreviations: EE, energy expenditure; HR, heart-rate; IC, indirect calorimetry; MET, metabolic equivalent tasks; PA, physical activity.

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in a chamber) (Schutz & Deurenberg, 1996). Nowadays, the development of computerized indirect calorimeters, min-by-min HR monitoring, doubly-labelled water ($^2H_2^{18}O$) and accelerometry techniques have made the measurement of total EE under free-living conditions and as a clinical tool possible (Gottrand, 1998). The $^2H_2^{18}O$ method, which is accurate during long-term EE determinations under free-living conditions, has two main disadvantages: (1) the high cost of the isotope ^{18}O and of analysis by spectrometry; (2) it gives a mean value of total daily EE for a period of 1–2 weeks, but it is not possible to measure EE during short-term PA periods or to analyse PA behaviours (Schutz & Deurenberg, 1996; Gottrand, 1998).

HR monitoring is a non-invasive, socially acceptable and accurate method in groups of children (Livingstone *et al.* 1992). It is based on the observation that when O_2 consumption increases is also associated with an increase in HR. This relationship varies among different individuals, so that individual calibration curves must be generated for each subject by calorimetry and HR monitoring, reflecting different intensities of exercise during free-living conditions (Livingstone *et al.* 1992; Bitar *et al.* 1995). Accelerometry techniques, especially triaxial accelerometers, were developed to detect body acceleration in the three planes of a space and it has been shown that it is an objective method to distinguish differences in activity levels between and within individuals (Welk & Corbin, 1995; Westerterp, 1999), but has low sensitivity for sedentary activities in adults (Bouten *et al.* 1997).

The objective of the present study was to compare measurements of EE in children under free-living conditions, obtained by three different method: (1) triaxial accelerometry; (2) activity diary; (3) HR monitoring with individual EE regression equations performed by IC.

Methods

Subjects

Twenty non-obese children, seven girls and thirteen boys, aged 5.5 to 16.0 years, all volunteers, participated in the current study after the purpose and the objectives were carefully explained (Table 1). All subjects passed a thorough physical and medical examination and were considered not to have any acute conditions (such as infection) known to interfere with EE. Written informed consent was obtained from children and parents, and the study was approved by the Lille University Research Ethical Committee (Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale).

Protocol

Subjects arrived by car at the Clinical Investigation Centre of Lille University Hospital, Lille, France (CIC-9301-INSERM-CHU) at 08.00 hours after a 12 h fast. Weight and height were first measured. Resting EE, postprandial EE and EE during PA were measured by IC with an adaptation period of 15 min under the ventilated canopy system before each measurement period. Resting EE was obtained for 30 min and postprandial EE after having breakfast. Breakfast provided approximately 20 % daily energy requirements for each child (World Health Organization, 1985) and was made up of milk, sugar, fruit juice, butter, jam and bread. EE was determined 2 hours after having breakfast during PA (described later). HR monitoring was obtained during all measurement periods. Results from the morning session were used to perform the individual regressions of HR *v.* EE. After this 'laboratory validation period', on the same day measurement of 24 h total EE under free-living conditions began. At the same time,

Table 1. Physical characteristics of subjects

Subjects	Sex	Age (years)	Height (m)	Weight (kg)	BMI (kg/m^2)
1	M	5·50	1·120	17·9	14·2
2	F	5·50	1·069	19·4	16·9
3	M	6·25	1·261	24·0	15·0
4	M	6·32	1·278	27·2	16·6
5	M	6·50	1·220	21·2	14·2
6	M	6·72	1·204	23·5	16·2
7	M	8·00	1·253	25·0	15·9
8	M	9·75	1·430	30·9	15·1
9	M	11·50	1·421	34·2	16·9
10	F	12·00	1·400	30·1	15·3
11	F	13·35	1·435	35·2	17·0
12	M	14·00	1·442	39·5	18·9
13	F	14·00	1·540	41·2	17·3
14	M	14·16	1·500	42·3	18·8
15	M	14·32	1·485	41·3	18·7
16	M	14·32	1·574	48·0	19·3
17	F	14·90	1·460	36·6	17·1
18	F	15·00	1·584	55·0	21·9
19	M	15·00	1·520	40·2	17·3
20	F	16·00	1·701	63·7	22·0
Mean (SD)		11·15 (3·8)	1·394 (0·166)	34·8 (12·0)	17·2 (2·2)

M, male; F, Female.

each child wore the triaxial accelerometer (TriTrac-R3D; Professional Products, Division of Reining International, Madison, WI, USA) and a HR recorder Holter 24–48 h recorder (synesis, ELA medical, Montrouge, France) for a 24 h period, carefully writing down each different activity and its duration in the activity diary. The free-living measurement day was chosen to be a usual school day.

