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ORIGINAL ARTICLE

A comparison of energy expenditure estimates from the Actiheart and Actical physical activity monitors during low intensity activities, walking, and jogging

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Abstract Combining accelerometry with heart rate monitoring has been suggested to improve energy estimates, however, it remains unclear whether the single, currently existing commercially available device combining these data streams (Actiheart) provides improved energy estimates compared to simpler and less expensive accelerometry-only devices. The purpose of this study was to compare the validity of the heart rate (HR), accelerometry (ACC), and combined ACC/HR estimates of the Actiheart to the ACC estimates of the Actical during low and moderate intensity activities. Twenty-seven participants (mean age 26.3 ± 7.3) wore an Actical, Actiheart and indirect calorimeter (K4b^2) while performing card playing, sweeping, lifting weights, walking and jogging activities. All estimates tended to underestimate energy, sometimes by substantial amounts. Viewed across all activities studied, there was no significant difference in the ability of the waist-mounted Actical and torso-mounted Actiheart (ACC, HR, ACC/HR) estimates to predict energy expenditure. However, the Actiheart provided significantly better estimates than the Actical for the activities in which acceleration of the pelvis is not closely related to energy expenditure (card playing, sweeping, lifting weights) and the Actical provided significantly better estimates for level walking and level jogging. Similar to a previous study, the ACC component of the Actiheart was found to be the weakest predictor of energy suggesting it may be responsible for the failure of the combined ACC/HR estimate to equal or better the estimates derived solely from a waist mounted ACC device.

Keywords Heart rate · Accelerometry · Indirect calorimetry · Energy expenditure · Activity

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Introduction

The relationship between lack of physical activity and chronic illnesses such as type II diabetes, heart disease and cancer has been well established (Paffenbarger et al. 1978; Saltin et al. 1979; US Department of Health and Human Services 2000). Consequently, accurate and objective methods to measure levels of physical activity are important in defining appropriate dose–response relationships between physical activity and health. The cost, invasiveness and technical sophistication of some currently available techniques used to measure physical activity, such as doubly labeled water and indirect calorimetry (Ainsile et al. 2003; Montoye et al. 1996; Speakman 1998) decrease their suitability for the general population. Questionnaires are easy to administer and low in cost but are subject to recall bias and may not produce valid results (Albanes et al. 1990; Fransson et al. 2008; Lissner et al. 2004; Rennie and Wareham 1998). In contrast, the objectivity, ease of application and low measurement burden of accelerometers make them an increasingly common method used for assessing activity in laboratory and free-living conditions. Accelerometers are typically small, wristwatch-size devices that measure body acceleration and provide data on intensity, frequency and total volume of physical activity

Commercially available accelerometers, such as the Actical (Respironics Inc., OR, USA) have been shown to be reliable and valid for estimating energy expenditure in children (Esliger and Tremblay 2006; Heil 2006; Pfeiffer et al. 2006) and adults (Crouter et al. 2006; Heil 2006; Welk et al. 2004). However, one limitation of accelerometers is the inability to measure energy expenditure not associated with acceleration, as occurs during activities such as isometric exercise, the carrying of loads, or walking up an incline. Combining accelerometry with heart rate monitoring has been suggested to address this limitation (Brage et al. 2003; Chen and Bassett 2005) as the measurement error of these two approaches is not positively correlated (Brage et al. 2003, 2005). This approach is currently commercially available as the Actiheart monitor (CamNtech Ltd, Cambridge, UK; or MetriSense, Bend, OR, USA). The Actiheart differs from the Actical and other traditional accelerometers in that it combines accelerometer (ACC) data with heart rate (HR) data. Although several studies suggest that the combination of ACC and HR data may improve energy estimates (Brage et al. 2003; Haskell et al. 1993; Moon and Butte 1996), these studies were performed on early versions of devices that are not currently commercially available or were proof-of-concept studies combining data streams from two independent commercially available devices. Currently, the Actiheart is the only commercially available device that combines ACC and HR data streams in a single unit and consequently there is substantial practical interest in investigating the potential for it to improve energy estimates compared to traditional ACC devices.

