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1 Introduction

Polar Electro launched its first optical heart rate (OHR) measurement devices more than 10 years ago. Since then, several generations of optical measurement configurations have been published in various products. [1,2] Now the current generation of measurement configuration provides Elixir™ technology to measure OHR and SpO_2.

Polar Elixir™ incorporates unique sensor fusion technology consisting of several LED wavelengths, motion sensor and skin contact measurement. All this information is processed using the Polar proprietary algorithm to provide accurate heart rate even in the most demanding conditions.

Blood oxygen saturation (SpO_2) is one physiological parameter which is used to monitor user status on daily basis. Arterial oxygen saturation is estimated by measuring the light absorbance of pulsating vascular tissue at two wavelengths.

2 Background

Physiological and technical background of OHR has been reviewed in the previous white papers [1,2]. Elixir™ uses light to measure volumetric changes of tissue at the sensor's location. These volumetric changes are caused by the heart pumping blood round your body. During systolic phase there is more blood in the arteries compared to the diastolic phase. A high volume of blood causes less light to return to the optical sensor, whereas a low volume increases the amount of returning light. In practice, light-emitting diodes (LEDs) emit light into the skin, and photodetectors capture the transmitted, reflected or back-scattered light. Changes in blood volume modulate the amount of light reaching the photodetectors, providing the basis for heart rate estimation.

Measuring the time difference between high and low light intensities enables the device to measure beat-to-beat time intervals and calculate heart rate from that data.

Figure 1. *Polar Elixir™ Biosensing solution in Polar Vantage V3*

Peripheral capillary oxygen saturation (SpO_2) is an estimate of arterial oxygen saturation (SaO_2), which refers to the amount of oxygenated hemoglobin in the blood. SaO_2 is the percentage of oxygenated hemoglobin (hemoglobin containing oxygen) compared to the total amount of hemoglobin in the blood (oxygenated and non-oxygenated hemoglobin). [3] Pulse oximetry provides an indirect measurement of arterial oxygenation (SaO_2) based on absorption of light at two wavelengths (Figure 2). The relationship between measured light absorbances and saturation is established empirically and is built into the device software.

Elixir™ enables reflective type of measurements for determining SpO_2 from wrist. SpO_2 can be measured as a simple one-time measurement during daytime.

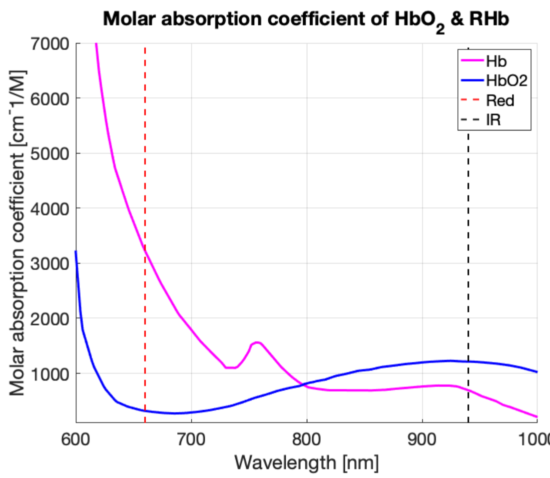

Figure 2. *Molar absorption coefficient of HbO_2 & RHb as a function of wavelength.*

It is known that SpO_2 will change if the altitude of the person changes. Frequent measurement of SpO_2 provides a method to monitor daily variation of SpO_2. Technology itself will also give its variation to the readings, when measuring the SpO_2 several times. [4]

3 Accuracy

The accuracy of Polar Elixir™ Biosensor in both SpO_2 & OHR have been validated. The OHR was validated internally by Polar and SpO_2 was validated by Russell et al. 2023 [5].

3.1 OHR accuracy

The OHR validation consisted of two different study setups done at Polar Research Center Lab. In both of the setups Polar H10 was used as a golden reference as suggested by Gilgen-Amman et al. 2019 [6]. In the initial setup, the validation of Polar Elixir™ Biosensor OHR was conducted within an uncontrolled environment to simulate real-world scenarios. This setup embraces a substantial participant pool to enhance the robustness of the findings. The study enlists a total of 30 individuals, comprising diverse backgrounds and fitness levels. Within this cohort, a comprehensive regimen of over 70 distinct exercise sessions per sports was executed. The exercises encompass a wide spectrum of sports activities, including running, cycling, walking, and strength training. This diversified exercise selection aims to emulate the multifaceted nature of real-world training routines.

The measurements were most precise during running exercises, as evidenced by a mean absolute error (MAE) of 2.4 beats per minute (bpm). Conversely, the monitoring exhibited the greatest errors during strength training sessions, with an observed MAE of 5.6 bpm. (Table 1)

***Table 1**. Accuracy results of the uncontrolled validation setup.*

Uncontrolled environment	***Mean absolute error [bpm]***	***$N_{exercises}$***
Running	2.40	80
Cycling	3.40	87
Walking	4.20	75
Strength training	5.60	77

The second setup, also referencing the Polar H10 device, endeavors to evaluate Polar Elixir™ OHR under controlled conditions.

To achieve this, 10 participants were recruited, ensuring a focused assessment of the intervention's impact. The participants (4 women and 6 men) were 34±7 years-old with mean weight and height 79.4±13.6 kg and 174±8 cm. Within this setup, a specialized protocol spanning 62 minutes was implemented, encompassing running, cycling, and strength training with free weights (Table 2). By concentrating on a specific subset of exercises, this controlled environment allows for a targeted analysis into the accuracy of OHR within a constrained timeframe, benchmarked against the Polar H10 device's established measurements.

