

## ORIGINAL ARTICLE

# Validation of the Actiheart activity monitor for measurement of activity energy expenditure in children and adolescents with chronic disease

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**Background/Objectives:** The purpose of this study was to develop an activity energy expenditure (AEE) prediction equation for the Actiheart activity monitor for use in children with chronic disease.

**Subjects/Methods:** In total, 63 children, aged 8–18 years with different types of chronic disease (juvenile arthritis, hemophilia, dermatomyositis, neuromuscular disease, cystic fibrosis or congenital heart disease) participated in an activity testing session, which consisted of a resting protocol, working on the computer, sweeping, hallway walking, steps and treadmill walking at three different speeds. During all activities, actual AEE was measured with indirect calorimetry and the participants wore an Actiheart on the chest. Resting EE and resting heart rate were measured during the resting protocol and heart rate above sleep (HRaS) was calculated.

**Results:** Mixed linear modeling produced the following prediction equation:

$$\text{Estimated AEE (J/kg/min)} = -93.7 + (4.8 \times \text{HRaS}) + (0.04 \times \text{Accelerometer Counts}) + (39.8 \times \text{Gender (girls = 0, boys = 1)}).$$

This equation results in a nonsignificant mean difference of 2.1 J/kg/min (limits of agreement: –144.2 to 148.4 J/kg/min) for the prediction of AEE from the Actiheart compared with actual AEE.

**Conclusions:** The Actiheart is valid for the use of AEE determination when using the new prediction equation for groups of children with chronic disease. However, the prediction error limits the use of the equation in individual subjects.

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**Keywords:** physical activity; measurement; indirect calorimetry; exercise; heart rate

## Introduction

Children with chronic disease are often sedentary and this behavior pattern can have various etiologies. For example in children with congenital heart disease and hemophilia, hypoactivity might be caused by overprotection by parents and educators (Bar-Or, 1987; Bergman and Stamm, 1967),

whereas in juvenile arthritis, children might be hypoactive because of painful joints (Takken *et al.*, 2003).

There is an increasing body of literature showing that children with a chronic disease or condition are able to improve their physical fitness levels through an exercise training program (Klijn *et al.*, 2004; Edouard *et al.*, 2007; Takken *et al.*, 2007; Verschuren *et al.*, 2007; Van Brussel *et al.*, 2008; Johnson, 2009). However, a frequently encountered problem is the deconditioning after the cessation of the structured exercise training program (Verschuren *et al.*, 2007; Van Brussel *et al.*, 2008). This may be caused by the fact that children with a chronic condition encounter many barriers in performing physical activities in their daily life. Many sport clubs are not equipped to have these children

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participate in their programs. Moreover, there may be perceived barriers to regular physical activity because of restriction in physical activity by parents, caregivers, health-care professionals, trainers and teachers, as well as the child's own perception of the consequences of activity on their condition (Edouard *et al.*, 2007; Murphy and Carbone, 2008).

Increasing daily physical activity levels for children with a chronic disease or condition might be an effective method to maintain their physical fitness levels (Morris, 2008). However, research in this area is limited because of a lack of robust direct measurement methods for assessing free-living physical activity in children with chronic disease. Activity monitoring seems to be a promising method to objectively assess and profile physical activity (Hoos *et al.*, 2004; Esliger and Tremblay, 2007; de Graauw *et al.*, 2010), and seems to be more valid than indirect assessments (for example, questionnaires and activity logs) (Adamo *et al.*, 2009).

A recent report has called into question the use of methodologies established for children without chronic disease when predicting energy expenditure (EE) in children with chronic disease (Stephens *et al.*, 2009). Stephens *et al.* (2009) assessed the validity of prediction equations based on healthy subjects for measuring EE by accelerometry (Freedson *et al.*, 1998; Puyau *et al.*, 2002) for children with chronic disease. In this study, EE was measured by indirect calorimetry (IC) during seven-activity tasks of variable intensities (Stephens *et al.*, 2009). Results showed significant differences between predicted EE and measured EE in children with chronic disease.

Therefore, the purpose of this study was to develop an activity energy expenditure (AEE) prediction equation for the Actiheart activity monitor for children with chronic disease and to assess the validity of the Actiheart to determine AEE in this population.

