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ORIGINAL ARTICLE

Accuracy of the Actiheart for the assessment of energy expenditure in adults

SE Crouter, JR Churilla and DR Bassett Jr

Department of Exercise, Sport, and Leisure Studies, The University of Tennessee, Knoxville, TN, USA

Background/Objective: The Actiheart (Mini Mitter, Sunriver, OR, USA) uses heart rate (HR) and activity data to predict activity energy expenditure (AEE). Currently, the Actiheart has only been tested during laboratory conditions. Therefore, the objective of this study was to validate the Actiheart prediction method against indirect calorimetry during a wide range of activities in a field setting.
Subjects/Methods: Forty-eight participants (age: 35 ± 11.4 years) were recruited for the study. Eighteen activities were split into three routines of six activities and each routine was performed by 20 participants. During each routine, the participants wore an Actiheart and simultaneously, AEE was measured with a Cosmed K4b^2 portable metabolic system. The manufacturer's HR algorithm, activity algorithm, and combined activity and HR algorithm were used to estimate AEE.
Results: The mean error (and 95% prediction intervals) for the combined activity and HR algorithm, HR algorithm, and activity algorithm versus the Cosmed K4b^2 were $0.02\,kJ\,kg^{-1}\,min^{-1}$ (-0.17, $0.22\,kJ\,kg^{-1}\,min^{-1}$), $-0.03\,kJ\,kg^{-1}\,min^{-1}$ (-0.24, $0.18\,kJ\,kg^{-1}\,min^{-1}$), and $0.14\,kJ\,kg^{-1}\,min^{-1}$ (-0.12, $0.40\,kJ\,kg^{-1}\,min^{-1}$), respectively.
Conclusion: The Actiheart combined activity and HR algorithm and HR algorithm provide similar estimates of AEE on both a group and individual basis.
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Keywords: motion sensor; physical activity; oxygen consumption; heart rate

Introduction

The ability to accurately track energy expenditure (EE) using objective methods is of increasing interest due to growing evidence that physical activity plays an important role in preventing and controlling many chronic diseases (Paffenbarger *et al*., 1978; Paffenbarger *et al*., 1986; Morris *et al*., 1990; Helmrich *et al*., 1991; Manson *et al*., 1999; Lee and Skerrett, 2001; Lee *et al*., 2003). However, most studies quantify physical activity through the use of questionnaires and significant errors may occur due to difficulty in recalling light and moderate activities performed by participants, thus decreasing the accuracy of the estimate of physical activity (Montoye *et al*., 1996).

Objective monitors such as accelerometers and heart rate (HR) monitors have certain advantages such as being able to estimate the duration and intensity of physical activity performed throughout the day, however, they each have limitations. Accelerometers are generally worn on the hip which limits their ability to detect upper body movements; they are also unable to detect changes in grade during walking, or when an individual is carrying objects (Bassett *et al*., 2000; Welk *et al*., 2000). HR has the advantage of being a physiological variable that is directly related to oxygen consumption, but errors in estimates of EE can occur during sedentary and light activities because HR can be elevated due to other factors such as stress, hydration, and environmental factors. Thus, some researchers have proposed the use of HR and accelerometry in combination to improve the estimate of physical activity energy expenditure (Haskell *et al*., 1993; Moon and Butte, 1996; Luke *et al*., 1997; Rennie *et al*., 2000; Strath *et al*., 2001; Brage *et al*., 2004).

Several investigators have shown that the simultaneous use of HR and motion sensors can provide accurate estimates of EE during free-living activities (Haskell *et al*., 1993; Rennie *et al*., 2000; Strath *et al*., 2001; Strath *et al*., 2002; Brage *et al*., 2004; Strath *et al*., 2005). However, a drawback to this method is that it requires individual HR-VO_2 (oxygen consumption) equations to be developed on each individual

Correspondence: Dr SE Crouter, Division of Nutritional Sciences, Cornell University, 279 MVR, Ithaca, NY 14853, USA.
E-mail: sec62@cornell.edu
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for both leg and arm work, which increases the burden on the participant. In addition, the data analysis is time consuming, thus limiting its use to studies involving small samples. Brage *et al*. (2004) has developed a simultaneous method which involves a branched equation model based on HR and physical activity data. In this model, one can choose to use either individualized or group-based HR-VO_2 regression equations. The results from this study found that when using this branched equation model, individual calibration may not be needed.

