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ORIGINAL ARTICLE

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Estimating relative physical workload using heart rate monitoring: a validation by whole-body indirect calorimetry

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Abstract Measuring physical workload in occupational medicine is fundamental for risk prevention. An indirect measurement of total and relative energy expenditure (EE) from heart rate (HR) is widely used but it has never been validated. The aim of this study was to validate this HR-estimated energy expenditure (HREEE) method against whole-body indirect calorimetry. Twenty-four-hour HR and EE values were recorded continuously in a calorimetric chambers for 52 adult males and females (19–65 years). An 8-h working period was retained, comprising several exercise sessions on a cycloergometer at intensities up to 65% of the peak rate of oxygen uptake. HREEE was calculated with reference to cardiac reserve. A corrected HREEE (CHREEE) was also calculated with a modification to the lowest value of cardiac reserve. Both values were further compared to established methods: the flex-HR method, and the use of a 3rd order polynomial relationship to estimate total and relative EE. No significant difference was found in total EE when measured in a calorimetric chamber or estimated from CHREEE for the working period. A perfect linear and identity relationship was found between CHREEE and energy reserve values for intensities ranging from 15% to 65%. Relative physical workload can be accurately assessed from HR recordings when expressed in CHREEE between 15% to 65%, and EE can be accurately estimated using the CHREEE method.

Keywords Energy expenditure · Sleeping metabolic rate · Heart rate · Physical workload · Physical activity

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Introduction

Heart rate (HR) monitoring is one of the most popular indirect methods to estimate energy expenditure (EE) as it is a practical and low-cost method that brings little inconvenience to the subject. Several HR methods estimating EE have been compared to the two gold reference techniques, whole-body indirect calorimetry (Dauncey and James 1979; Spurr et al. 1988; Ceesay et al. 1989; Westerterp et al. 1994; Bitar et al. 1996; Morio et al. 1997) and doubly labeled water (Schultz et al. 1989; Livingstone et al. 1990; Van den Berg-Emons et al. 1996; Davidson et al. 1997; Morio et al. 1997) in adults (Dauncey and James 1979; Spurr et al. 1988; Ceesay et al. 1989; Schultz et al. 1989; Livingstone et al. 1990; Westerterp et al. 1994; Bitar et al. 1996; Davidson et al. 1997), children (Emons et al. 1992; Livingstone et al. 1992; Bitar et al. 1996; Falgairette et al. 1996), elderly (Goran and Poehlman 1992; Morio et al. 1997; Rutgers et al. 1997), obese people (Fogelholm et al. 1998), and physically or mentally disabled children (Van den Berg-Emons et al. 1995, 1996).

The estimation of EE from HR recordings supposes an individual calibration in the laboratory of the HR–EE relationship. Several individual relationships have been widely explored and proposed, such as exponential (Li et al. 1993; Bitar et al. 1996), logarithmic (Schultz et al. 1989), 2nd order (Schultz et al. 1989; Bitar et al. 1996; Davidson et al. 1997) and 3rd order (Bitar et al. 1996) polynomial relationships and, probably the most widely used, the flex-HR method (Spurr et al. 1988; Ceesay et al. 1989; Schultz et al. 1989; Livingstone et al. 1990; Van den Berg-Emons et al. 1995, 1996; Fogelholm et al. 1998). It seems that the best estimation of EE and the most adequate HR–EE values on the whole intensity range are obtained with a 3rd order polynomial relationship, at least in children (Bitar et al. 1996). However, one bias of this method relies on the fact that the HR–EE relationship is linear at high exercise intensities (Montoye et al. 1996). The flex-HR (defined as the mean HR value between the highest HR during rest and the lowest HR during exercise) method supposes a linear relationship between HR and EE above this "transition point", the mean EE corresponding to the resting metabolic rate (Spurr et al. 1988; Livingstone et al. 1990, 1992; Van den Berg-Emons et al. 1996) or basal metabolic rate (Ceesay et al. 1989; Schultz et al. 1989) below this point. However, this HR value needs to be corrected by +5, +10, +15 or +20 beats min^{-1}; the correction depends on the population studied, and the type and number of activities used to determine the so-called resting metabolic rate. Considering all these variables, there is still possible confusion when talking about the flex-HR and its associated method to estimate EE.