## Subjects and methods

### Participants

In total, 63 participants with chronic disease were recruited from several clinics of the Wilhelmina Children's Hospital,

University Medical Center Utrecht, the Netherlands. Diagnostic distribution and descriptive characteristics of participants can be found in Table 1. Participants included children and adolescents in that ages ranging from 8 to 18 years. All participants' parents gave written informed consent and participants aged 12 years and older signed their own assent form. This study was approved by the medical ethics committee of the University Medical Center Utrecht, the Netherlands. Participants were not included in the study if they used medications that interfered with heart rate (HR) response to exercise or if they were unable to ambulate and/or cooperate. One patient with a Fontan circulation had a rate responsive pacemaker. This cohort was a subsample of a larger multicenter study on accelerometry, using different activity monitors.

### Anthropometry

Weight was determined using an electronic scale (Seca, Hamburg, Germany), and a wall-mounted stadiometer was used to measure height. Body mass index was calculated by dividing body mass (in kg) by height squared (in meters).

### Testing protocol

Participants participated in one testing session with a duration of ~1.5 h, which consisted of three protocols:

**Resting protocol.** Expired gas was collected using IC to determine resting metabolism over 20 min with the participant supine in a quiet room. Recordings were taken at 1-min intervals for the duration of the last 10 min of rest. The average values for HR and EE over the last 10 min were taken as resting HR (RHR) and resting EE as this provided steady-state values for RHR and resting EE.

IC measurements were performed with the same equipment as used in the Activities protocol.

**Activities protocol.** The participants completed a questionnaire on the computer while seated. In addition they performed a 6-min cleaning task (sweeping), a 6-min hallway walking task (at a self-selected comfortable walking pace) and a 6-min stair-stepping routine at a metronome-guided

**Table 1** Characteristics of the participants (mean  $\pm$  s.d.)

| Group             | Age (years)     | Height (cm)      | Weight (kg)     | BMI (kg/m <sup>2</sup> ) | BMI for age (Z-score)         | HR <sub>rest</sub> (b.p.m.) | REE (J/kg/min)   |
|-------------------|-----------------|------------------|-----------------|--------------------------|-------------------------------|-----------------------------|------------------|
| CF (N=9)          | 13.3 $\pm$ 3.53 | 155.7 $\pm$ 15.7 | 43.3 $\pm$ 12.8 | 17.5 $\pm$ 2.03          | -0.55 $\pm$ 0.55 <sup>a</sup> | 74.1 $\pm$ 14.4             | 173.9 $\pm$ 44.8 |
| JDM (N=9)         | 13.9 $\pm$ 1.96 | 159.0 $\pm$ 9.0  | 55.1 $\pm$ 10.5 | 21.6 $\pm$ 2.42          | 0.89 $\pm$ 0.97 <sup>a</sup>  | 74.9 $\pm$ 14.4             | 113.6 $\pm$ 20.9 |
| JIA (N=10)        | 11.7 $\pm$ 2.58 | 152.5 $\pm$ 11.5 | 41.2 $\pm$ 12.1 | 16.2 $\pm$ 6.19          | -0.43 $\pm$ 1.55              | 78.8 $\pm$ 8.77             | 153.7 $\pm$ 43.8 |
| Hemophilia (N=10) | 12.5 $\pm$ 3.31 | 166.0 $\pm$ 17.6 | 59.3 $\pm$ 22.5 | 20.7 $\pm$ 4.73          | 0.94 $\pm$ 0.98 <sup>a</sup>  | 70.5 $\pm$ 5.15             | 129.3 $\pm$ 33.5 |
| CHD (N=8)         | 14.4 $\pm$ 3.20 | 159.1 $\pm$ 13.2 | 49.8 $\pm$ 10.8 | 19.7 $\pm$ 2.62          | -0.02 $\pm$ 1.68              | 71.2 $\pm$ 10.3             | 128.0 $\pm$ 29.9 |
| NMD (N=17)        | 13.3 $\pm$ 3.41 | 159.9 $\pm$ 15.4 | 48.8 $\pm$ 13.0 | 20.1 $\pm$ 6.34          | -0.12 $\pm$ 1.25              | 75.4 $\pm$ 8.99             | 137.2 $\pm$ 36.0 |

Abbreviations: BMI, body mass index; CHD, congenital heart disease; CF, cystic fibrosis; HR<sub>rest</sub>, resting heart rate; JDM, juvenile dermatomyositis; JIA, juvenile idiopathic arthritis; NMD, neuromuscular disorders; REE, resting energy expenditure.

<sup>a</sup>Significantly different from Dutch growth charts.

pace of 70 steps per min. A 6-min duration was chosen to allow for a steady-state oxygen uptake within the first 4 min of each activity.

