Polar H10 Heart Rate Sensor System

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Polar Research and Technology

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1 Introduction

In 1983, Polar Electro launched the world's first heart rate monitor based on a simple concept of having a chest strap as a sensor and a wristwatch as a heart rate display, memory and user interface [1].

Since then the basic concept has remained the same but there has been lots of development in the materials of the strap electrodes, material of the strap itself, measurement electronics, algorithm for QRS detection and in the communication technology for transmitting the heart rate information to the user device [2].

The current version presents the 5th generation of Polar Heart Rate (HR) technology and offers improvement to the previous generation of H7 technology, whose performance has been acclaimed and it has been widely used as a reference for wearable HR measurement systems [3].

2 Technology Background

The Electrocardiogram (ECG) measures the electrical activity of the heart. Each heartbeat is associated with corresponding signal phase and characteristics on the ECG. For heart rate measurement, the most important signal phase is the QRS complex that represents the contraction of the ventricles.

In theory, measuring the heart rate accurately is straightforward as it only needs accurate detection of the change in the electrical polarity of the heart. However, doing this correctly and consistently during sport activities is very difficult.

If we break down the strap solution for heart rate measurement, we have the following seven distinct areas that have to be engineered to a high-quality level to achieve the best possible performance.

Starting from the skin, this is where the ECG signal enters into the system and traverses through to the fine-tuned HR reading that is given to the user.

1) The strap has to fit close to the person, sit comfortably and without moving (Fig 1.).
2) The strap must reject electrical disturbances and noise from entering the electrodes.
3) The electrodes on the strap must provide adequate contact to the skin.
4) Signal processing has to detect QRS complex accurately with sub millisecond resolution from the ECG signal.
5) The heart rate calculation algorithm must use state-of-the-art filtering to discard unacceptable readings but allow rapid reaction to changing heart rate.

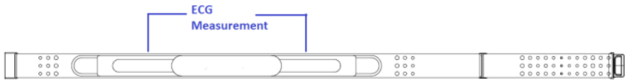

Figure 1. Polar Pro Strap.

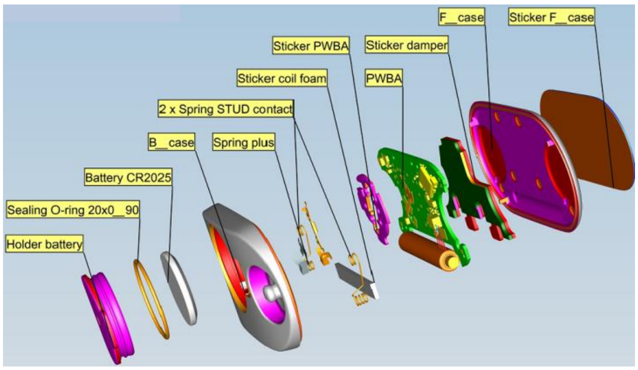

Figure 2. Polar H10 sensor.

3 Validation of HR measurement

In the early days of Polar Electro, the key question was if the heart rate measurement with the chest strap and a small sensor attached to it is as accurate as measurement with a hospital grade ECG monitor. Several scientific studies showed that this was the case [4, 5], and nowadays it is taken for granted that as a technical solution a chest strap is a reliable method for heart rate measurement. Therefore, the challenge nowadays is to measure heart rate and R-R intervals accurately when the test person is moving freely in the most demanding environmental conditions.

In the hospital settings, the standard device for measuring heart rate in a freely moving person is a Holter monitor. In our H10 accuracy tests, Holter monitors from three different manufacturers where included. In addition three competing strap solutions were included as well as four different solutions from Polar Electro.

3.1 Validation with the physiological criteria

Already the initial tests with the H10 sensor together with the Pro Strap show that for measuring a freely moving person during sports like running and weight training, there are not any devices that could be used as a reference, as the accuracy of the H10 is superior to all of them.

This led us to apply so called "physiological criteria" for performance analysis. The physiological criteria provide an absolute reference in the form of a physiologically possible interval limit for consecutive heartbeats. If the heartbeat does not occur inside the limit, it is considered erroneous. The error rate is calculated by dividing the total time of erroneous heartbeats with the total time of all heartbeats (Fig 3. and 4.).

