Energy expenditure can be accurately estimated from HR without individual laboratory calibration

A. Pulkkinen[1], S. Saalasti[1], H.K. Rusko[2], FACSM

[1]KIHU-Research Institute for Olympic Sports and [2]Department of Biology of Physical Activity, University of Jyväskylä, Finland

ENERGY EXPENDITURE CAN BE ACCURATELY ESTIMATED FROM HR WITHOUT INDIVIDUAL LABORATORY CALIBRATION
A. Pulkkinen[1], S. Saalasti[1], & H.K. Rusko[2], FACSM.
KIHU – [1]Research Institute for Olympic Sports and [2]Department of Biology of Physical Activity, University of Jyväskylä, Finland.

Current heart rate (HR) based energy expenditure (EE) estimation methods are inaccurate. Flex-HR method is currently most accurate, but it requires individual calibration in laboratory limiting applicability for large-scale daily use under free-living conditions. A recent method utilizing RR-interval (RRI) derived data on HR, respiratory frequency and On-Off dynamics has increased the accuracy of HR-based VO_2-estimation (RRI_{EST}, Pulkkinen et. al., MSSE 36(5), 2004). **PURPOSE:** To evaluate whether EE during real life tasks and physical exercises can be estimated accurately using RRI_{EST} without individual laboratory calibration. **METHODS:** RRI and breath-by-breath VO_2 data from 16 male and 16 female healthy untrained adults (age of 38±9 years, weight 70±11 kg, height 172±8 cm and VO_{2max} 44±9 ml/kg•min^{-1}) were collected 5 minutes prior to, during and 15 minutes after 10-min exercises at 40% and 70% VO_{2max} and maximal stepwise test (MAX) on bicycle ergometer. Two 50 min series of simulated low intensity real life tasks (RLT1 & RLT2, mean HR 101±8 and 105±9 bpm) were also carried out. Steady-state periods from MAX were used to construct individual ($FLEX_{IND}$) and mean for all subjects ($FLEX_{ALL}$) equation slopes and intercepts to calculate EE. Flex HR under which EE was assumed to be at resting level was determined as the mean of the highest 1 min HR during baseline and lowest HR during MAX. RRI data was used to calculate EE with RRI_{EST} model (Pulkkinen et. al., 2004). Accuracy was evaluated using mean absolute error (MAE) and r^2 between the estimated and the measured. **RESULTS:** Across all subjects and conditions, MAE and r^2 between measured and estimated EE for RRI_{EST}, $FLEX_{IND}$ and $FLEX_{ALL}$ were 139, 185 and 191 kcal, and 0.81, 0.77 and 0.77, respectively. RRI_{EST} was significantly ($p<0.05$) more accurate during RLT1 and MAX compared with both FLEX-methods, whereas during 40% exercise $FLEX_{IND}$ was more accurate than RRI_{EST} or $FLEX_{ALL}$. **CONCLUSIONS:** RRI_{EST} provided accurate EE estimation during simulated real life tasks and physical exercises. EE can be estimated accurately using RRI_{EST} model without individual laboratory calibration making the RRI_{EST} method especially suitable for field use.

INTRODUCTION

Heart rate (HR) recording is a very common method to estimate energy expenditure (EE), because relationship between HR and EE is near-linear at moderate intensity exercise. HR to EE equation is affected by several confounding factors, e.g., non-physical activity related HR reactivity at low intensity, dynamic changes in exercise intensity, type of the exercise and environmental conditions. HR to EE relationship is also highly individual requiring currently laboratory calibration. Flex-HR method has been developed assuming EE to be at resting level below so called flex-HR reducing error at low HRs. A recent neural network method utilizing RR-interval (RRI) derived data on HR, respiratory frequency and On-Off dynamics has increased the accuracy of HR-based VO_2-estimation (RRI_{EST}, Pulkkinen et. al., MSSE 36(5), 2004). **The purpose was to evaluate whether EE can be accurately estimated using method utilizing RR-interval data compared with individually calibrated flex-HR method and two methods not requiring individual calibration.**

METHODS

Descriptive data on the subjects is presented in table 1. Subjects completed bicycle ergometer (Ergoline, Bitz, Germany) exercises and real life tasks (RLT) described in figure 1. Resting HR and EE values were recorded during 15-minute baseline (BL) period at different postures. RLT's included simulated low intensity household, recreational and occupational tasks, such as: sweeping the floor, walking, walking in stairs, carrying load, pushing shopping wheels, lifting and moving light weights, computer tasks and free standing and sitting. Beat-by-beat HR-data was collected with rr-recorder (Polar Electro Oy, Kempele, Finland). VO_2 data was collected breath-by-breath using Vmax (Sensor Medics, California, Palo Alto, USA) during bicycle ergometer exercises and with portable Cosmed K4 analyzer (S.r.I, Italy) during RLT's. Energy expenditure was calculated from VO_2 using non-protein caloric equivalents for oxygen.