The cardiac cost method (Kamal et al. 1991; Chamoux et al. 1993; Falgairette et al. 1996) based on HR-estimated energy expenditure (HREEE) is used to estimate a relative physical workload in occupational medicine (Chamoux et al. 1985), but it has never been validated against a reference method. As many occupations average a low-intensity physical strain on an 8-h basis, this raises the problem that low metabolic power needs to be accurately reported by low HR values, which is not necessarily true below 50% of peak oxygen uptake (peak $\dot{V}O_2$) (Astrand and Rodahl 1986). However, the linearity between HR and EE has been extensively reported (Chamoux et al. 1990; Swain and Leutholz, 1997; Swain et al. 1998) and used in the flex-HR method (Spurr et al. 1988; Ceesay et al. 1989; Schultz et al. 1989; Livingstone et al. 1990; Van den Berg-Emons et al. 1996).

Thus, the purpose of this study was to validate this HREEE method using whole-body indirect calorimetry with reference to existing methods (3rd order polynomial relationship and the flex-HR method), and to estimate the error brought by the HREEE method when measuring absolute and relative EE.

Methods

Subjects

The study group comprised 52 Caucasian people (26 females, 26 males) from Clermont Ferrand in France, all of working age [42.6 (20.1) years, range 19–65 years], who were informed of the study modalities before giving written consent. The subjects underwent a complete medical examination before performing a maximal incremental test on a cycle ergometer. Volunteers were selected based on the absence of a history of health disorders and the validity of the maximal incremental test. Those excluded were all subjects with a medical history, those who were not of working age and those who refused the study modalities. Local and national ethical committees approved the study.

Timing of measurements and program of activities in the laboratory

An afternoon was dedicated to the medical examination and the maximal incremental test providing the individual HR–EE calibration. The measurements were carried out 1 h after arrival at the laboratory and 2 h after the last meal. During the period of rest, EE values were recorded by respiratory gas exchange on an open-circuit indirect calorimeter with a ventilated hood system. Subjects were lying, sitting on a chair, sitting on the bicycle and standing, and the measurements were made in steady state. Measurements during moderate to heavy exercise were conducted on a cycle ergometer at a constant pedaling frequency of 60 rpm. HR was recorded continuously with an electrocardiogram (Schiller, Cardiovit CS-6/12, Baar, Switzerland). The subjects performed several successive 2.5-min steps against braking forces, which increased by 25 W, until exhaustion. During the last 30 s of each step, expired air was collected in a Douglas bag by using a two-way, non-breathing valve and a noseclip. The volume of expired air was determined with a Tissot spirometer. The fractions of O_2 and CO_2 in expired air were determined by using a paramagnetic O_2 analyzer (model OM11, Beckman; scale 16–21%) and an infrared CO_2 analyzer (model LB2, Beckman; scale 0–5%). The accuracy of each gas analyzer was 0.1% of the scale. The gas analyzers were calibrated with a standard gas before each exercise session. The criteria for reaching the peak $\dot{V}O_2$ were a respiratory quotient above 1.1, a maximal HR within 5% of the theoretical maximal HR and physical exhaustion. This procedure of calibration was carried out 1 week before the measurements in the calorimetric chambers, and they allowed us to determine the flex-HR (Spurr et al. 1988).

Timing of measurements and program of activities in the calorimetric chambers

An evening and a complete night had to be spent in the calorimetric chambers before the actual measurement session began. This was to allow the volunteers adapt themselves to this new environment, as well as to adjust gas concentrations. Following the adaptation period, a 24-h measurement period started, beginning at 7:00 a.m.

The subjects followed a definite activity program: waking and getting up at 7:00 a.m., having meals or a snack at 7:30 a.m., 12:30 p.m., 4:30 p.m. and 7:30 p.m., going through four periods of exercise at 40, 60, 50 and 65% of peak $\dot{V}O_2$ on a cycle ergometer, each lasting 20 min and taking place at least 1.5 h after the end of a meal. During the rest of the time, activities were free, and supervision was continuous during the whole stay in the chambers. Food intake was not recorded accurately, but the diet composition was fairly standardized. The hypothetical working period was considered to last 8 h, from 8:00 to 12:00 and 14:00 to 18:00, including the four exercise bouts.

