# Polar Smart Calories

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## 1 Introduction

The human body consumes energy. Organs need energy to maintain vital functions and muscles need energy to perform mechanical work. The accurate measurement of the energy consumption of the human body is an important parameter for many applications. For example, the intensity of physical exercise can be evaluated based on the energy consumed during exercise and dietary guidance can be given based on total daily energy expenditure.

The exact measurement of human energy expenditure requires laboratory methods, such as measuring respiration gases (indirect calorimetry) or analysing saliva, urine samples, or doubly labeled water. These methods are not easily accessible or affordable.

In Polar products, a consumer-friendly measurement of energy expenditure was first introduced as a heart rate-based estimate during exercise. Later the accelerometer sensors in wrist units were introduced to measure energy expenditure also in daily life as well as during exercise. Recently, the introduction of optical heart rate measurement to wrist units and further development of accelerometers have opened up new possibilities in measuring energy expenditure during exercise as well as outside of exercise, around the clock.

## 2 Physiological and technological background

### 2.1 Human energy expenditure

Total energy expenditure in humans can be divided into three parts: resting energy expenditure required to maintain vital operations at rest (60–75% of total daily energy expenditure), thermic effect of food (10%), and energy expenditure from the mechanical work of muscles (15–30%).

The primary energy stores in the human body are carbohydrates, fats, and to some extent, proteins. Energy is extracted from carbohydrates, fats, and proteins to bonds of adenosine triphosphate (ATP) molecules. The ATP molecules are then used to transfer the energy and used as the energy source for the biological work. The ATP reserves in the human body are relatively small and thus during physical activity energy is constantly converted from carbohydrates, fats, and proteins to ATP. In aerobic metabolism oxygen is present when ATP molecules are generated, whereas in anaerobic metabolism oxygen is not present.

The SI-unit for energy is the joule (J). However, the amount of energy consumed by the human body is typically reported as kilocalories (kcal). One kcal is equivalent to 4.184 J. Another common measure of human energy expenditure is the metabolic equivalent (MET). MET value expresses how large energy expenditure is compared to resting metabolic rate (1 MET). When applying MET values as an exact energy expenditure measure it should be noted that there is some variation in the exact definition of MET in scientific literature [1].

### 2.2 Wrist movement and energy expenditure

The measurement of wrist acceleration from the non-dominant hand is a commonly used method to estimate human energy expenditure. It has several advantages: Measuring wrist acceleration is comfortable for the user. The (electrical) energy cost of accelerometer sensors is low. Accelerometers are cheap components, so it is possible to manufacture low-cost wrist devices for consumers to measure their energy expenditure around the clock.

The acceleration signal itself is usually processed representing the amount of movement such as mean amplitude deviation of acceleration [2] or other similar parameters [3]. These parameters usually correlate with the measured reference for energy expenditure (Figure 1), but the relation between wrist acceleration and energy expenditure is in most sports and activity types only empirical. In sports and activities where external resistance is applied, e.g. when carrying bags or during strength training at gym, or when an external device is used to move the human body such as in cycling, this empirical relation usually fails.

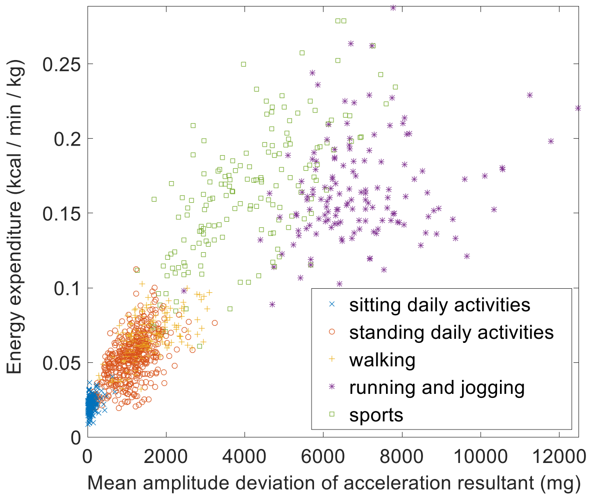


Figure 1. The relationship between acceleration measured from wrist and reference energy expenditure measured with indirect calorimetry. The acceleration is shown as mean amplitude deviation of the resultant of 3D acceleration signal.