Furthermore, participants were asked to walk or jog on a treadmill at three speeds. The treadmill protocol selected depended on the walking speed chosen during the hallway walking task. For participants who walked with a self-selected walking speed of >3.5 km/h, a high-function treadmill protocol was used (5 min at each of 3.5, 5 and 6.5 km/h). When the walking speed was <3.5 km/h, a low-function protocol was used (5 min each of 2.0, 3.5 and 5.0 km/h).

#### Actiheart

The Actiheart (AH2; CamnTech, Cambridge, UK) is a chest-mounted, combined-unit, synchronized HR monitor and accelerometer capable of storing time-sequenced data. Acceleration is measured by a piezoelectric element within the unit with a frequency range of 1–7 Hz. The Actiheart unit was clipped to two ECG electrodes (3M Red Dot 2271 Monitoring Electrodes; 3M Nederland BV, Zoeterwoude, the Netherlands) adhered to the child's chest. The Actiheart was positioned at the level of the third intercostal space (Brage *et al.*, 2006). Acceleration movement counts and HR from Actiheart were sampled every 15 s. The participants wore the Actiheart unit during the entire testing session. The existing AEE prediction equation developed on healthy children for the Actiheart used HR above sleep (HRaS) as a variable (Corder *et al.*, 2007). Accordingly, we converted RHR to HRaS using the following formula from healthy children (Corder *et al.*, 2007):  $\text{HRaS} = 0.4195 \times \text{RHR} + 27.4$ .

Actiheart accelerometry counts and HRaS were converted to AEE using the established equation of Corder *et al.* (2007) developed in healthy children:

$$\text{AEE (J/kg/min)} = (5.17 \times \text{HRaS}) + (0.61 \times (\text{gender} (0 = \text{girls}, 1 = \text{boys}) \times \text{HRaS})) + (0.07 \times \text{activity counts}) - (0.6 \times \text{gender}) - 74$$

#### Indirect calorimetry

During all tasks, expired gas was collected through a face mask to measure oxygen uptake ( $\text{VO}_2$ , l/min) and carbon dioxide exhalation ( $\text{VCO}_2$ , l/min) breath-by-breath, to determine EE. Data were averaged over a 15-s epoch. A portable respiratory gas analysis system was used during all activities (Cortex Metamax; CORTEX Biophysik GmbH, Leipzig, Germany). The Cortex Metamax was calibrated against ambient air and a standard calibration gas mixture provided by the manufacturer (15%  $\text{O}_2$  and 4%  $\text{CO}_2$ ), and volume calibrated before every exercise test session.  $\text{VO}_2$  and  $\text{VCO}_2$  data were converted to EE using the de Weir equation (de Weir, 1949):

$$\text{EE (J/kg/min)} = (3.9 \times \text{VO}_2 + 1.1 \times \text{VCO}_2) \times 4184$$

Resting EE was determined from the average of the last 10 min of the resting protocol. AEE of the activities protocol

were derived from the measured total EE of each task minus resting EE. The metabolic and activity data of the last 2 min of each task were averaged and used for analysis of actual AEE.

#### Statistical analysis

To best predict AEE from accelerometry counts and HR we used mixed linear modeling techniques using SAS 9.1 (SAS Institute, Cary, NC, USA, 2009). Mixed linear regression modeling is similar to simple linear regression only it allows for one to account for correlated data as well as nonconstant variability. This difference in modeling techniques means that each subject's data contribute to the overall model as a random effect, which allows for more accurate inferences to be made about the overall population effect rather than just being confined to making inferences about the existing data. AEE determined by IC was entered into the model as the main outcome. HRaS, accelerometer counts and gender were entered into the model as fixed effects. We also included random effects for HRaS and counts to account for the variation in each individual's response over the seven physical tasks. Further, as each subject was tested using seven tasks a repeated term was used to account for the within subject correlation (Singer, 1998).

The difference between estimated AEE and actual AEE was analyzed using Bland–Altman plots and limits of agreement (Bland and Altman, 1986). Moreover, Lin's concordance coefficient (LCC) and the corresponding 95% confidence interval (CI) were also used to determine the agreement between the two methods (Lin, 1989). The LCC measures both precision (Pearson correlation) and accuracy (bias correction factor) to determine whether the observed data deviate significantly from the line of perfect concordance, which occurs at 45°; that is, it assesses the linear relationship. The Bland–Altman plots and LCC were calculated using MedCalc 10.0. (Medcalc BVBA, Mariakerke, Belgium). A *P*-value of <0.05 was considered as statistically significant.