At the time of this study there were two versions of the Actiheart available: a UK version (Cambridge Neurotechnology, Cambridge, UK) and a US version (MiniMitter, OR, USA). The US Minimitter version of the Actiheart is no longer commercially available. Currently there is a single version of the Actiheart available, which is manufactured and distributed by CamNtech in Europe and also distributed by MetriSense in the USA. The validity of the previous version of the Actiheart (Cambridge Neurotechnology) has been assessed in three studies (Corder et al. 2005; Thompson et al. 2006; Brage et al. 2005). In general, these studies found that the Actiheart provided reasonable estimates of energy expenditure in children (Corder et al. 2005) and adults (Thompson et al. 2006; Brage et al. 2005) walking or running on a treadmill or performing a variety of low-to-moderate level activities.

There have been two studies of the previous US Minimitter Actiheart. Crouter et al (2008) used the default formulas (group calibration equations) to predict energy across a variety of both laboratory and field activities and found that the combined ACC/HR energy estimates were slightly superior to the HR-alone estimates, and much superior to the ACC-alone estimates. The default formulas used by Crouter et al. in this study were derived using the UK version of the Actiheart. The more recent study by Barreira (Barreira et al. 2009) also examined treadmill and field activities and found the previous US Minimitter Actiheart to predict energy well across all activities.

Although the studies described above generally suggest that the Actiheart estimates energy expenditure accurately, it remains unclear whether the Actiheart device provides improved energy estimates compared to simpler and less expensive ACC devices such as the Actical. The relative burdensomeness of the Actiheart and Actical may be comparable depending on lifestyle and dress. The Actiheart is worn on the chest (under clothing) while ACC devices are most commonly worn around the waist. Two studies have compared the Actiheart to ACC-only devices (Barreira et al. 2009; Crouter et al. 2008); both studies suggest that the Actiheart did not provide improved energy estimates compared to the ACC devices (comparison of the Actiheart to the Actical and Actigraph, respectively; Crouter et al. 2008; Barreira et al. (2009)). Additional comparisons of these devices may be of practical importance for researchers given that the Actiheart imposes higher costs and complexity compared to an ACC device. Consequently, the purpose of this study was to determine if the Actiheart provides improved energy estimates compared to an existing ACC-only device, known as the Actical (Respironics Inc.) during low intensity activities, walking, and jogging.

Methods

Subjects

Twenty-seven adult subjects participated in this study. Volunteers were recruited via fliers posted at the Brooklyn Campus of Long Island University, Brooklyn, NY, USA. Study activities were conducted in the Human Performance Laboratory at Long Island University, Brooklyn, NY, USA. Subjects were excluded if they were younger than 18 or older than 45 years old, had a BMI $\leq$ 40, or had a history of injury/disease that prevented them from safely performing the study protocol. The study was approved by the IRB of Long Island University.

Measurement Instruments

After providing informed consent and being instructed on the protocol, each participant was outfitted with an Actical device attached at the left anterior hip at the level of the anterior iliac spine as per manufacturer's recommendations. A detailed description of the Actical can be found elsewhere (Crouter et al. 2006). The Actical estimates energy from ACC-only. The Actical collected data (128 Hz) using 1-min epochs and produced data points at 1-min intervals. The formulae used by the Actical device within this study were developed by Klippel and Heil (2003) and were provided by the current manufacturer (Respironics Inc.).

Each participant was also outfitted with one Actiheart (Mini-Mitter) comprised of two sensors linked by a cord. The device was attached on the left chest below the clavicle as per manufacturer's recommendations using 3M Red Dot EKG (3M, MN, USA) electrodes. The ACC component resides within the sensor placed medially on the chest. The Actiheart collected continuous HR (32 Hz) and ACC data using 1 min epochs and produced data points at 1-min intervals, reflecting the average HR and total ACC counts for each minute.

