BODYMEDIA® MARKETING/APPLICATIONS FLASH

N : 01-2006

Date : Oct 2006

Does Heart Rate Predict Energy Expenditure?

Yes, But…..

J Farringdon & D Wolf.
BodyMedia Inc. Autumn 2006.

There is a common assumption regarding the ability of heart rate monitors to predict energy expenditure. This is partly because there are many consumer products available that attempt to do just that, for example heart rate chest-strap monitors with wrist watches or software that estimate calories burnt. Plus there is literature that describes accurate energy expenditure estimation from heart rate recordings.
However a closer look at the products and the literature shows that predicting energy expenditure (EE) from heart rate (HR) is

1) only appropriate for certain activities
and
2) only accurate after a lengthy and complicated calibration processes has been performed for each subject.

This means that it is inappropriate to use HR to estimate EE in free living situations (those outside of controlled settings and activities) and for unseen subjects.

The Basis of Heart Rate and Energy Expenditure

The basis for calculating EE from heart rate measurements can be summed up in a single sentence: for moderate to strenuous activity a person's heart rate increases linearly with oxygen consumption (Freedson & Miller, 2000). Crouter (*et al*, 2004) summed it up as: "HR is linearly related to oxygen uptake for dynamic activities involving large muscle groups".

These simple statements relating heart rate to energy expenditure hide a great deal of complexity, which is discussed point by point below.

The frequent use of HR to estimate EE is somewhat due to the ease of use and acquisition of the HR and is based on an assumption that there is a linear relation between HR and Oxygen Consumption (VO2) which is either known for a specific individual or generalisable over large groups of people. The HR-EE relation is valid during dynamic exercise, performed with large muscular masses, however every subject has his or her own personal HR-EE equation.

For HR to be a reliable parameter of an EE estimator we should therefore determine the HR-VO2 relationship of every subject in the lab through a per-subject calibration process, this is usually unpractical because of the expense in time and cost.

We must also bear in mind that heart rate, during exercise or rest, can be influenced by several factors such as emotional stress, hydration level, caffeine drinks, and ambient factors (temperature, humidity, altitude). The HR is also influenced by gender, the presence of obesity, fitness level, the type of exercise, which parts of the body are exercising (such as the upper body) and if there is an isometric component or a partial isometric component.

Equipped with this knowledge we can now explore the circumstances under which this linear-relationship holds true and why a "linear relationship" is not simple to employ in practice.

In order to discuss the HR–EE relationship we should be mindful of HR monitoring technology which is practical for this purpose. Traditional EKG electrodes are ideal for "laboratory and clinical" use but are usually limited to that environment. “Professional” use HR and pulse monitors can be characterised as “chest strap” models. Other means such as wrist monitors etc. are used in “recreational” situations and do not form a suitable basis for EE estimation. For example wrist units worn on the left arm require the user to touch the unit with the right hand in order to take a reading. Such units and other non-ECG HR monitors are usually unsuitable for taking continuous readings and are inaccurate during activity.

