Is the Arte*ACC* Index a Valid Indicator of Free-Living Physical Activity in Adolescents?

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Abstract

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Objective: The principal aim of this study was to validate a proposed new index of physical activity, the activity-related time equivalent based on accelerometry (Arte*ACC*), in adolescents. A secondary aim was to develop regression equations for prediction of total energy expenditure (TEE) and activity energy expenditure [AEE = 0.9 × TEE − resting metabolic rate (RMR)].

Research Methods and Procedures: RMR and energy expenditure (EE) under standardized exercises were measured by indirect calorimetry in 36 adolescents (14 to 19 years old). TEE was measured by the doubly labeled water method, and physical activity was assessed simultaneously with an accelerometer for 14 days. AEE, AEE in relation to body weight (AEE per kilogram), and activity-related time equivalent based on energy expenditure (Arte*EE* = AEE/[EE reference activity − RMR]) were calculated from laboratory and free-living EE data. Arte*ACC* was calculated as total activity counts/activity counts of reference activity.

Results: Arte*ACC* was significantly related to AEE per kilogram ($r = 0.57$; $p < 0.0001$) and Arte*EE* ($r = 0.68$; $p < 0.001$). The absolute amount of time (minutes per day) spent in physical activity was significantly lower when calculated from Arte*ACC* than from Arte*EE* ($p < 0.001$). TEE was significantly influenced by RMR, sex, and Arte*ACC* ($r^2 = 0.89$). AEE was significantly influenced by sex and Arte*ACC* ($r^2 = 0.59$).

Discussion: Despite an absolute difference between the two indexes, Arte*EE* and Arte*ACC*, Arte*ACC* seems to be a valid indicator of free-living physical activity. It contributed significantly, by 3.3% and 12.5%, to the explained variations in TEE and AEE, respectively.

Key words: accelerometry, activity energy expenditure, activity-related time equivalent, adolescents, total energy expenditure

Introduction

Overweight and obesity are a consequence of an imbalance between energy intake and energy expenditure (EE).[1] Knowledge of the underlying mechanisms of this imbalance has at least partly been limited by the lack of reliable and accurate methods for direct measurement of physical activity. Thus, there is clearly a need for new and better assessment techniques for investigating habitual physical activity patterns and, in the long term, for facilitating assessments of effects of environmental changes on public health (1).

Objective methods for assessing free-living habitual physical activity in humans include measures based on EE, primarily from the doubly labeled water (DLW) method, measures based on heart rate, and measures based on whole-body accelerometry. The DLW method provides accurate estimates of the total energy expenditure (TEE), and, in combination with measurement of the resting metabolic rate (RMR), it allows the activity energy expenditure (AEE) to be calculated. AEE is considered a useful measure of the physical activity-related EE, although it requires corrections for differences in body size (2). Generally, AEE is calculated taking the diet-induced thermogenesis (DIT) into account (AEE = 0.9 × TEE − RMR), assuming DIT makes up 10% of TEE. However, the DLW method does not

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[1] Nonstandard abbreviations: EE, energy expenditure; TEE, total energy expenditure; RMR, resting metabolic rate; AEE, activity energy expenditure; DIT, diet-induced thermogenesis; Arte*EE*, activity-related time equivalent based on energy expenditure; MTI, Manufacturing Technology Inc.; Arte*ACC*, activity-related time equivalent based on accelerometry; AC, activity count; $\dot{V}O_2$, oxygen uptake; MET, metabolic energy turnover; ANCOVA, analysis of covariance; PAL, physical activity level.

provide any information on the time spent at different intensity levels of physical activity.

Recently, a new measure, the activity-related time equivalent based on energy expenditure (Arte*EE*), was proposed (3). This provides an index of the amount of time spent at an EE level equivalent to that of one or more reference activities and is calculated as: Arte*EE* (minutes per day) = AEE/(EE reference activity − RMR). This approach may allow comparison among subjects with different energy costs of movement due to differences in body mass and/or in movement efficiency (1).