As mentioned previously, since this study was performed, the Minimitter US Actiheart has been replaced with a newer version of the Actiheart manufactured and distributed by CamNtech in Europe and also distributed by MetriSense in the USA. To assure that the findings from the use of the older version of the Actiheart would be valid for the currently commercially available version of the Actiheart, the manufacturer (CamNtech) was contacted regarding possible differences in data collection and analysis. The new Actiheart has additional options for analysis which were not available in the older US version (e.g., individual calibration, measurement of inter-beat intervals, etc.). These options for analysis were not examined in the current study. However, as per the manufacturer's unpublished data (personal communication; CamNtech), the older Minimitter version of the Actiheart accelerometer is calibrated to produce less counts for similar accelerations compared to the newer version. Also, a revised formula (Brage et al. 2007) based on group calibration for estimating energy is now available within the newer model.

To assure that the findings from the current study validly represent findings which can be expected from the currently available Actiheart, the count and HR data (and associated demographic data) were provided to the manufacturer who re-calibrated the count values (increased by 20%) to be consistent with the currently available Actiheart device. Energy expenditure estimates from the count and HR data were then derived by the investigators using the formulae within the software from the currently available Actiheart. There are a variety of formulae available within the current Actiheart device, which can be selected to produce estimates. This study used the most recent group calibration equations developed by Brage et al. (2007), which have been described previously. Estimates produced were based on HR data alone, ACC data alone, and the combination of ACC/HR data streams through branched equation modeling. As the prediction equations for the Actiheart require the individuals' sleeping HR, which was unavailable, we converted resting heart rate to sleeping HR by the formula: Sleeping HR = 0.83 × resting HR, as has been used in other studies (Brage et al. 2005; Strath et al. 2005). Resting heart rate was calculated as the mean HR occurring during minutes 4, 5 and 6 of the initial 8-min resting period.

After being outfitted with the Actical and Actiheart devices, subjects wore an indirect calorimeter (telemetric gas analysis system; K4b^2 Cosmed Inc., Rome, Italy) comprised of a small metabolic analyzer, a battery pack and a mask harnessed onto the subject and worn like a backpack. The K4b^2 has been validated previously (Husswirth et al. 1997; McLaughlin et al. 2001) and was therefore used as the criterion for the measurement of energy expenditure in the current study. Prior to testing, the oxygen and carbon dioxide analyzers were calibrated according to the manufacturer's instructions and the flow turbine was calibrated using a 3-L syringe.

While wearing the accelerometer devices and the indirect calorimeter each participant performed 8 min each of eight separate activities in the following order: resting, card playing, sweeping, light weight lifting, flat and inclined treadmill walking, and flat and inclined treadmill jogging. The indirect calorimeter, Actical and Actiheart devices were synchronized to the internal clock of the laptop computer.

Procedures

During the resting period the subjects were seated and motionless except for the movements associated with reading (e.g., turning pages). The card shuffling activity consisted of turning cards over one after another on a table without stopping. The sweeping activity was performed while standing using a standard broom to sweep a six square foot area. For weight-lifting, subjects lifted 1–3 lbs in each hand (based on body weight) beginning with a biceps curl followed by a bilateral "press" over the head returning to start position, completing 1 cycle/beat to the sound of a metronome set at 40 beats/min. Subjects then walked and jogged on a treadmill at four different combinations of speed and incline in the following order: 4.0 kph (2.5 mph) and level; 4.0 kph (2.5 mph) and 5° incline; 7.2 kph (4.5 mph) and level, and 7.2 kph (4.5 mph) and 5° incline.

Data analysis

For each subject the mean of the per minute energy expenditure for minutes 4, 5 and 6 was calculated for the initial rest period and for each activity to create an estimate of steady state per minute energy expenditure. These calculations were conducted on data from the Actical device (ACC waist mounted estimate), the Actiheart device (ACC torso mounted estimate, HR estimate, and combined ACC/HR estimate), as well as the indirect calorimeter (K4b^2) device, which was used as the criterion estimate of energy expenditure.