Despite the fact that the relation between wrist acceleration and energy expenditure is only empirical, the overall estimates for daily energy expenditure based on wrist acceleration provide fairly accurate values that are usable in many applications. Wrist acceleration is also very good in detecting rapid intensity changes immediately. For instance changes in running speed during interval running are reliably detected with it, whereas heart rate reacts too slowly to be an exact indicator of momentary energy expenditure (see next paragraph).

### 2.3 Heart rate and energy expenditure

The physiological basis of heart rate-based energy expenditure estimation is the estimation of consumed oxygen in aerobic metabolism. The oxygen from respiration is used to burn fat and carbohydrates when energy is consumed in aerobic metabolism. If fats are used as the fuel, one litre of oxygen is used to generate 4.74 kcal of energy. Similarly if carbohydrates are the fuel, one litre of oxygen consumption corresponds to 5.06 kcal of energy.

Oxygen is delivered to the working muscles and organs in blood. The amount of circulated blood depends on the heart rate (HR) and stroke volume (SV) i.e. the volume of blood ejected from heart to aorta in one heartbeat. The oxygen rich blood leaves from heart via aorta and the oxygen poor blood returns to heart via veins (Figure 2). It should be noted that the oxygen in oxygen rich blood is never consumed completely and thus the blood in veins always contains some oxygen. For energy expenditure calculation we need to thus consider the net decrease in oxygen content between oxygen rich (arterial) and oxygen poor (venous) blood.

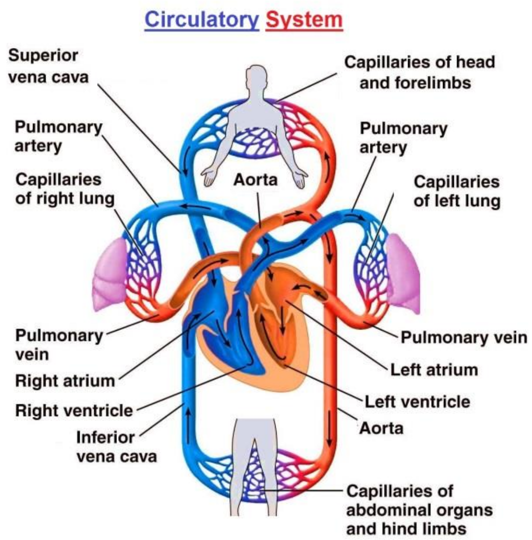


Figure 2. Circulatory system. Oxygen rich blood is delivered from left ventricle of heart via aorta to working muscles. The oxygen poor blood returns via venous veins to right atrium of heart. [http://diagramscharts.com/tag/circulatory-system/]

The previous description of oxygen consumption-based energy expenditure (E with unit kcal/min) can be represented in one equation as

$$E = HR \times SV \times \Delta avO_2 \times \gamma \qquad (1)$$

where

HR × SV = amount of circulated blood (bpm x l)

$\Delta avO_2$ = net difference of oxygen content between aorta and vein (litres of oxygen / litre of blood)

γ = oxygen-to-energy coefficient (~5 kcal/l).

The practical challenge is that SV and $\Delta avO_2$ are not constants (Figure 3 and Figure 4). They vary according to various parameters such as characteristics of the person and exercise type, intensity, and duration. Usually when the intensity of activity is at least moderate, but below anaerobic conditions, the SV and $\Delta avO_2$ can be estimated reliably. In Polar's own research we have found that the lowest possible heart rate from which it is possible to reliably estimate energy expenditure is 30–50 bpm above resting heart rate.