Whole-body accelerometry is based on the use of activity monitors that are designed to measure the acceleration of the body in one, two, or three dimensions. A number of accelerometers are commercially available. One of these, the Manufacturing Technology Inc. (MTI) activity monitor (formerly known as the Computer Science and Applications Inc. activity monitor), has been validated during standardized activities in the laboratory (4–7) and in the field (8,9). In addition, this monitor has been validated under free-living conditions for a prolonged period of time (i.e., 10 to 14 days) against AEE and physical activity level (PAL) (PAL = TEE/RMR) calculated by the DLW method (10–12). The output from the MTI activity monitor seems to be a valid indicator of the total amount of physical activity in children (11) and in adolescent athletes when expressed as total counts adjusted for registered time (counts per minute per day), although the data have to be interpreted carefully in specific groups (10). A recently suggested new measure for use with accelerometry is the activity-related time equivalent based on accelerometry (Arte*ACC*) index, i.e., activity-related time based on accelerometry. This approach is similar to the Arte*EE* index and has been introduced to take interindividual differences in biomechanical efficiency of movement into account (1). It is calculated as: Arte*ACC* (minutes per day) = total daily activity counts (ACs) (counts per day)/reference exercise ACs (counts per minute).

In a previous study, we found that, compared with a normal weight control group, obese adolescents showed a decreased level of physical activity, as assessed by accelerometry, although they did not differ in activity-related EE (13). In the present study, we combined the data from the two groups to evaluate the validity of the Arte*ACC* index for estimating the amount of time spent in physical activity, above that of reference activities, under free-living conditions. As criterion measures, we used the Arte*EE* index and AEE. The absolute validity of the Arte*ACC* index was evaluated by comparison with the Arte*EE* index. We hypothesized that there would be no differences between the Arte*ACC* and the Arte*EE* index in the amount of time spent in physical activity. A secondary aim of this study was to develop regression equations for the prediction of TEE and AEE.

Research Methods and Procedures

Subjects

Thirty-six adolescents, 14 to 19 years of age and with a wide variation in BMI (range from 18.7 to 43.1 kg/m^2), were recruited and agreed to participate in the study. The subjects were not using any medication on a regular basis, except for 5 girls who used oral contraceptives. All were classified as being in pubertal stage 4 and 5 according to Tanner (14). All subjects and the parents of those under 18 years of age provided written informed consent. The Ethics Committee of the Örebro County Council approved the study protocol.

Study Protocol

The subjects were admitted to the laboratory in the evening on Day 0. After collection of a baseline urine sample, they were given an oral dose of labeled water. They then returned home by car for an overnight fast. In the morning of Day 1, the subjects arrived at the laboratory at ~7 AM, again being transported by car. The subjects were asked to minimize all physical activity on Day 0. RMR, body weight, height, and body composition were measured in the fasting state. Thereafter, the subjects were served a light breakfast, and a second urine sample was collected. After breakfast, all subjects performed an exercise test consisting of walking on a treadmill, including two steady-state workloads.

At the end of the visit, the subjects were instructed how to wear an accelerometer and how to record their food intake. They returned to the laboratory on Day 8 to provide fourth and fifth urine samples. A 7-day dietary record was also returned at this time. A third visit to the laboratory was scheduled for Day 15 when two more urine samples were obtained and the accelerometer was returned.

Measurements

Anthropometrics and Body Composition. Height was measured to the nearest 0.5 cm using a standard wall-mounted stadiometer. Body mass was measured after an overnight fast on Days 1 and 15, on a standard laboratory scale, to the nearest 0.1 kg in light underwear. Total body composition was measured by dual-energy X-ray absorptiometry using a Lunar DPX-L densitometer (Lunar Corp., Madison, WI). The subjects were scanned in light clothing while lying horizontally on their backs. The adult scan mode was used for all subjects, and the densitometer was calibrated by the procedures provided by the manufacturer before each test.

RMR. RMR was measured between 7 and 8 AM after an overnight fast. After arriving in the laboratory, the subject rested in the supine position for ~30 minutes. Expired air was then collected in Douglas bags using a two-way non-rebreathing valve (Hans Rudolph Inc., Kansas City, MT) and a noseclip. For all measurements, expired air was collected in two Douglas bags for exactly 15 minutes each. The oxygen content was analyzed with an electrochemical oxygen analyzer (Ametek S-3A, Thermox Instruments, Pittsburgh, PA), and the carbon dioxide content was analyzed with an infrared CO_2 analyzer (Ametek CD-31, Thermox Instruments). The analyzers were calibrated against gases of known concentration before each test. The volume of air in each Douglas bag was measured with a gas meter (Elster Agmainz, Mainz-Kastel, Germany) under constant flow. This system was calibrated against a 350-liter Tissot spirometer. RMR was calculated from each of the two Douglas bags according to Weir (15), and the lower of these two values was taken as RMR. The subjects were visually monitored to make sure that they were lying still but awake.