Energy estimates from the indirect calorimeter were converted from units of kcal/min to kJ/kg/min by the appropriate energy conversion factor and by dividing by the respective body weight of each subject in kilograms. Further, as estimates of energy expenditure from the indirect calorimeter included the resting metabolic rate while estimates from the Actical and Actiheart devices did not, the resting metabolic rate for each subject during the resting trial (mean of minutes 4,5 and 6) as determined by the indirect calorimeter was subtracted from the indirect calorimeter values.

Statistical analysis

Statistical analyses were carried out using SPSS version 16.0. The mean per minute energy expenditure was calculated across all individuals to estimate the mean population steady state energy expenditure for the participants for the resting period and for each activity. To examine differences between the indirect calorimeter and the estimates from the Actical and Actiheart devices paired *t* tests with Bonferroni adjustments were performed. To compare the ability of the Actical and Actiheart to estimate energy relative to the criterion measure the mean bias was examined using paired *t* tests with Bonferroni adjustments. Root mean square error (RMSE) was calculated for each estimate for each activity relative to the criterion value. Figures were created describing the mean values of all devices for each activity and as well as the variability in the error scores for the Actical and the Actiheart ACC/HR estimates using Bland Altman plots (Bland and Altman 1986).

Results

Twenty seven people were recruited for the study and Table 1 describes their demographic characteristics. One subject did not complete the level jogging task and two subjects did not complete the inclined jogging task due to fatigue. Consequently, complete data were obtained on the inclined walking task and the inclined jogging task for 26 and 25 subjects, respectively. All subjects ($n = 27$) completed all other tasks. Prior to analysis the data were observed for missing values and to assure that all data were within physiological limits. There were 18 HR values missing during minutes used for analysis (2.7%). When HR values were missing, all values derived from HR were also removed from analysis (Actiheart estimates: HR and ACC/HR). All VO_2 (ml/min) and VCO_2 (ml/min) values during minutes used for analysis within all tasks were within physiological limits except for one value (during rest) which was not used in the analysis. The range of values (0.67–1.13) for the respiratory exchange ratio were within normal limits (mean 0.821; ±0.040) for the exercise intensities imposed.

Table 2 shows the population mean and standard deviation per minute energy expenditure for each activity as estimated by the indirect calorimeter, the Actical, and each of the three estimates provided by the Actiheart (ACC, HR, ACC/HR) and describes the values that were significantly different from the indirect calorimeter. To assist in understanding the values, visual comparison can be made with Fig. 1, which displays the means of all devices for each activity. Generally, all devices tended to significantly underestimate energy requirements (except Actiheart HR and ACC/HR overestimated some low level activities). Only 6 estimates out of 28 (21.4%) were not significantly different from the criterion value. Further, when averaged across all activities, all of the estimates were significantly different from the criterion value.

Table 3 describes the mean bias, the RMSE and displays the results of the paired *t* tests examining the difference between the Actical and criterion versus the difference between the Actiheart ACC/HR and the criterion. The Actiheart ACC/HR estimates were significantly better than

Table 1 Subject characteristics

	Age (years)	Height (cm)	Weight (kg)	BMI (m^2/kg)	Resting heart rate (bpm)
Male ($n = 16$)	23.80 (2.09)	172.91 (6.61)	72.34 (9.12)	24.23 (2.89)	66.25 (13.12)
Female ($n = 11$)	30.00 (10.40)	161.09 (7.97)	60.75 (8.75)	23.42 (2.93)	64.30 (12.91)
Total ($n = 27$)	26.37 (7.32)	168.10 (9.20)	67.62 (10.54)	23.90 (2.88)	65.46 (12.83)

All values in mean (SD)