Measurement of EE in the calorimetric chambers

Whole-body indirect calorimetry was used to determine EE. The two calorimetric chambers and the equipment for gas analysis used have been described elsewhere (Bitar et al. 1995). O_2 consumption and CO_2 production were measured continuously. The time of response of the calorimeters (1.5 min for CO_2 and 3 min for O_2) was taken into account in the computations. The accuracy for gas exchange measurements was determined gravimetrically by continuous injections of CO_2 and N_2 into the chambers. The recovery was 99.5 (0.6)% for periods of 2–8 h, and 97.2 (1.6)% for periods of 15 min (Bitar et al. 1995). All physical and physiological parameters were continuously recorded by a data logger every minute during the periods of exercise, and every 5 min for the rest of the day. EE was calculated from O_2 consumption and CO_2 production by using Brouwer's equation (Brouwer 1965): $EE = [16.18(O_2) + 5.02(CO_2)]0.99$, where O_2 consumption and CO_2 production are measured in liters, and EE is measured in kilojoules. The 0.99 coefficient was used to take into account the catabolism of protein, since urinary nitrogen was not measured over the 24-h period. HR was measured continuously by telemetry (Lifescope 6), and was averaged over 1 min during the periods of exercise, and over a 5-min period for the rest of the day and the night.

EE was measured continuously over 24 h including the night, the artificial working period, high-intensity exercise bouts and resting activities. EE can be expressed either in absolute terms (kilojoules per time span) or in relative terms (metabolic power, noted percentage of an energetic reserve, noted %ER). The energetic reserve is delimited by peak $\dot{V}O_2$ and sleeping metabolic rate, which is defined as the median value of the 6 h of sleep when the metabolic rate is the lowest (EE_{sleep}). The basal metabolism was estimated by Schofield's equation (Schofield et al. 1985; Fredrix et al. 1990).

The HREEE method

This method, based on HR recordings, expresses a relative physical workload in percentages of a cardiac reserve delimited by maximum HR (HR_{max}) and a sleeping HR (HR_{rest}), which is defined as the median value of the 6 h of sleep when HR values are lowest (Chamoux et al. 1985). We chose this HR_{rest} for its objectiveness, easiness of measure, its stability and its relevance in defining a controversial resting HR (Chamoux et al. 1985, 1990). The relative HREEE and corrected HREEE (CHREEE) are percentages of the cardiac reserve with, for the HREEE, a correction of 15 beats min^{-1} to the HR_{rest} in order to take into account the hemodynamic modifications induced by the awakened state (Chamoux et al. 1985, 1990):

$$HREEE = [(HR - HR_{rest})/(HR_{max} - HR_{rest})]100$$

$$CHREEE = [(HR - HR_{rest} + 15)/(HR_{max} - HR_{rest} + 15)]100$$

Estimation of EE from cardiac parameters

A 3rd order polynomial HR–EE relationship and a flex-HR relationship was established for each volunteer. Six HREEE–%ER and CHREEE–%ER linear relationships, beginning from 0% to 30% ER were then tested. An estimation of the working period total EE was calculated from the most interesting CHREEE–%ER relationship for each participant, and for the whole group, and compared to the actual EE value measured in the calorimetric chamber.

Statistical analysis

Comparison and agreement between the CHREEE method and the whole-body indirect calorimetry for determining total EE was assessed by using the method of Bland and Altman (1986). A high correlation does not mean that the two methods agree. The lack of agreement between the methods can be evaluated by calculating the bias, estimated by the mean difference and the standard deviation of the differences. If the differences are normally distributed (Gaussian), 95% of the differences are considered to lie between mean difference $\pm$ 1.96 SD.

Results are given as means (SD) for the whole population. Student's *t*-test was used to compare males and females after verifying the normality of the groups with the test of Kolmogorov–Smirnov. Differences were significant at $P < 0.05$.