TEE. TEE was measured by the DLW method as described by Westerterp et al. (16). The estimated CV for TEE measured by DLW was 3.9% in the Maastricht laboratory (17). The subjects were given a weighted dose of a mixture of 99.8 atom% ^2H_2O in 10.0 atom% $H_2{}^{18}O$ so that the baseline levels (parts per million) of deuterium and oxygen-18 were increased by ≥150 and ≥300 ppm, respectively. Additional urine samples were then collected from the second void of the day and during the evening on Days 1, 8, and 15. Samples were analyzed in duplicate with an isotope-ratio mass spectrometer (Optima; VG Isogas Ltd., Micromass, Manchester, UK). CO_2 production was converted to TEE using an energy equivalent based on the individual food quotient calculated from the macronutrient composition of the diet as described by Black et al. (18), assuming the respiratory quotient to be equal to food quotient. A 7-day precoded food record (19) was used for recording of food intake. The energy intake was calculated using commercial software (MATs; Rudans Lättdata, Västerås, Sweden) and the food composition data from the Swedish National Food Administration.

AEE was calculated as 0.9 × TEE − RMR, taking into account a 10% thermic effect of feeding (20). AEE was also expressed in relation to body weight (AEE per kilogram).

Laboratory Calibration. The subjects walked for 5 minutes at both 4 and 6 km/h. Oxygen uptake ($V\text{O}_2$) was measured using an on-line, open circuit system (Medical Graphics Inc., St. Paul, MN), and ACs were measured simultaneously in 15-second intervals using the MTI uniaxial accelerometer (model WAM 6471; MTI, Fort Walton Beach, FL). The same accelerometer unit was used in all subjects during the calibration procedure. The accelerometer was secured directly to the skin on the lower part of the back (lumbar vertebrae 4 to 5) using an elastic belt. Before the measurements, the accelerometer was calibrated using the calibrator provided by and procedures recommended by the manufacturer (21). $V\text{O}_2$ and ACs were averaged over the last 2 minutes at each workload. One subject was not able to complete the 6 minutes while walking on the treadmill at 6 km/h and, therefore, was excluded from further analyses.

Arte*EE* is an index of time spent in physical activity, which corrects AEE for differences in body weight and also for the economy of performing physical activities (3). Arte*EE* was calculated as: Arte*EE* (minutes per day) = [AEE (kilojoules per day)/reference activity EE (kilojoules per minute) − RMR (kilojoules per minute)]. A mean of the EE obtained during walking on the treadmill at the two different speeds was determined individually and used as the reference activity EE.

Arte*ACC* is an index of the amount of time spent in accelerometer-measured activity equivalent to that of a reference exercise task and is suggested to take into account differences in biomechanical efficiency of movement among subjects (1). Arte*ACC* was calculated as: Arte*ACC* (minutes per day) = [total daily ACs (counts per day)/exercise ACs (counts per minute)]. The reference exercise activity was determined in the same way as with Arte*EE* (i.e., the mean ACs obtained during walking at 4 and 6 km/h).

The absolute intensity while exercising on the treadmill, expressed according to the metabolic energy turnover (MET) classification, was calculated individually by setting 1 MET to equal RMR.

Free-Living Physical Activity. Physical activity was assessed with the same accelerometer as described above. Six different accelerometers were used during the free-living measurements, and all were calibrated before each measurement as described above. Activity data from the accelerometer were sampled on a minute-by-minute basis. The accelerometer was attached to the body in the same way as during laboratory calibration. The subjects wore the accelerometer during the daytime except during water activities. In addition, they recorded in a diary the time when the monitor was attached and removed each day and when all exercises (including bicycling and walking) were performed.

Activity data were analyzed and processed using a special written macro based on Microsoft Excel (Microsoft, Redmond, WA). All activity data were averaged over the 14-day period. Only days with more than 600 minutes of registration were included in the analysis. The output from the macro included, on a day-by-day basis, the total ACs (counts per day) and the total amount of time (minutes) registered.

Statistics. Differences between sexes were tested by one-way ANOVA. The effects of sex and method (Arte*EE* and Arte*ACC*) on time spent in physical activity were analyzed by analysis of covariance (ANCOVA), where method and sex were considered as fixed factors with age as a covariate. All assumptions for ANOVA/ANCOVA were fulfilled, and the residuals showed a satisfactory pattern. The relationship between ACs and MET during laboratory calibration was tested by linear regression analysis. The relationships among the free-living physical activity variables (AEE,

Table 1. Physical characteristics and energy expenditures of subjects ($n = 35$)