Table 2 Mean and standard deviation per minute energy expenditure [kJ/kg/min] for minutes 4, 5, and 6 for each activity for indirect calorimetry, the Actical, and each of the three values provided by the Actiheart (ACC, HR, ACC/HR), as well as counts and heart rate for each device

Activity	Indirect calorimeter energy	Actical		Actiheart				
		Counts[a]	ACC energy	Counts[a]	ACC energy	HR	HR energy	ACC/HR energy
Card playing	0.02 ± 0.02	0.00 ± 0.00	0.00 ± 0.00*	6.49 ± 6.83	0.01 ± 0.01*	81.90 ± 19.15	0.05 ± 0.05*	0.03 ± 0.02
Sweeping	0.11 ± 0.05	48.28 ± 60.29	0.01 ± 0.01*	95.23 ± 51.98	0.08 ± 0.03*	95.62 ± 18.09	0.12 ± 0.09	0.10 ± 0.05
Weightlifting	0.09 ± 0.03	12.15 ± 42.33	0.01 ± 0.02*	39.81 ± 26.67	0.04 ± 0.02*	102.66 ± 19.09	0.15 ± 0.10	0.10 ± 0.05
Level walk	0.20 ± 0.03	1692.38 ± 332.77	0.17 ± 0.02*	293.53 ± 103.85	0.15 ± 0.02*	97.44 ± 15.73	0.15 ± 0.08*	0.15 ± 0.04*
Incline walk	0.30 ± 0.04	1801.82 ± 461.59	0.18 ± 0.02*	304.20 ± 114.95	0.16 ± 0.03*	111.65 ± 16.50	0.23 ± 0.09*	0.20 ± 0.05*
Level jog	0.60 ± 0.07	11119.36 ± 1676.19	0.57 ± 0.07	1448.41 ± 753.89	0.40 ± 0.17*	150.80 ± 15.46	0.47 ± 0.10*	0.46 ± 0.09*
Incline jog	0.75 ± 0.09	11563.31 ± 1617.43	0.58 ± 0.08*	1571.95 ± 838.59	0.38 ± 0.18*	163.62 ± 15.39	0.55 ± 0.11*	0.53 ± 0.10*
Average for all activities	0.29 ± 0.26	3279.66 ± 523.82	0.21 ± 0.24*	470.10 ± 237.43	0.17 ± 0.17*	109.65 ± 16.67	0.24 ± 0.19*	0.22 ± 0.19*

Values are means ± standard deviation

ACC Accelerometry, *HR* heart rate (beats/min)

* Significantly different using Bonferroni adjustments ($P < 0.00156$) compared with indirect calorimeter

[a] Per minute

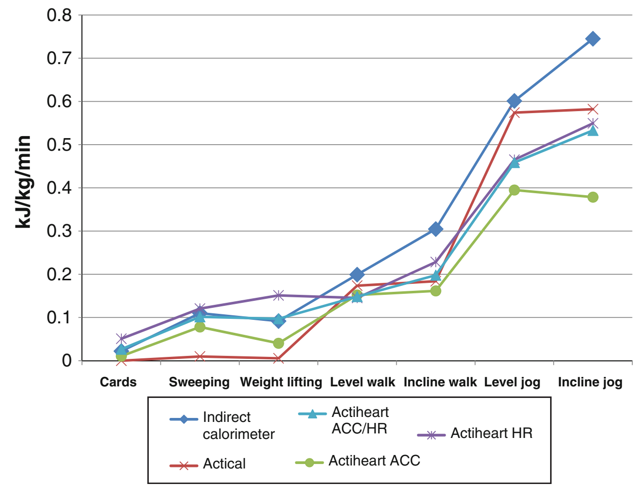

Fig. 1 Means of measured (indirect calorimeter) and predicted (Actical, Actiheart: ACC, HR, ACC/HR) activity energy expenditure

the Actical estimates for card playing, sweeping, and weight lifting while the Actical estimates were significantly better for level walking and level jogging. There was no significant difference in bias between the two estimates for inclined walking or jogging or the average of all activities. The RMSE error averaged across all activities ranged from 0.1124 to 0.1958 kJ/kg/min with the Actical having the least amount of error and the Actiheart ACC having the most error. Figure 2 displays Bland–Altman plots of the error associated with the Actical and the Actiheart ACC/HR, respectively.

