Estimation of Energy Expenditure among Malaysian Young Adults: A Pilot Study Comparing Heart Rate Monitoring (HRM) Method and Activity Diary (AD) Method

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ABSTRACT

Introduction: Accurate yet inexpensive methods for measuring free-living energy expenditure (EE) are much needed. The aim of this study was to determine the feasibility of heart-rate monitoring method (HRM) in measuring EE as compared to the established activity diary (AD) method. **Methodology:** Minute-by-minute HRM and an activity diary (AD) were used simultaneously in 34 young adults (18 females, 16 males; mean age 21.5 ± 1.5 years). Estimates of the EE from HRM were based on individual calibration using the Flex-HR procedure while EE from AD were calculated using both individually measured and published energy cost of various activities. Total daily energy expenditure (TDEE) and its components (EE during sleep, during rest and during physical activity) were compared using Student paired-t tests. **Results:** TDEE from HRM method averaged 8.17 ± 2.00 MJ/day compared to 8.50 ± 1.28 MJ/day from AD method. Although large intra-individual differences were found (ranging from -36.9% to 47.4%), there was no significant difference between the two methods (mean difference -3.6 ± 19.4%). The limits of agreement (mean ± 2SD) were -3.77 and 3.11 MJ/day. There were no significant differences for any of the TDEE components between the two methods, except for EE during sleep ($p<0.05$). **Conclusion:** HRM method was found to be a feasible method for assessment of EE, and was comparable to AD for group assessment of TDEE and its components.

Keywords: **Physical activity, energy expenditure, heart rate, activity diary, factorial method**

INTRODUCTION

A decline in energy expenditure has been identified as one of the main contributing factors to the current emergence of global obesity epidemic[1]. In a way, this reemphasized the importance of assessing energy expenditure (EE) accurately and precisely in human studies to evaluate the energy requirement of the population, as stated by the FAO/WHO/UNU report (1985)[2]. Activity diaries (AD) have been frequently used in large epidemiological studies to assess physical activity pattern, although the accuracy of this subjective tool in quantifying energy expenditure has been questioned[3]. Because self-reported AD method relies heavily on the subject's ability to accurately recall daily activities, its application in children, the illiterate and disabled populations is limited. Being an objective yet inexpensive tool, heart rate monitoring (HRM) has recently emerged as an alternative approach for measuring energy expenditure in field studies.

Doubly-labelled water (DLW) method, which uses deuterium oxide isotopes ^{18}O and $^{2}H_2$ dilution technique, is an accurate but costly method to validate free-living energy expenditure. The use of HRM in measurement of energy expenditure in field studies has been validated against this gold standard method[4-6]. However, the major weakness of HRM method lies in its tedious calibration procedures for each subject in order to establish a representative energy expenditure-heart rate (EE-HR) relationship to free-living conditions. Furthermore, non-exercise factors such as emotional state, body posture, ambient temperature, time of day, hydration status and food intake can confound the heart rate response to physical activity[7]. These confounding effects are greater during sedentary activities, where HR-EE relationships are non-linear and least established. The availability of portable heart rate monitors and the development of Flex-heart-rate (Flex-HR) technique, a method which measures EE above a predetermined threshold heart rate, has further exploited the potential of HR methodology. Not surprisingly, HRM is one of the most frequently used objective method in studies on physical activity and energy balance[8].

To the best of our knowledge, this study has not been duplicated in local studies. Hence, this pilot study aimed to assess the feasibility of the minute-to-minute HRM method in estimating energy expenditure and its components

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in free-living Malaysian adults in comparison to the recommended AD method. We hypothesized that HRM is a comparable method to AD in the measurement of total daily energy expenditure.

METHODOLOGY

Study design

This study was carried out in two measurement phases; namely Phase I – individual calibration and basal metabolic rate (BMR) measurement, followed by Phase II - free-living EE measurement. Phase I measurements were done in the Physiology Lab of University Malaya's Sports Centre. This phase was initiated by measurement of basal metabolic rate (BMR), followed by individual calibration to determine resting energy expenditure and to establish relationship between HR and EE. Phase II measured energy expenditure under free-living conditions. HRM and AD were used simultaneously on a randomly selected day. Approval to conduct the study was obtained from the Faculty of Allied Health Sciences, Universiti Kebangsaan Malaysia and Sports Centre, University of Malaya.