## Results

The descriptive characteristics of the participants are provided in Table 1. The body mass index *Z*-scores were significantly increased in the patients with juvenile dermatomyositis and hemophilia and was significantly decreased in the patients with cystic fibrosis.

Five participants (one cystic fibrosis, one juvenile dermatomyositis, two juvenile idiopathic arthritis and one Hereditary Motor Sensory Neuropathy) were not able to finish fast treadmill walking because of joint pain or exhaustion. Two participants with JDM stopped already at the start of slow treadmill walking because of exhaustion.

Table 2 reports the regression coefficients of the prediction of AEE from activity counts, HRaS and gender. The new regression equation for prediction of AEE was:

$$\begin{aligned} \text{AEE (J/kg/min)} = & -93.7 + (4.8 \times \text{HRaS}) \\ & + (0.04 \times \text{Accelerometer Counts}) \\ & + (39.8 \times \text{Gender (girls = 0, boys = 1)}) \end{aligned}$$

The mean estimated AEE of the prediction equation of Corder *et al.* (2007) and the currently developed prediction equation for each task are shown in Table 3 and Figure 1. The Corder *et al.* equation significantly overpredicted the AEE compared with the currently developed AEE prediction equation. In addition, the Bland–Altman plot analyzing the differences between actual AEE and estimated AEE is shown in Figure 2. The current equation gives a mean difference of 2.1 J/kg/min (limits of agreement: –144.2 to 148.4) for the overall estimation AEE compared with actual AEE, instead of a mean difference of 49.1 J/kg/min (limits of agreement: –89.3 to 187.5;  $P < 0.05$ ) using the model of Corder *et al.* (2007) developed in healthy children. The LCC for the Corder *et al.* equation with IC-AEE was 0.81 (95% CI: 0.78–0.84),  $r = 0.87$ , bias correction factor: 0.93. The LCC for the current AEE prediction with actual AEE was 0.81 (95% CI: 0.77 to 0.84),  $r = 0.82$ , bias correction factor: 0.99.

**Table 2** Results from the mixed linear regression modeling for the prediction of AEE in children with chronic disease using the Actiheart heart rate and activity counts

| Model <sup>a</sup>         | Estimate | Standard error | T-value | Significance |
|----------------------------|----------|----------------|---------|--------------|
| (Constant)                 | –93.7    | 14.078         | –6.66   | <0.0001      |
| Counts                     | 0.039    | 0.0142         | 20.36   | <0.006       |
| HRaS                       | 4.776    | 0.235          | 2.76    | <0.0001      |
| Gender (girl = 0, boy = 1) | 39.79    | 13.34          | 2.98    | 0.0042       |

Abbreviation: HRaS, heart rate above sleep.

<sup>a</sup>Dependent variable, activity energy expenditure (J/kg/min).

**Table 3** Comparison of the actual AEE with the estimated AEE from Actiheart using the prediction equation of Corder *et al.* and the currently developed prediction equation