Discussion

This study examined the accuracy of an ACC and a combined ACC/HR device, using software and algorithms within each device, to determine energy during low intensity and walking and jogging activities. Generally, both devices underestimated energy expenditure, frequently by substantial amounts (exceptions: the Actiheart HR and ACC/HR values overestimated energy expenditure slightly during the non-ambulatory activities). Examined across all activities the Actical and Actiheart ACC, HR, and ACC/HR produced estimates that were less than the criterion by approximately 28, 41, 17, and 24%, respectively (0.0772, 0.1196, 0.0487, 0.0699 kJ/kg/min, respectively).

Relative to the primary question of this study to determine if the Actiheart provides improved energy estimates compared to an existing ACC-only device, the results are mixed and appear to primarily depend on which activities are examined. The Actiheart performed better than the Actical during activities in which energy expenditure is not

Table 3 Mean bias (criterion minus estimate) and root mean squared error (RMSE) by activity for the Actical, and each of the three values provided by the Actiheart (ACC, HR, ACC/HR) in kJ/kg/min

Activity	Actical		Actiheart ACC		Actiheart HR		Actiheart ACC/HR	
	Bias	(RMSE)	Bias	(RMSE)	Bias	(RMSE)	Bias	(RMSE)
Card Playing	0.0222*	(0.0268)	0.0116	(0.0182)	−0.0287	(0.0577)	−0.0045	(0.0277)
Sweeping	0.1002*	(0.1091)	0.0320	(0.0464)	−0.0107	(0.0948)	0.0085	(0.0573)
Weightlifting	0.0863*	(0.0925)	0.0515	(0.0574)	−0.0594	(0.1175)	−0.0052	(0.0570)
Level walk	0.0256#	(0.0454)	0.0473	(0.0606)	0.0539	(0.0998)	0.0510	(0.0716)
Incline walk	0.1207	(0.1286)	0.1432	(0.1503)	0.0763	(0.1213)	0.1068	(0.1245)
Level jog	0.0270#	(0.1089)	0.2063	(0.2770)	0.1352	(0.1762)	0.1417	(0.1786)
Incline Jog	0.1631	(0.1966)	0.3667	(0.4134)	0.1928	(0.2524)	0.2093	(0.2606)
Average for all activities	0.0772	(0.1124)	0.1196	(0.1958)	0.0487	(0.1415)	0.0699	(0.1318)

Values are means

ACC Actiheart counts, *HR* Actiheart heart rate, *ACC/HR* Actiheart combined

* Difference between the Actical and indirect calorimeter estimates is significantly larger than the difference between the Actiheart ACC/HR and indirect calorimeter estimates

Difference between the Actical and indirect calorimeter estimates is significantly smaller than the difference between combined Actiheart ACC/HR and indirect calorimeter estimates