The Actiheart (Mini Mitter, Sunriver, OR, USA) is the first commercially available device that combines a HR monitor and accelerometer into a single unit. Only three studies (one in children and two in adults) have been published on the accuracy of the Actiheart for the prediction of physical activity energy expenditure (AEE). In general, the Actiheart has been shown to provide accurate estimates of low-to-moderate activities performed in a laboratory setting (Thompson *et al*., 2006) as well as treadmill walking and running in adults (Brage *et al*., 2005) and children (Corder *et al*., 2005). However, no studies have been published that report its accuracy in a field setting over a wide range of activities. In addition, the Actiheart used in the studies by Brage *et al*. (2005) and Corder *et al*. (2005) were from Cambridge Neurotechnology (Cambridge, UK), and the software incorporates a step test that permits individual HR-VO_2 calibration. The Actiheart sold in the US uses the exact same hardware, but the software utilizes group HR-VO_2 calibrations for the algorithms to estimate AEE. In addition, the US model uses the same equations as those that were used in the study by Thompson *et al*. (2006). Therefore, the purpose of this study was to validate the Actiheart (Mini Mitter, Sunriver, OR, USA) prediction method, using group-based HR-VO_2 regression equations, against indirect calorimetry during a wide range of activities in a field setting.

Materials and methods

Subjects

Twenty-four men (age: 36±12.8 years, body mass index (BMI): 25.7±5.2 kg m^{-2}) and 24 women (age: 35±10.3 years, BMI: 22.7±4.0 kg m^{-2}) from the University of Tennessee, Knoxville and surrounding community volunteered to participate in the study. The procedures were reviewed and approved by the University of Tennessee Institutional Review Board before the start of the study. Each participant signed a written informed consent and completed a Physical Activity Readiness Questionnaire (PAR-Q) before participating in the study. Participants were excluded from the study if they had contraindications to exercise or were not physically capable of completing the activities. Before testing, participants had their height and weight measured (in light clothing, without shoes) using a stadiometer constructed from 2 m sticks and a sliding right-angled piece of wood and a Health-O-Meter balance bean scale (Bridgeview, IL, USA), respectively. Body mass index was calculated according to the formula: body mass (kg) divided by height squared (m^2). The physical characteristics of the participants are shown in Table 1. Previously, we published a paper on the validity of existing regression equations to predict EE with the ActiGraph model 7164 (Crouter *et al*., 2006b) and another paper comparing the predictive validity of the Actical, ActiGraph, and AMP accelerometers (Crouter *et al*., 2006a) from the same study.

Procedures

Participants performed various lifestyle and sporting activities that were divided into three routines consisting of sedentary activities, leisure time physical activities, and household activities. Each routine consisted of six activities and each activity was performed for 10 min with a 1–2 min break between activities. Indirect calorimetry (Cosmed K4b^2, Rome, Italy) was used for continuous oxygen consumption (VO_2) measurements and an Actiheart was worn for the duration of the routine. When entering body mass, 2 kg was added to the participant's body mass to account for the added mass of the devices. Since there were also other devices being worn during the study (Actigraph, Actical, AMP-331, and three tri-axial accelerometers), the total mass of these devices plus the Cosmed K4b^2 and Actiheart equaled 2.0 kg.

Twenty participants performed each routine. The routine (sedentary, leisure time activities, and household activities) was assigned to participants by the investigator using criteria such as age and self-assessed ability to perform a specific routine.

Table 1 Physical characteristics of the participants who performed each routine (mean±s.d. (range))

Variable	*Routine 1 (N=20)*	*Routine 2 (N=20)*	*Routine 3 (N=20)*	*All participants (N=48)*
Age (years)	32±9.5 (21–55)	32±10.0 (22–59)	39±11.7 (23–69)	35±11.4 (21–69)
Height (cm)	174.1±10.8 (153.0–188.5)	173.0±10.5 (155.4–188.5)	172.4±8.8 (159.2–188.5)	172.7±9.7 (152.9–188.5)
Body mass (kg)	73.9±21.6 (45.4–139.6)	70.9±14.9 (50.8–96.9)	72.7±20.5 (45.4–141.0)	73.1±19.6 (45.4–141.0)
BMI (kg·m^{-2})	24.1±5.4 (17.9–40.4)	23.5±2.9 (18.7–27.3)	24.2±5.1 (17.9–40.6)	24.2±4.8 (17.9–40.6)

Abbreviation: BMI = body mass index.

Indirect calorimetry
The participants wore a Cosmed K4b^2 portable metabolic system for the duration of each routine. Before each test, the oxygen and carbon dioxide analyzers and the flow turbine were calibrated according to the manufacturer's instructions. For more detail on the Cosmed K4b^2 and the calibration procedure, see Crouter *et al*. (2006a, b).