Resting energy expenditure and postprandial energy expenditure by indirect calorimetry

EE was measured by an indirect open-circuit ventilated hood system, Deltatrac II (Datex Instrumentation Corporation, Helsinki, Finland). The RER was calibrated by alcohol-burning tests every 6 months according to the calorimeter's manufacturers (Datex Instrumentation Corporation). The calorimeter's manufacturer's certified a CV $<2\,\%$ for each measurement of V_{CO_2}, V_{O_2} flows and the RER. Before each measurement, gas analysers were calibrated with a reference gas mixture (CO_2–O_2, 5:95 v/v, Datex Instrumentation Corporation), and the flow transducer was tested by injecting a known standard volume repeatedly (Matarese, 1997). Expired CO_2 (V_{CO_2}) and inspired O_2 (V_{O_2}) flows were recorded as well as the RER. EE was calculated min-by-min from O_2 consumption (V_{O_2}, ml/min) and CO_2 production (V_{CO_2} ml/min) using the Weir (1949) formula without protein correction: EE (kJ) = $(3{\cdot}9 \times V_{O_2} + 1{\cdot}1 \times V_{CO_2} \times 6{\cdot}02)$. After an adaptation period of 15 min, continuous respiratory exchange measurements were initiated. During resting EE and postprandial EE measurements, children rested quietly in a bed watching videotapes. Only steady-state values were taken into account for analysis (data with a CV $< 10\,\%$ for both V_{O_2} and dilution air flow, and $<5\,\%$ for RER).

Energy expenditure during physical activity period by indirect calorimetry

EE during PA was determined by IC for consecutive levels of calibrated physical exercise consisting of cycling on a cycloergometer (CARE 910, Bobigny, France), beginning at 0 W and increasing the braking force ever 30 s, 2·5 W for children aged <12 years and 5 W for children aged >12 years, in order to obtain maximal HR close to the theoretical maximal heart frequency (220 − age (years)). The seat height, handlebars and pedal crank of the cyclergometer were adjusted to the child's size. The pedalling rate was imposed by the cyclergometer screen at 50 rotations/min.

Heart-rate monitoring

The heart-rate recorder (ELH medical) had two channels of electrocardiographic data. This recorder has an event marker and a continuous digital time display that were used to note the different times of the study and to synchronize HR and EE data. HR values defined as the mean of the HR recorded ever min over the specific time periods were calculated with the SYNETEC software (version 1.1; ELA medical).

Individual regression equations of heart-rate v. energy expenditure and measurement of total energy expenditure by heart-rate monitoring

Results for HR and EE, recorded simultaneously during laboratory periods (at rest and during postprandial and PA periods), were used to calculate individual polynomial third-order non-linear regression equations (HR *v.* EE) as described by Bitar *et al.* (1995). EE and HR were recorded by techniques explained earlier.

Total EE measured by heart-rate monitoring (total EE_{HR}) under free-living conditions was derived from the min-by-min recorded HR by reference to the subject's regression equation for EE *v.* HR. PA-EE by HR monitoring ($PA\text{-}EE_{HR}$) was calculated with the formula:

$$\mathrm{PA{-}EE_{HR}(kJ/min) = total\ EE_{HR}(kJ/min)} \\ \mathrm{- resting\ EE(kJ/min)},$$

where resting EE value is obtained by IC. During the night, HR is often lower than in resting periods and HR–EE equations overestimate night-time EE compared with IC. We therefore used the formula resting EE − resting EE/10 to compute night-time EE in children (Beghin *et al.* 2000).

Total energy expenditure by accelerometry

Total EE measured by triaxial accelerometry (total EE_T) under free–living conditions was obtained with the Tri-Trac–R3D (Professional Products, Madison, WI, USA). The device weighs 170 g and measures $12 \times 6{\cdot}5 \times 2{\cdot}2$ cm. It measures acceleration in three individual planes and integrates acceleration to yield one value called 'vector magnitude' (square root of the sum squared of activity counts in each vector). The formula used to convert the 'vector magnitude' to EE from PA is a proprietary formula which will not be released by the manufacturer. Total EE_T (kJ/min) is calculated at 1 min intervals by TriTrac-R3D software with the 'vector magnitude' and subject's age, sex, height and weight (Hemokinetics Inc, 1993; Westerterp, 1999). The TriTrac-R3D was worm firmly attached to the anterior torso of the subject at the level of the waist, perpendicular to the mid-line of the anterior thigh.