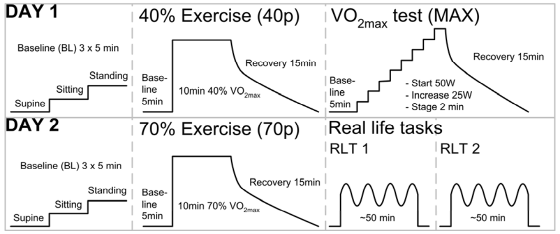

Figure 1. The procedure.

EE was estimated using five methods:

1. RRI_{EST}: EE was derived from RRI using specialized neural network method that uses information on heart rate, RRI-derived respiration rate and on- and off-dynamics (Firstbeat Technologies Oy, Jyväskylä, Finland). No individual fit for HR to EE equation. Parameters included maximal MET, maximal heart rate and maximal respiration rate.
2. $FLEX_{IND}$: EE derived from HR using individual fit between HR to EE acquired from steady-state data during MAX.
3. $FLEX_{ALL}$: EE derived from HR using mean of individual slopes and intercepts between $\%HR_{MAX}$ and $\%EE_{MAX}$ acquired from steady-state data during MAX.
4. $RENN_{EST}$: EE estimated form HR using Rennie et al. (2001) model, which estimated flex-HR, resting EE, slope and intercept between HR to EE based on parameters: age, gender, weight, sitting HR and BMI.
5. $HIIL_{EST}$: EE estimated from HR using Hiilloskorpi et al. (2003) heart rate reserve model, which used different equations for male and female based on weight. High activity formula was selected, because exercise tasks in this study included high intensity exercises exceeding 3 METs.

For $FLEX_{ALL}$ and $FLEX_{IND}$, flex-HR under which EE was assumed to be at resting level was determined as the mean of the highest 1 min HR during BL and first 1 min HR during MAX-exercise. Baseline EE was determined as mean of the lowest 3 min EE period during both day's BL.

Measured and estimated EE's for each individual and each task including baseline, exercise and recovery was calculated (EE_{40p}, EE_{70p}, EE_{MAX}, EE_{RLT1}, EE_{RLT2}). Also sum of EE (EE_{SUM}) for each subject including all tasks was calculated ($EE_{40p}+EE_{70p}+EE_{MAX}+EE_{RLT1}+EE_{RLT2}$).

Accuracy was evaluated in two ways with mean absolute error (MAE) and r_2 between the measured and estimated EE: 1) Across subjects: MAE of EE_{SUM}. 2) Across tasks: MAE of EE_{40p}, EE_{70p}, EE_{MAX}, EE_{RLT1} and EE_{RLT2}.

Table 1. Descriptive data on the subjects.

	Male, n=16		Female, n=16	
	Mean±SD	Range	Mean±SD	Range
Age (yr)	36±8	24-50	39±10	25-54
Height (cm)	179±5	168-185	165±5	158-176
Weight (kg)	76.4±8.3	64.7-93.0	63.6±9.2	52.0-86.7
BMI (kg·m^{-2})	23.9±2.3	19.9-27.5	23.3±2.8	19.4-30.0
VO_{2MAX} (ml/kg/min)	49±8	38-66	40±7	30-53
HR_{MAX}(bpm)	182±10	160-197	177±9	161-195
HR rest (bpm)	63±7	51-73	67±10	48-80