Actiheart
The Actiheart is a relatively new device that combines HR and a movement sensor into a single unit that weighs 10 g and is 188 mm in length. A detailed description of the Actiheart is available elsewhere (Mini Mitter Company Inc., 2004; Brage *et al*., 2005). During all activities, the Actiheart was attached to the chest using electrocardiogram (ECG) electrodes (3M Red Dot 2271, London, Ontario, Canada). The Actiheart was initialized using 15 s epochs and synchronized with a digital clock before testing. During the testing, the Actiheart was positioned at the level of the third intercostal space. At the conclusion of each test, the data from the Actiheart were downloaded to a laptop computer for subsequent analysis.

The Actiheart (US version) provides estimates of AEE (kcals kg^{-1} min^{-1}) using prediction equations included in the Actiheart user manual (UK version) (Cambridge Neurotechnology Ltd, 2004). The equations used in the US version of the Actiheart were presented by Soren Brage during a poster session at the North American Association for the Study of Obesity in October of 2003. These prediction equations are used in conjunction with a branched equation model described by Brage *et al*. (2004) to estimate AEE (kcals kg^{-1} min^{-1}). Table 2 contains the Actiheart prediction equations.

Data analysis
Breath-by-breath data were collected using the Cosmed K4b^2. For each activity, the VO_2 and VCO_2 data were used to calculate gross EE (kcals kg^{-1} min^{-1}), which the resting EE (kcals kg^{-1} min^{-1}) was subtracted from to obtain net EE (i.e. AEE). The AEE (kcals kg^{-1} min^{-1}) was multiplied by 4.186 to get AEE (kJ kg^{-1} min^{-1}), which was used for comparison with the Actiheart prediction equations.

For the Actiheart HR and combined activity and HR algorithms, the individual's sleeping HR (SHR) is needed, therefore we converted lying HR to SHR by the following equation; SHR = 0.83*lying HR (Brage *et al*., 2005; Strath *et al*., 2005). In addition, the AEE from the Actiheart was converted to kJ kg^{-1} min^{-1} as described above and averaged from 4 to 9 min for each activity.

Statistical analyses
Statistical analyses were carried out using SPSS version 13.0 for Windows (SPSS Inc., Chicago, IL, USA). For all analyses, an alpha level of 0.05 was used to indicate statistical significance. All values are reported as mean $\pm$ standard deviation. One-way analysis of variance (ANOVAs) were used to examine differences in anthropometric variables between those who performed each routine. To examine differences between the Cosmed K4b^2 and the Actiheart prediction, equations for each activity and all 18 activities combined, pairwise comparisons with Bonferroni adjustments were performed. In addition, the root mean square error (RMSE) was calculated for each Actiheart prediction equation for each activity.

Modified Bland–Altman plots were used to graphically show the variability in the individual error scores (measured metabolic equivalent (METs) minus predicted METs) (Bland and Altman, 1986). This allows for the mean error score and the 95% prediction interval to be shown. Prediction algorithms that are accurate display a tight prediction interval around zero. Data points below zero signify an overestimation, while data points above zero signify an underestimation. The Bland–Altman plots are modified on the *x*-axis where only the criterion measure is shown, which is different from the original method in which the *x*-axis is the average of the two methods.

Table 2 Prediction equations for the Actiheart activity, heart rate, and combined activity and heart rate algorithms

Activity algorithm (AEE, kcals kg^{-1} min^{-1})	
<133 counts min^{-1}	((((0.203*133)−(0.75*age) + (83 * sex) + 46)/133)*counts min^{-1})/4186.8
⩾133 counts min^{-1}	((0.203*counts min^{-1})−(0.75*age) + (83*sex) + 46)/4186.8
Heart rate algorithm (AEE, kcals kg^{-1} min^{-1})	
HRaS <23 beats min^{-1}	(((5.95*HRaS) + (0.23*age) + (84*sex)−134)/23)*HRaS)/4186.8
HRaS ⩾23 beats min^{-1}	5.95*HRaS) + (0.23*age) + (84*sex)−134)/4186.8
Combined activity and heart rate algorithm (AEE, kcals kg^{-1} min^{-1})	
<25 counts min^{-1} and HRaS <23 beats min^{-1}	((0.1*HR AEE) + ((1−0.1)*accelerometer AEE))
HRaS between 23 and 80 beats min^{-1}	((0.5*HR AEE) + ((1−0.5)*accelerometer AEE))
>25 counts min^{-1} and HRaS ⩾80 beats min^{-1}	((0.9*HR AEE) + ((1−0.9)*accelerometer AEE))

Abbreviations: AEE, activity energy expenditure; HRaS, heart rate above sleep.
Sex: 0 = female, 1 = male, age is in years.