Total energy expenditure by activity diary

Children and participating parents were instructed to keep detailed self-reports on the types of behaviours and the times at which these active behaviours began and ended during the 24 h period when accelerometer and HR monitoring equipment were worn. Upon return of the self-report sheets, they were reviewed by a trained staff member and discrepancies were resolved with the parent and child. Only activities recorded for duration of 10 min or more were considered in the comparsion analyses between methods. Activity was converted to multiples of resting metabolic rate in kJ/kg per h using metabolic equivalent tasks (MET) using values from a compendium of PA (Ainsworth *et al.* 1993). The questionnaire was scored for the activity categories of sedentary (1·0–2·0

MET), light–moderate PA (2·5–5·0 MET) and hard PA (>5 MET). PA-EE by activity diary (PA–EE_{AD}) was calculated with the formula:

$$PA-EE_{AD}(kJ/min) = total\ EE_{AD}\ (kJ/min) - resting\ EE_{AD}(kJ/min),$$

where resting EE_{AD} is the resting metabolic rate with a corresponding MET value of 1.

Statistical analysis

Since duration of different measurement periods varied, with resting periods usually longer than PA periods, mean EE values were expressed in kJ/min to avoid the influence of period duration and to allow comparison of results. Results are expressed as mean values and standard deviations. Paired *t* tests were used to compare mean differences between the TriTrac–R3D self–reported activity and HR monitoring EE during measuring periods. A linear regression analysis was used to examine the relationship between EE derived from the TriTrac–R3D, self-reported activity and HR monitoring measurements. Agreement between methods for determining EE was assessed using the Bland & Altman (1986) method. The lack of agreement between methods can be evaluated by calculating the bias estimated by the mean difference, standard deviation of the difference and CI for the bias. Correlations were tested using the Spearman test with significance set at $P<0·05$ Statistical analyses were performed using SPSS (version 7.0 for Windows, SPSS, Chicago, IL, USA).

Results

Total EE_{HR} under 24 h free-living conditions in this group of children was 5965 (SD 1911) kJ/d. There were no statistical differences between total EE_{HR} and total EE_T (6389 (SD 979) kJ/d, r^2 0·73) but the mean difference total EE_{HR} − total EE_T was −424 (SD 1184) kJ/d (Fig. 1(a)), 95 % CI for the bias was −978, 130 and the 95 % CI for the lower and upper limit of agreement were −3753, −1833 and 984, 2905 respectively. These intervals are wide, reflecting the small sample size and the great variations of differences. Between total EE_{HR} and total EE_{AD} (5904 (SD 1756) kJ/d, r^2 0·72) there were no statistically significant differences, but the mean difference total EE_{HR} − total EE_{AD} was 58 (SD 1013) kJ/d (Fig. 1(a)), 95 % CI for the bias was −414, 534 and the 95 % CI for the lower and upper limit of agreement were −2788, −1145 and 1265, 2908 respectively. These intervals are as wide as those reported in the Fig. 1(a).

Using an activity diary, 402 different periods could be distinguished according to the level of activity, summarizing all twenty subjects' 24 h period data (122 periods of PA, 258 periods of sedentary activity and twenty sleeping periods). The results of correlation and statistical difference analysis are shown in Table 2. Comparing the activity diary with HR monitoring, total EE_{AD} was significantly higher than total EE_{HR} during PA periods, but lower during sedentary periods; when analysing PA-EE, results remained significantly higher during PA periods. In contrast, during sedentary activity periods there were no statistical differences between activity diary and HR monitoring results even though correlation between these two methods remained low (r^2 0·38). When comparing total EE_{HR} and total EE_T there were only statistical differences during PA and sleeping periods and the TriTrac-R3D overestimated total EE during these periods. When analysing PA-EE by HR monitoring and the TriTrac-R3D, there were no differences during PA periods, although significant differences were observed during sedentary periods.

In general, compared with EE measurements by HR monitoring, TriTrac-R3D differences were smaller than activity diary differences (Table 2). We can summarize

Table 2. Energy expenditure measured by heart-rate monitoring, activity diary and a triaxial accelerometer (TriTrac-R3D‡) §
(Mean values and standard deviations for twenty children and adolescents)