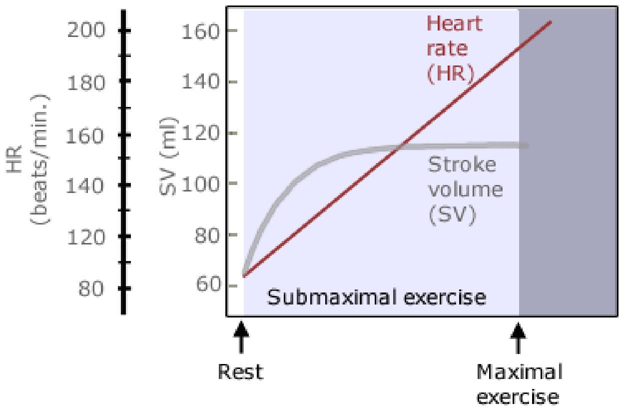


Figure 3. Schematic figure of change in stroke volume and heart rate when intensity of exercise is increased. [http://www.medicine.mcgill.ca/physio/vlab/exercise/muscle.htm]

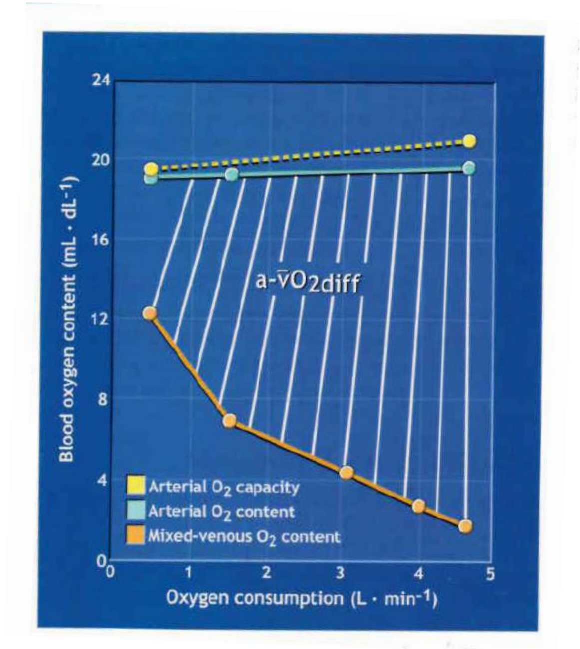


Figure 4. Change in arterial and venous oxygen content when oxygen uptake is increased (e.g. by increasing the intensity of exercise) [McArdle et al. "Exercise Physiology" LWW; 8th edition (March 4, 2014)]

The heart rate-based estimate for energy expenditure works best during long aerobic exercise with constant intensity. During rapid intensity changes, e.g. when running intervals, the challenge is that the heart rate increases and decreases slowly compared to the intensity change in the exercise.

# 3 Smart Calories approach to energy expenditure estimation

## 3.1 Resting energy expenditure

The resting energy expenditure estimate in Polar Smart Calories is based on the Schofield equation [4] which has been modified according to Polar's own research results. The basis for estimating resting energy expenditure is that the size of a person (weight and height) determines the required energy to maintain vital operations. Age and gender are also taken into account in the calculation.

## 3.2 Energy expenditure from physical activity

The energy expenditure calculation for physical activity is a modular system. It takes movement acceleration and heart rate signals as input, but can also operate if a heart rate signal is not available.

The acceleration-based estimate for energy expenditure is based on the amplitude deviation of acceleration signals. The heart rate-based estimate is based on a known equation (1). The final Smart Calories energy expenditure estimate is a combination of acceleration and heart rate-based estimates.

The principle is that in low intensity activities more weight is given to the accelerometer-based estimate, and in moderate to high intensity activities more weight is given to the heart rate-based estimate. The exact weight factor varies depending on the activity type (24/7 daily activity, different sports). Also, in the case of rapid intensity changes the weight factor for accelerometer-based estimate is increased.

## 4 Performance and validity

The Polar Smart Calories model has been fitted using data from three different studies where wrist acceleration, heart rate, and reference value for energy expenditure were measured for 26 different activities. The total number of successfully measured test persons varied from 60 to 70 depending on the activity. Measured VO2max, maximum heart rate and resting heart rate parameters were used in Smart Calories algorithm as an input when they were available.