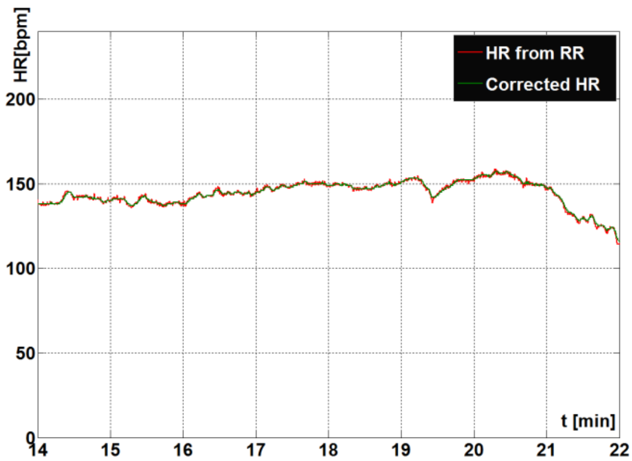

Figure 3. Heart rate when the ECG quality is excellent.

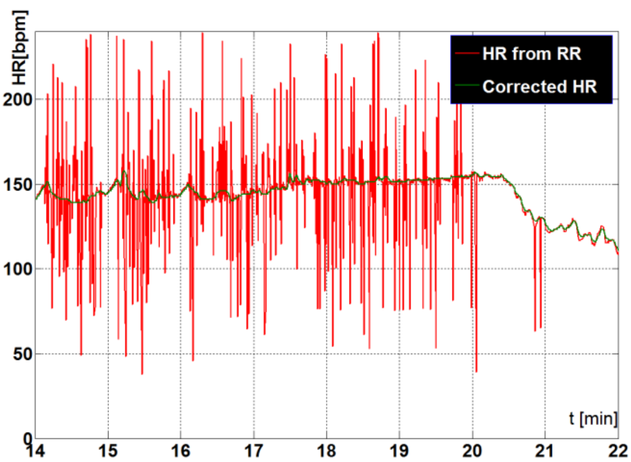

Figure 4. Heart rate when the ECG signal quality is poor.

3.2 *Validation based on RR intervals*

In previous studies, ECG Holter monitors were used as a reference for validating Polar RR measurement accuracy. These studies showed that Polar H7 measures 95 % of RR intervals within a 2 millisecond resolution [6].

RR interval accuracy is calculated based on the assumption that the waveform of consecutive sinus-based QRS complexes is similar. In reality, this is not the case as noise causes distortion to the QRS complexes and the exact timing of the RR interval. This enables us to estimate how much error there is in measured RR intervals.

Figures 5. and 6. illustrate good and poor-quality ECG-signals. An RR accuracy estimation has been carried out only for Polar H10 and Holter monitors an ECG signal was not available from the other devices.

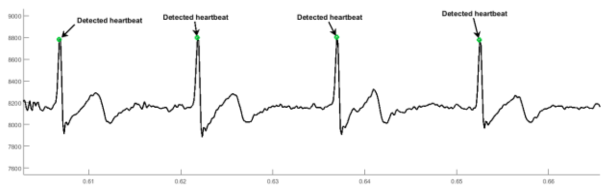

Figure 5. Good quality ECG where QRS complexes are regular and identical.

Figure 6. Poor quality ECG where QRS complexes are distorted.

3.3 *Subjects and test protocol*

The most difficult condition for heart rate measurement is when the skin is cold and there is no sweat on the skin and when the user is performing an intensive sport like running or cycling. For the H10 tests, this was the condition used for running. In the other sports, the skin was already warmed up before the test started (Table 1).

- Subjects: there were 10 subjects (7 men, 3 women), the ages varied from 34 to 53, and BMI 21.3 to 26.9.
- Heart rate monitors used in study:
  - Polar H10 with Pro Strap
  - Polar H7 with Soft Strap
  - Polar H7 with Pro Strap
  - Polar Team Pro Sensor with Polar Team Shirt
  - Wahoo Tickrx HR sensor with Tickrx Strap
  - Garmin HR Sensor with Soft Strap Premium
  - Suunto Smart Sensor with Suunto Smart Sensor Strap
- Holter monitors used in study (portable medical device for cardiac monitoring)
  - Braemar DL900
  - Medilog AR12
  - Faros 360.
- Exercise tests protocol (see Table 1):
  - Treadmill running in standard conditions,
  - Stationary bicycling,
  - Gym exercises with weights.
- In each test a Heart rate monitor and a Holter monitor were used simultaneously (Fig. 7). For practical reasons, Polar Team Pro Shirt was tested alone without the Holter monitor.

Table 1. Test protocol.