Results

Table 3 and Figure 1 show the AEE (kJ kg^{-1} min^{-1}) and for the Cosmed K4b^2 and each Actiheart prediction algorithm for each of the 18 activities and for all activities combined. The combined activity and HR algorithm predicted all activities within 0.09 kJ kg^{-1} min^{-1} (0.02 kcals kg^{-1} min^{-1}) and was only significantly different from actual AEE (kJ kg^{-1} min^{-1}) for three activities (standing, vacuuming, and ascending/descending stairs) ($P<0.05$). The HR prediction equation was significantly different from the six sedentary to light activities (lying, computer work, standing, filing papers, washing dishes, and washing windows) and one moderate activity (raking grass/leaves) ($P<0.05$). The activity prediction equation was significantly different from all 18 activities except for slow walking ($P>0.05$). Observed power was greater than 0.9 for all statistical tests except for slow walking (0.63) and fast walking (0.80). Table 4 provides the mean counts min^{-1}, HR, and HR above sleep (HRaS) for each activity. In addition, Table 4 provides the relative contribution of the activity counts and HRaS when used in conjunction with the Actiheart combined activity and HR algorithm.

Figure 2a–c shows the Bland–Altman plots for the Actiheart combined HR and activity, activity, and HR algorithms. The mean AEE error for the combined activity and HR algorithm had a mean bias of 0.02 kJ kg^{-1} min^{-1} and 95% prediction intervals (95% PI) of −0.17, 0.22 kJ kg^{-1} min^{-1}. The HR algorithm had a mean bias of −0.03 kJ kg^{-1} min^{-1} and 95% PI of −0.24, 0.18 kJ kg^{-1} min^{-1}. The activity algorithm had a mean bias of 0.14 kJ kg^{-1} min^{-1} and 95% PI of −0.12, 0.40 kJ kg^{-1} min^{-1}.

Discussion

The Actiheart was developed with the intent of overcoming the limitations of using solely HR or accelerometer data to predict AEE. Theoretically, the addition of a physiological variable (HR) should provide a better estimate of AEE, than accelerometry data alone, over a wide range of activities (Haskell *et al*., 1993; Strath *et al*., 2002). Several investigators have shown that the simultaneous use of HR and motion sensors provides a more accurate estimate of EE than using HR or motion sensors alone, demonstrating that this technique has promise (Haskell *et al*., 1993; Rennie *et al*., 2000; Strath *et al*., 2001; Strath *et al*., 2002; Brage *et al*., 2004; Brage *et al*., 2005). However, these studies typically use individualized HR-VO_2 regression lines, which the US Actiheart algorithms do not use (although the Actiheart from the UK has a step test in the software for individual calibration). The US algorithm uses SHR and an algorithm developed on a group of individuals (Brage *et al*., 2004; Cambridge Neurotechnology Ltd, 2004), which contributes to the errors seen for the prediction of AEE on an individual basis.

The main finding of this study is that the combined activity and HR algorithm and HR algorithm provide similar values for mean AEE (J kg^{-1} min^{-1}) on both a group and

Table 3 Activity energy expenditure (AEE, kJ kg^{-1}·min^{-1}) for the Cosmed K4b^2 and Actiheart during 18 structured activities