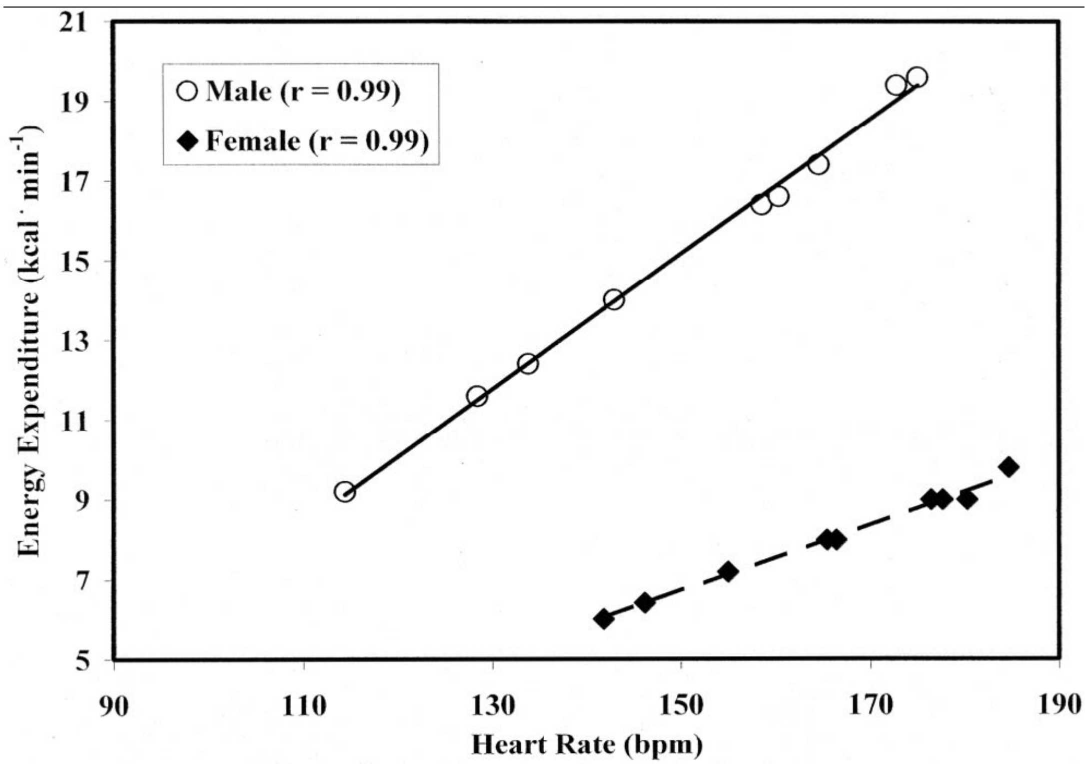
A Chest Strap Heart Rate Monitor

Crouter (*et al*, 2004) investigated the "Accuracy of Polar S410 Heart Rate Monitor" with respect to predicting EE. "The Polar S410 devise uses a nonexercise prediction equation based on user information (age, height, weight, gender, physical activity level) and resting heart rate information" to estimate HR_{max} and VO_{2max} for each subject. "The participants defined their physical activity level (low, middle, high, top) based on descriptions given by the Polar S410 user’s guide." Crouter's study (2004) also found the true HR_{max} and $VO_{2\ max}$ by using an appropriate protocol with indirect calorimetry.

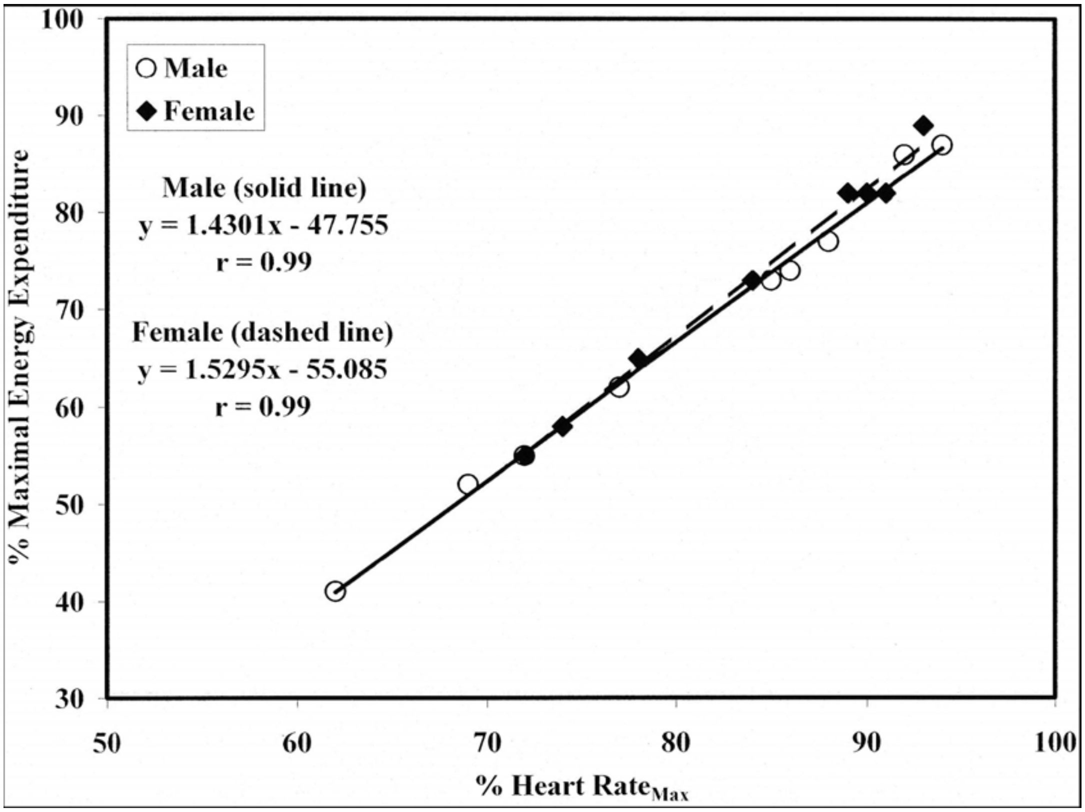
Crouter found that "When the predicted values of $VO_{2\ max}$ and HR_{max} are used, the Polar S410 HRM provides a rough estimate of EE during running, rowing, and cycling. Using the actual values for $VO_{2\ max}$ and HR_{max} reduced the individual error scores for both genders, but in females the mean EE was still overestimated by 12%."