	Males ($n = 16$)	Females ($n = 19$)
Age (years)	18.1 ± 1.3	17.3 ± 1.9
Height (m)	1.82 ± 0.04	1.66 ± 0.07*
Body weight (kg)	93.2 ± 24.1	81.9 ± 27.5
Fat free mass (kg)	63.2 ± 8.6	42.9 ± 6.8*
Fat mass (kg)	24.3 ± 15.6	33.8 ± 18.6
Body fat (%)	25.1 ± 12.0	41.2 ± 10.8*
RMR (MJ/d)	8.2 ± 1.4	6.8 ± 1.3‡
TEE (MJ/d)	14.6 ± 1.7	11.4 ± 1.7*
AEE (MJ/d)	4.7 ± 1.2	3.4 ± 0.7*
AEE (MJ/kg per day)	0.056 ± 0.022	0.046 ± 0.015

* $p < 0.001$.
† $p < 0.05$.
‡ $p < 0.01$.

Table 2. Mean (±SD) ACs, $V\text{O}_2$, and MET (MET = $V\text{O}_2$/RMR) for the individual calibration during walking at 4 km/h and 6 km/h on the treadmill

	Males ($n = 16$)	Females ($n = 19$)
4 km/h		
AC (counts/min)	1361 ± 376	1407 ± 560
$V\text{O}_2$ (mL/kg per minute)	11.1 ± 1.6	11.2 ± 0.9
METs	3.6 ± 0.5	3.8 ± 0.7
6 km/h		
AC (counts/min)	3501 ± 732	3401 ± 1001
$V\text{O}_2$ (mL/kg per minute)	15.8 ± 2.6	15.9 ± 1.8
METs	5.1 ± 0.7	5.5 ± 1.0

AEE per kilogram, Arte*EE*, and Arte*ACC*) were also tested by linear regression analysis. The degree of agreement between time (minutes per day) spent in physical activity as assessed by Arte*EE* and Arte*ACC* was determined by the method described by Bland and Altman (22). Step-wise multiple regression analysis was used to determine which of the independent variables contributed to the variations in TEE and AEE. The independent variables included age, sex, height, fat mass, fat-free mass, RMR, and Arte*ACC*. In all analyses for gender, females were coded = 0 and males = 1. The level of statistical significance was set as $p < 0.05$. SPSS/PC statistical program (version 10.0 for Windows; SPSS, Inc., Chicago, IL) was used for all statistical analyses.

Results

On average, the accelerometers were worn for 786 ± 56 minutes during 13.1 ± 1.2 days of the 14-day measurement period. Table 1 summarizes the physical characteristics and EE variables of the subjects. In Table 2, the observed ACs, $V\text{O}_2$ values, and METs ($V\text{O}_2$/RMR) from the two different steady-state walking exercises are presented. There were no significant relationships between free-living AEE and EE during the two calibration exercises ($r = -0.06$ and $r = -0.04$), indicating that the Arte*EE* index complies with statistical principles. Similarly, total counts obtained under free-living conditions were not significantly correlated ($r = 0.20$, $p = 0.24$) to ACs from the standardized exercise tasks. ACs obtained while walking at 4 km/h were significantly related to those at 6 km/h ($r = 0.77$, $p = 0.001$). No significant correlations were observed between ACs and either $V\text{O}_2$ (milliliters per kilogram per minute) or METs during the calibration activities. Figure 1 displays the distribution of ACs obtained during walking at 4 (Figure 1a) and 6 (Figure 1b) km/h.

Table 3 shows the relationships among the free-living physical activity variables (AEE, AEE per kilogram, Arte*EE*, and Arte*ACC*). All correlations among the variables were significant ($p < 0.05$), except that between AEE and Arte*ACC*. After adjustment for sex, however, the partial correlation between AEE and Arte*ACC* was significant ($r = 0.36$, $p = 0.038$). The relationship between Arte*ACC* and AEE per kilogram is displayed in Figure 2. Unadjusted ACs (counts per minute) were also significantly correlated to AEE per kilogram ($r = 0.51$, $p < 0.01$) and to PAL ($r = 0.40$, $p < 0.05$).

ANCOVA revealed a significant effect of method ($p < 0.001$) on time spent in physical activity, whereas no significant effect of sex ($p = 0.27$), age ($p = 0.57$), or interaction between sex and method ($p = 0.15$) was observed. According to Arte*EE*, the time spent in physical activity averaged 232 ± 85 min/d, as compared with 150 ± 70 min/d when calculated from Arte*ACC*. The degree of agreement between the two indexes is illustrated by a Bland and Altman plot in Figure 3. The mean difference was 81 min/d ($p < 0.001$), and the limits of agreement (±2 SD) were −75 and +237 min/d.

