Polar Optical Heart Rate

Polar Research and Technology

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CONTENT

1 Introduction

In 1983, Polar Electro launched the world's first heart rate monitor based on the simple concept of having a chest strap as a sensor and a wristwatch as a heart rate display, memory and user interface [1]. This concept has been trustworthy and a norm for sport heart rate measurement for decades.

A couple of years ago, advancement in several technological areas like LED's, batteries, acceleration sensors and microprocessors made it possible to integrate optical heart rate measurement into a wristwatch. Concurrently, the need for easier and more comfortable usability than what is offered with a chest strap, especially in low and moderate level exercising, has steadily increased.

There has been some skepticism about the accuracy of wrist-based heart rate measurement compared to chest strap measurement that has been proven to be as accurate as ECG (Electro Cardio Graph) monitors used in hospitals. Some of the wrist heart rate products currently on the market indicate that the accuracy can be a problem if thorough understanding from several design areas of wrist heart rate measurement are not in place [2].

After carefully studying and researching the pros and cons of wrist heart rate measurement Polar Electro has verified that it is possible to implement wrist heart rate measurement in such a high quality level that it meets the expectations of our customers.

2 Physiology Background

The ECG measures the electrical activity of the heart. Each heart beat is associated with corresponding signal phase and characteristics. For heart rate measurement, the most important signal phase is the QRS complex that represent the contraction of the ventricles.

Contraction of the left ventricle pumps blood through the aorta to the systemic circulation. At rest, each contraction pushes around 0.1 litres of blood volume to the circulation causing a pressure pulse that travels through the arteries and capillaries diminishing along the way (Fig. 1).

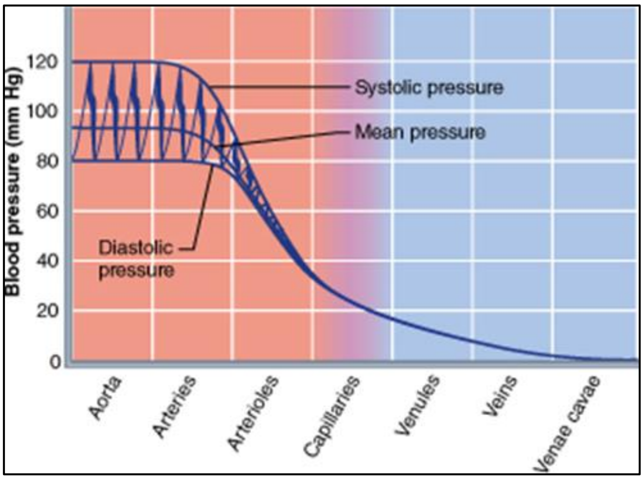

Figure 1*. Blood pressure pulse through circulation.*

At heart rate of 50 bpm the heart pumps 5 litres of blood in a minute. As this is approximately the amount of blood in an average person all blood will go through the heart and through circulatory system once in a minute (Fig. 2). This is an average, and in reality some blood goes through the circulation faster and some slower (reaching to the furthest place of the body, like the toe).

Figure 2. *Heart as a blood pump.*

In most locations of the human body, it is possible to detect the pressure pulse by measuring the light absorbance with a sensor on the skin. This is the basis for the Polar Wrist Heart Rate measurement.

3 Technology Background

In the core of the Wrist Heart Rate measurement, there are two opto-electronic components: the LED (Light Emitting Diode) and the photodiode. The LED acts as a light source illuminating the skin, whereas the photodiode is the detector measuring the intensity of the light reflecting and scattering back from the skin (Fig. 3).

Figure 3. *Optical measurement at the back of the wrist unit. Configuration a) two green LEDs as light emitters and one photodiode as the light detector between the LEDs; configuration b) six green LEDs around one photodiode.*

In the practical implementation, LED is pulsed On and Off so that the On-time is very short, typically even less than a thousandth part of a second. This reduces the current consumption and increases the operation time of the device upto to several days.

Sensor configuration, where the light source and the detector are located next to each other on the skin, is called reflectance measurement. The most commonly used color of the light for reflectance measurement is green as scientific studies have shown that green is the best choise for this measurement configuration [3].

The measured light intensity varies syncronously with the blood pulse: the intensity is low when the pulse pressure under the sensor is high (systole) and high between pulses (diastole). In the medical context the signal representing the blood pulse is called the PPG (PhotoPlethysmoGraph) and usually inverted in graphical presentations [4] (Fig 4).

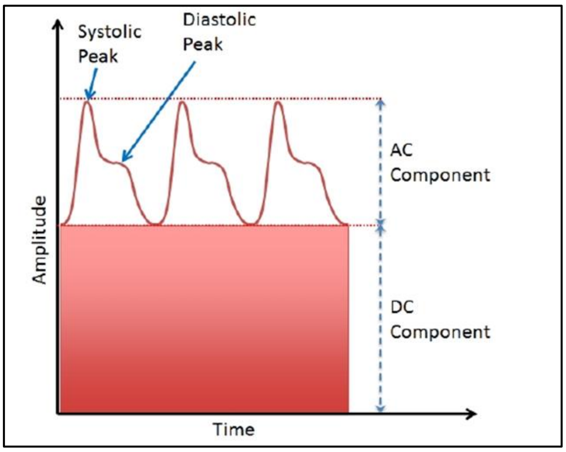

Figure 4. *Measured light intensity changes with blood pressure.The AC component is typically 0.5 to 1.5% of total amplitude and exaccerated in the picture.*