	Cosmed K4b^2 measured values	*Actiheart combined activity and HR algorithm*		*Actiheart activity algorithm*		*Actiheart HR algorithm*	
	Mean (s.d.)	*Mean (s.d.)*	*r.m.s.e.*	*Mean (s.d.)*	*r.m.s.e.*	*Mean (s.d.)*	*r.m.s.e.*
Lying	0.00 (0.00)	0.00 (0.00)	0.00	0.00 (0.00)	0.00	0.03 (0.02)*	0.03
Computer work	0.01 (0.01)	0.02 (0.02)	0.02	0.00 (0.00)	0.01	0.06 (0.05)*	0.06
Standing	0.02 (0.01)	0.04 (0.03)*	0.04	0.00 (0.00)*	0.02	0.09 (0.06)*	0.09
Filing papers	0.05 (0.02)	0.05 (0.04)	0.03	0.00 (0.00)*	0.05	0.10 (0.07)*	0.08
Washing dishes	0.08 (0.01)	0.10 (0.05)	0.05	0.01 (0.01)*	0.07	0.19 (0.09)*	0.14
Washing windows	0.15 (0.04)	0.13 (0.04)	0.06	0.04 (0.03)*	0.11	0.21 (0.06)*	0.10
Slow walk (avg. 82 m min^{-1})	0.17 (0.05)	0.15 (0.04)	0.05	0.14 (0.04)	0.06	0.16 (0.06)	0.06
Vacuum	0.19 (0.04)	0.11 (0.04)*	0.09	0.04 (0.02)*	0.16	0.19 (0.06)	0.08
Sweep/mop	0.19 (0.04)	0.16 (0.04)	0.07	0.06 (0.04)*	0.14	0.24 (0.05)	0.09
Raking grass/leaves	0.22 (0.05)	0.24 (0.10)	0.10	0.08 (0.04)*	0.16	0.32 (0.10)*	0.14
Fast walk (avg. 103 m min^{-1})	0.24 (0.07)	0.22 (0.06)	0.06	0.19 (0.04)*	0.08	0.24 (0.08)	0.07
Lawn mowing	0.37 (0.06)	0.33 (0.11)	0.12	0.11 (0.05)*	0.26	0.40 (0.10)	0.11
Stationary cycling (avg. 99 W)	0.37 (0.10)	0.28 (0.15)	0.18	0.03 (0.02)*	0.36	0.40 (0.12)	0.15
Ascending/descending stairs	0.39 (0.05)	0.31 (0.11)*	0.14	0.14 (0.06)*	0.26	0.38 (0.09)	0.10
Racquetball	0.41 (0.10)	0.43 (0.12)	0.12	0.15 (0.04)*	0.28	0.48 (0.12)	0.14
Basketball	0.49 (0.08)	0.47 (0.10)	0.11	0.19 (0.05)*	0.31	0.51 (0.10)	0.11
Slow run (avg. 157 m min^{-1})	0.54 (0.09)	0.53 (0.08)	0.13	0.43 (0.09)*	0.16	0.54 (0.09)	0.08
Fast run (avg. 191 m min^{-1})	0.65 (0.12)	0.60 (0.10)	0.17	0.46 (0.12)*	0.25	0.61 (0.12)	0.18
Average for all activities	0.25 (0.20)	0.23 (0.19)*	0.09	0.11 (0.14)*	0.15	0.29 (0.19)*	0.10

Abbreviations: HR, heart rate; r.m.s.e., root mean squared error.
* Significantly different from Cosmed K4b^2 ($P<0.05$). Observed power was greater than 0.9 for all statistical tests except for slow walking (0.63) and fast walking (0.80).

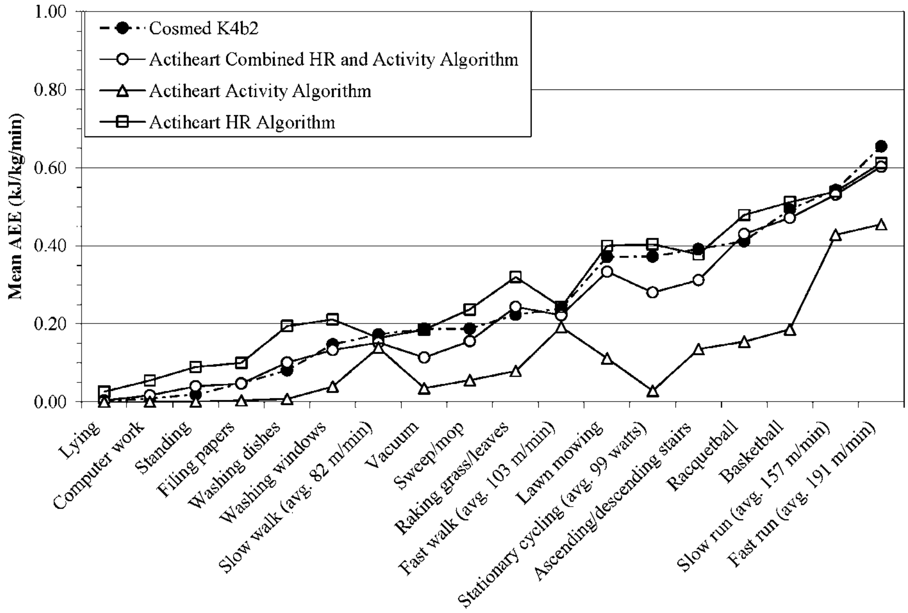

Figure 1 Measured (Cosmed K4b^2) and predicted (Actiheart HR, activity, and combined activity and HR algorithm) activity energy expenditure (AEE) for 18 different activities.