The 3rd order polynomial CHREEE–%ER relationship was calculated for every participant serving as the reference relationship and the relevance of a CHREEE method to estimate a relative working intensity from a linear CHREEE–%ER relationship ranging from 0, 5, 10, 15, 20, 25, or 30 to 65% of ER was tested. The relative error between the 3rd order polynomial CHREEE–%ER relationship and the linear CHREEE–%ER relationship on the selected range was calculated for every subject and for the whole group [($y_{\%ER}$

$_{poly}-y_{\%ER\ linear})/(y_{\%ER\ poly})$, where y is the given ordinate value calculated from the (C)HREEE–%ER linear or polynomial relationship].

Results

Volunteers

The main characteristics of the volunteers are presented in Table 1. Mean age, HR_{max} and body mass index were not significantly different between men and women. Peak $\dot{V}O_2$ was significantly higher in men than in women.

HR_{rest}

Mean HR_{rest} for the whole population was 57.4 (7.4) beats min^{-1}. There was a significant difference between women and men [60.9 (6.6) vs 54.0 (6.5) beats min^{-1} respectively, $P<0.05$].

EE_{sleep} and basal metabolism

EE_{sleep} was 5.5% lower than the basal metabolism calculated with Schofield's equation (72.83 vs 76.83 W). There was a significant difference between men and women [82.17 (11.17) vs 63.67 (6.67) W], a difference that disappears if the body mass is taken into account (Van Etten et al. 1995) [1.14 (0.15) vs 1.10 (0.16) W kg^{-1}]. Age did not affect HR_{rest} or EE_{sleep}.

Flex-HR

The flex-HR was significantly higher than the $HR_{rest+15}$ (88.5 vs 72.4 beats min^{-1}). There was a significant difference between men and women (85.6 and 91.4 beats min^{-1}, respectively). When expressed in %ER, HREEE or CHREEE, the flex-HR was no longer different between women and men. It was noticeable that the flex-HR appeared to be the same percentage of energetic reserve and CHREEE [respectively, 15.8 (4.3)% and 15.4 (5.9)%].

The HREEE–%ER relationship

The best fitting HREEE–%ER relationship for the whole population was obtained with a 3rd order polynomial relationship ($\%ER = aHREEE^3 + bHREEE^2 + cHREEE + d$, where a = 0.00007, b = 0.0155, c = 0.1404, and d = 0.3251) ($R^2 = 0.91$). A simple linear HREEE–%ER regression over the whole range of intensities (0–65% of ER) explained only 75% of the variance (Fig. 1). The mean EE of the artificial working period was 4,746.0 (912.0) kJ, with an average HREEE of 20.9 (5.7)% when measured in the calorimetric chamber. Using the preceding linear HREEE–%ER relationship, the estimated EE was 4,855.0 (1,066.0) kJ, which is not significantly different from EE measured in the calorimetric chambers (Fig. 2). In only two individuals did the estimated EE lie outside the confidence interval (−796 to 1,014 kJ) determined by the Bland and Altman method (Fig. 2).

The relative error at the mean HREEE of 20.9% (average intensity of the artificial working day) was 33.0%, with a maximum of 54.0% at a HREEE of 11.0%.

Other linear relationships were explored, depending on the range of intensities, as shown in Table 2. The relationship seemed to stabilize from a HREEE of 20% on, with a constant term of approximately −15 and a linear coefficient of 1.16 ($R^2 = 0.82$). A simplified equation could be $\%ER = 1.16HREEE - 15$. All relationships considered were independent of age or sex.

The CHREEE–%ER relationship

The best fitting CHREEE-%ER relationship was a 3rd order polynomial relationship ($r^2 = 0.91$). Table 3 presents the CHREEE–%ER linear relationships for different intensity ranges. There was a near perfect identity (Fig. 3) between CHREEE and %ER between the values of 15% and 65%. In this range of intensities, any relative

Table 1 Physical characteristics, maximum heart rate (HR_{max}) and maximum rate of oxygen uptake ($\dot{V}O_{2max}$) of the population. Results are presented as means (SD) and with extreme values. BMI Body mass index, *NS* not significant