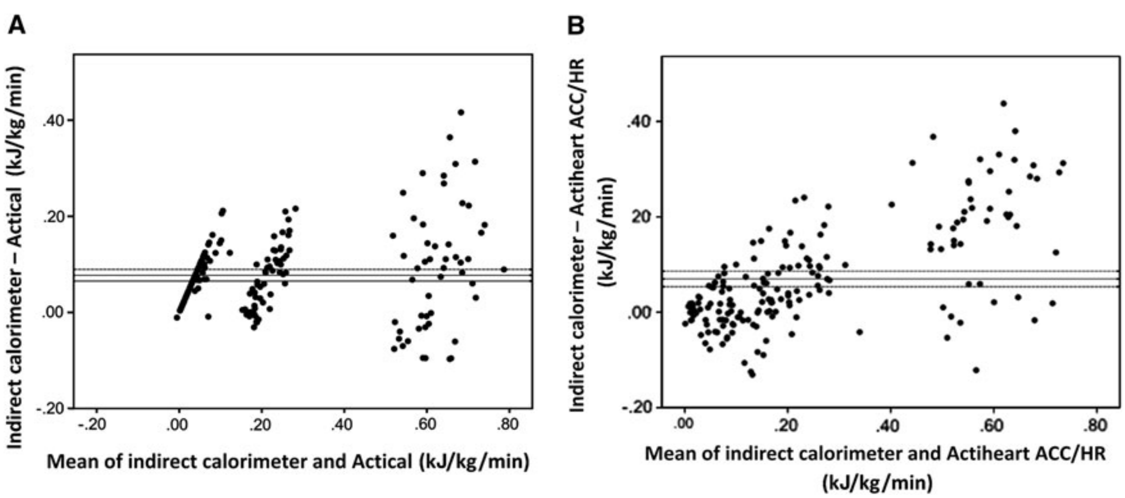

Fig. 2 Bland–Altman plots depicting error scores (indirect calorimetry activity energy expenditure minus predicted activity energy) for the (**a**) Actical and (**b**) Actiheart ACC/HR algorithms [kJ/kg/min]

directly related to pelvic acceleration (card playing, weight lifting, and sweeping) with the ACC/HR estimates not being significantly different than the criterion values (Table 2) and being significantly closer to the criterion value than the Actical (Table 3). Unsurprisingly, during these activities the Actical essentially registered the absence of energy expenditure [ranges 0–0.01 kJ/kg/min]. Conversely, the Actical produced an estimate for level jogging that was not significantly different than the criterion value (Table 2) and was significantly closer to the criterion value than the Actiheart for both level walking and level jogging (Table 3). Neither device produced estimates significantly closer to the criterion value for the inclined walking and jogging or when averaged across all activities.

It is not surprising that the Actiheart estimates are more accurate than the Actical estimates during low movement tasks given the additional input of HR, however, it is less clear why the Actiheart did not produce estimates equaling the accuracy of the Actical during level walking and level jogging. One potential explanation may be the poor relative performance of the ACC component of the Actiheart. Viewed across all activities, the ACC component of the Actiheart had the highest level of bias and highest level of

RMSE, and was the only estimate significantly different from the criterion value during every activity. Crouter et al. (2008) suggested that the location of the Actiheart ACC component on the chest may be problematic. This may be due to the significant damping of acceleration forces which occurs in the torso during walking, compared to acceleration that occurs at the pelvis (Menz et al. 2003; Prince et al. 1994; Ratcliffe and Holt 1997).

The values in Table 3, and Fig. 1, demonstrate that the Actiheart ACC component senses the upper extremity movements in the more sedentary activities better than the Actical, however, in the ambulatory activities the Actiheart ACC consistently has more negative bias than the Actical estimate, and contributes a great deal of error to the combined Actiheart ACC/HR estimate, particularly during the inclined jogging activity. It is precisely this kind of activity that the Actiheart ACC/HR estimate should, in theory, predict better than the Actical. We speculate that a combined ACC/HR device using a torso mounted HR component and a waist mounted ACC component (synchronized in time) may improve energy estimates compared to a single unit device placed on the torso.

Our findings are in general agreement with those of Crouter et al. who performed a single study on a variety of treadmill and free living tasks, the results of which were described in two papers; one focused on the Actiheart (Crouter et al. 2008) and one focused on the Actical (Crouter and Bassett 2008). Crouter et al. used the same versions of the Actiheart, Actical and indirect calorimeter as used in the current study, however the activities examined and the algorithms used were different from those in the current study. Further, at the time of the Crouter et al. study, the authors were not aware that the Minimitter Actiheart devices produced less counts per acceleration (by 20%) than the original Actiheart upon which the algorithms used by Crouter et al. were based.

