

Research article

Net heart rate to prescribe physical activity in middle-aged to older active adults

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Abstract

This study had a twofold purpose: i) to develop a regression equation to estimate metabolic equivalent (MET) in walk/run by heart rate increment above rest (NetHR), and; ii) to determine NetHR thresholds for light, moderate, and vigorous physical activity (PA), from middle aged to elderly. Sample 1 (prediction sample) comprised 39 subjects (19 male and 20 female), with 58.2 ± 11.0 years old. Sample 2 (validation sample) comprised 40 subjects (18 male and 22 female) with 63.3 ± 7.0 years old. Each participant did the following activities in sequence, a 15min rest period in supine position, walk at 3km/h, walk at 4.5km/h, and walk at 6km/h, for 6 min at each walk velocity interval. The oxygen up-take (VO_2) and heart rate (HR) were continuously and simultaneously assessed. A hierarchical linear model was used to analyze the relationship between metabolic equivalent (MET) and NetHR. The regression equation for MET prediction was: $MET = 1.265780 + 0.109479 \text{ NetHR}$. The NetHR thresholds (upper limit) for light, moderate and vigorous PA were 16 and 35 and 70 bpm, respectively. NetHR is a practical, valid and non-invasive method to prescribe physical activity, taking in account individual characteristics (HR at rest combined with NetHR) in middle-aged to older adults.

Key words: Net heart rate, physical activity thresholds, MET, exercise prescription, oxygen up-take.

Introduction

There are epidemiological and clinical evidences that physical activity (PA) can contribute to the prevention and rehabilitation of several chronic diseases, such as cardiovascular disease (Adamu et al., 2006), diabetes (Fodor and Adamo, 2001) and obesity (Pedersen et al., 2006).

Indirect and direct calorimetry, as well as doubled-labelled water, although accurate in measurement of energy expenditure (EE), are not useful for practical and field PA monitoring under various conditions: they can cause interference in habitual PA patterns, and are extremely costly to use on regular basis (Valanou et al., 2006). Because of these limitations, an appropriate methodology to assess PA intensity is necessary for field assessments by PA practitioners. Heart rate (HR) has been widely used to estimate both energy expenditure and PA intensity. HR methodologies seem particularly valid when calibrated against referenced methods (Garet et al., 2005; Livingstone et al., 1990; McCrory et al., 1997; Moon and Butte, 1996; Spurr et al., 1988). EE estimation based on HR monitoring relies on the assumption that there is a linear relationship between HR and oxygen up-take

(VO_2) (Bassett, 2000). This is especially true for the same activity/task and with intensities ranging between 15-85% of reserve energy (Garet et al., 2005; Li et al., 1993).

There are several approaches to estimate EE from HR, such as Flex HR method, %HR reserve (Hiilloskorpi et al., 2003), % energy reserve, corrected heart rate-estimated energy expenditure (CHREEE) (Garet et al. 2005), and average net heart rate (Andrews, 1971; Hiilloskorpi et al., 2003). Nevertheless, most of these methodologies need a maximum value, such as VO_{2max} or/and HR_{max} . It is recognized by the scientific community as well as by field practitioners that these maximal values are extremely hard to obtain in older adults. The elderly are commonly unable to satisfactorily complete a maximum effort in a standard exercise stress test (Dinan et al. 2005). Moreover, maximal testing is time consuming, carries a health risk, is expensive, and usually only available in laboratory settings.

Usually, PA prescription is completed by adopting: (i) a HR reference such as % HR_{max} or %HR reserve (Swain and Leutholtz, 1997; Swain et al., 1998); (ii) a VO_2 reference, as a % VO_{2max} ; (iii) rate of perceived exertion (Dunbar et al. 1992), or; (iv) MET's estimation (ACSM, 1999). The MET thresholds has been widely used to quantify the time spent in light (<3 METs), moderate (3 to 6 METs) and vigorous (6 to 9 METs) physical activities (ACSM, 1991).