***Table 2**. Multisport protocol.*

Protocol phase	***Duration (min)***	***Overall duration (min)***
Rest HR while sitting	3	3
Rest HR while standing	3	6
Treadmill running	20	26
Rest	1	27
Indoor cycling	20	47
Rest	1	48
Dumbbell squat	0.75	48.75
Rest	1	49.75
Dumbbell squat	0.75	50.5
Rest	1	51.5
Dumbbell bench press	0.75	52.25
Rest	1	53.25
Dumbbell bench press	0.75	54
Rest	1	55
Dumbbell bicep curl	0.75	55.75
Rest	1	56.75
Dumbbell bicep curl	0.75	57.5
Rest	1	58.5
Dumbbell side lateral raise	0.75	59.25
Rest	1	60.25
Dumbbell side lateral raise	0.75	61
Rest	1	62

The average MAE for heart rate during running was found to be 1.1 bpm with a standard deviation of ±0.5 bpm. In cycling, the average MAE was slightly lower at 1.0 bpm with a standard deviation of ±0.3 bpm. Conversely, the MAE in heart rate monitoring during strength training exhibited a significantly higher mean of 9.1 bpm with a notable standard deviation of ±7.4 bpm. (Table 3). These studies are unpublished.

***Table 3**. Controlled study results.*

	Running	*Cycling*	*Strength training*
Average of Mean absolute error [bpm]	1.1 ± 0.5	1.0 ± 0.3	9.1 ± 7.4
Median of Mean absolute error [bpm]	0.8	0.9	6.7

3.2 SpO_2 accuracy

Russel et al. 2023 conducted an independent validation study with twenty-eight (28) participants. The study followed the International Standard ISO 80601-2-61 protocol for peripheral pulse oximetry validation. In the protocol, the participants inspired stepwise O_2 reductions which resulted in a set of five plateaus of SaO_2 between 70-100%. In each plateau phase, five blood samples from a radial arterial catheter were collected in order to compare SaO_2 to SpO_2 values calculated by the Polar Elixir™.[5]

The accuracy was calculated by using root mean squared error (RMSE) and Pearson correlation coefficients and the analysis range was 70-100%. The RMSE between SaO_2 of the blood samples and Polar Elixir™ was 2.67% with correlation of 0.89. The mean difference between the SpO_2 and the SaO_2 values was 0.52%.[5]

The ISO standard (80601-2-61) specifies the accuracy limit for a valid reflectance pulse oximeter to be <= 4 % (RMSE) compared to SaO_2 in range of 70-100% [7]. Based on results the Polar Elixir™ Biosensing solution is well in line with the ISO requirements.

4 Discussion

In general, the Polar Elixir™ demonstrated a commendable level of accuracy in OHR. The precision of OHR notably improved in controlled environment during running and cycling exercises.

A controlled environment, characterized by a stable temperature and ensured correct device placement, notably amplified the precision of the OHR. Indoor usage further contributed to this accuracy by eliminating potential artifacts induced by sun exposure or cold wind, ensuring a reliable and consistent measurement environment.

Conversely, in uncontrolled environments where devices were distributed to users for real-world use, the accuracy of heart rate monitoring remained very good, albeit with added challenges. This setup emulates real user scenarios and introduces variations in activities and environmental conditions. Despite the inherent complexity of indirect measurements in such settings, the Polar Elixir™ OHR maintained a high level of accuracy, underscoring its reliability even in challenging real-life conditions.

The ability of Polar Elixir™ to maintain accuracy even in dynamic and challenging environments, such as during running, cycling, or strength training, is a testament to its advanced sensor technology and robust design. This precision empowers users to fine-tune their workouts, ensuring they train at the right intensity and achieve their fitness goals more effectively.

The meaningfulness of heart rate accuracy lies in its implications for tracking and managing one's health and fitness. Accurate heart rate data is pivotal for monitoring exercise intensity, ensuring optimal training zones, assessing recovery, and even detecting anomalies or potential health issues. For individuals using heart rate monitoring for fitness goals or health management, precise and reliable data is essential for making informed decisions and adjustments to their exercise routines.

5 User benefits of SpO_2

It is known that environmental factors might affect SpO_2. SpO_2 values decrease when altitude increases, especially at altitudes above 2500m sea level. This has been found in all age groups [8].

SpO_2 values can be measured manually to follow daily variation and effect of varying altitude. High altitude training is a common method for elite athletes as a part of their training program [9]. When exposed to high altitude training, SpO_2 reading will decrease. The readings partly recover during acclimatization [10]. In addition, different hypoxic training methods have been used to improve performance of athletes [11].

Different ranges of SpO_2 are well known. SpO_2 values commonly are set to the following categories: Normal (95-100%), Below normal (90-94%), Low (<90%) [12,13]. Some evidence can be found in literature that there are daily variations in SpO_2 and a bit lower readings might be expected during nights. [14,15]

The accuracy of Polar Elixir™ SpO_2 (2.67 % RMSE) is in line with the requirements of ISO and the Polar Elixir™ is a valid tool for measuring peripheral oxygen saturation in daily basis.

6 Limitations

Even though the Polar Elixir™ Biosensing solution meets the accuracy criteria of the ISO (80601-2-61), the Polar Elixir™ and it´s measurements are not intended for medical use.

7 References

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