Subjects

An a priori power analysis was calculated based on the medium effect size (dz 0.63), an alpha level of 0.05 and a power of 0.80[9]. Assuming a 20% dropout rate, we determined that a total sample of 28 subjects was required. Subsequently, our final sample comprised 34 subjects (18 females and 16 males).

These healthy, young volunteers were recruited from four universities in Kuala Lumpur. They fulfilled the inclusion criteria of normal body mass index (18.5 - 24.9 kg/m^2), disease-free, medication-free and non-handicap. Each subject received detailed explanations on the procedures of the study and signed an informed consent prior to participation in the study. All subjects completed both phases of the study.

Phase I: Laboratory measurement of basal metabolic rate (BMR) and individual calibration

After overnight 12-hours fast, subjects were driven by car to the lab in the early morning. Height was measured to the nearest 0.5cm with a wall-mounted stadiometer while weight was taken to the nearest 0.1kg in light clothing (Health O Meter Inc., Illinois, USA). Body mass index (BMI) was calculated. Body composition (fat-free mass, fat mass and total body water) was measured using the bioelectrical impedance technique (Bodystat, Isle of Man).

Basal metabolic rate was measured for 30 minutes using a ventilated hood system (Deltatrac Metabolic Monitor MBM-200, Datex Instrumentation Corporation, Helsinki, Finland). In the calculation of BMR, the first ten minutes were omitted. The metabolic rate was calculated from oxygen consumption (VO_2) and carbon dioxide production (VCO_2) according to Weir formula (1949)[10] as follows:

$$\text{EE (kJ/min)} = 0.0163\ VO_2\ \text{(ml/min)} + 0.0046\ VCO_2\ \text{(ml/min)}$$

Two-hours after a standardized breakfast (providing approximately 600 calories), subjects were put to familiarise on a spirometry system Metamex II (Cortex Biophysik Metamex II portable CPX system, Germany) which was attached to a heart rate monitor (Polar Electro Oy, Kempele, Finland). Heart rate, volumes of oxygen consumption and carbon dioxide production were measured simultaneously while subjects performed five standardised calibration activities, namely lying supine, sitting at rest, standing, slow walking at 1.7mph 8% gradient and fast walking at 2.5mph of 12% gradient on a treadmill (Trackmaster TM500-E, Jas Fitness Systems). Preliminary stabilisation periods (of approximately 1-3 minutes) followed by three minutes of sampling periods were allocated for each calibration activity, in accordance to procedures set by Livingstone *et al*. (2000)[11]. EE was calculated using the Weir formula[10] and the HR-EE relationship was established individually using polynomial second-order regression equation.

Phase II: Field measurement of free-living energy expenditure

Within three weeks after Phase I, subjects' free-living energy expenditure were measured using HRM and AD concurrently on a randomly selected day. Heart rate was recorded minute-by-minute using a heart rate monitor during waking periods (Polar S810TM, Polar Electro Oy, Kempele, Finland). In order to familiarise subjects with the heart rate monitor, they were fitted with the chest transmitter on the night prior to measurement day.

Because heart rate data were transmitted between the chest transmitter and the watch receiver, the heart rate monitor can sometimes be subjected to electromagnetic interference and occasional failure to record data due to loose contact with the chest walls, especially among female subjects with small frame size. These data (HR<35 or >200 bpm), considered invalid, were removed and replaced with the average heart rate of the day before subsequent data calculation and analyses. Only 3.5% of our data, averaging 35 minutes per day, was invalid and had to be replaced.

In addition, subjects were required to record activities performed in a day to the closest five minutes using a modified time-activity structured diary[12] on the same heart-rate monitoring day. Subjects were asked to mark a line across the five-minute activity blocks that corresponded to the time that the activity was performed. Not limiting to a fixed range of activities, this activity diary was easy, fast and simple for self-administration.