In a very pragmatic manner, we can describe the underlying pulse phenomena in Wrist Heart Rate measurement as follows (Fig 5):

1. Pulsatile change in measured light intensity
2. Measured on the skin when skin is illuminated with light
3. Pulsatile change relates to blood pressure change
4. Blood pressure change is generated by heart beat

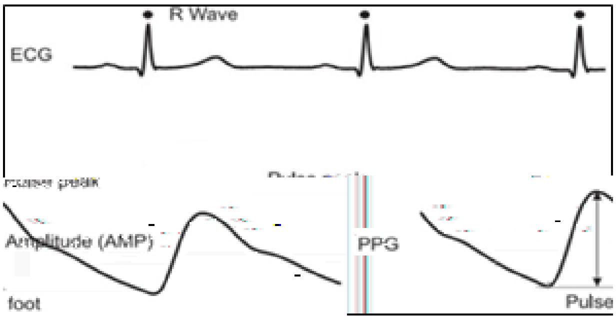

Figure 5. *PPG pulse follows synchronously ECG R- wave.*

4 Signal processing

The signal from the detector follows the light's intensity changes, and therefore determining the frequency of the pulses gives Wrist Heart Rate readily.

This is straightforward when the signals are good which is not the case for many sports where hand movements are involved.

The optical measurement is very sensitive to motion [5]. 1 millimeter movement in the distance from the sensor to the skin will totally deteriorate the pulse wave signal. Without adequate and efficient motion artefact removal the pulse wave would be unrecognizable and heart rate would not be available.

The compensation of motion artefacts is the most important and most demanding part of the signal processing of Wrist Heart Rate measurement. The compensation is based on a motion sensor located in the wrist unit and measuring very accurately the movements of the hand.

The signal processing algorithms for Polar Wrist Heart Rate measurement are proprietary to Polar.

5 Performance

In good measuring conditions, the performance of the wrist heart rate measurement is comparable to chest strap based measurement. Luckily, there are some things that the user can do to enhance good measuring conditions.

An important factor is the correct tightness of the wristband. The optical sensor at the back of the device should be firmly against the skin, but not too firmly to prevent circulation or otherwise be uncomfortable. Firm contact between the sensor and the skin minimize motion induced artefacts.

The location of the wristband is also important. The right place is just next to the wrist bone, a little bit to the direction of the elbow.

Once correct tightness and right location of the wristband are secured, there are still some minor things that can be done to enhance the measurement. In cold conditions, it can happen that blood circulation on the skin is so weak that adequate pulse signal amplitude is not available.This situation can be solved by warming the skin on the wrist or doing some exercise to increase blood flow and temperature on the tissue and on the skin.

A typical behavior of the Wrist Heart Rate measurement is poor signal and thus some wrong heart rate values during the first 10 to 15 minutes of exercise and improved signal and most accurate performance after this initial phase (Fig 6).

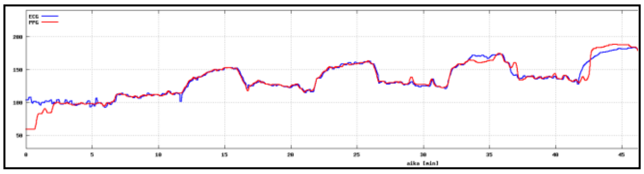

Figure 6. *Test result from an interval training: red curve = wrist heart rate, blue curce = ecg heart rate.*

Horton et.al. compared Polar M600 optical heart rate to ECG heart rate in several sports (cycling, walking, jogging and running) and conclude that it is accurate in steady-state conditions but some lag exist during intensity changes [6]. For weight training they recommend to use the optical measurement for monitoring HR during the recovery periods.

6 Maintenance

The wrist heart rate measurement is maintenance free and does not need calibration or any configuration from the user. For the best possible operation it is recommended to keep the back of the wrist-device clean as the measurement is based on measuring tiny changes in the light intensity and even small amount of dirt in a wrong place may decrease the performance of the device.

Similarly, scratches on the sensor may scatter the light from the LEDs into unwanted directions and not directly into the skin. Less light to the skin means less light back to the detector, and therefore increased noise and reduced signal. This may impair the measurement performance of the device.

So the maintenance instructions for the Wrist Heart Rate sensor are simple: keep it clean, prevent scratches.

7 Summary

Wrist Heart Rate measurement offers a new, interesting and user-friendly possibility to heart rate measurement. With proper use it is as accurate as chest strap based heart rate measurement but – being completely different both from the physiological and technical point-of-view – it needs adaptation and learning from the user.

Most importantly, the wristband has to be in the correct position on the wrist, and secondly, the tightness of the wristband has to be correct. To help the user to get these critical steps right from the very beginning, Polar will offer different sizes of wristbands to fit properly to different sizes of wrists.

Hopefully, the ease of use of the Wrist Heart Rate measurement will engourage more people to use heart rate as a guide to high quality training regardless of their target fitness level or the type of the exercise they want to pursue (Fig 7).

Figure 7. *Treadmill running is as suitable to Wrist Heart Rate measurement as any other sport.*

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