To further assess the validity of the Arte*ACC* index, the determinants of TEE were examined by step-wise multiple regression analysis in a randomly selected sample ($n = 23$) of study participants and subsequently cross-validated in the remaining sample ($n = 12$). The model for the prediction of TEE included sex, age, height, RMR, and Arte*ACC* (Table 4). TEE was significantly influenced by RMR (adjusted r^2 = 78%), sex, and Arte*ACC*, with a total model r^2 of 89%. A similar approach was made regarding AEE. The AEE

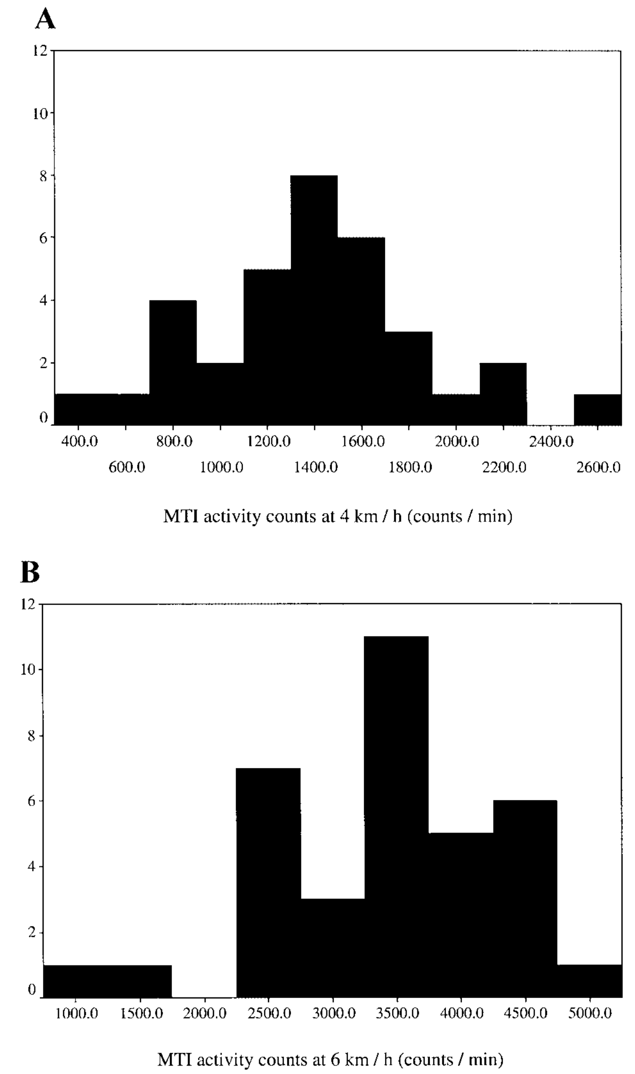

Figure 1: The distribution of ACs during standardized walking in the laboratory at 4 (A) and 6 (B) km/h ($n = 35$).

regression model included sex, age, fat mass, fat-free mass, and Arte*ACC* (Table 5). AEE was significantly influenced by sex (adjusted $r^2 = 46.5\%$) and Arte*ACC*, with a total model r^2 of 59%. When Arte*ACC* was substituted by unadjusted ACs (counts per minute), in a step-wise multiple regression model, it did not contribute to the explained variance in either TEE or AEE.

Pair-wise comparison between predicted TEE and TEE measured by the DLW method are presented in Figure 4. The mean difference between predicted and measured TEE was −0.36 MJ/d ($p = 0.24$), and the limits of agreement (±SD) were −2.50 and +1.78 MJ/d. The same comparison was made for AEE (Figure 5). The mean difference between predicted and measured AEE was −0.34 MJ/d ($p = 0.23$), and the limits of agreement (±SD) were −2.26 and +1.58 MJ/d. Predicted TEE was significantly correlated to measured TEE ($r = 0.60$, $p = 0.04$), and predicted AEE was significantly correlated to measured AEE ($r = 0.86$, $p = 0.001$).