Although HR determination would be possible in many contexts, the HR_{max} 's estimation present some limitations: The HR_{max} 's estimation through the formula $220 - \text{age}$ has not yet been validated (Robergs and Landwehr, 2002) and the estimation error by these formula is higher in older people (da Silva et al., 2007). Robergs et al. (Robergs and Landwehr, 2002) selected 30 similar equations to estimate HR_{max} . They found that HR_{max} estimation error can be higher than 11 bpm. Concerning this issue, Robergs and Landwehr (2002) concluded that it is likely that those current estimation equations were not accurate enough for prescribing exercise training intensity for a large number of individuals. Another study (da Silva et al., 2007) compared HR_{max} values measured during a graded exercise test with those calculated from prediction equations. They found that prediction equations significantly overestimated HR_{max} measured during maximum graded exercise test in elderly women.

Literature review shows that MET estimation based on HR increment above rest (NetHR), even if presented many years ago (Andrews, 1971), it was not

Table 1. Subjects characteristics. Data are means (\pm SD).

	Sample 1			Sample 2		
	Males	Females	Pooled	Males	Females	Pooled
Body mass (kg)	77.1 (8.9)	68.8 (9.3)	72.8 (9.9)	79.0 (.09)	73.2 (17.3)	75.8 (14.5)
Height (m)	1.71 (.06)	1.57 (.06)	1.64 (.09)	1.67 (.05)	1.53 (.08)	1.59 (.09)
BMI (kg·m ⁻²)	26.3 (2.0)	27.7 (3.3)	27.0 (2.8)	28.4 (2.9)	30.8 (5.4)	29.7 (4.6)
Age (years)	55.8 (12.7)	60.4 (8.9)	58.2 (11.0)	62.8 (6.8)	63.8 (7.2)	63.3 (7.0)

implemented as a methodology to control PA. This method seems adequate, because it is based on an individual parameter, HR rest, which can be related to an individual's aerobic capacity as well (Brooks et al., 2000; Gole et al., 2009; McArdle et al., 1994).

This study had a twofold purpose: i) to develop a regression equation to estimate metabolic equivalent (MET) in walk / run by NetHR, and; ii) to determine NetHR thresholds for light, moderate, and vigorous PA, in middle aged to older adults.

Methods

Subjects and samples

Seventy-nine subjects were assessed. All of them were physically active and engaged in PA programs. These were based on walking and head-out aquatic exercises sessions (one hour per day, three or more days per week). All subjects were more than 39 years-old, were healthy and active people. None of the subjects suffered any cardiac disease or was taking any HR blunting medication. Subjects with history of cardiovascular disease were therefore excluded.

The Institutional Review Board of the Polytechnic Institute of Bragança approved the study design, and appropriate consent was obtained.

Subjects were included in one of the following samples: (i) the sample for energy expenditure prediction equation (sample 1) comprising 39 subjects (19 male and 20 female; 58.2 ± 11.0 years-old; (ii) the sample for validation of prediction model (sample 2) including 40 subjects (18 male and 22 female; 63.3 ± 7.0 years old. The subjects' characteristics are presented in Table 1.

Procedures

VO₂ and HR were measured continuously for each subject while performing the following activities in sequence: rest, walk on treadmill at 3 km·h⁻¹, walk at 4.5 km·h⁻¹, and walk at 6 km·h⁻¹. Resting VO₂ was collected after 15 min in a supine position, in a silent and dimly lit room. Participants were not allowed to sleep. Minutes 6–15 were used for data analysis. For walk bouts, VO₂ and heart rate were collected during a 6 min period, and the mean value of the last 3 min was used for data analysis. In those time periods subjects were considered as being at energy expenditure steady-state (Robergs and Roberts,

1997).

The participants visited the laboratory twice. During the first visit subjects walked on the treadmill in order to get used to it. During the second visit the VO₂ and HR measurement protocol was applied. The same procedures were applied to sample 1 and sample 2.

Data collection

Height was measured to the nearest 0.1 cm using a digital stadiometer (Seca, Model 242, Hamburg, Germany). Body mass was measured to the nearest 0.1 kg on an electronic scale (Seca, 884, Hamburg, Germany). All evaluations were carried out twice and the average value computed.