Across 18 activities, Crouter et al. (2008) found that the Actiheart had a mean RMSE of 0.09 kJ/kg/min and a negative bias of 8%. In the second paper the authors found that the Actical had a mean RMSE that varied from 0.0143 to 0.0996 kJ/kg/min and a mean RMSE that varied from 2.5 to 29%. The large range of values in the second paper is due to the authors examining three distinct algorithms and performing two analyses, one based on the inclusion of cycling and one without the inclusion of cycling. This was done because cycling creates high levels of energy demand but little movement for the Actical to register. Direct comparisons to the Crouter et al. papers are difficult as the methodology differs and the bias and error are largely influenced by the type of activities examined. For example, in the Crouter et al. paper, the addition of a cycling activity to the analysis increased the mean bias for the Actical by approximately 82% and the mean RMSE by approximately 25%. Similarly in the current study, the activities chosen to examine greatly influenced the relative accuracy of the devices. Although the current study found, across all activities, that the RMSE varied from 0.1124 to 0.1958 kJ/kg/min and the mean bias varied from 17 to 41%, it can be easily appreciated from Fig. 1 and Table 3 that inclined jogging created a large portion of this average error.

There is only one other study that has compared the Actiheart and an ACC device. (Barreira et al. 2009) Comparisons to the current study are difficult as Barreira et al. used the older formula within the Actiheart (Brage et al. 2005), the comparison was made to the Actigraph (Actigraph LLC, Pensacola, FL, USA) rather than the Actical, and the activities were dissimilar. Barreira et al. examined three speeds of treadmill walking/running (3.2, 6.4, and 9.6 km/h) comparing estimates to the measured values obtained by a metabolic cart. Although analysis did not directly compare the two devices during the treadmill walking/running, both devices produced estimates which were not significantly different than the criterion value, with the exception of a negative bias found in the Actiheart at the 9.6 km/h running level. Barreira et al. also compared the Actiheart and Actigraph estimates across 30 min of "free-living" activities (chosen by participants). Across the free-living conditions there was no significant difference in the estimates of the two devices. The authors did not specify whether the estimate analyzed from the Actiheart was derived from the ACC, HR, or combined ACC/HR data.

The question of whether or not the Actiheart possesses equivalent measurement validity compared to ACC-only devices for activities dissimilar to those studied here was not addressed. The findings in this study should apply to the currently available Actiheart (MetriSense; CamNtech) when the most recent default group calibration equations are used (Brage et al. 2007), however, Actiheart estimates are likely to be improved if individual calibration is performed.

The information provided by this study may be useful to researchers attempting to make practical decisions regarding the selection of ACC or ACC/HR devices. Perhaps most importantly, researchers must clearly consider the specific activities being examined so the aims of the study can be aligned with the appropriate choice of measurement device. This study suggests that, if the group calibration equations with the currently available Actiheart are to be used, there may be a limited number of physical activities for which the increased cost and complexity of the Actiheart is balanced by the degree of improvement in energy estimates.

Conclusion

All estimates tended to underestimate energy, sometimes by substantial amounts. Using the most current default group calibration formulas within each device, and viewed across all of the activities studied, there was no significant difference in the ability of the waist-mounted Actical and torso-mounted Actiheart (ACC, HR, ACC/HR) estimates to predict energy expenditure. However, the Actiheart provided significantly better estimates than the Actical for the activities in which acceleration of the pelvis is not closely related to energy expenditure (card playing, sweeping, lifting weights) and the Actical provided significantly better estimates for level walking and level jogging. Similar to a previous study, the ACC component of the Actiheart was found to be the weakest predictor of energy suggesting it may be responsible for the failure of the combined ACC/HR estimate to equal or better estimates derived solely from a waist mounted ACC device.

Acknowledgments The authors of this manuscript certify that all experiments conducted during this study were in compliance with the current laws of the USA.

Conflict of interest The authors declare that they have no conflict of interest.

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