CONTENTS

1 Introduction

Polar Electro has pioneered the use of electrocardiogram (ECG) based HR sensor for sport applications. Measurement of heart's electrical activity with Polar H10 sensor enables heart rate (HR), heart rate variability (HRV) and RR-time interval (time between two consecutive R-peaks) recording over time. These parameters are calculated based on the analysis of QRS complex of the measured ECG signal. This ECG-based data provides the basis for development of training guidance and tracking of recovery. [1]

Wrist-ECG sensor enables measurement of ECG signal without the Polar H10 sensor. Elixir™ opens up new application possibilities with selected Polar wrist units.

2 Physiological background

Electrocardiography (ECG) means the recording of heart's electrical activity and presenting the measured voltage as a function of time. The measurements are taken with electrodes placed on the skin. The electrodes measure tiny electrical changes of the heart during the cardiac cycle.

Typically, ECG is measured with 12-lead connection in a hospital setting and is also the golden standard reference measurement system. Instead of 12-lead connection, Wrist-ECG refers to single lead connection (lead I). This is one of the standard limb leads in the Einthoven triangle, namely from right arm to left arm (Figure 1). [2,3].

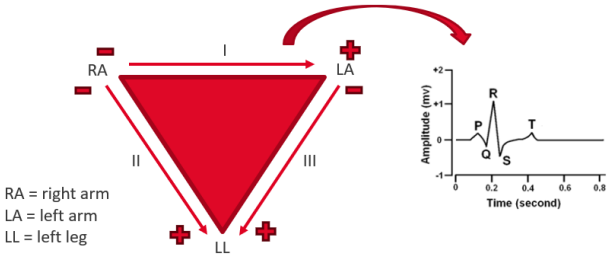

Figure 1. *Einthoven triangle and marked limb leads.*

ECG signal contains information from the heart operation during the cardiac cycle. Following information can be typically seen from the graph: P-wave, QRS-complex, and T-wave (Figure 1).

3 Technological background

Single lead ECG connection means a design where two electrodes are used. They can be placed in the chest strap or in the wrist unit with one electrode being one of the buttons (negative electrode) and the other electrode being the back of the watch (positive electrode). A bipolar ECG-lead is derived by recording the voltage difference over time between the finger on the button and the watch's back electrode on the other arm's wrist, thereby simulating Einthoven's ECG lead I. Figure 2 depicts the measurement principle.

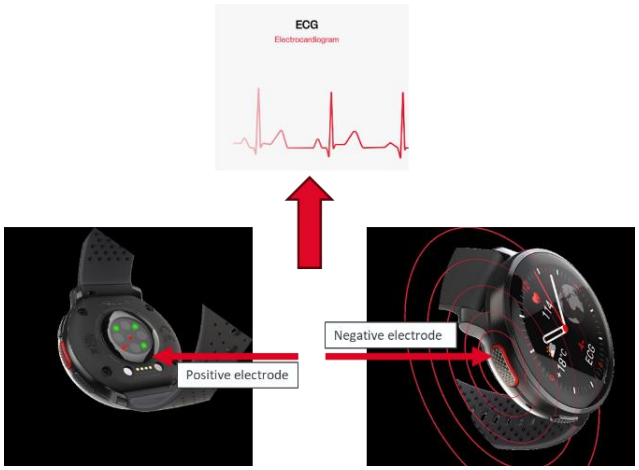

Figure 2. *ECG-measurement principle of the wrist unit.*

4 Validity and accuracy

4.1 ECG signal quality

In order to validate the accuracy and reliability of Polar Elixir™ Wrist-ECG a study with Medilog AR12+ Holter ECG monitor and Polar Vantage V3 was conducted at Polar Research Center Sports Lab in 2023 (unpublished).

In this study, a total of 20 participants were recruited, each undergoing the prescribed protocol twice. Vantage V3 was used in a data collection mode (only available for research purposes) in order to perform the protocol. The protocol emulates multiple successive Wrist-ECG tests that is found in Polar Vantage V3. The protocol involved participants holding their finger on the light button (negative electrode) for 25 seconds, repeated five times with a 5-second detachment in-between each trial, while wearing the device on their wrist. The Medlilog AR12+ was utilized as the reference device for data collection.

To assess the quality of the ECG data obtained, specific criteria were designed and implemented. These criteria were scaled in to a relative scale of 0-100% and was called, 'ECG Quality'.

In figures 3 and 4, there are examples of overlayed cardiac cycles with clearly distinguishable PQRST-waves. The less deviations in the signals, the better the quality and more reliable the signal.