VO₂ and HR were measured using a stationary breath-by-breath electronic metabolic device (Cortex, Model MetaLyzer 3B, Leipzig, Germany). The device includes a heart rate transmitter (Polar Electro Oy, Kempele, Finland). The apparatus was calibrated with standard gases before each test. According to the manufacturer manual the standard error is 0.1% for O₂ and CO₂ sensors. The walk/run activities were done on a treadmill (Woodway, model 55 Sport, Germany).

Statistical analysis

In order to account for dependence among repeated measures taken in the same subject, a hierarchical linear model was used to analyze the relationship between NetHR and MET over the walk/run activity intensities.

Restricted maximum likelihood estimates of random effects and maximum likelihood estimates of fixed effects were obtained using specific software (SPSS Inc., SPSS for Windows, Rel. 13, Chicago, USA). Coefficients associated with quadratic and cubic trends in third polynomial model were not found to be significantly different from zero. The contribution of body mass index (BMI), and gender were tested. None of these variables was found to contribute significantly to the fit of the model. Thus only results from the unadjusted linear mixed model are reported here.

The concordance correlation coefficient ρ_c (Mitchell et al., 1989), which evaluates the degree to which pairs of observations fall on the 45° line through the origin, was computed between the predicted and the actual values.

Table 2. Heart rate, NetHR, VO₂, NetHR per MET, and MET score for each physical activity intensity, for sample 1. Data are means (\pm SD).

Activity	Heart rate (bpm)	NetHR ¹ (bpm)	VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	NetHR per MET (bpm)	MET score ²
Rest	63.9 (8.3)	--	2.66 (.71)	--	1
Walk @ 3 km/h	86.7 (11.4)	22.8 (8.3)	10.1 (2.0)	5.8 (1.7)	4.0 (1.1)
Walk @ 4.5 km/h	96.9 (13.0)	32.9 (10.1)	13.3 (2.6)	6.4 (1.7)	5.3 (1.4)
Walk @ 6 km/h	113.7 (12.0)	49.5 (8.9)	19.0 (2.7)	6.7 (1.5)	7.6 (1.5)

¹NetHR = HR measured – HR_{Rest}. ²MET score = (Activity VO₂ - ml·kg⁻¹·min⁻¹) / (Individual resting VO₂ - ml·kg⁻¹·min⁻¹)

Table 3. Heart rate, NetHR, VO₂, NetHR per MET, and MET score for each physical activity intensity, for sample 2. Data are means (±SD).

Activity	Heart rate (bpm)	NetHR ¹ (bpm)	VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	NetHR per MET (bpm)	MET score ²
Rest	66.0 (9.4)	--	2.65 (.69)	--	1
Walk @ 3 km/h	92.6 (13.9)	26.6 (10.4)	10.3 (2.4)	6.7 (2.3)	4.0 (1.1)
Walk @ 4.5 km/h	109.1 (16.0)	43.1 (12.9)	15.4 (3.2)	7.3 (2.0)	6.1 (1.6)
Walk @ 6 km/h	125.4 (17.1)	60.0 (14.4)	21.2 (4.9)	7.6 (2.0)	8.2 (2.0)

NetHR corresponding to the MET cut-offs for light, moderate, vigorous and very vigorous levels of PA, were computed from the derived equation.

Receiver operating characteristics (ROC) analysis was then applied. The sensitivity [true positives/(true positives + false negatives)] and specificity [true negatives/(true negatives + false positives)] of the thresholds for NetHR were calculated. The cut-offs NetHR were selected having in consideration the highest values of sensitivity and specificity that had simultaneously the largest area under the curve. This was done using data provided by both samples.

Results

The differences between the two samples (males and females combined) in height, body mass, BMI and rest VO₂ were not statistically significant.

The data obtained during the experimental protocol are in Table 2 and Table 3, respectively for sample 1 and sample 2. In both samples the VO₂, NetHR and MET scores increased over different PA intensities. In the same way, there were no significant differences between samples in these variables. MET scores were calculated dividing activity VO₂ (ml·kg⁻¹·min⁻¹) by individual resting VO₂.