Measurement method...		HR monitoring (kJ/min)		Activity diary (kJ/min)			TriTrac-R3D (kJ/min)		
	n	Mean	SD	Mean	SD	r^2‖	Mean	SD	r^2‖
Total EE all periods	402	5·01	2·5	5·35*	3·2	0·84	5·09†	1·8	0·93
Total EE physical activity periods	122	5·76	2·9	7·81***	4·5	0·68	6·22*	2·3	0·83
Total EE light–moderate physical activity	102	5·47	2·8	6·22***	2·3	0·83	5·93*	2·1	0·82
Total EE hard physical activity	20	7·35	7·6	16·0***	4·0	0·73	7·81†	3·0	0·88
Total EE sedentary periods	258	4·80	2·1	4·43***	1·5	0·80	4·68†	1·1	0·91
Total EE sleeping periods	20	2·96	0·6	2·38***	1·0	0·66	3·67***	0·5	0·87
PA-EE all periods	402	2·30	2·3	3·21***	3·1	0·36	1·58***	1·7	0·51
PA-EE physical activity periods	122	3·05	2·7	5·76***	4·3	0·54	2·80†	2·2	0·71
PA-EE light–moderate physical activity	102	2·67	2·4	4·01***	1·6	0·62	2·46†	1·9	0·66
PA-EE hard physical activity	20	4·76	3·3	14·0***	3·9	0·63	4·43†	2·9	0·80
PA-EE sedentary periods	258	1·92	1·8	1·92†	0·8	0·38	1·00***	0·9	0·54

EE, energy expenditure; HR, heart-rate; PA, physical activity.
Mean values were significantly different from those measured by HR monitoring (*t* test): *$P<0·05$, ***$P<0·001$.
Mean values were not significantly different from those measured by HR monitoring (*t* test): †$P>0·05$.
‡ Professional Products, Division of Reining International, Madison, WI, USA.
§ For details of subjects and procedures, see Table 1 and p. 624.
‖ r^2 from linear regressions of EE measured by HR monitoring, *v*. EE measured by activity diary or TriTrac-R3D.