The reference measurements for energy expenditure were taken using commercial indirect calorimetry measurement devices. The measurement error of these devices is generally stated to be as low as a few percent. However, in practice it seemed that the chosen experimental protocol, differences between laboratories and devices, and human errors while doing the experiments all caused errors. In total the error in reference data was around 5–10%, and in some cases even more. Therefore we agreed that energy expenditure estimates with less than 10% difference from the reference measurements can be considered to represent good accuracy, and estimates with less than 20% difference are still acceptable.

Table 1 summarizes the performance of the Smart Calories algorithm against the reference data. The mean values indicate how well the Smart Calories algorithm performs for a population and the standard deviation values indicate how much variation there is between different test persons.

**Table 1. Comparison of Smart Calories against reference measurements.**

| | | **Difference to reference (mean ± standard deviation (%))** | |
|---|---|---|---|
| **Activity** | | *Acceleration* | *Acceleration + HR* |
| **Daily activities** | Standing act.* | -0.2 ± 17.5 | 4.9 ± 17.6 |
| | Sitting act.** | -4.1 ± 20.8 | -3.8 ± 20.7 |
| **Sports** | Walking | -1.5 ± 16.5 | 3.5 ± 16.8 |
| | Running | -1.7 ± 13.2 | -1.5 ± 10.4 |
| | Cycling | -70.5 ± 7.0 | 2.4 ± 15.9 |
| | Soccer and Tennis | -28.7 ± 9.6 | -0.8 ± 12.7 |

** Measured activities while standing: household chores such as sweeping and cleaning floors, tidying up, clearing the table, washing dishes, dusting, ironing, mowing the lawn, mopping, climbing stairs, teaching, vacuuming, standing, kitchen work*

*** Measured activities while sitting: office/computer work, cognitive test at computer, sitting, arranging magazines, reading*

In all the activity and sport types the accuracy of the results of the fusion of acceleration and heart rate signals was, on average, good. With only an acceleration signal the results are good in many activities, but there are some exceptions (cycling, soccer, and tennis). The relationship between measured wrist acceleration from the non-dominant hand and energy expenditure varies highly depending on activity type. In some activities the non-dominant hand takes an active part in the activity (e.g. walking and running), whereas in some activities it has a more passive role from an acceleration signal point of view (e.g. playing tennis or cycling as an extreme example).

When considering both mean and standard deviation of the accuracy, the best results are measured in high intensity sports using both acceleration and heart rate signals. In high intensity activities, the heart rate can be used as an accurate input signal for measuring energy expenditure. Furthermore, in sports where the human body is concentrated on doing physical work for a long timeunder more or less constant conditions, the calculation and physiology of energy expenditure is more straightforward and stable.

In an independent validation study of Polar Smart Calories, the systematic bias was 3.3% and mean absolute error was 20.6% compared to MetaMax 3B ergospirometer (5). The accuracy was activity dependent. Compared to other available wrist-worn EE monitors, Polar was considered to among the best performers.

## 5 Summary

The energy expenditure of the human body is typically measured in kilocalories. The factors contributing to daily energy expenditure are the basal metabolic rate (60–75%), the thermic effect of food (10%), and the energy expenditure from the mechanical work of muscles 15–30% . The estimate of energy expenditure provided by Polar Smart Calories is based on the physical characteristics of the person, acceleration measured from the wrist, and heart rate measured either with a transmitter or optically. The energy expenditure is calculated from these variables using proprietary algorithms. The energy expenditure estimate in Polar Smart Calories is in good agreement with the reference measurements. The best overall results are obtained when both acceleration and heart rate are used as input signals.

## 6. Patents

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US7917198B2

## 7. References

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5. Gilgen-Ammann et al. Accuracy of the Multisensory Wristwatch Polar Vantage´s Estimation of Energy Expenditure in Various Activities: Instrument Validation study. JMIR MHealth UHealth 2019;7(10):e14534).