The data of all PA intensities and the data obtained at rest were used to derive the equation for MET estimation. This procedure was the way to place the intercept term of the equation on the low end of energy expenditure.

Equation 1 estimates MET using NetHR increments:

$$\text{MET} = 1.265780 + 0.109479 \cdot \text{NetHR} \quad (\text{Eq 1})$$

The measured MET values, in sample 1, were regressed against the estimated MET values (Figure 1). The correlation (r) is 0.903, so 82% of the variation in measured energy expenditure (in MET) in sample 1 was explained by NetHR.

The regression equation derived in sample 1 for predicting MET was used to estimate MET in sample 2. The estimated MET, in sample 2 was correlated with the measured MET values (r = 0.919, p < 0.001).

The value of concordance correlation coefficient between the predicted and the actual values of both samples together was high ($\rho_c = 0.897$).

NetHR thresholds (upper limit) corresponding to light (<3 MET), moderate (3–6 MET), vigorous (6–9 MET), and very vigorous (>9 METs) levels of PA and data from ROC analysis are presented in Table 4. The resulting ROC curve characterized the performance of a binary classification by describing the trade-off between sensitivity and specificity over an entire range of possible thresholds. NetHR values given by the inverted MET equation were used in ROC analysis.

Values between 15 and 20 NetHR were tested for the threshold for light-moderate. For moderate-vigorous threshold were tested values between 34 and 48 NetHR, and for vigorous-very vigorous threshold Net-HR values between 69 and 75 bpm. The results of ROC analysis are

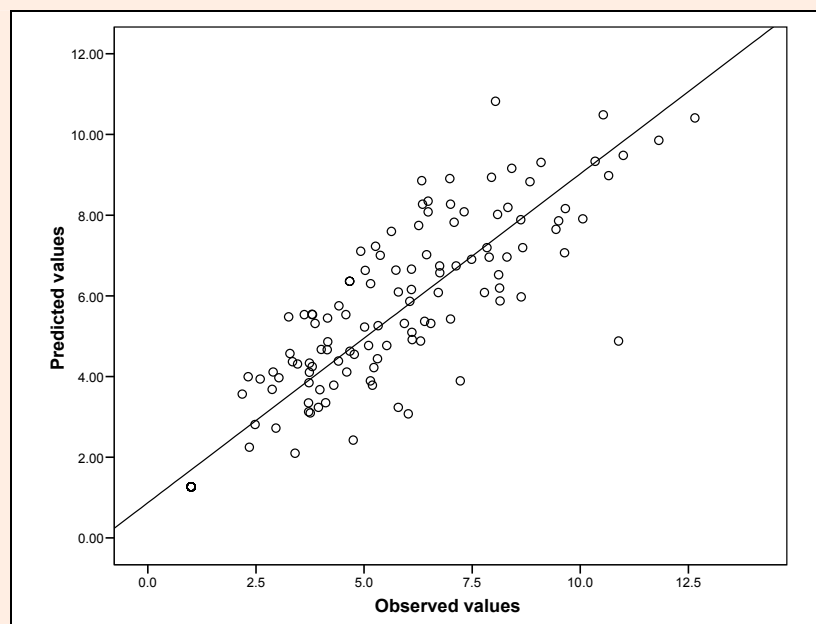


Figure 1. Scatter plot of the estimated MET regressed versus observed MET in sample 1 ($r^2 = 0.82$).

Table 4. Net-HR thresholds for light, moderate and vigorous levels of physical activity, corrected by ROC analysis.

Physical activity level	NetHR Thresholds ¹ (bpm)	Sensitivity	Specificity	Area under the curve
Light / moderate	16	1	.95	.97
Moderate / vigorous	35	1	.44	.72
Vigorous / very vigorous	70	.99	.19	.59

¹ Upper limit

quite good in defining the cut-off values of NetHR for PA intensity levels.