Table 3. Correlation coefficients and partial correlation coefficients, with adjustment for sex, for the relationships among AEE (AEE = 0.9 × TEE − RMR), AEE per kilogram of body weight, Arte*EE*, and Arte*ACC* ($n = 35$)

	Correlation coefficients with Arte*ACC*	Partial correlation coefficients with Arte*ACC*
AEE	0.20 ($p = 0.24$)	0.36 ($p = 0.038$)
AEE per kilogram	0.57 ($p < 0.001$)	0.57 ($p < 0.001$)
Arte*EE*	0.68 ($p = 0.001$)	0.54 ($p = 0.001$)

Discussion

To our knowledge, this is the first study addressing the relationship between Arte*ACC* and other variables of physical activity measured under free-living conditions. We compared the Arte*ACC* index with Arte*EE* and AEE calculated from the DLW method. Significant, although moderate, correlations between Arte*ACC*, on one hand, and Arte*EE* and AEE per kilogram, on the other, suggest that Arte*ACC*, calculated from the MTI activity monitor, is a valid indicator of the time devoted to physical activity in

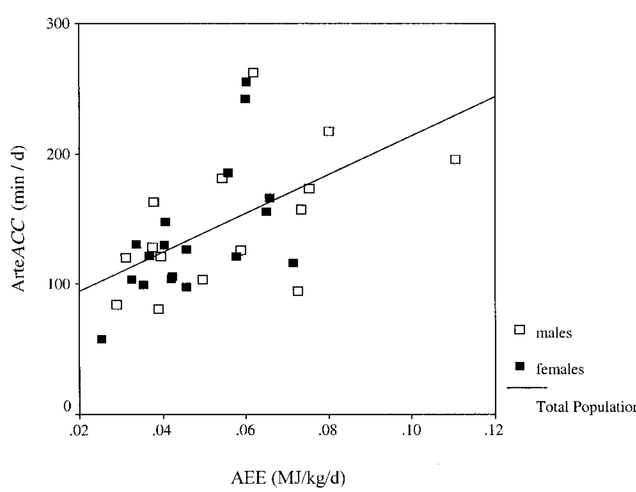

Figure 2: The relationship between Arte*ACC* and AEE expressed in relation to body weight (AEE per kilogram) ($r = 0.57$; $p < 0.001$; $n = 35$).

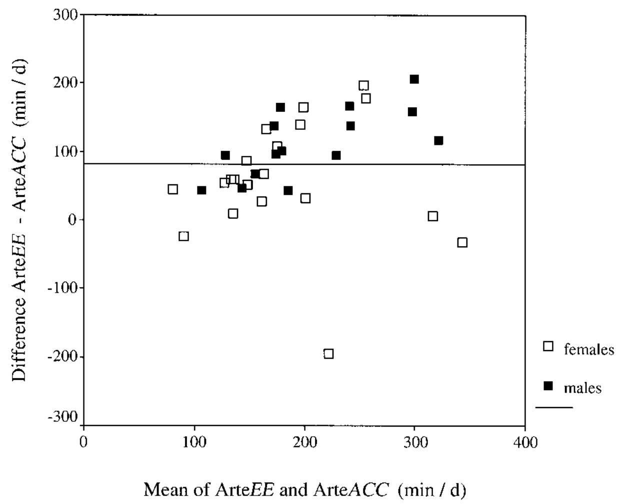

Figure 3: The degree of agreement between the Arte*EE* and Arte*ACC* indexes. The mean difference was 81 min/d ($p < 0.001$), and the limits of agreement ($\pm$2 SD) were -75 and $+237$ min/d ($n = 35$).

free-living adolescents. The high interindividual variability while walking on the treadmill in the laboratory, probably due to differences in biomechanical efficiency of movement, indicated the need for individual calibration.

The standardized calibration activities used as a basis for calculating the Arte*EE* index differed from those originally described (3). In the latter study, the subjects performed five standardized tasks (level walking, grade walking, cycling, stair climbing, and walking carrying a small load) as compared with level walking at two different speeds (4 and 6 km/h) in the present study. The two level walking activities were chosen to make the Arte*ACC* and the Arte*EE* indexes comparable. ACs (as used in the calculation of Arte*ACC*) are closely related to EE during different speeds of level walking (4–6). On the other hand, for activities such as cycling, stair climbing, and uphill walking, this relationship is weaker. Thus, to be able to compare the two different indexes, we decided to use the same standardized calibration activities (i.e., level walking). Moreover, level walking is probably the most typical activity performed under free-living conditions.

Table 4. Final model from the step-wise regression analysis for the prediction of TEE (megajoules per day) ($n = 23$)

Covariates	β-Coefficient	SE	Adjusted r^2	p Value
RMR	1.105	0.149	0.782	0.001
Sex	1.888	0.45	0.856	0.001
Arte*ACC*	0.07063	0.003	0.889	0.019
Intercept	2.795	1.055	–	0.016

Overall model: $r^2 = 0.89$; sex: males = 1, females = 0.

Table 5. Final model from the step-wise regression analysis for the prediction of AEE (megajoules per day) ($n = 23$)

Covariates	β-Coefficient	SE	Adjusted r^2	p Value
Sex	1.678	0.306	0.465	0.001
Arte*ACC*	0.06262	0.002	0.590	0.013
Intercept	2.506	0.411	–	0.001

Overall model: $r^2 = 0.59$; sex: males = 1, females = 0.