Calculation of total energy expenditure

Total daily energy expenditure (TDEE) from HRM was calculated using the Flex-HR procedure[13]. Flex-HR is an empirical heart rate defined as the average of the highest heart rate at rest and lowest of exercise. Sleeping energy expenditure (SEE) was calculated as (BMR-BMR/20)[14]. For periods where HR was less than Flex-HR, EE (Resting Energy Expenditure, REE) was determined from the average energy cost for resting activities (lying supine, seating resting and standing quietly). Otherwise, active energy expenditure (AEE) was calculated from the individually-derived HR-EE regression equation. Thus, TDEE was equal to the summation of SEE, REE and AEE.

For AD method, TDEE was calculated using both measured and published metabolic cost. Using this factorial approach, the amount of time spent on various activities was multiplied by the metabolic cost of activities. REE referred to lying and sitting activities while AEE referred to moderate and vigorous activities[15].

Statistical analysis

Data are presented as mean ± standard deviation (SD). Mean difference of total daily energy expenditure (TDEE) and its components were compared between HRM and AD methods by using the Student's paired t-test, while correlation and the level of agreement between these two methods was assessed using the Pearson correlation, Bland-Altman and cross-classification test. Significant level was set at $p<0.05$. All statistical analyses was done using Microsoft Excel program (Microsoft, Seattle, USA) and SPSS version 14 (Statistical Package for Social Science, SPSS Inc., Chicago).

RESULTS

The physical characteristics of subjects are summarised in Table 1. Although female subjects were significantly lighter and shorter than their male counterparts, while mean BMI was not significantly different between the sexes.

Table 1. Physical characteristics of subjects (mean ± SD, range)

Variables	Female (n=18)	Male (n=16)
Age (years)	21.7 ± 1.5	21.4 ± 1.5
	(19.3 – 23.8)	(19.6 – 23.5)
Body weight (kg)	52.8 ± 5.8	60.2 ± 6.4*
	(44.6 – 63.4)	(154.0 – 178.5)
Height (cm)	160.8 ± 6.8	169.1 ± 5.9*
	(147.5 – 173.5)	(50.0 – 74.5)
Body Mass Index (kg/m^2)	20.4 ± 1.6	20.9 ± 1.7
	(18.8 – 24.2)	(18.5 – 23.6)
Body fat (%)	24.8 ± 3.6*	14.0 ± 2.3
	(19.3 – 31.3)	(10.2 – 18.4)
Lean body mass (%)	75.2 ± 3.6	86.0 ± 2.3*
	(68.7 – 80.7)	(81.6 – 89.8)

* Unpaired t-test showed significant difference between the sexes ($p<0.05$)

The gas exchange rate and heart rate of the five calibration activities are listed in Table 2. Based on the significant correlation between the heart rate and energy expenditure ($r=0.983$, $p=0.03$), HR-EE curves were plotted and regression equations were derived individually for each subject. Figures 1 and 2 show examples of HR-EE plots established from five calibration points for a male and female subject, respectively. The relatively flat slope of the female calibration curve signifies the varying fitness levels and gender difference in HR response to the standard calibration activities.

Table 2. Oxygen uptake (VO2), carbon dioxide output (VCO2) and heart rate (HR) during calibration (mean ± SD)

Activity	n	Measured Parameters		
		VO_2 (liter/minute)	VCO_2 (liter/minute)	HR (beats/minute)
Lying resting	34	0.234 ± 0.045	0.201 ± 0.042	68 ± 6
Sit quietly	34	0.245 ± 0.045	0.206 ± 0.039	76 ± 6
Stand quietly	34	0.277 ± 0.054	0.224 ± 0.041	88 ± 8
Slow walk (1.7 km/h, 8% gradient)	34	1.002 ± 0.168	0.845 ± 0.154	117 ± 11
Fast walk (4.0 km/h, 12% gradient)	34	1.563 ± 0.253	1.484 ± 0.230	153 ± 17