Crouter's study used data from two subjects to illustrate the linear relationships between heart rate and energy expenditure. They used these observations to deduce how their heart rate monitor may estimate EE.

"We examined the relationship between estimated EE and HR, when the actual $VO_{2\ max}$ and HR_{max} were programmed into the watch. Figure 1 is a representative graph for two participants (one male and one female); showing that there is a strong linear relationship (r =0.99) between HR and estimated EE, but it is unique to each participant. Therefore, we reasoned that the Polar heart watch must be taking into account the individual's
HR_{max} and $VO_{2\ max}$. Figure 2 illustrates the positive, linear relationship between the percentage of HR_{max} and the percentage of maximal energy expenditure for the same two participants in Figure 1. This time, the regression line was nearly identical for each participant, and it was similar for all participants, regardless of fitness level, gender, or other variables. Thus, it appears that the Polar S410 is using the percentage of HR_{max} to estimate the percentage of $VO_{2\ max}$,which is then converted to caloric expenditure." (Crouter *et al*, 2004).



(Crouter *et al*, 2004), FIGURE 1—Representative data for two participants (one male and one female), showing the relationship between predicted energy expenditure and heart rate.
Male: open circles with solid regression line ($VO_{2\ max}$ = 52.7 mL·kg_1·min_1, HRmax _ 186 bpm, Fitness level _ top).
Female: closed diamonds with dashed regression line ($VO_{2\ max}$ _42.8 mL·kg_1·min_1, HRmax _ 198 bpm, Fitness level _ middle).



(Crouter *et al*, 2004), FIGURE 2—Representative data for two participants showing the relationship between the percent of maximal energy expenditure and the percent of maximal heart rate. Male: open circles with solid regression line ($VO_{2\ max}$ = 52.7 mL·kg_1·min_1, HRmax _ 186 bpm, Fitness level _ top). Female: closed diamonds with dashed regression line ($VO_{2\ max=}$ 42.8 mL·kg_1·min_1, HRmax _ 198 bpm, Fitness level _ middle).

Estimating EE from Heart Rate is Only Appropriate for Certain Activities Under Controlled Conditions

Keim (*et al*, 2004) describes "A limitation of employing heart rate as a surrogate for energy expenditure is that the relationship between HR and VO2 is weak at low activity levels, which are the levels characteristic of most sedentary individuals. For example, in a seated subject heart rate can rise or fall solely in response to emotions, caffeine intake, ambient temperature, or illness (Montoye, 1996). "

Keim goes on to describe "Another important consideration before using heart rate monitors for physical activity assessment is usability. In a recent study measuring physical activity across a 2-week period, highly motivated subjects showed poor compliance in wearing a heart rate monitor for all waking hours on select days (Forrest *et al*, 2004)."

Crouter (2004) reminds us that "The use of HR does have limitations due to influence of other factors that can affect exerciser HR. These include stress, hydration level, environmental factors such as temperature and humidity, mode of exercise (upper vs.
lower body), gender, and training status."

Personal Calibration Required

In order to accurately predict EE from HR a personal calibration needs to be made for each subject. Recall that there is a linear relationship between HR and EE under certain circumstances. However this linear relationship is different from person to person. Keim (2004) explains that a "submaximal, graded exercise test is required to calibrate the subject's heart rate to simultaneous oxygen consumption." Furthermore the subject's fitness may change over time suggesting the need to periodically re-evaluate the HR-EE relationship.

Kurpad (*et al*, 2006) acknowledges that "the relationship between HR and energy expenditure needs to be defined in each subject, this method requires the use of indirect calorimetry, which can be difficult and expensive". Krupad's interest is in "simplifying the HR technique, such that there is no need for the use of indirect calorimetry, allowing for its use in resource-poor locations". They suggest a "simple" method which "characterized the relationship between the HR and selected activities of varying intensity for which the PAR is known" (PAR = physical activity ratio, Krupad's language for METS).