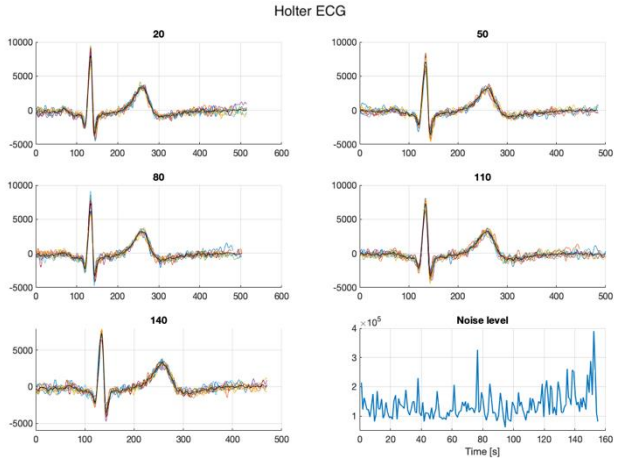

Figure 3. *Medilog AR12+ Holter ECG with cardiac cycles overlayed.*

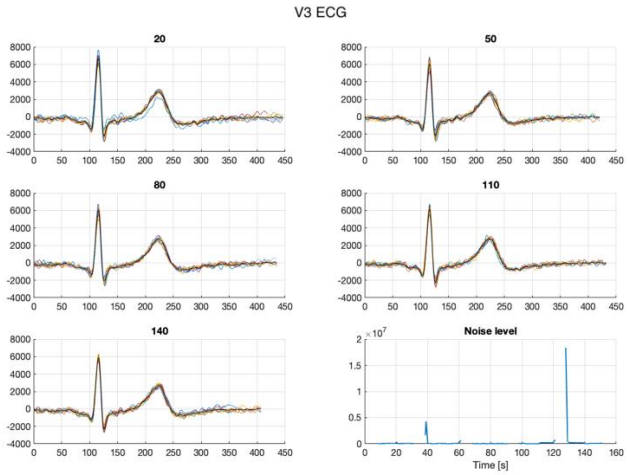

Figure 4. *Polar Vantage V3 Wrist-ECG with cardiac cycles overlayed.*

In a total of 40 measurements conducted, a noteworthy pattern emerged. Precisely half of the measurements, 20 out of 40, of the analyzed ECG qualities were within a tight range of ±2% of each other (Medilog AR12+ Vs Polar Vantage V3).

Among these measurements, in 12 out of 40 cases, the Holter device demonstrated superior signal quality. Specifically, the ECG quality was at least 3% higher compared to the Vantage V3, indicating its efficiency in capturing precise cardiac signals.

In the remaining 8 out of 40 cases, the Polar Vantage V3 showcased superior ECG signal quality, surpassing the Holter by at least 3% (Table 1).

Table 1. *ECG quality comparison per case.*

Vantage V3 (>2% better quality)	*Reference device (>2% better quality)*	*Equal (quality diff =< 2%)*
8/40	12/40	20/40

Overall, both devices demonstrated high signal quality. The overall deviation in quality was slightly larger with Vantage V3 (9.5 %) than Holter ECG (5.5%). The difference in mean of median quality was 2.15% in the favor of Holter device (Table 2).

Table 2. *Mean of median and deviation quality over the protocol.*

Vantage V3	*Medilog Holter*
93.35 ± 9.5	95.5 ± 5.5

Polar Vantage V3 has demonstrated notable suitability for ECG measurement due to its advanced sensor technology and precise signal processing capabilities. Its design incorporates high-fidelity sensors that efficiently capture subtle electrical signals generated by the heart, ensuring accurate and reliable ECG data.

Additionally, the device's signal processing algorithms effectively filter noise and artifacts, enhancing the clarity and quality of the ECG recordings, making it an optimal choice for precise cardiac monitoring.

4.2 RR-accuracy

From the same dataset as the ECG signal, quality of the accuracy of the RR-intervals was also studied. Both of the signals (V3 ECG & Medilog Holter ECG) were passed through the same proprietary RR-detection algorithm.

In 50% of the cases (20 out of 40), the RR-interval accuracy was within a remarkable 1 ms of the reference value. Moreover, in a significant 90% of cases (36 out of 40), the RR-interval accuracy was within a tight margin of 2 ms from the reference (Table 3).

Only in a small fraction, 5% of cases (2 out of 40), did the RR detection encounter substantial errors primarily induced by noise in the source signal. Overall, the observed accuracy remains highly satisfactory, affirming the proficiency of the ECG signal (Table 3).

Table 3. *Number of measurements for different RR-accuracy criteria with median difference between V3 & Holter*

diff < 1 ms	*diff < 2 ms*	*diff >=10*
20/40	36/40	2/40

5 Advantages of use

Orthostatic test -originally from medical use- is a well-known method in sports to measure recovery [4-6]. Making the test was previously possible with Polar H10 sensor [7]. Now the test can also be taken with the Vantage V3 wrist unit (Figure 5). The protocol has been unchanged, two minutes laying and two minutes standing [8]. Accuracy of the orthostatic test with wrist unit has been validated against Polar H10 sensor.

Figure 5. *Polar Vantage V3.*

Other user benefits from Wrist-ECG measurement include collecting training and recovery related data, like HR, HRV and RR.

For successful and repeatable measurements, the following guidelines are recommended:

- Take the measurement always in the morning after waking up.
- Remain still and keep the finger with stable connection to the button.
- Rest for 10 minutes before the test after exercise
- Wear the device for at least 10 minutes before taking the measurement.

6 Discussion

The studies defined earlier in this paper of RR-accuracy and ECG quality has yielded valuable insights into the performance of the Polar Elixir™ and Polar Vantage V3. The RR-accuracy results demonstrate a significant level of precision in capturing RR-intervals, a critical parameter for evaluating heart rate variability and cardiac health. Remarkably, in half of the cases (20 out of 40), the RR-interval accuracy was within an impressively narrow range of 1 ms from the reference value. Additionally, in a substantial majority (90%) of cases, the RR-interval accuracy was within a 2 ms margin from the reference. These findings underscore the reliability and accuracy of the devices in detecting RR-intervals, a fundamental aspect of ECG analysis.

Moreover, the ECG quality assessment revealed substantial accuracy and consistency. In half of the cases (20 out of 40), the ECG qualities were remarkably close, displaying a high level of uniformity with deviations within a mere 2%. Furthermore, the study observed that in the majority of cases (90%), the ECG qualities remained within a 2% range, demonstrating the devices' robustness in capturing precise ECG signals.

Overall, the findings affirm Polar Elixir™ and Polar Vantage V3 efficacy in providing accurate RR-interval measurements and consistent ECG quality. These aspects are vital for monitoring cardiac health and heart rate variability accurately.

7 Limitations

Polar Wrist-ECG measurement is not intended for medical use.

8 References

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