Despite a significant correlation between Arte*ACC* and Arte*EE*, the absolute amount of time (minutes per day) spent in physical activity was significantly smaller when derived from the Arte*ACC* index compared with Arte*EE*. Furthermore, a wide interindividual variation in accuracy was observed. This is probably due to the inability of the activity monitor to assess all the different types of body movement performed under free-living conditions and the between-individual differences in length of time performing different types of activities. The MTI activity monitor is a uni-axial accelerometer, which is designed to detect body movements in the vertical plane. It is most likely that the subjects participating in the present study performed a variety of physical activities that increased their AEE above that of the reference EE (i.e., the mean EE while walking at

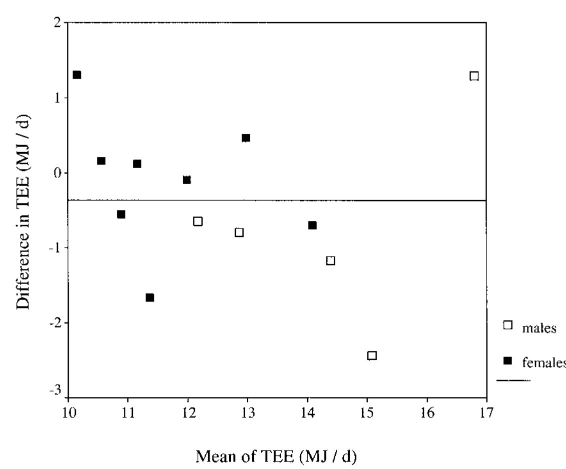

Figure 4: The degree of agreement between TEE predicted from RMR, sex, and Arte*ACC* and TEE measured by the DLW method. The mean difference was -0.36 MJ/d ($p = 0.24$), and the limits of agreement ($\pm$ SD) were -2.50 and $+1.78$ MJ/d ($n = 13$).

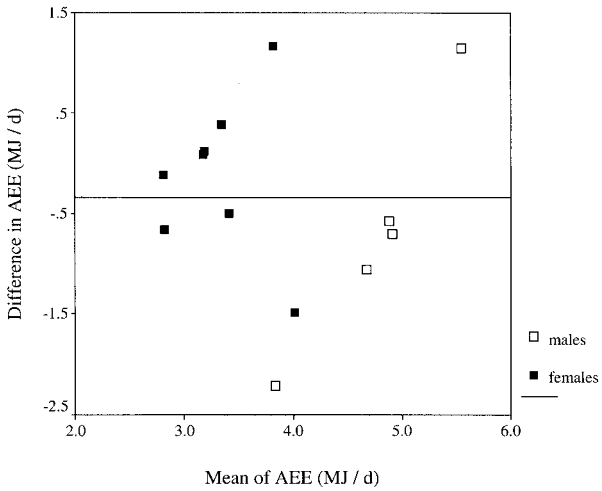

Figure 5: The degree of agreement between AEE predicted from sex and Arte*ACC* and AEE calculated from TEE and RMR. The mean difference between predicted and measured AEE was −0.34 MJ/d ($p = 0.23$), and the limits of agreement (± SD) were −2.26 and +1.58 MJ/d ($n = 13$).

4 and 6 km/h). However, an activity monitor placed around the waist would not detect activities performed mainly by the arms. Similarly, although activities such as walking up stairs and walking while carrying goods would be detected by the activity monitor, the corresponding ACs would not correctly reflect the amount of energy expended. It has been shown that activity monitors are unable to detect the elevated EE resulting from inclines during walking and running on a treadmill (23). Thus, even if the two measures are related to each other, they should not be used interchangeably.

A number of previous studies have addressed the validity of the MTI activity monitor (model WAM 7164) during controlled laboratory settings in adults (4), in patients with coronary artery disease (6), and in children (5,7,24,25). In addition, validation studies of the monitor have been performed for specific tasks under field conditions using portable indirect calorimetry as the criterion instrument (8,9). Results from these studies have indicated that the MTI activity monitor is able to discriminate between different walking and running speeds, and, in addition, relatively high correlations have been found between ACs and EE ($r = 0.77$ to 0.94). However, this relationship seems to be dependent on the activities performed. Hendelman (8) reported a significantly lower correlation ($r = 0.59$) for a combination of walking and daily life activities (e.g., playing golf, vacuuming, dusting, cleaning windows, and lawn mowing) and found that the metabolic costs of these activities were underestimated by 30% to 60% when based on the EE equations derived from walking.