"Simple" in this context means "simplifying the HR technique, such that there is no need for the use of indirect calorimetry". Calibration is still far from simple however, requiring "a calibration curve that involved the fitting of two straight lines at low and high PAR activities, respectively, to the PAR and HRR data." (Physical activity ratio = PAR; heart rate ratios = HRR, ratio of observed to resting HR).

While "simple" may be simpler than using indirect calorimetry for individual calibration, this protocol shows how involved this method is: "subjects stayed overnight in the laboratory, and were assessed in the woken, fasted state. The HR monitor (Polar S720i, Finland) was attached to the subject, and they were instructed to lie quietly in bed for thirty minutes so that a steady state could be defined. The subjects then undertook five to six minutes each of a set of tasks, which included lying down at rest, sitting quietly, walking at 2.4 and 4.8 km/h on a treadmill and spot jogging at a rate of 120 steps/min, using a metronome." (Kurpad *et al*, 2006). Then the experimenter would construct calibration linear regressions, "Known PAR values for each task were taken from literature …. except for the value of sitting …. the values thus used were 1 for resting, 1.2 for sitting quietly, 2.0 for walking at 2.4 km/h, 3.3 for walking at 4.8 km/h and 8 for spot jogging at 120 steps/min." (Kurpad *et al*, 2006).

Conclusions :

HR as an individual parameter relating to EE has certain merits for specific measurements, in controlled environments and is a good index of aerobic capacity when looking at the max HR value.

However the limitations of using HR "alone" as a predictor of EE are now clear and proven, particularly for extended periods of time, in un-controlled situations, with un-calibrated subjects, etc. The accepted calibration process involves indirect calorimetry on every subject.

Alternative calibration processes may be cheaper in terms of equipment cost but can be more expensive in terms of time. In general non-exercise calibration, say by means of self assessment questionnaire, can not result in an accurate calibration.

Bodymedia is currently working on integrating HR into the Sensewear Armband. This is not specifically to improve the accuracy of the EE calculation which is now “acceptable” for clinical and research use, in “free-living” conditions, but because several applications are interested in looking at this parameter over time, features such as HR min, max, average, plus valuable RR variability analyses. Plus for high-end sports applications adding HR to the Bodymedia EE algorithm can further increase EE accuracy. Of prime concern is the quality of “wearability” (the armband's comfort, acceptance and simplicity), while acquiring ECG signals and recording for several days without replacing the electrodes. Once these concerns are resolved, the Sensewear Armband will add one more important parameter, heart rate, to the broad range of “lifestyle” parameters that the device can acquire.

References:

SE Crouter, C. Albright, and D. R. Bassett, JR. (2004). Accuracy of Polar S410 Heart Rate Monitor to Estimate Energy Cost of Exercise. *Med. Sci. Sports Exercise*., Vol. 36, No. 8, pp. 1433–1439, 2004.

A Forrest, M Gustafson-Storms, B Gale, C Blanton, W Horn, N Keim, M Kretsch. (2004). Subject compliance using digital activity log, accelerometer and heart rate monitor to record physical activity. *FASEB J*. 2004;18:A112.

PS Freedson, K Miller. (2000). Objective monitoring of physical activity using motion sensors and heart rate. *Res Q Exerc Sport*. 2000;71(suppl 2):S21-S29.

Nancy L. Keim, PhD, RD; Cynthia A. Blanton, PhD, RD; Mary J. Kretsch, PhD, RD. (2004). America’s Obesity Epidemic: Measuring Physical Activity to Promote an Active Lifestyle. *Journal of THE AMERICAN DIETETIC ASSOCIATION*. pp 1398-1409. September 2004 Volume 104 Number 9

AV Kurpad, R Raj, KN Maruthy and M Vaz. (2006). A simple method of measuring total daily energy expenditure and physical activity level from the heart rate in adult men. *European Journal of Clinical Nutrition* (2006) 60, 32–40

HJ Montoye. (1996). *Measuring Physical Activity and Energy Expenditure*. Champaign, IL: Human Kinetics; 1996.

BODYMEDIA®

4 Smithfield Street
11th Floor
Pittsburgh, PA 15222
USA
P.412.288.9901
F.412.288.9902
www.bodymedia.com

BodyMedia International Srl
Via G. Balzaretti, 15
20133 Milan, Italy
P.+39-02-2774121
F.+39-02-27741250
www.bodymedia.eu