Table 4 Mean ($\pm$s.d.) Actiheart activity counts min^{-1}, heart rate (HR), and HR above sleep during 18 structured activities

	Activity counts min^{-1}	*HR (b.p.m.)*	*HR above sleep (b.p.m.)*	*Relative contribution of activity counts and HR to the combined Actiheart algorithm*	
				Activity (%)	*HR (%)*
Lying	0.1 (0.2)	66 (15.5)	11 (2.6)	90	10
Computer work	0.3 (0.8)	73 (17.7)	19 (8.8)	90	10
Standing	1.2 (1.3)	81 (15.7)	27 (6.9)	50	50
Filing papers	5.0 (5.1)	83 (21.8)	29 (12.4)	50	50
Washing dishes	10.6 (7.6)	104 (26.6)	52 (24.3)	50	50
Washing windows	59.1 (34.4)	102 (16.0)	50 (11.8)	50	50
Slow walk (avg. 82 m min^{-1})	101.9 (157.2)	105 (35.0)	51 (31.9)	50	50
Vacuum	54.3 (18.9)	99 (16.1)	46.9 (11.2)	50	50
Sweep/mop	77.5 (32.6)	109 (15.9)	56.9 (11.2)	50	50
Raking grass/leaves	117.9 (40.5)	120 (20.7)	68 (16.4)	50	50
Fast walk (avg. 103 m min^{-1})	597.1 (132.1)	103 (17.2)	54 (12.6)	50	50
Lawn mowing	250.7 (46.2)	136 (24.6)	85 (22.8)	10	90
Stationary cycling (avg. 99 W)	43.7 (31.1)	135 (22.4)	81 (18.0)	10	90
Ascending/descending stairs	351.0 (103.1)	130 (25.7)	76 (16.0)	50	50
Racquetball	424.6 (95.8)	143 (24.9)	95 (22.0)	10	90
Basketball	610.6 (156.5)	150 (22.1)	101 (19.5)	10	90
Slow run (avg. 157 m min^{-1})	1776.0 (286.3)	155 (18.9)	106 (16.4)	10	90
Fast run (avg. 191 m min^{-1})	1908.4 (466.8)	170 (15.1)	121 (11.8)	10	90
Average for all activities	367.2 (577.4)	114 (35.1)	62 (34.1)	50	50

Sleeping heart rate (SHR) was calculated using the formula: SHR = 0.83*lying HR.
The last two columns represent the relative contribution for the activity counts min^{-1} and HR above sleep, which is used in the equations for the Actiheart combined activity and HR algorithm.

individual basis for all activities combined. However, the combined activity and HR algorithm was only significantly different from the Cosmed K4b^2 for one sedentary or light activity, while the HR algorithm was significantly different from the Cosmed K4b^2 for all six sedentary and light activities. The current study is in agreement with the findings of Thompson *et al.* (2006) who examined the Actiheart combined activity and HR algorithm in 10 males and 10 females during low to moderate intensity (1.9–4.3 METs) physical activities performed in a laboratory setting.