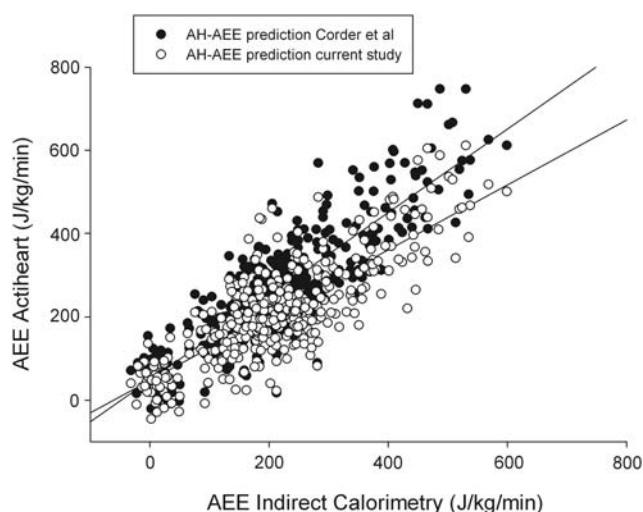
| Task            | Actual AEE (J/kg/min) | Estimated AEE Corder prediction (J/kg/min) | Actual AEE–AEE Corder prediction (correlation, r) | Estimated AEE current AH prediction (J/kg/min) | Actual AEE–current AH prediction (correlation, r) |
|-----------------|-----------------------|--|---|--|---|
| Computer        | 19.2 ± 43.8           | 63.3 ± 40.0                                | 0.07  | 48.3 ± 39.5                                    | 0.11  |
| Sweeping        | 139.6 ± 42.9          | 182.8 ± 63.0                               | 0.25*   | 150.2 ± 55.0                                   | 0.27*   |
| Hallway walking | 249.7 ± 78.6          | 293.3 ± 99.0                               | 0.71*   | 232.9 ± 81.3                                   | 0.31*   |
| Steps           | 202.9 ± 50.8          | 254.7 ± 82.1                               | 0.50*   | 209.6 ± 71.7                                   | 0.51*   |
| Slow TW         | 178.9 ± 36.3          | 231.5 ± 68.4                               | 0.32*   | 187.3 ± 61.6                                   | 0.42*   |
| Moderate TW     | 263.7 ± 47.6          | 318.6 ± 76.9                               | 0.47*   | 257.9 ± 66.3                                   | 0.47*   |
| Fast TW         | 424.5 ± 72.9          | 487.2 ± 125.0                              | 0.69*   | 393.7 ± 102.8                                  | 0.69*   |
| All activities  | 206.0 ± 125           | 257.83 ± 143.2                             | 0.87*   | 208.4 ± 118.2                                  | 0.81*   |

Abbreviations: AEE, activity energy expenditure; AH, Actiheart; TW, treadmill walking.

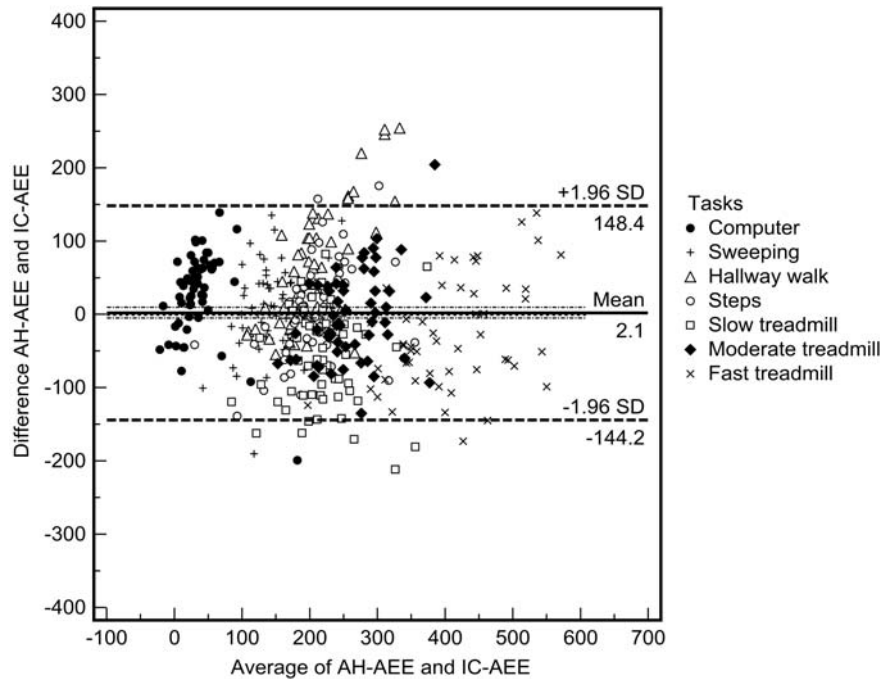
\*Significant ( $P < 0.05$ ).

## Discussion

The results of this study suggest that although activity monitors are regarded as an objective measure of physical activity, it remains a quite crude measure for estimating AEE in children with chronic disease. The derived prediction equation using both HR and activity counts accounted for 65% of the variance in actual AEE. The large range of the 95% CI in estimated AEE indicates that prediction equation seem to be more accurate for groups (for example, research) than for individuals (for example, clinical practice). The observed limits of agreement from the Bland–Altman plots were comparable with those reported in healthy adults using the Actiheart (Crouter *et al.*, 2008). The diversity of chronic conditions included in these analyses may have



**Figure 1** Scatter plot of actual AEE as measured by indirect calorimetry and estimated by two Actiheart prediction equations (according Corder *et al.* (2007) and the current study).