Characteristics	Men ($n=26$)	Women ($n=26$)	Total ($n=52$)	P
Age (years)	43.8 (19.9) 20–65	41.4 (20.6) 19–65	42.6 (20.1) 19–65	NS
Height (cm)	174.9 (6.64) 166–187	161.5 (6.67) 147–173	167.9 (9.3) 147–187	<0.05
Mass (kg)	73.5 (10.88) 57–96.8	60.3 (7.4) 42–71	66.6 (11.1) 42–96.8	<0.05
BMI (kg m^{-2})	24.03 (3.28) 18.6–29.7	23.2 (3.04) 15.8–28.1	23.59 (3.16) 15.8–29.7	NS
HR_{max} (beats min^{-1})	174.6 (16.5) 148–199	177 (15.1) 148–202	175.8 (15.7) 148–202	NS
$\dot{V}O_{2max}$ (ml min^{-1} kg^{-1})	39.74 (9.34) 24.4–59.9	29.63 (7.65) 17.1–45.5	34.33 (9.77) 17.1–59.9	<0.05

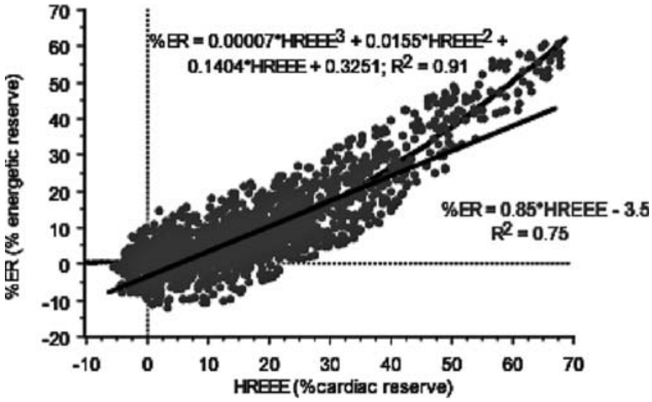

Fig. 1 Linear and 3rd order polynomial heart-rate-estimated energy expenditure (*HREEE*)–percentage of energetic reserve (*%ER*) relationships over the whole range of intensities

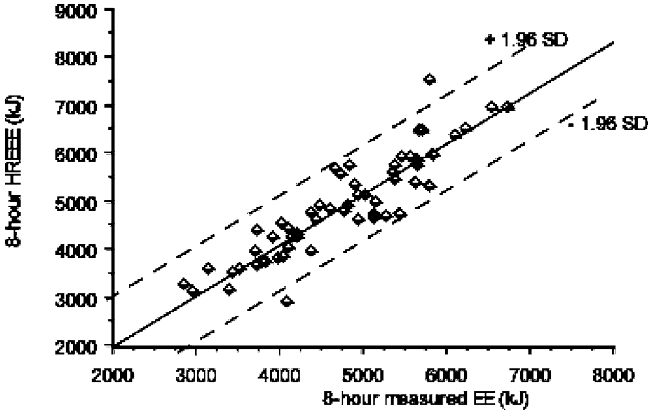

Fig. 2 Total energy expenditure (*EE*) measured in a calorimetric chamber versus total EE estimated by the linear %ER–HREEE relationship over the whole range of intensities

intensity expressed in CHREEE corresponds to the same relative intensity expressed in %ER. The relationship seemed to stabilize from a CHREEE value of 13% onwards, with a linear coefficient approaching 1.0 and a constant term approaching 0 ($R^2=0.83$).

The flex-HR corresponds to a CHREEE of 15.4%. The linear CHREEE–%ER relationship between the flex-HR and the highest intensities is therefore similar to Spurr's approach of the linearity between HR and metabolic power over a wide range of intensities.

The average CHREEE of the artificial working day was 10.6% (%ER = 11%). For such low intensities, the relationship was not as accurate, with a relative error of 22.4%. In terms of absolute EE values, the difference was significant when estimated by the CHREEE method at 10.6%, implying that the CHREEE–%ER linear relationship can only be used in relative terms between 15% and 65%.

Discussion

The main result of this study is the demonstration of a linear identity relationship between CHREEE and relative metabolic power between 15% and 65%. In addition to this, the CHREEE method allows an accurate estimation of total EE at the average intensity considered.