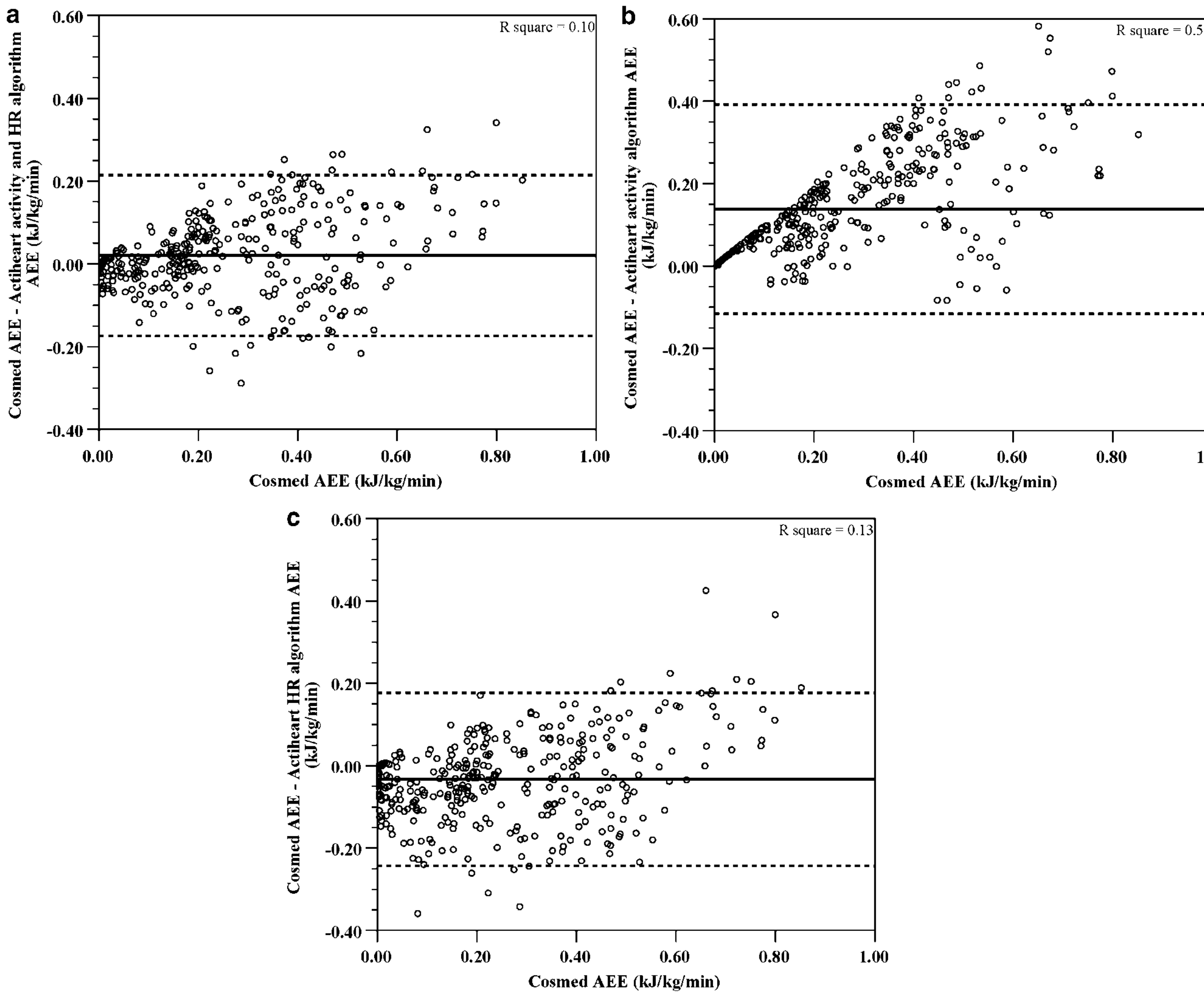

Figure 2 Modified Bland–Altman plots depicting error scores (indirect calorimetry (Cosmed K4b^2) activity energy expenditure (AEE) minus predicted AEE) for the (**a**) Actiheart combined activity and HR algorithm, (**b**) Actiheart activity algorithm, and (**c**) Actiheart HR algorithm. These are modified by only using the criterion measure on the *x*-axis rather than an average of the two measures.

They found that the Actiheart provided close estimates of AEE versus indirect calorimetry with no fixed or proportional bias. We have expanded on this study by examining all three Actiheart algorithms over a broader range of activities (sedentary behaviors to vigorous physical activities) performed both in a laboratory and field setting and have found that the combined activity and HR algorithm is also suitable for more moderate to vigorous physical activities, in addition to the low to moderate physical activities.

The current study highlights some important limitations of using HR or accelerometry alone. In general, HR alone is not as useful for predicting AEE of light physical activities compared to moderate and vigorous physical activities, which the current study confirms. The Actiheart HR algorithm was significantly different from the Cosmed K4b^2 for sedentary activites and light physical activities; however, it was only significantly different from one moderate to vigorous physical activity. The accelerometer AEE estimates obtained in the current study were close to actual AEE for walking; however, it underestimated the actual AEE of most other activities. In general, hip-mounted accelerometers overestimate sedentary and light physical activities, while underestimating moderate to vigorous physical activities that involve upper body movement, walking uphill, and climbing stairs. In the current study, the Actiheart accelerometer algorithm was significantly different from the Cosmed K4b^2 for all activities except slow walking. Three possible factors that may contribute to the differences seen with the accelerometer algorithm used in this study and studies that use accelerometers worn on the hip. First the accelerometer equations used in the Actiheart were developed on a small sample size and a limited number

Table 5 Mean bias (criterion minus estimate) and 95% prediction interval (95% PI) for ActiGraph, Actical, and Actiheart energy expenditure prediction equations