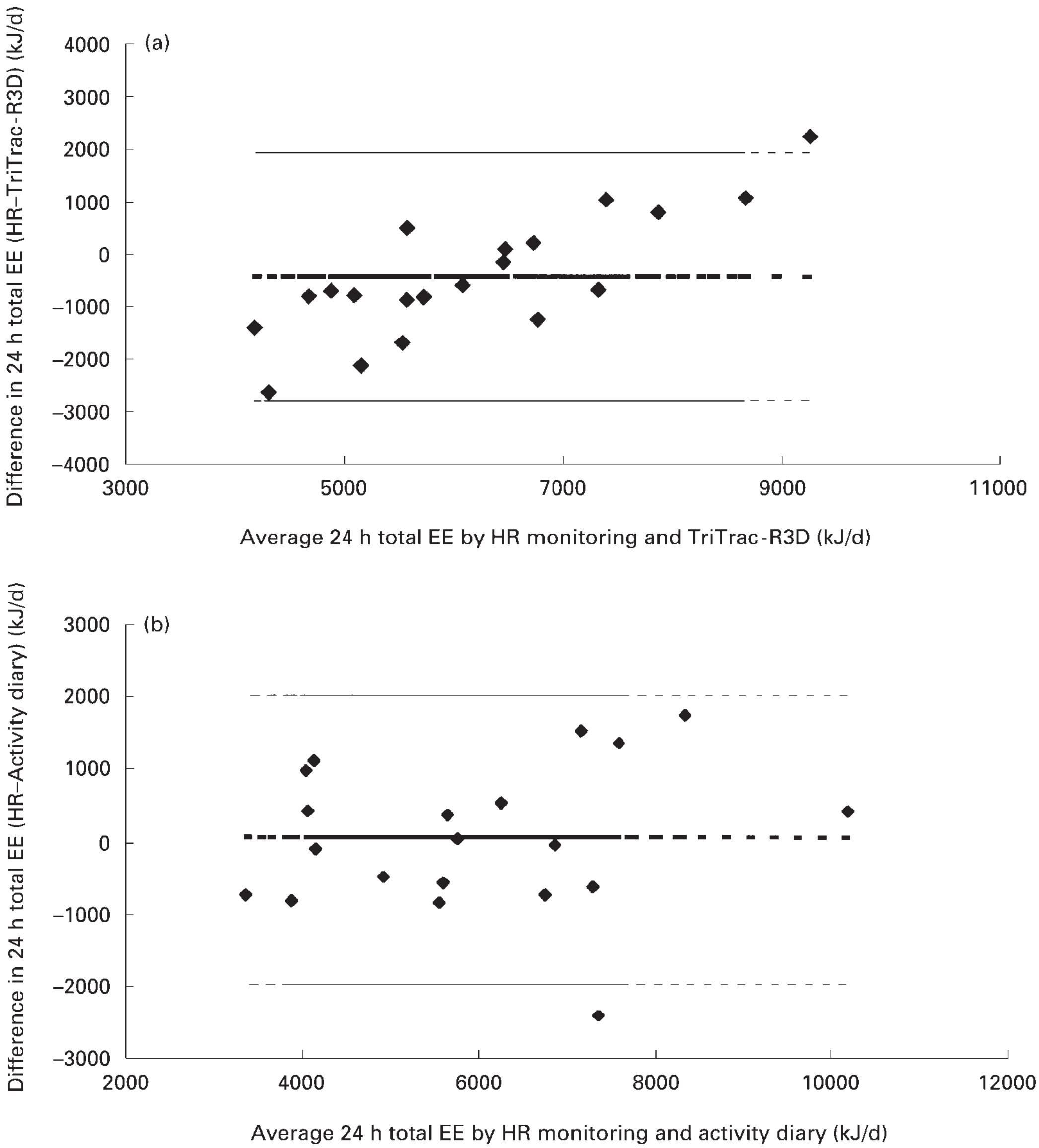

Fig. 1. Difference against mean for 24 h total energy expenditure (EE) results assessed by (a) heart-rate (HR) monitoring and axial accelerometer (TriTrac-R3D; Professional Products, Division of Reining International, Madison, WI, USA), (b) HR monitoring and activity diary (Bland & Altman (1986) plots). For details of subjects (*n* 20) and procedures, see Table 1 and p. 624. **---**, Mean value; -—-, + or −2 SD.

the lack of agreement between TriTrac-R3D and HR monitoring PA-EE measurements by calculating the bias, estimated by mean difference and the standard deviation of differences (Table 3). During sedentary periods, PA-EE mean difference was very large (−0·87 (SD 1·4) kJ/min; 95 % CI 0·66, 1·04). In a Bland–Altman plot, the difference between TriTrac-R3D and HR monitoring against mean PA-EE during all measurement periods is represented in Fig. 2. The scatter of the differences increases as mean PA-EE increases and then, agreement would be wider apart than necessary for small PA-EE. In contrast, when a logarithmic transformation was used to avoid a possible relation between the differences and the mean PA-EE, results showed better agreement for the higher mean values (Fig. 3). In addition, we found the best agreement between PA-EE data during PA periods with a mean difference $PA\text{-}EE_{HR} - PA\text{-}EE_{T}$ of 0·25 (SD 1·9) kJ/min, the 95 % CI for the bias was −0·08, 0·58 and the 95 % CI for the lower and upper limit of agreement were −4·3, −3·1 and 3·6, 4·8 respectively (Fig. 4). Correlation between the vector magnitude generated by the TriTrac-R3D accelerometer and PA-EE of all activities derived from HR in each children is high: r^2 ranged from 0·51 to 0·90 ($P < 0·001$, Spearman correlation).

Discussion

Assessment of EE in human subjects under free-living conditions is limited to very few practical methods. The $^2H_2^{18}O$ method is considered accurate for long-term EE determinations but it is expensive and total EE components cannot be measured (Schutz & Deurenberg, 1996;

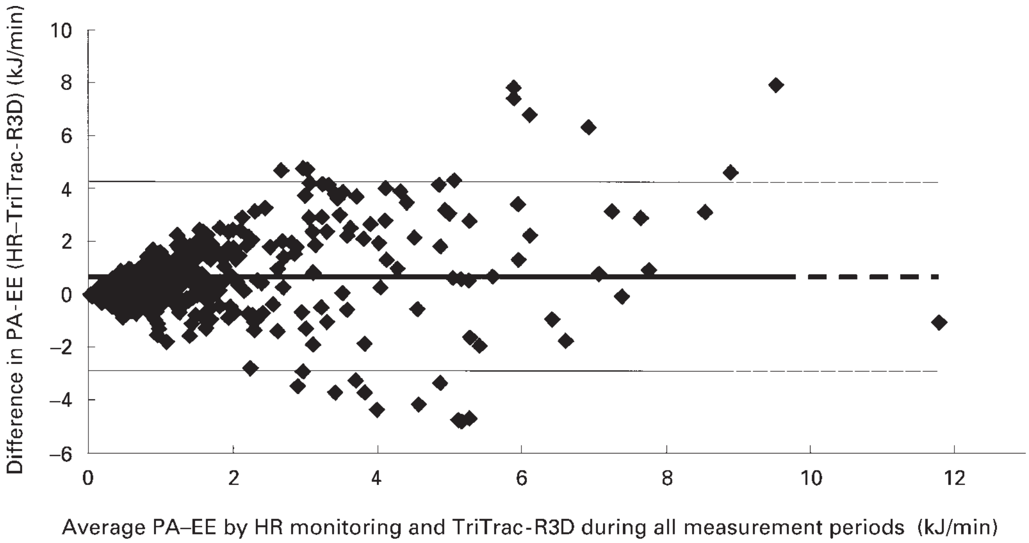

Fig. 2. Difference against mean for physical activity (PA) energy expenditure (EE) results during all measurement periods assessed by heart-rate (HR) monitoring and axial accelerometer (TriTrac-R3D; Professional Products, Division of Reining International, Madison, WI, USA) (Bland & Altman (1986) plot). For details of subjects (*n* 20) and procedures, see Table 1 and p. 624. ---, Mean value; –––, + or − 2 SD.

