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Validity of resting energy expenditure estimated by an activity monitor compared to indirect calorimetry

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The use of activity monitors (triaxial accelerometers) to estimate total energy expenditure in kilocalories is dependent on the estimation of resting energy expenditure (REE). However, the REE estimated by activity monitors has not been validated against more precise techniques, such as indirect calorimetry (IC). Therefore, the objective of the present study was to compare REE estimated by the Actical activity monitor (ActMon) to that measured by IC and standard prediction equations of REE. Fifty healthy adults between 18 and 43 years of age were measured for weight and percentage of body fat using a digital scale and bioelectrical impedance. The REE estimated by the ActMon was only 129 kJ/d higher, but not statistically different ($P > 0.05$), than the REE measured with IC. Using multiple linear regression, there was a positive relationship for men, but not for women, between fat mass (kg) and percentage of body fat and the difference in REE estimated by the ActMon compared to IC ($P < 0.001$). Therefore, in the cohort studied, the use of an activity monitor to estimate REE is valid when compared to IC, but not to a standard prediction equation of REE.

Activity monitors: Resting energy expenditure: Validation: Indirect calorimetry: Body composition

Activity monitors (i.e. triaxial accelerometer) provide objective estimates of energy expenditure for physical activity (EEPA) by tracking movements in one-, two- or three-axes to estimate EEPA(1,2). Given that the prevalence of obesity continues to increase worldwide(3,4), studying modifiable aspects of energy balance, such as EEPA, has become a priority. Thus, the use of activity monitors has increased greatly as many investigators conduct studies on the aetiology or prevention of obesity(5–7). Recently, some activity monitors have introduced estimates of total energy expenditure (TEE) by coupling estimates of EEPA and resting energy expenditure (REE). However, there is a serious lack of data on the validity of activity monitors to estimate REE, a key and significant component of TEE.

Currently, techniques used to measure TEE or EEPA are either accurate, costly and labour intensive (e.g. doubly labelled water for TEE) or inaccurate, simple and inexpensive (e.g. prediction equations or questionnaires). Doubly labelled water is reported to be as precise as direct calorimetry (± 3–7 %), but can be technically and fiscally prohibitive, especially for investigators in less developed countries(8). On the other hand, prediction equations or questionnaires are relatively inexpensive, but are generally inaccurate in terms of quantifying TEE or EEPA(9–11). Thus, the use of activity monitors to provide an unbiased, objective estimate of EEPA and/or TEE has proven useful for investigators without the financial or technical ability to employ more precise techniques.

Some manufacturers of activity monitors have added a feature that estimates REE, using age, sex, height and weight, and provide a reasonable estimate of TEE by adding the estimated REE to the estimated EEPA(12–15). However, not all of these models have been validated for estimates of TEE, nor have they been shown to produce a reliable estimate of REE. More importantly, it has not been reported whether or not the estimates of REE used by activity monitors are valid for persons of low or high percentage of body fat (BF), results that could over- or underestimate the TEE of thin or obese individuals. In fact, a recent study reported that, while the activity monitor used was valid for TEE, great attention needs to be provided to the estimation of REE(16). Thus, the objective of the present study was to compare the REE estimated by an activity monitor to that measured with indirect calorimetry (IC) and standard prediction equations of REE, in a group of adult men and women to determine the differences in the estimates by either sex or body composition.

Experimental methods

Subjects

We studied fifty healthy men and women who were recruited from the general population of faculty, staff and students at Rutgers University via flyers and announcements. Subjects who had a chronic disease (e.g. cancer,

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Abbreviations: ActMon, Actical activity monitor; BIA, bioelectrical impedance analysis; BF, body fat; EEPA, energy expenditure for physical activity; FM, fat mass; IC, indirect calorimetry; REE, resting energy expenditure; TEE, total energy expenditure.

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type 2 diabetes, etc.), were pregnant, had a history of thyroid disease or were currently taking medication known to influence metabolism (e.g. insulin, over-the-counter diet pills) were excluded from the study. The protocol used in the present study was approved by the Rutgers University Institutional Review Board for the Protection of Human Subjects and informed written consent was obtained from all volunteers.

Anthropometrics

Height was measured to the nearest 0·1 cm using a stadiometer, body weight was measured to the nearest 0·1 kg and percentage of BF was measured to the nearest 0·1 % using a leg-to-leg bioelectrical impedance analysis (BIA) scale (Tanita BF-578, Tanita Corp, Tokyo, Japan).