**Figure 2** Bland–Altman plot of actual AEE (in J/kg/min) as measured by indirect calorimetry and AEE estimated using the Actiheart (current prediction equation).

contributed to the individual variability. However, the derived prediction equation performs significantly better in children with chronic disease than a previously developed equation for healthy children (Corder *et al.*, 2007).

There are several potential explanations for why the equation of Corder *et al.* might be inaccurate for use in children with chronic disease. These include delayed gross motor skill development among children with chronic disease, inefficiency of movement from disease complications, increased resting and AEE associated with heart and lung function (Hjeltnes *et al.*, 1984; Knops *et al.*, 1999; Groen *et al.*, 2010), higher HR for a given  $\text{VO}_2$  because of deconditioning (Bar-Or and Rowland, 2004) and altered movement patterns to reduce pain (Broström *et al.*, 2007). Each of these would increase HR and EE for a given activity, which may explain why the equation of Corder *et al.* consistently overestimated AEE (Figure 1).

In our study, a large group of children with different types of chronic diseases was tested to assess the validity of the Actiheart to determine AEE in this population. A strong overall correlation was found between estimated AEE from Actiheart with actual AEE for the complete exercise testing session. This suggests high overall criterion validity in measurement. The Actiheart showed no significant correlation with IC for working at the computer and a moderate to strong correlation for other activities. The correlations between predicted and measured AEE increased with higher intensity activities. From the current data it seems that

the Actiheart becomes accurate starting from activities with an intensity of  $\sim 2.5$  metabolic equivalents.

The lack of correlation between Actiheart AEE estimation for working at the computer and IC can be explained by the fact that the activity monitor measures almost no acceleration of the chest during sedentary activities and low HRs (Crouter *et al.*, 2008). In general, the Actiheart, and activity monitors, are better suited to predict EE during activity, rather than during sedentary activities (Crouter *et al.*, 2008; De Bock *et al.*, 2010).

As HRaS was a significant predictor of AEE in the mixed linear regression modeling (Table 2), AEE estimation in participants with a blunted HR response to exercise (for example, chronotropic incompetence or  $\beta$ -blocking medication usage; Thoren, 1967) might impede the validity of this combined HR and activity counts prediction equation.

Our results indicate that other approaches should be explored to improve the estimation of AEE for individual subjects. A study with adults with acquired brain injury suggested an individual calibration of the activity monitor output (for example, activity counts) with actual AEE (Tweedy and Trost, 2005). Moreover, our Actiheart prediction equation was developed using the mean HR response in a group of subjects; which compromises the accuracy at the individual level (Brage *et al.*, 2005). Future studies should examine approaches that take into account individual HR response at known exercise intensities to improve the accuracy of the prediction of AEE.

Another approach to improve accuracy might be a more advanced mathematical modeling. Zakeri *et al.* (2010) have recently used multivariate adaptive regression splines modeling in healthy children and adolescents to predict EE using the Actiheart activity monitor.

This study has a number of strengths. It is the first study to validate an objective measure of physical activity (Actiheart) in children and adolescents with chronic disease using actual EE (IC) as a criterion measure. The use of several different activities with both self-selected exercise intensities as well as a standardized treadmill protocol allows our findings to be generalizable to free living activities.

This study had a few important limitations. We defined chronic disease using a noncategorical approach that considers chronically ill young people as one population rather than specific disease classes (Stein and Jessop, 1982). The current sample size prohibited a subgroup analysis in specifying the disease classes, however, a secondary analysis revealed no significant effects between groups. Furthermore, it is unclear whether this equation is also valid for other pediatric patient groups including younger children.

In addition, the HRaS was calculated using an equation developed in healthy 12-year-old children (Corder *et al.*, 2007). Unfortunately, we do not have overnight HR data of the participants to confirm this equation. Finally, the derived prediction equation should be confirmed in a cross-validation study using similar and different activities; we only measured AEE during structured activities and did not measure AEE during free-play activities of the participants.

A limitation of the practical use of the current prediction equation is the necessity of the determination of RHR. However, if overnight data are obtained, HRaS can be directly obtained from the data when the monitors are worn during sleep.

In conclusion, these results demonstrate that Actiheart is valid for determining AEE when using the new prediction equation for groups of children with chronic disease. However, the prediction error limits the use of the equation in individual subjects.

Future research should determine the need for disease-specific AEE prediction equations and the applicability of the new prediction equation in other patient groups. Moreover, additional approaches should be explored to improve the prediction of AEE for individual subjects.

## Conflict of interest

The authors declare no conflict of interest.

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