Gottrand, 1998). In contrast, HR monitoring allows a close estimation of total EE and its components when an individual regression equation of HR *v.* EE is determined previously. This method is inexpensive, objective, simple and popular with subjects. HR monitoring is appropriate and accurate for predicting group estimates of habitual total EE and levels of PA in free-living adults and children (Livingstone *et al.* 1992; McCrory *et al.* 1997). For calculation of individual prediction equations of EE from HR, we have used in the present study a single third-order polynomial relationship which has shown the best fit in children (Bitar *et al.* 1995; Beghin *et al.* 2000).

Because of the disadvantages of the reference methods in the assessment of total EE or PA-EE, especially in young children, other less accurate methods are used under free-living conditions (Schutz & Deurenberg, 1996; Gottrand, 1998). Self-report activity diaries have been found to provide close estimation of total EE in adolescents and children compared with the results of $^{2}H_2^{18}O$ or physical working capacity by HR (Bouchard *et al.* 1983; Bratteby *et al.* 1997*a*), and it has also been used to compare EE and daily levels of PA between different groups of population (Sallis, 1991; Bratteby *et al.* 1997*b*). As well as the activity diary, a new research instrument, the TriTrac-R3D activity monitor (Professional products), has recently been developed and has already shown very high correlation with HR monitoring during free-play situations in children (Welk & Corbin, 1995). The TriTrac-R3D can be used to distinguish differences in activity levels between and within individuals (Westerterp, 1999), but it has limitations in quantifying EE (Jakicic *et al.* 1999). The reliability of estimates of EE using the TriTrac-R3D has also been tested in adults using indirect calorimetry as reference (Jakicic *et al.* 1999; Nichols *et al.* 1999). Inter-instrument and intra-instrument reliability studies show a significant correlation (ranging from 0·73 to 0·92) and differences were not significant during various modes and intensities of exercise (Nichols *et al.* 1999).

Our present study shows total EE and PA-EE results during different level periods of PA, measured using the TriTrac-R3D, self-reporting activity diary and HR

Table 3. Physical activity energy expenditure bias of the triaxial accelerometer (TriTrac-R3D*) compared with heart-rate monitoring†

	n	Mean difference, HR monitoring − TriTrac-R3D (kJ/min)‡		95 % CI for the bias (kJ/min)‡
		Mean	SD	
PA-EE all periods	402	0·66	1·7	0·45, 0·83
PA-EE physical activity periods	122	0·25	1·9	−0·08, 0·58
PA-EE light−moderate physical activity	102	0·25	1·9	−0·12, 2·42
PA-EE hard physical activity	20	0·33	2·3	−0·75, 1·42
PA-EE sedentary periods	258	0·87	1·4	0·66, 1·04

PA, physical activity; EE, energy expenditure.
* Professional Products, Division of Reining International, Madison, WI, USA.
† For details of subjects and procedures, see Table 1 and p. 624.
‡ Mean difference and SD for PA-EE results and 95 % CI for the bias as described by Bland & Altman (1986).