Using a 3rd order polynomial relationship to estimate EE seems to be the best fitting relationship, which confirms previous results in children (Bitar et al. 1996). The flex-HR method is similar to the present CHREEE method as it relies on a linear relationship above this specific inflexion HR value. One further interesting result of this study is that the flex-HR was systematically found to be around 15% of CHREEE. This result is of potential use in the determination of the flex-HR as, in previous studies, corrections of +5, +10, +15 or +20 beats min^{-1} had to be made, depending on the population studied. This value of 15% could be considered as a threshold from which a variation in HR reflects the same relative variation in metabolic power, and it could represent an alternative, less subjective way to assess this inflexion point.

Many studies have explored the mechanisms affecting HR without necessarily affecting EE, and it is known that posture or the type of exercise (Ceesay et al. 1989; Rayson et al. 1995) as well as heat, emotion (Moss and Wynar 1970; Gaudemaris et al. 1998), alcohol, caffeine or cigarette consumption (in Li et al. 1993) can modify HR without greatly affecting EE. In the long term, training level, body composition or aging may also modify the HR–EE relationship (in Li et al. 1993). All these factors affect the HR–EE relationship all the more that the physical activity considered is performed in a low intensity range, where respective variations in HR and EE are largely independent from each other. This is a limit to the present CHREEE–%ER relationship, as the almost perfect identity stands between 15% and 65% only. Indeed, %ER = 1.002×CHREEE + 0.4 implying that one percentage point of ER corresponds to the

Table 2 Linear relationships between heart-rate-estimated energy expenditure (*HREEE*) and percentage of energetic reserve (*%ER*) depending on the range of intensities. Fc-flex-65% stands for from Fc-flex value (i.e. from 15.4% of CHREEE) to 65%

	Intensity range (%ER)						
	0–65%	5–65%	10–65%	15–65%	20–65%	25–65%	Fc-flex–65%
Linear relationship	0.85×HREEE −3.5	0.997×HREEE −8.03	1.06×HREEE −10.59	1.12×HREEE −12.95	1.157×HREEE −14.74	1.161×HREEE −14.8	1.15×HREEE −14.495
R^2	0.75	0.80	0.81	0.82	0.82	0.82	0.83

Table 3 Linear corrected HREEE (*CHREEE*)–%ER relationships over different ranges of intensities

	Intensity range in %ER			
	0–65%	5–65%	10–65%	15–65%
Linear relationship	0.967×CHREEE +2.07	0.978×CHREEE +1.98	0.988×CHREEE +1.1	1.002×CHREEE +0.4
r^2	0.82	0.82	0.83	0.83

same percentage of CHREEE and thus the same relative physical workload. However, this intensity range corresponds precisely to the relative physical workloads encountered in most occupations. Some sedentary occupations induce a lower physical workload and thus cannot be estimated correctly by the CHREEE method. Nevertheless, as the aim of this method in occupational medicine is to prevent the production of an effort that is too intensive over an 8-h time-span (46% of peak $\dot{V}O_2$ for Saltin, 43% of CHREEE for Chamoux), the inadequacy of the relationship below intensities of 15% is therefore of reduced importance. At those low relative intensities, the employee is not in physical overload or pain.

The extreme values determining the cardiac and energetic reserve are of major importance in this CHREEE method. There is still no consensus regarding the lowest values. In the present study, HR_{rest} was chosen for its ease of measure, its reproducibility and its relevance in representing an objective resting state (Chamoux et al. 1985, 1990). However, it cannot properly represent a diurnal-state resting HR. Therefore, we used the $HR_{rest+15}$ to take into account the hemodynamic changes induced by the awakened state (vigilance, posture, noise, heat...). In this and other studies, the $HR_{rest+15}$ appeared to be a correct estimation of a HR corresponding to the theoretical minimal rate of oxygen uptake (Chamoux et al. 1990). This arbitrary correction does not take into account the subjects' characteristics, but is counterbalanced by the easy but accurate determination of an individual HR_{rest}. Moreover, affecting an arbitrary value to a resting state has been used in other scientific approaches such as the flex-HR method where

