Ever wondered how your smartwatch measures your heartbeat and blood oxygen?

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Heart Rate

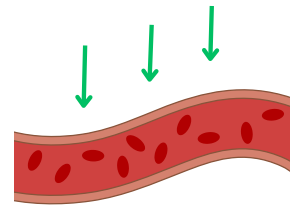
It shines green light into your skin and reads what bounces back.

The technical name is photoplethysmography, or PPG.

A green LED emits light onto your wrist, and a photodiode next to it measures how much of it comes back.

The photodiode sees a wave. The algorithm counts the peaks to estimate your **heart rate**.

Green LEDs shine light into the wrist.



Blood absorbs some of the green light. As blood volume rises and falls with each heartbeat, the amount of light returning to the sensor also changes.

The watch measures the light that bounces back. The amount changes with each pulse.

Blood Oxygen

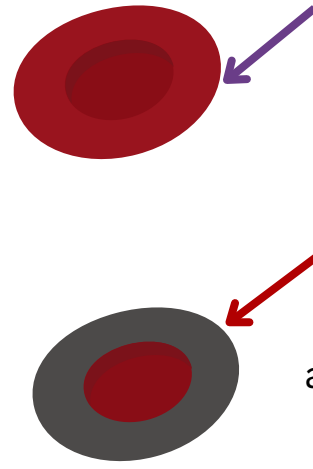
It shines two colors of light and reads the difference.

The technical name is pulse oximetry.

Red and infrared LEDs shine into your wrist. Oxygenated blood absorbs more infrared while deoxygenated blood absorbs more red.

The device measures the ratio of red to infrared reflection. That ratio maps to your blood oxygen percentage, which is used to calculate your **SpO_2.**

Red and IR LEDs shine light into the wrist.



Sensor Measures = R/IR

Sources of Error

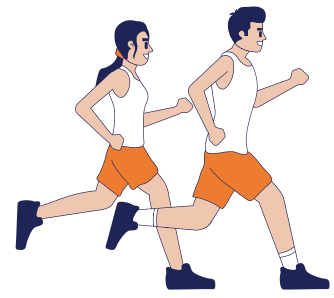
Light-based readings can get noisy.

Anything that changes how light travels between the LED and the sensor changes the reading.

Factors affecting
1) Skin Tone
2) Tattoos
3) Motion

Melanin can absorb and scatter light, changing how much light reaches the sensor.

Dark or dense ink can block or scatter the sensor's light before it reaches blood vessels. Apple and Garmin both note this in their support docs.



When the watch moves, the sensor may read movement along with the blood signal. This is especially important during exercise.

Context

Wellness vs Healthcare Decisions

For wellness, these numbers can be useful. They can show trends.

But healthcare decisions need a higher bar.

For heart rate, skin-tone bias appears less consistent across studies. Motion, device type, and fit often matter more.

The **same basic light-based principle is used in clinical pulse oximeters,** often clipped to the fingertip.

Clinical pulse oximeters can overestimate oxygen levels in people with darker skin. That means low oxygen is missed more often, and care is delayed

Skin-tone bias appears less consistent for heart rate.

Why HR may be less affected?

Heart rate mostly depends on counting repeated pulse peaks.

Studies have shown that pulse oximeters can overestimate oxygen levels in people with darker skin.

Why is SpO_2 harder?

Blood oxygen depends on comparing red and infrared light. Small optical differences can shift that ratio.

What is changing

The Way Forward

Devices should be tested across skin tones, real-world movement, tattoos, different body sites, and different lighting conditions.

They should also tell users when the signal is weak instead of giving a confident-looking number.

A recent study (Liao et al., Nature, 2026) points in an interesting direction to improve HR measurement. Researchers used smartphone camera video to estimate heart rate passively during everyday phone use. Results achieved industry accuracy target across all three skin-tone groups.

<u>This does not solve blood oxygen bias.</u>
That's the next problem worth solving.

Facial video-based PPG

Smartphones were able to produce accurate estimates of daily Resting Heart Rate