Indirect calorimetry

REE was measured using IC while the subject was resting, but not sleeping (VMax Spectra 29N, Sensormedics, Inc., Yorba Linda, CA, USA). As we were measuring REE and not basal metabolism, the subjects were allowed to drive to the metabolic unit where they were asked to rest for 30 min before beginning the measurement. All subjects were asked to fast for 12 h and refrain from exercise 16 h before the measurement. No records of dietary intake were kept and the food quotient of the antecedent day was not estimated, as this has been found to influence substrate oxidation, but not REE. While the phase of the menstrual cycle does not have an effect on substrate oxidation(17), there is no real consensus on the influence of the menstrual cycle on REE(17–19), and female participants were measured in any phase of their menstrual cycle. Also, daily exercise can increase REE for up to 24 h(20,21), but we did not ask the subjects to alter their normal exercise routines since we were assessing REE within the subjects under normal living conditions. The REE was measured at 20 s intervals for 30 min and the first 10 min of data were not used in the calculation of REE. Movement during the measurement was minimised by having a staff member remain in the metabolic unit to either wake the subjects who appeared to be sleeping or remind the subjects to remain still. The IC was calibrated before each measurement using a standard gas containing carbon dioxide (4 %) and oxygen (16 %).

Activity monitor

The activity monitor (Actical® physical activity monitor, Mini Mitter, Bend, OR, USA) was programmed according to the manufacturer's instruction by entering the height, weight, age and sex of each subject. The subjects were instructed to place the Actical activity monitor (ActMon) on his or her waist and wear it for the entire time during which baseline readings were measured. The data from the activity monitor were downloaded using the manufacturer's software and then entered into SPSS (SPSS Inc., Chicago, IL, USA).

Prediction equations for estimating REE. Since it is assumed that the proprietary algorithm used is most likely based on a prediction equation to estimate REE, it was of interest to compare the REE estimated by the ActMon with standard equations. The Harris–Benedict and Mifflin equations are two such prediction equations that have been shown to be valid in both normal-weight and obese populations and are often used in research and clinical practices to predict REE(22,23). We used each equation to estimate REE and performed paired *t* tests to compare the value predicted by each equation to that of the ActMon.

Statistical analysis

The subjects were analysed as a group and by sex. The data were normally distributed and differences between the two methods studied were analysed using paired-sample Student's *t* test. Pearson's correlations were calculated to determine the relationship between the REE estimated from the ActMon and that from the IC. The Bland–Altman plots(24,25) of the differences between REE estimated by the ActMon and REE measured using IC *v*. the average of the two methods were used to show the reliability of the REE predicted by the activity monitor. Multiple linear regression analyses were conducted, in which we used the difference in REE between the two methods (REE estimated by the ActMon − REE measured by IC) as the dependent variable and fat mass (FM) and fat-free mass as the independent variables: model 1, FM, fat-free mass, height, sex and age; model 2, percentage of BF, height, sex and age. Only significant predictors of the difference in REE between the two methods were allowed to remain in the analyses. For model 1, while fat-free mass was not a significant predictor, it is a large component of body weight, a key variable used in prediction equations, and was allowed to remain in the analyses. There was significant collinearity between percentage of BF and FM with sex, so the data were split by sex. Also, one male subject was found to be a statistical outlier for FM as determined by a stem-and-leaf plot and test for outliers, but he was left in the dataset as there was no change in the statistical significance of the models when he was excluded from the analyses, and there was no technical or biological reason to believe that his values were spurious. All analyses were conducted using SPSS 13.0 for Windows (SPSS Inc.) and statistical significance was set at $P < 0·05$.

Results

The group studied consisted of nineteen men and thirty-one women with a mean BMI (kg/m^2) of 24·1 and 22·6, respectively, and percentage of BF of 15·8 and 25·4, respectively (Table 1).

The REE predicted by the ActMon was not significantly different from that measured by IC when analysed combined or by sex (Table 2). The Bland–Altman plots of the differences in these values are shown in Fig. 1. When compared to standard prediction equations (Table 2), the ActMon estimated an REE that was not significantly different from the Mifflin equation, combined or by sex, but it did estimate an REE that was significantly lower than the Harris–Benedict equation for the group and each sex ($P < 0·001$). Estimated and measured REE were significantly correlated (Table 3), even when split by sex.

The relationship between the differences in estimated and measured REE and body composition was analysed by sex, as stated previously, and is summarised in Tables 4 and 5.