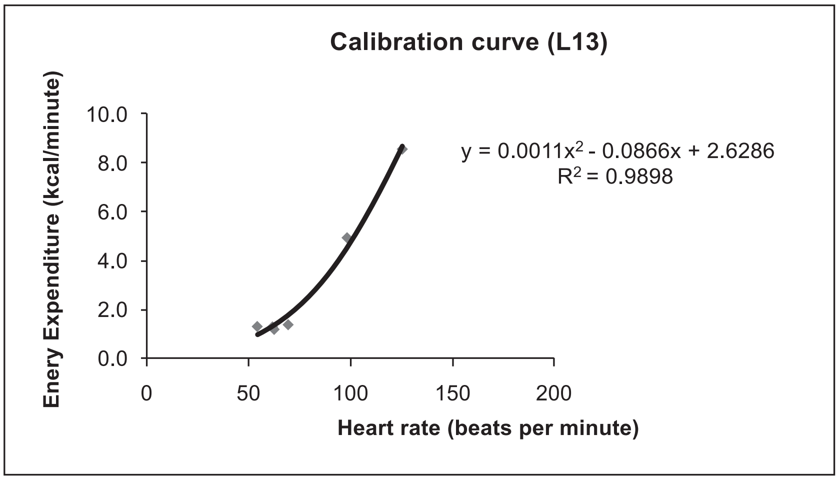

Figure 1. Regression line between energy expenditure (EE) and heart rate (HR) for a male subject

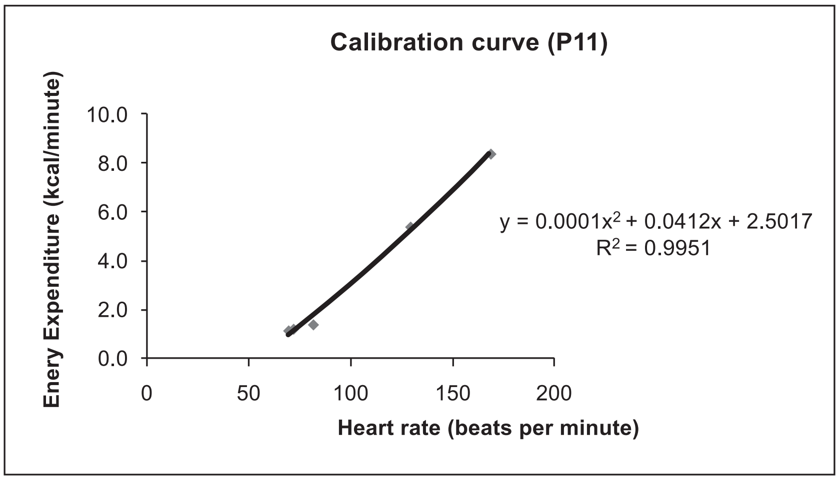

Figure 2. Regression line between energy expenditure (EE) and heart rate (HR) for a female subject

Estimates of Energy Expenditure

The estimated total daily energy expenditure (TDEE) by HRM and AD methods are compared in Table 3. Individually, the estimates of TDEE ranged from -36.7% to 47.4% between the two methods, and this range of difference was wider in female subjects as compared with male subjects.

Table 4 presents the group estimates of TDEE and its components (sleeping, resting and active) using the HRM and AD methods. On average, the TDEE was 8.17±2.00 MJ/day (1962±481 kcal/day) and 8.50±1.28 MJ/day (2041±308 kcal/day) for HRM and AD methods, respectively. For male subjects, TDEE was significantly higher than female subjects in both methods ($p<0.05$) and this was mainly due to the significantly higher AEE for HRM method ($p<0.05$) and SEE ($p<0.01$) for both methods. The mean difference of TDEE estimates by the two methods was 0.33±1.72 MJ/day. All estimates of EE and its components did not differ significantly except for SEE ($p<0.05$).

Table 3. Estimates of total daily energy expenditure by HRM (TDEEHR) and AD methods (TDEEAD) (mean ± SD)

Subject	$TDEE_{HR}$		$TDEE_{AD}$		Mean MJ/day	Difference (%)[a]
	kcal/day	MJ/day	kcal/day	MJ/day		
Female (n=18)	1657± 256	6.90 ± 1.07	1919 ± 266	7.99 ± 1.11	-1.09 ± 1.27	-12.8 ± 14.6
Male (n=16)	2306 ± 443	9.60 ± 1.84	2178 ± 300	9.07 ± 1.25	-0.33 ± 1.72	6.7 ± 19.4
All	1962±481	8.17±2.00	2041±308	8.50±1.28	8.33±1.44	-3.6± 19.4