Only a limited number of studies have dealt with the validity of the MTI activity monitor when used for a prolonged period of time (i.e., weeks) under free-living conditions. In a previous study (11), we found a significant relationship between AEE and the total amount of physical activity (counts per minute per day) ($r = 0.54$) as assessed by the MTI activity monitor and concluded that the outcome from the MTI activity monitor is a valid indicator of the overall physical activity in 9-year-old children. On the other hand, it was also shown that a laboratory-developed equation (5) for predicting TEE significantly underestimated TEE when applied to free-living activity data. Similarly, Leenders et al. (12) concluded that in women the free-living AEE calculated from a laboratory-based prediction equation (4) was significantly underestimated as compared with AEE calculated by the DLW method. Thus, there seems to be a need for establishing TEE and AEE prediction equations based on free-living physical activity measured by accelerometry and EEs estimated simultaneously by the DLW method. In fact, it has been suggested that indicators of physical activity are essential for the modeling of TEE into prediction equations for energy requirement from DLW data (26).

The three components of TEE are RMR, DIT, and AEE. RMR is the largest component of TEE and has been reported to explain ~50% to 60% of the variation in TEE (26,27). AEE represents ~30% of TEE and is the most variable component (26,28). In the present study, RMR accounted for 78% of the variation in TEE. Further, a strong relationship was observed between TEE and RMR ($r = 0.82$, $p = 0.001$). Sex and Arte*ACC* explained an additional 11% of the variation in TEE. The influence of sex on TEE is similar to that found in adults (26,29) and to observations in prepubertal children (30). However, Goran et al. (30) concluded that the influence of sex on EE is mainly explained by an effect on RMR. No significant effect of sex on RMR was found, however, after adjustment for fat-free mass, fat mass, and physical activity as analyzed by ANCOVA in the present study (data not shown). The difference between studies is probably due to the similarity in body composition between the prepubertal boys and girls studied by Goran et al. (30) and the heterogeneity in fat mass and fat free mass in the adolescent subjects in the present study. It is worth noting that the Arte*ACC* index contributed, albeit to a small extent (i.e., 3.3%), to the explained variation in TEE.

Given the costs and complexity of measuring TEE by the DLW method, alternative methods are warranted. The combination of calculating physical activity by means of the Arte*ACC* index and measuring RMR may be an alternative. In addition, assessment of physical activity by accelerometry under free-living conditions also provides information about the patterns of physical activity.

Sex and Arte*ACC* significantly influenced AEE and were the only determinants that remained significant in the final regression model. This finding is consistent with our previous results in 9-year-old children (11). In that study, we found that 45% of the variability in AEE could be explained by sex and physical activity as assessed by the MTI activity monitor, compared with 59% in the present study.

The cross-validation of the developed regression equations showed no significant difference between predicted and measured TEE and AEE. However, the relatively large SE and the wide limits of agreement preclude individual prediction. It seems that Arte*ACC* calculated from objectively assessed physical activity by means of the MIT activity monitor is a valid indicator of the overall physical activity and, together with RMR measured by indirect calorimetry and sex, could be used for the prediction of TEE and AEE in groups of adolescents.

Intensity thresholds corresponding to intensity categories (light, $<$3 METs; moderate, 3 to 6 METs; vigorous, $>$6 METs) have been defined for the MTI activity monitor (4,8,9). These cutoff points could be used for estimating the amount of time spent at different intensity levels while using the MTI activity monitor. However, such a time estimate is different from the Arte*ACC* index because the former estimate represents the accumulated time (minutes per day) spent above the predetermined cutoff point. The Arte*ACC* index, on the other hand, is the ratio of the total daily ACs to the standardized exercise ACs. In other words, the Arte*ACC* index is an index of the amount of time a subject spends with accelerometer readings equivalent to that of a reference exercise task taking the total daily ACs into consideration. Given the large variability in cutoff points corresponding to physical activity of moderate intensity (3 to 6 METs), with a range from 190 (8) to 1952 counts/min (4) depending on the calibration activities performed, common use of the Arte*ACC* index may be recommended for comparisons between studies.

In summary, if the inherent inability of the MTI activity monitor to detect all different types of movement can be tolerated, the results of the present study indicate that the Arte*ACC* index calculated from the MTI activity monitor is a valid measure of the amount of time spent above that of the reference activity. Regression equations for the prediction of TEE and AEE were developed and cross-validated. It was shown that the Arte*ACC* index significantly contributed to the explained variations in TEE and AEE.

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