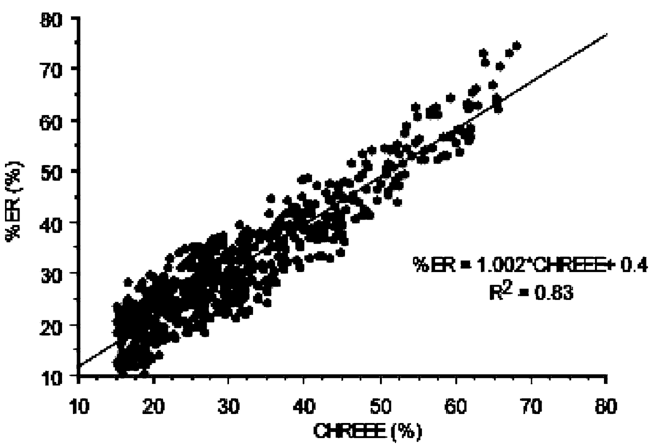

Fig. 3 Linear corrected HREEE (*CHREEE*)–%ER relationship between 15 and 65%

EE is considered as being equivalent to the basal metabolism (Spurr et al. 1988; Ceesay et al. 1989) below this HR-flex.

This basal metabolism, estimated by Schofield's equation, was compared to the EE_{sleep} as we defined it, and it appeared to be 5.5% higher than EE_{sleep}, in accordance with the literature (Fredrix et al. 1990; Thompson et al. 1995). Therefore, we kept the EE_{sleep} to set the lowest value of the ER for the same reasons we used the HR_{rest} or the $HR_{rest+15}$ to set the lowest limit of the cardiac reserve. The main reasons for this were that we thought it reflected the most objective resting state (quietness, neutral thermal environment, inactivity...) and seemed to be more reproducible, less controversial (Westerterp et al 1994; Van Etten et al. 1995; McCrory et al. 1997), and less subject to variations in measuring conditions. The higher EE_{sleep} values for men compared to women can be explained by the difference in mass (Fredrix et al. 1990; Westerterp et al. 1994; Van Etten et al. 1995) or fat-free mass (Fredrix et al. 1990; Goran and Poehlman 1992) between these two groups.

Concerning the population's characteristics, the large SD indicateded an important heterogeneity. We wanted the population to represent the working population as closely as possible, which meant a variety of ages, physical characteristics and inclusion of both sexes, since the field method evaluated is to be used for any employed person.

The difference in total EE measured by whole-body indirect calorimetry and estimated by HREEE was not significant at 20.9% (the average HREEE level on the simulated working day). This result has to be tempered because the relative error fluctuates with the intensity considered, being maximal at 5.1% of ER, thus at very low intensities. This outlines the importance of the average workload considered. Indeed, the greatest difference in EE estimated by the two methods occurred with a subject having the lowest HREEE (16.8%) over the 8 h considered. This subject also had the greatest ER and cardiac reserve, suggesting an eventual limitation of the HREEE method in highly trained individuals having a higher EE with lower HR. Overall, the HREEE–%ER linear relationship is less interesting in estimating a relative intensity than the CHREEE–%ER linear relationship over a selected range of intensities, and in order to estimate total EE, the 3rd order polynomial relationship should be used.

These laboratory results need to be validated on larger and less-selective cohorts (including trained athletes, disabled persons, elderly or individuals with heart failure), and in free-living conditions or real working simulation in calorimetric chambers. Higher intensities should also be explored in order to get a greater vision of the CHREEE–%ER relationship over the whole intensity range.

In conclusion, in these very standardized environmental conditions, and with our specific population, %ER = 1.002×CHREEE + 0.4, or in a simplified way, %ER = CHREEE. The CHREEE seems more suitable than the HREEE in estimating relative metabolic power. Extreme values determining the cardiac and energetic reserve need to be further explored, especially in terms of reproducibility and physiological significance. In occupational medicine, HR recordings transformed in CHREEE in reference to $HR_{rest+15}$ seem to be valid and recommended estimates of relative physical workload between 15% and 65% during an 8-h working day, and it may be interesting to use them in other fields such as physical activity or rehabilitation.

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