Table 1. Physical characteristics of the study participants

(Mean values and standard deviations)

	Total sample (*n* 50)		Men (*n* 19)		Women (*n* 31)	
Variable	Mean	SD	Mean	SD	Mean	SD
Age (years)	22·7	4·5	22·2	2·6	23	5·3
Height (m)	1·67	0·01	1·77	0·07	1·62	0·06
Weight (kg)	65·3	12·9	75·1	13·3	59·4	8·2
BMI (kg/m^2)	23·0	2·6	24·1	3·6	22·6	2·3
Percentage of body fat	21·6	7·7	15·8	5·7	25·4	6·3

Table 2. Resting energy expenditure estimated by the Actical activity monitor (ActMon) and standard prediction equations or measured by indirect calorimetry (IC), and the differences between the ActMon estimate and each method

(Mean values and standard deviations)

		ActMon (kJ/d)		IC (kJ/d)		Difference	Mifflin (kJ/d)		Difference	Harris–Benedict (kJ/d)		Difference
Sample	*n*	Mean	SD	Mean	SD	Mean	Mean	SD	Mean	Mean	SD	Mean
All	50	6190	1225	6062	1092	− 129	6222	1020	− 31	6577	1039	− 386*
Men	19	7128	1258	7134	668	− 6	7320	658	− 192	7666	842	− 537*
Women	31	5616	777	5404	712	211	5548	457	68	5910	354	− 294*

*$P < 0.001$.

For men, FM (model 1) and percentage of BF (model 2) each had a significant positive relationship with the difference in REE estimated by the ActMon compared to that measured by IC ($P < 0.001$), such that for those with a low FM or percentage of BF, the ActMon underestimated REE, while for those with a high FM or percentage of BF, REE was overestimated. Similar results were not found for women.

Discussion

The worldwide need to better understand the aspects of daily energy expenditure, such as EEPA, becomes more important as the prevalence of obesity continues to increase worldwide$^{(26-29)}$. Methods to measure TEE and EEPA are needed for large studies of free-living adults, but most accurate methods are technically difficult and prohibitively expensive. Activity monitors are relatively easy to use, accurate and cost-effective tools, which can estimate TEE and EEPA. However, activity monitors that use algorithms to estimate REE, a key component in calculating TEE, have not been evaluated for their reliability. More importantly, the influence of body composition on REE estimated by activity monitors has not been reported. Briefly, we found that the REE estimated by the ActMon was similar to that measured by IC. However, the REE for men was overestimated by the activity monitor as FM or percentage of BF increased. Thus, the use of an activity monitor for estimating TEE may be limited when used in persons with FM or percentage of BF at the extremes, similar to what is expected from traditional prediction equations.

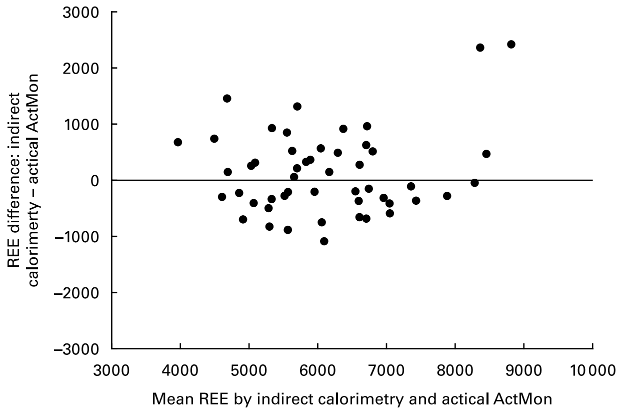

Fig. 1. Bland–Altman plots of the differences in resting energy expenditure (REE, kJ/d) measured by indirect calorimetry (IC) and REE estimated by the Actical activity monitor (ActMon).

The major implication of the present results is that, while the mean estimate from the ActMon differed from IC by only 129 kJ/d (6 kJ/d for men and 211 kJ/d for women), the absolute value of the differences indicated that the ActMon overestimated the REE by 566 kJ/d (636 kJ/d for men and 524 kJ/d for women). For individuals, the difference in estimated *v*. measured REE was as high as 1100 kJ/d. Thus, the use of activity monitors for individual measurements should be conservative since there is a chance of real under- or overestimation of energy requirements. These issues may be relevant when one considers that activity monitors may be used for studies or

Table 3. Correlation between resting energy expenditure estimated by the Actical activity monitor and measured by indirect calorimetry for the total sample as well as for men and women