[a] $TDEE_{HR}$-$TDEE_{AD}$/$TDEE_{AD}$ x 100

Table 4. Group estimates of total daily energy expenditure (TDEE) and its components by HRM and AD methods (mean ± SD)

	Heart Rate Monitoring (HRM)		Activity Diary (AD)	
	Female (n=18)	Male (n=16)	Female (n=18)	Male (n=16)
TDEE				
MJ/day	6.90 ± 1.07	9.60 ± 1.84**	7.99 ± 1.11	9.07 ± 1.25*
kcal/day	1657± 256	2306 ± 443	1919 ± 266	2178 ± 300
TDEE/body weight				
kJ/kg/day	132 ± 22	161 ± 32**	152 ± 15	151 ± 13
kcal/kg/day	32 ± 5	39 ± 8	36 ± 3	36 ± 3
SEE				
MJ/day	1.42 ± 0.29	1.90 ± 0.28**	1.50 ± 0.30	2.02 ± 0.43**
kcal/day	341 ± 71	456 ± 68	362 ± 72	485 ± 103
REE				
MJ/day	3.71 ± 0.63	4.45 ± 1.02*	3.50 ± 0.98	3.98 ± 1.03
kcal/day	903 ± 154	1070 ± 245	842 ± 236	956 ± 247
AEE				
MJ/ day	1.72 ± 1.40	3.25 ± 2.58*	2.98 ± 1.40	3.07 ± 1.43
kcal/day	413 ± 337	781 ± 620	716 ± 337	737 ± 342

Independent t-test showed significant difference between sexes: * $p<0.05$; ** $p<0.01$

Agreement between HRM and AD Methods

Pearson correlation test showed that the HRM and AD methods were significantly and moderately correlated in the estimates of TDEE (r=0.524, p=0.001). When approached with the Bland-Altman test, it was observed that the HRM method was more likely to underestimate TDEE for subjects with low EE compared to the AD method. The limit of agreements was -3.77 and 3.11 MJ/day. Despite two points which fell somewhat outside two SD of the mean difference, the level of agreement between the two methods was good (Figure 3).

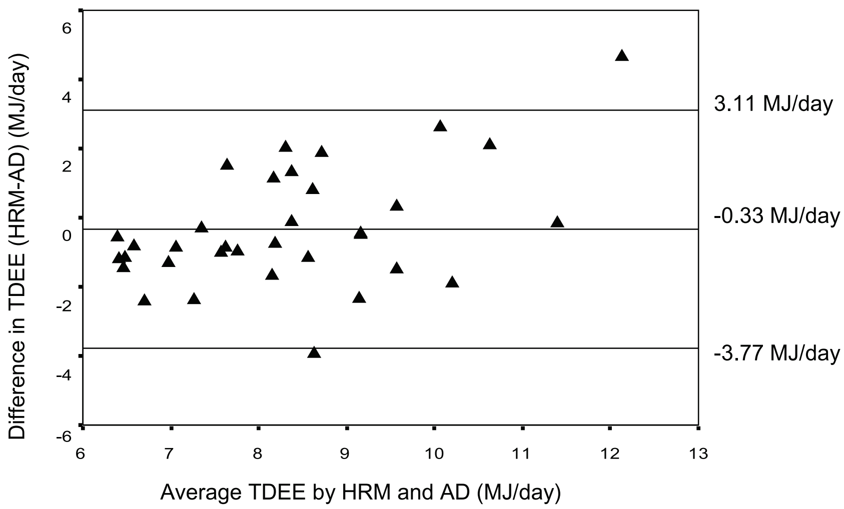

Figure 3. Bland-Altman Plot of difference between estimates of total daily energy expenditure (TDEE) by heart-rate monitoring (HRM) and activity diary (AD) methods (n=34)

Table 5 shows the distribution of subjects into three levels of EE, namely low (below 25th percentile), moderate (between 25th till 75th percentile) and high level (above 75th percentile) based on the cumulative percentiles for TDEE. It was observed that 38.9% female subjects and 43.8% male subjects were correctly classified. On the other hand, none of male subjects and only 5.6% female subjects was grossly misclassified. This cross classification test demonstrated that the two methods were in good agreement in the estimates of TDEE.