Discussion

This study had a twofold purpose: a) to develop a regression equation to estimate metabolic equivalent (MET) in walk/run by heart rate increment above rest (NetHR), and; b) to determine NetHR thresholds for light, moderate, and vigorous PA, from middle aged to elderly. The main finding was that the NetHR is appropriate to control walk/run training intensity from middle aged to elderly subjects and to estimate MET.

We chose walk/run activities because the most frequent PA done by the old adults is mostly walking (Owen et al. 2004). Of all aerobic endurance activities, walking has the most natural relationship to activities of daily life and is easier to integrate into lifestyle and functional tasks (Dinan et al. 2005).

It was found that oxygen uptake average values for one MET were equal to $2.66 \pm 0.71 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $2.65 \pm 0.69 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for sample 1 and sample 2, respectively. These values were lower than those usually adopted for adult population (i.e., $3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). So, it was decided to use the subject's actual resting values for MET's estimation. This procedure was intended to minimize bias in the estimated energy cost of the PA measured in these adult people, and in consonance with the decline of rest metabolic rate (RMR) with age (Vaughan et al. 1991; Poehlman et al. 1993). The generalized use of $\text{MET} = 3.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ does not seem to be an accurate value for all population groups (Byrne et al. 2005). Byrne et al. (Byrne et al. 2005) found that rest VO_2 is equal to $2.67 \pm 0.47 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ of oxygen for men and of $2.54 \pm 0.39 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ for women. In this sense, authors justified the importance of a correct one MET value for energy expenditure estimation.

The most common procedure to control the PA intensity is targeting a training HR, which uses either a percentage of HRmax or HR reserve (Dinan et al., 2005). These methods have limitations: unless a true measure of HRmax has been obtained, the main disadvantage relies on the fact that HRmax must be estimated. Moreover, HRmax estimation is quite unreliable in older people (Dinan et al., 2005). The majority of older adults have physical limitations, and maximum efforts are not suitable for practical and/or ethical reasons. The use of NetHR can minimize these problems. In addition, NetHR takes into account HR at rest, which is an individual objective characteristic usually related with aerobic capacity and endurance training. Low HR rest, (i.e., less than 60 bpm) is considered on regular basis as a milestone of aerobically trained individuals, explained by an increasing stroke volume (Brooks et al., 2000). Bradycardia at rest is likely due to a couple of factors resulting from training:

(i) endurance training induces vagal tone that slows the heart, or/and; (ii) the heart muscle strengthened through endurance training is able to complete a more forceful stroke within each contraction (McArdle et al. 1994).

It was found that the NetHR thresholds (upper limit) for light (<3 MET), moderate (3 to 6 MET) and vigorous (6 to 9 MET) PA were 17, 43 and 67 bpm, respectively. This means that with NetHR methodology it is not necessary to know the real individual value of one MET ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) to prescribe light, moderate and vigorous PA intensity thresholds. We can prescribe these thresholds for a specific person, knowing his/her resting HR. According to data computed from equation 1, NetHR per MET increment is 9.1 bpm, except in transition from rest to 2 MET (which is 6.7 bpm). This reflects a positive intercept in equation 1, probably due to the effect of moving from supine to upright position, which demands increased energy for posture and thermodynamics.

In the present study, we obtained a high validity value ($r^2 = 0.82$), which is similar to other validation studies (Freedson et al., 1998; Welk et al., 2003). The result of the inner validation was also good ($r^2 = 0.84$).

Conclusion

NetHR is an easy, practical, valid, and non-invasive method to prescribe different PA intensity thresholds, taking into account individual characteristics (HR Rest combined with NetHR) from middle aged to older active people.

Besides that, NetHR-based methodology seems particularly suitable in population sets (e.g., large groups, subjects with a given physical condition) where maximum values (HRmax or $\text{VO}_{2\text{max}}$) are difficult to assess.

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Key points

- Physical activity intensity can be prescribed by NetHR, in middle aged to older active adults.
- NetHR thresholds (upper limit) for light (<3 MET), moderate (3 to 6 MET) and vigorous (6 to 9 MET) PA were respectively 17, 43 and 67 bpm.
- We can estimate MET intensity level by equation: MET = 1.265780 + 0.109479 .NetHR.

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