Time (min)	**Sport**
0-1	Rest
1-20	Running
20-25	Rest
25-35	Stationary bicycling
35-40	Rest
40-62	Weight training
62-65	Rest

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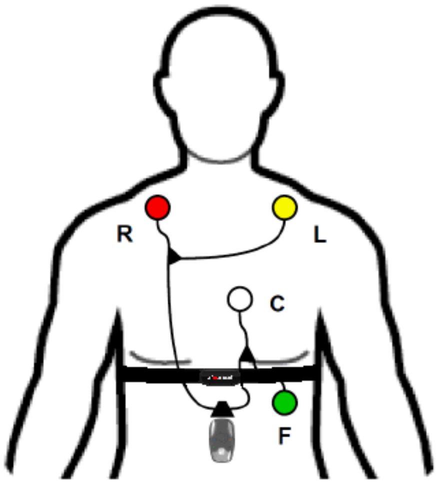


Figure 7. Illustration of the simultaneous testing of Polar H10 sensor (with Pro Strap) and Faros360 (Holter monitor with 5 disposable electrodes).

4 Results

4.1 Results from physiological criteria

Validation method based on physiological criteria was explained in chapter 3.1.

The blue bar in figures 8. to 11. shows the average error, and the black bar shows the 2σ deviation, which indicate the range where 97.5 % of test results reside.

We classify the results to Excellent, Good, Fair and Poor according to the error percentages: less than 4%, between 4% and 10%, between 10% and 30%, and over 30%, respectively.

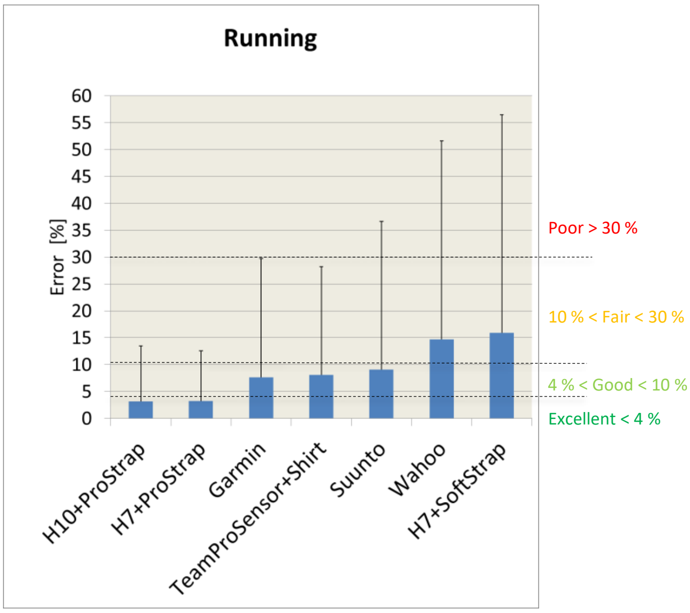


Figure 8. HR accuracy performance in running.

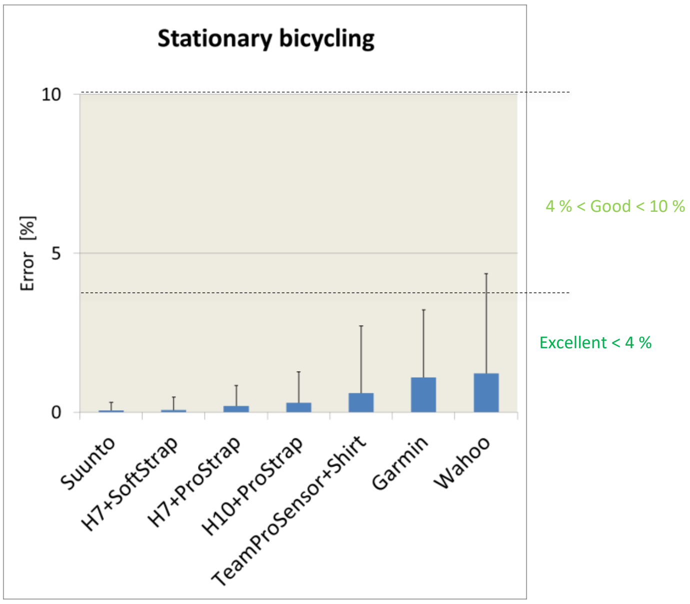


Figure 9. HR accuracy performance in stationary bicycling.