Table 5. Classification of subjects into low, moderate and high energy expenditure level by heart-rate monitoring (HRM) and activity diary (AD) methods

			TDEE Tertile (AD)		
			Low	Moderate	High
Female (n=18)	TDEE Tertile (HRM)	Low	1	3	0
		Moderate	2	6	3
		High	1	2	0
Male (n=16)		Low	1	2	0
		Moderate	3	4	2
		High	0	2	2

DISCUSSION

This pilot study employed the validated Flex-HR method[4] to examine the feasibility of HRM as an alternative approach to AD in the estimation of free-living EE in a small group of young adults. The measuring of individual basal metabolic rate using the indirect calorimetry in this study was plausible. Although time- and labour-consuming, this study also undertook individual calibration rather than group calibration as a better approach to address individual variability in establishing the HR-VO2 relationship[16]. In addition, the five calibration activities (lying supine, sitting, standing, slow and fast walk) were carefully selected to represent the largely sedentary lifestyles of university students.

The feasibility of this individual calibration procedure had been well-demonstrated by Wareham and colleagues in a relatively large population study of 775 adult subjects[17]. For broader application of HRM in population studies of energy balance, Smolander and colleagues have recently suggested a heart rate variability-based method for the estimation of oxygen consumption without the need of individual laboratory calibration. However, the validity of this new method in EE measurement has yet to be determined[18].

Overall, the EE estimates by HRM method did not differ from that of AD method, except for the EE in sleep (SEE). This was more likely to be associated with the limitation of the research design, where the recording of sleeping period was different in both methods. For HRM, SEE was equal to the non-recording time in a 24-hour cycle; as opposed to the AD method where SEE was recorded from time 0000 till 2400 in a day. Thus, for subjects who slept in the daytime but stayed awake for long hours after midnight, SEE appeared to be higher in AD than in the HRM method. This problem could be alleviated if heart rate was monitored consecutively for at least three days[19], preferably on two weekdays and a weekend day. Nonetheless, due to the lack of equipment and time constraint, it was not possible to record HR for more than a day in this pilot study.

Despite a strong linear HR-EE relationship at physical activity above basal output, there appears to be a weak uncertain HR response during resting activities. As substantial amount of daily HR were spent around the Flex-HR where the predictive power is known to be poorest, the reproducibility of Flex-HR was critical[20]. In this study, the Flex-HR of 106±8 bpm for female subjects was significantly higher than for male subjects (98±7 bpm) ($p<0.01$). Since this predetermined Flex-HR value was high and difficult to achieve under free-living conditions, it could explain the underestimation of TDEE by HRM than AD method in female subjects. Psychologically driven tachycardia, blood pooling effect and other factors that influence heart rate besides physical activity during calibration period could contribute to this inappropriate definition of Flex-HR[8].

In order to avoid underestimation of short bouts of activities, this study applied a modified AD which imposed recording of all performed activities to the closest five minutes. This recording of activities however, may have interfered with the subject's habitual activity pattern and undermined the validity of EE estimates. Besides, the use of published energy costs in the literature to calculate EE, compliance of subjects in recording of activities also influenced the outcome of this study.

In agreement with previous studies[4,8,21], this study observed that HRM provides a better estimate of TDEE in groups, although large intra-individual difference existed between the two methods. For individuals with low energy expenditure, Bland-Altman analysis showed that HRM tend to underestimate compared to the AD method. Otherwise, HRM yielded reasonable correlation and agreement with the AD method in quantifying EE and classifying EE level. Nevertheless, the accuracy of this method could only be determined when validated against a gold standard method such as doubly-labelled water.

Finally, this study demonstrated that HRM is a robust, non-intrusive, affordable physical activity measuring tool that is well-accepted by subjects. With its objectivity, HRM could potentially serve as a valuable tool in quantifying the EE and physical activity in population-based studies, especially in children and disabled populations where accurate self-recording of AD is not possible.

CONCLUSION

Heart-rate monitoring and activity diaries are comparable methods for group assessment of energy expenditure and its components, although individual assessments lack precision. This pilot study demonstrated that using HRM was a feasible and valuable alternative method to the standard AD method for the estimation of free-living energy expenditure.

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