Device	*Prediction equation*	*Mean bias (METs)*	*95% PI (METs)*	*Reference*
ActiGraph	Hendelman lifestyle equation (Hendelman *et al*., 2000)	0.5	−3.4, 4.5	Crouter *et al*. (2006a)
Actiheart	Activity only algorithm	1.9	−1.6, 5.5	Present study
ActiGraph	Freedson equation (Freedson *et al*., 1998)	1.0	−2.3, 4.4	Crouter *et al*. (2006a)
ActiGraph	Nichols equation (Nichols *et al*., 2000)	0.9	−2.5, 4.3	Crouter *et al*. (2006a)
ActiGraph	Swartz lifestyle equation (Swartz *et al*., 2000)	0.1	−3.2, 3.5	Crouter *et al*. (2006a)
Actical	Single regression equation (Klippel and Heil, 2003)	1.1	−1.9, 4.1	Crouter *et al*. (2006a)
Actical	Two regression equation (Klippel and Heil, 2003)	1.1	−1.9, 4.1	Crouter *et al*. (2006a)
Actiheart	HR algorithm	0.2	−2.8, 3.2	Present study
Actiheart	Combined activity and HR algorithm	0.8	−2.0, 3.5	Present Study
ActiGraph	Crouter 2-regression model (Crouter *et al*., 2006b)	0.1	−1.4, 1.5	Crouter *et al*. (2006b)

Abbreviation: HR, heart rate.
Actiheart data presented in this report was converted to metabolic equivalents (METs) for comparison. The data for the ActiGraph and Actical were collected during the same study from the same participants performing same activities and are reported elsewhere (Crouter *et al*., 2006a, b).

of activities (treadmill walking and running). Second, the accelerometer used in this study is placed on the sternum where there could be a small attenuation in the acceleration signal detected, compared to a waist-mounted accelerometer. In addition, unlike waist-mounted accelerometers, the Actiheart accelerometer has a minimal weight on the end of a cantilevered beam, which will cause a decrease in the voltage signal detected.

It is important to know how the Actiheart compares to other currently available methods, but direct comparisons are difficult due to different testing protocols, subject populations, and how EE is expressed. The participants in the current study also wore an Actical and ActiGraph accelerometer positioned at the hip while performing the various activities (Crouter *et al*., 2006a, b). This allows for a direct comparison of other devices with the Actiheart, however the output from the accelerometers is gross EE (METs). Thus, the Actiheart data from the current study were converted to METs so that a comparison could be made with the Actical and ActiGraph (Table 5).

Several previous studies have used combined activity and HR techniques, although comparisons should be made with caution due to differences in participants and methods used. Strath *et al*. (2005) examined the use of a HR plus motion sensor technique (Strath *et al*., 2001) and a branched equation model (Brage *et al*., 2004) to predict AEE using individual and group calibrations to determine the HR-VO_2 curves. The data were collected on 10 individuals while wearing a Cosmed K4b^2 during 6 h of free-living activity. Their study used the branched equation model, which is similar to the branched equation model used by the Actiheart. Strath *et al*. (2005) found that when using individual HR-VO_2 calibration curves, the branched equation model had a mean bias of 0.02 net METs and 95% PI of −1.3, 1.4 net METs (0.00 kJ kg^{-1} min^{-1}, 95% PI −0.09, 0.10 kJ kg^{-1} min^{-1}). When a group HR-VO_2 calibration curve was used, which is similar to what the Actiheart uses, the branched equation model had a mean bias of 0.1 net METs and 95% PI of −1.4, 1.6 (0.01 kJ kg^{-1} min^{-1}, 95% PI −0.10, 0.11 kJ kg^{-1} min^{-1}). Although, the mean bias for the group calibration curve was significantly different from actual AEE, it was still considered acceptable due to the narrow 95% PI. The mean bias and 95% PI found in the current study for the Actiheart combined activity and HR algorithm (mean bias 0.02 kJ kg^{-1} min^{-1}, 95% PI −0.17, 0.22) are slightly worse than that found by Strath *et al*. (2005); however, the 95% PI provide evidence that the Actiheart would be suitable for larger epidemiological studies. It is important to note that the current study used structured 10 min bouts of activity, whereas the study of Strath *et al*. (2005) used 6 h of free-living activity, which would account for some of the differences seen.

In conclusion, based on the mean bias and 95% PI for the individual error scores, the Actiheart combined activity and HR algorithm and HR algorithm provided similar estimates of AEE compared with the Cosmed K4b^2. The Actiheart activity algorithm provided a less accurate estimate of AEE for all activities except walking. While the Actiheart shows promise for being a valid tool for the estimation of AEE over a wide range of activities, the Actiheart HR algorithm was developed using the mean HR response on a group of individuals; thus, the predictive accuracy at the individual level is compromised. Future studies should examine algorithms that take into account individual HR variability at known work rates in an effort to yield more precise estimates of EE.

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