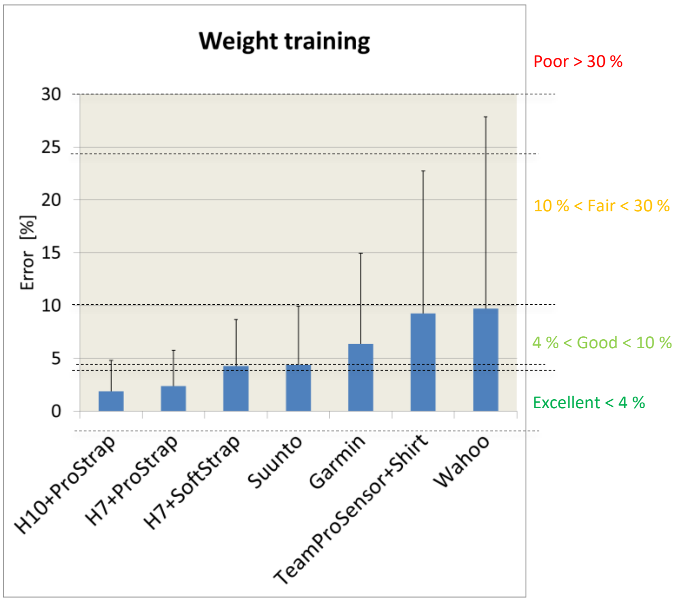
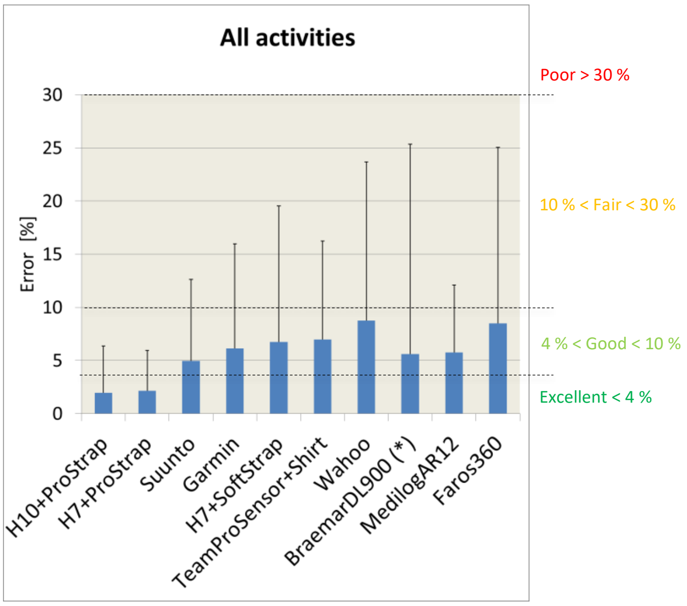


Figure 10. HR accuracy performance in weight training.



(*) Calculated by H10 algorithm

Figure 11. HR accuracy performance in all activities, with Holter monitor results included.

4.2 Results from RR intervals

Validation method based on RR intervals was explained in chapter 3.2.

The following results were achieved in RR interval measurement accuracy.

H10 detects RR intervals within 2 ms accuracy
92.9 % in running,
99.3 % in cycling,
95.3 % in weight training,
95.6 % in all activities combined.

Holter monitors detect RR intervals within 2 ms accuracy
84.4 – 89.5 % in running,
98.5 – 98.9 % in cycling,
90.6 – 91.2 % in weight training,
91.1 – 92.4 % in all activities combined.

5 Summary of tests

Results from validation tests show that H10 together with Pro Strap offer the best heart rate measurement accuracy of the tested systems. Its accuracy is best compared to similar strap solutions and it is also better than any of the Holter monitors used in the tests.

Second best according to the test is Polar H7 together with the Pro Strap.

From a Smart Coaching point-of-view the results are the following:

- Results show excellent average performance for both Polar H10 and Polar H7 used together with Pro Strap.
- Polar´s latest technology (H10, Pro Strap and Team Pro Shirt) show average performance was good in all three exercise modes, running, cycling and weight training, which predict good Smart Coaching validity.
- Results show fair performance for Polar Team Pro Sensor and Shirt in both error

variables (average and 2σdeviation) in running, cycling and weight training exercises. Measurement quality is around the same level as competitors HR straps have.

6 Conclusion

The H10 sensor and Pro Strap are the outcome of Polar Electro’s long commitment to develop the best heart rate measurement system for sport and fitness activities. In the tests, the H10 sensor together with the Pro Strap (Fig. 12.) has proven to be more accurate than any of the competitor´s strap solutions and also more accurate than any of the Holter monitors tested.

Figure 12. Polar H10 with Pro Strap.

Until now the H7 sensor from Polar Electro has widely been used as a reference system in heart rate accuracy validations, both in product comparisons and in scientific studies. We believe that H10 together with the Pro Strap will take this demanding position in the future.

In addition to excellent heart rate measurement performance, the H10 sensor answers widely to user requirements and needs for water resistance to 30 meters, transmitting HR also in swimming and having a memory for stand-alone operation. Over The Air (OTA) upgrades of the H10 firmware expands the lifecycle as the software will always have the latest innovations from Polar Electro.

7 Patents

US6600942B2
US8489021B2

Patent pending (published):

US20160000336A1

8 References

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