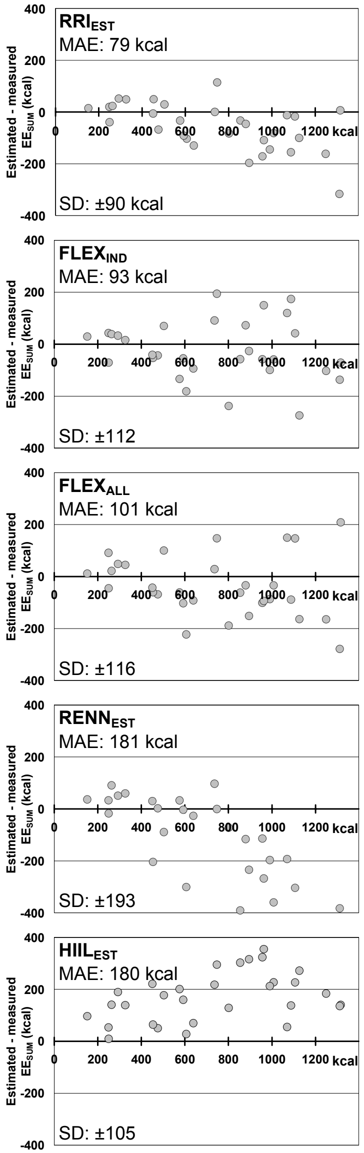

Figure 2. Difference between the estimated and measured EE_{SUM} as a function of the corresponding measured EE_{SUM}. Each dot represents one subject. SD from difference between measured and estimated EE_{SUM}.

RESULTS

Flex-HR was on average 93±10 bpm. Mean EE across all five tasks for subjects was 740±342 kcal. Measured EE and mean HR for each task is presented in table 3. All subjects did not complete all five tasks.

Across subjects, MAE was smallest with RRI_{EST} and highest with $RENN_{EST}$ and $HIIL_{EST}$ (figure 2). Estimated EE_{SUM} differed significantly form measured EE_{SUM} with RRI_{EST} ($p<0.01$), $RENN_{EST}$ ($p<0.001$) and $HIIL_{EST}$ ($p<0.001$).

Across tasks, all EE estimates differed significantly from measured EE during RLT's (table 3). RRI_{EST} was the only method that did not differ from measured during all ergometer exercises.

Sum of MAE of different tasks (table 3) and r^2 between measured and estimated EE for RRI_{EST}, $FLEX_{IND}$, $FLEX_{ALL}$, $RENN_{EST}$ and $HIIL_{EST}$ were 139, 185, 191, 270 and 246 kcal, and 0.81, 0.77, 0.77, 0.71 and 0.77, respectively.

Table 3. Mean HR as well as measured EE and MAE (both in kcal and mean of subjects) across different tasks including baseline, exercise and recovery phases.

	EE_{40p}	EE_{70p}	EE_{MAX}	EE_{RLT1}	EE_{RLT2}
n	*23*	*28*	*22*	*19*	*25*
Mean HR (bpm)	71±11	83±9	119±8	92±11	99±10
Measured EE	81±23	127±29	248±100	242±33	269±48
RRI_{EST}	12±8	13±10	15±11	39±28**	60±31***
$FLEX_{IND}$	7±7	17±15	39±21***	58±34***	65±35***
$FLEX_{ALL}$	12±10	16±14	40±33***	59±35***	64±37***
$RENN_{EST}$	22±17***	28±17*	54±37	81±40***	85±49***
$HIIL_{EST}$	43±19***	47±21***	70±38***	52±33***	34±29**

*$p<0.05$, **$p<0.01$, ***$p<0.001$ significantly different from measured EE.

DISCUSSION

The results indicate that RRI_{EST} provided smallest MAE as evaluated both across subjects and across different tasks. Additional information on respiration and On- and Off-dynamics as derived from RR-interval data seems to reduce error when including different dynamic exercise conditions from baseline to exercise and to recovery. RRI_{EST} was more accurate compared to $FLEX_{IND}$ even though it did not include individually calibrated HR to EE equation.

The results suggest, that by using conventional laboratory calibrated flex-HR methods ($FLEX_{IND}$, $FLEX_{ALL}$), EE can be estimated with reasonable accuracy during bicycle exercises. Although error distributed around the mean with no trend to under- or overestimation, variance is rather great and leads to higher absolute error. This is highlighted with non-significant difference from measured EE_{SUM} across subjects, but higher MAE compared with RRI_{EST}.

Although $RENN_{EST}$ did not significantly differ from measured EE during MAX and MAE of $HIIL_{EST}$ was the lowest during RLT2, these methods did not provide as accurate means for estimating EE compared with other methods examined. $RENN_{EST}$ tended to underestimate EE_{SUM} and $HIIL_{EST}$ overestimate EE_{SUM}, probably because exercises included also baseline and recovery phases.

In conclusion, RRI_{EST} provided an accurate and practical method for estimating EE without individual laboratory calibration making it especially suitable for field use.

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