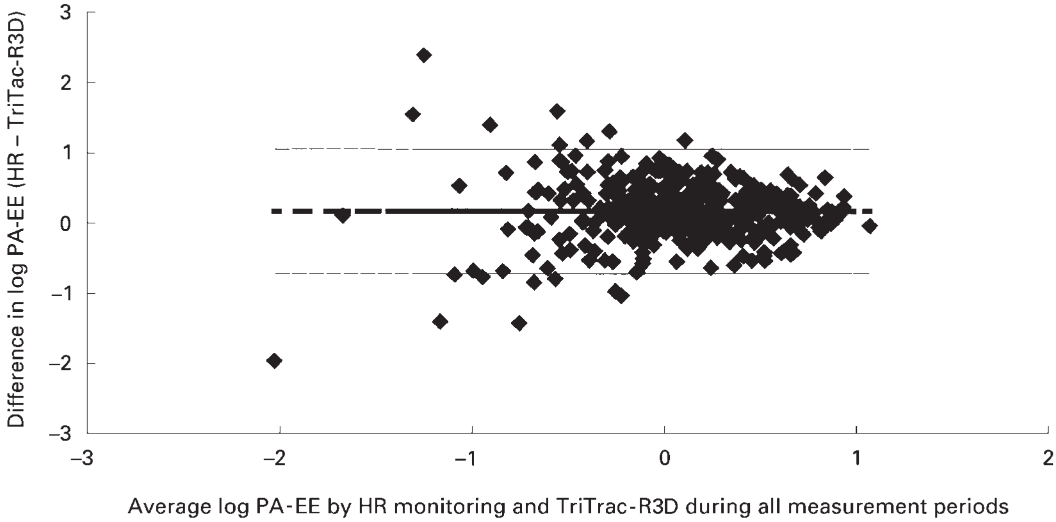

Fig. 3. Difference against mean for physical activity (PA) energy expenditure (EE) results, after logarithmic transformation, during all measurement periods assessed by heart-rate (HR) monitoring and axial accelerometer (TriTrac-R3D; Professional Products, Division of Reining International, Madison, WI, USA) (Bland & Altman (1986) plot). For details of subjects (*n* 20) and procedures, see Table 1 and p. 624. ---, Mean value; ---, + or −2 SD. *y* = log10 (PA-EE by HR) −log10 (PA-EE by TriTrac-R3D); *x* = (log10 (PA-EE by HR) + log10 (PA-EE by TriTrac-R3D))/2.

monitoring performed at the same time, under free-living conditions in the same children population. Considering total daily EE as a whole, the subject sample is probably too limited for a study in children aged 5·5 to 16·0 years. Dividing each measurement day into different PA periods and considering periods of 10 min or more, 402 different periods with 122 PA periods could be analysed, allowing correlation and comparison between the three methods. Free-living conditions have generated a small group (*n* 20) of hard PA periods because an ordinary schoolday was chosen and sustained periods of moderate to vigorous PA are not typical of young people's PA patterns (Armstrong, 1998).

Our self-report activity diary results showed a good correlation with 24 h total EE_{HR} and differences are not significant. Other previous studies have reported the same results compared with $^{2}H_{2}^{18}O$ results (Bratteby *et al.* 1997*a*). When analysing total EE during different activity periods, activity diary overestimates total EE during PA periods and underestimates total EE during sedentary periods. Total EE_{PA} during sleep periods is smaller but PA-EE_{PA} sedentary values do not present differences; obviously, the cause of the underestimation of total EE_{PA} during sedentary periods is an underestimation of resting EE_{PA}. We have considered that 1 MET of the compendium of physical activities is the resting EE_{PA} (Ainsworth *et al.*

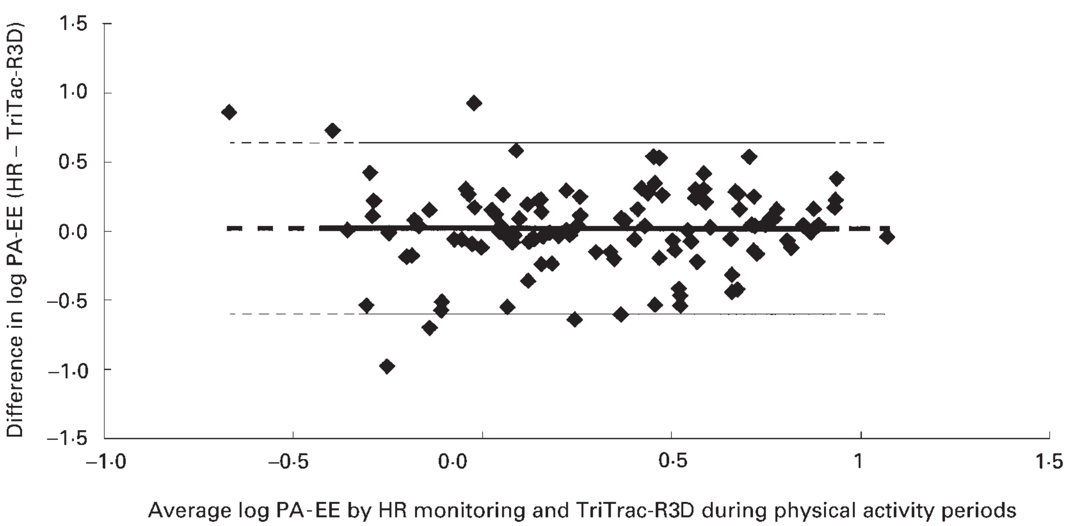

Fig. 4. Difference against mean for physical activity (PA) energy expenditure (EE) results, after logarithmic transformation, during PA periods assessed by heart-rate (HR) monitoring and axial accelerometer (TriTrac-3RD; Professional Products, Division of Reining International, Madison, WI, USA) (Bland & Altman (1986) plot). For details of subjects (*n* 20) and procedures, see Table 1 and p. 624. ---, Mean value; ---, + or −2 SD. *y* = log10 (PA-EE by HR) − log10 (PA-EE by TriTrac-R3D); *x* = (log10 (PA-EE by HR) + log10 (PA-EE by HR) + log10 (PA-EE by TriTrac-R3D))/2.