	Pearson's correlation	*P*
Total sample	0·797	0·000
Men	0·690	0·001
Women	0·666	0·000

Table 4. Multiple linear regression analyses of the relationship between body composition (fat mass and fat-free mass) in men (model 1a) and women (model 1b) and the difference in resting energy expenditure estimated by the Actical activity monitor and indirect calorimetry

Variable	Coefficients	SE	*P*
Model 1a: adjusted	R^2 0·798		
Constant	−2857	862	0·004
Fat mass (kg)	107	18	0·000
Fat-free mass (kg)	24	15	0·134
Model 1b: adjusted	R^2 0·222		
Constant	−3124	1445	0·034
Fat mass (kg)	21	21	0·309
Fat-free mass (kg)	69	36	0·063

Table 5. Multiple linear regression analyses of the relationship between body composition (percentage of body fat (%BF), height, sex and age) in men (model 2a) and women (model 2b) and the difference in resting energy expenditure estimated by the Actical activity monitor and indirect calorimetry

Variable	Coefficients	SE	*P*
Model 2a: adjusted	R^2 0·70		
Constant	−10 156	3307	0·006
%FM	130	21	0·000
Height (cm)	122	47	0·020
Model 2b: adjusted	R^2 0·01		
Constant	−666	442	0·142
%FM	35	17	0·050

%FM, percentage of fat mass.

programmes involving persons who are overweight or obese. It would thus seem prudent for investigators to balance the benefits of a quantitative measure of EEPA, such as using an activity monitor, with the potentially biased estimate of REE due to differences in body compositions; similar issues that already exist with existing prediction equations.

Prediction equations to estimate REE or TEE are reported to be acceptable for large population studies given their ease of use and general reliability(30–32). A limitation of prediction equations is that the differences in body composition can bias estimates, a bias that will carry forward when used to predict TEE. Activity monitors, similar to prediction equations, do not accommodate differences in body composition and the predicted REE may be biased for persons with low or high percentage of BF. As we report, the REE estimated by the activity monitor was similar to one (Mifflin), but significantly different from the other (Harris–Benedict) prediction equation. Hustvedt *et al.* (16) reported that the use of IC coupled with activity monitors can eliminate some bias introduced by prediction equations. Yet, the REE estimated by the ActMon was in close agreement with the Mifflin equation, but not with the Harris–Benedict equation. Nonetheless, the real advantage of using activity monitors is that estimates of EEPA can be coupled with REE to estimate TEE. Also, activity monitors can provide unbiased and quantitative, minute-by-minute or hourly estimates of EEPA to quantify activity patterns, a feature that cannot be met by either prediction equations or doubly labelled water. However, it may be best to promote the use of activity monitors for large groups of normal-weight individuals to minimise the bias introduced by a large FM.

It is important to discuss limitations of the present study. First, each subject was only measured once, thereby not allowing us to estimate the intra-individual variation in REE. Yet, it is unlikely that this factor alone would result in a systematic bias of the differences in REE estimated by the ActMon and IC as there is no reason that all subjects studied would have a higher or lower REE than usual on the day of the study. Second, it would be helpful to conduct additional measurements in which we recruited more men with high body FM as we had only two men with percentage of BF greater than 25, but these results did not influence the fact that REE estimated by the ActMon was close to that measured by IC, the main objective of the present study. Third, to facilitate recruitment and data collection on a relatively large clinical sample, we did not control for all factors that could influence REE, such as daily exercise or menstrual phase, but these factors are not likely to produce a systematic bias of the results. Fourth, there were three pairs of twins who participated in the study, but the relatedness of these twins was not controlled for in our analyses. Finally, BIA, our measure of body composition, is not without criticism. For example, there was no way to ensure that all of the subjects in the present study had the same level of hydration, a factor that is known, during either dehydration or overhydration, to influence body-composition estimates by BIA(33–35). The BIA equipment we used only estimated leg-to-leg body composition and not total body composition, but several studies have reported that leg-to-leg BIA is comparable to total body BIA(34,36).

In conclusion, based on the results of the present study, we found that the ActMon provides a reliable estimate of REE compared to IC, but there may be a potential for the overestimation of both REE and TEE when used on men who have a high FM or percentage of BF, a factor that warrants additional research on more overweight men. Yet, activity monitors can be useful by providing information on EEPA without subject bias. In conclusion, activity monitors are valuable tools, but limitations may exist if used in a cohort with a high proportion of overweight or obese adults and may be inappropriate for individual assessment of energy requirements.

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