1993). Similarly, Bouchard *et al.* (1983) used the same equivalence and the energy cost of resting in bed or sleeping was 1 MET. Bratteby *et al.* (1997*a*) improved this latter method with a new denomination: PA ratios (or multiples of resting EE); in that study, resting EE was calculated with a children prediction formula, which avoided resting EE_{PA} underestimation, but maintained categorical activity levels similar to Bouchard's classification: resting in bed is 0·95 PA ratio or 0·95 resting EE value, walking outdoors represents 3·3 PA ratio, work of moderate intensity as dancing or cycling (17–20 km/h) represent 6·5 PA ratio and running (10 km/h) or playing tennis 10 PA ratio. There are at least two factors that could explain the overestimation observed when total EE_{AD} and PA-EE_{AD} are compared with HR monitoring results: (1) under free-living conditions, more than 80 % of children failed to demonstrate a single 10 min sustained period with HR $\geq$140 beats/min (Atkins *et al.* 1997); (2) on revising our total EE data by calorimetry, when children were cycling close to the theoretical maximal heart beat rate, the maximal total EE: resting EE ratio was 4·7 (SD 1·4) PA ratio. This suggests that MET given in the compendium are not well adapted to activities usually accounted in free-living conditions in children. Therefore, an activity diary can be used to compare the time spent at the different categories of PA in population groups and for estimating daily total EE in epidemiological studies (Pols *et al.* 1997), but not for measuring total EE or PA-EE during specific PA periods.

The accelerometer utilizes the 'vector magnitude' movement count to calculate PA-EE for each min and provides an estimate of resting EE using formulas that were developed for healthy adults. These equations overestimate resting EE by 7 % in children (Bray *et al.* 1992; Epstein *et al.* 1996) and the formula used to convert the vector magnitude to EE from PA is a proprietary formula which will not be released by the manufacturer. It is difficult to accept the presentation of results which are based on 'mysterious' calculations that cannot be a matter of discussion. This meant that we have studied in depth, on the one hand, the agreement between the TriTrac-R3D and HR monitoring in the assessment of PA-EE and, on the other hand, the correlation between the real movement variable generated by the accelerometer (vector magnitude) and EE of activities derived from HR monitoring. The results show a good agreement between the two methods in relation with PA-EE measurements only during PA periods and high correlation in all subjects between vector magnitude and PA-EE from HR monitoring.

As shown in Tables 2 and 3, TriTrac-R3D significantly underestimates PA-EE during sedentary periods. This discrepancy has already been observed in adults, TriTrac-R3D underestimates EE compared with the calorimetry method (Jakicic *et al.* 1999). Shortcomings of this technique are its low sensitivity to sedentary activities and the inability to register static exercise (Bouten *et al.* 1994, 1997). Another factor that could explain underestimation of EE by the TriTrac-R3D is that diet-induced thermogenesis is not considered with this technique. Diet-induced thermogenesis in children ranges from 5 to 10 % total EE (Durnin, 1991) and during sedentary periods from 16 almost 100 % PA-EE (Bouten *et al.* 1994). Calorimetry methods can consider diet-induced thermogenesis when individual regression equations of HR *v.* EE are performed, but the accelerometer technique would need a diet-induced thermogenesis correction factor. This would be possible for 24 h total EE measurements but difficult for different PA period EE measurements in children under free-living conditions.

In summary, there are no statistical differences between 24 h total EE measured by HR monitoring and activity diary under free-living conditions in children but, when different periods of PA are considered, activity diary underestimates total EE during sedentary periods and overestimates total EE and PA-EE during PA periods because of the high energy cost equivalence of activity levels. Otherwise, although agreement and correlation between TriTrac-R3D and HR monitoring are good during PA periods, TriTrac-R3D cannot be considered as a valid method for the assessment of total EE or PA-EE in children until adapted formulas are developed in further studies. For the assessment of children's EE under free-living conditions, when compared with the HR method, TriTrac-R3D and the activity diary are not systematically accurate and must be used carefully depending on the purpose of each study.

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