Skin temperature

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1 Introduction

Body temperature is a key indicator of health because changes in body temperature often signal disturbances in body homeostasis. Additionally. body temperature is also closely related to the circadian rhythm and influenced by the menstrual cycle. When speaking about body temperature, it is good to distinguish between core body temperature (CBT) and skin temperature. With the help of wearables, temperature can be conveniently monitored through the skin surface, providing valuable individual trends.

This white paper provides an overview of body temperature regulation and highlights the employment of Polar technology for measuring skin temperature. It also describes how nightly skin temperature is visualized on Polar devices.

2 Background

Core body temperature refers to the temperature within the body, specifically within the inner organs. Under normal conditions, it is maintained at a relatively stable level of around 37 °C (36.5-37 °C), although it slightly varies throughout the day and night. Optimal cellular and enzymatic function occurs at approximately 37 degrees, while excessively high or low body temperatures can be detrimental to our tissues and metabolism. The body constantly adjusts to maintain the stability of core body temperature in response to changes in the external and internal environments. This process is known as thermoregulation, with the primary regulator being the thermoregulatory center located in the hypothalamus. The body's superficial and deep thermoreceptors provide information on body temperature to the thermoregulatory center.

Temperature homeostasis refers to the balance between heat input and heat output to maintain a stable core body temperature. The body naturally generates heat through normal metabolism, and additional heat is produced by working muscles during exercise. External sources, such as warm objects, can also contribute to an increase in body temperature. On the other hand, heat is lost from the body to the environment through various processes, including conduction, convection, radiation, and evaporation.

The skin, with its extensive surface area,serves as the primary medium for heat exchange with the environment. Regulating blood flow to the skin is the most effective mechanism for heat transfer, and the body can also locally adjust blood flow as needed. When the body needs to dissipate heat, blood flow increases near the skin, and the blood vessels close to the skin dilate, a process known as vasodilation. Sweating is another means of heat loss. Conversely, if body temperature drops, such as during exposure to cold temperatures, the blood vessels near the skin constrict, reducing blood flow to the skin and preserving heat. The body may also initiate shivering or employ other heat-generating or heat-preserving mechanisms. In addition to these autonomous physiological changes, individuals often regulate their body temperature by modifying their clothing, huddling, seeking sunlight or shade, for example.

Reference measurement sites for core body temperature include the pulmonary artery, rectum and esophagus, among others (Tamara *et al.* 2018). However, these sites are impractical for continuous monitoring, even at a hospital. In everyday life, measurements taken from the ear are commonly used to estimate core body temperature. Similarly, temperature is measured on the body's surface, specifically the skin, often from the armpit or forehead. In recent years, the advent of weareables has enabled the continuous tracking of skin temperature, typically from the fingers and wrist, given their suitability for 24/7 use.

Skin temperature can undergo significant changes to keep the core temperature stable. Readings of skin temperature depend on the measurement site, environmental conditions, and physiological state (such as physical activity or sleep). Typically, these readings are higher in the torso compared to distal areas. The lowest readings are typically found in the hands and feet. In hot conditions, skin temperature readings in the extremities approach those of torso, while in cold conditions the difference can be several degrees. Moreover, in warm conditions, skin temperature can be close to core body temperature, but several degrees lower in cold conditions. Due to these factors, the absolute values of skin temperature readings can vary from moment to moment.

Body temperature shows a circadian rhythm and a menstrual cycle-associated rhythm. Both core body temperature and distal skin temperature, such as on the wrist, follow a circadian rhythm of approximately 24 hours. During the night, core body temperature slightly decreases and is typically at its lowest point around 4-6 hours after falling sleep. Conversely, wrist skin temperature tends to increase during the night and decrease during the daytime, displaying an opposite pattern to core body temperature. This phenomenon is endogenous and independent, observed even under controlled conditions where subjects are not allowed to sleep or engage in any kind of physical activity throughout the night (Martinez-Nicolas *et al.* 2013, Sarabia *et al.* 2008).

In women of reproductive age who experience menstrual cycles, that typically occur over the course of approximately 28 days, body temperature is affected by hormonal changes that happen throughout the cycle. During the luteal phase, an elevated level of progesterone is responsible for a slight increase in body temperature, while in the follicular phase, the increased estrogen level has a temperature-lowering effect (Baker *et al.* 2020).

Having a fever indicates that the body temperature is higher than normal. Core body temperature continues to be regulated but is actively defended at an elevated level. While wrist skin temperature readings do not directly equate to core body temperature, research has demonstrated that they are higher in the case of fever or infection (Chen et al., 2020; Holt et al., 2020). Latest studies show that wrist or finger temperature and other biosignals, such as heart rate, heart rate variability, and breathing rate, tracked with wearables can be used to detect the onset of infection with the help of machine learning (Smarr *et al.* 2020, Mason *et al.* 2022, Risch *et al.* 2022). These changes in biosignals are most prominent during sleep. (Mason *et al.* 2022).

3 Polar measurement technology and validation

The latest Polar watches offer automatic tracking of skin temperature. Skin temperature is measured using a small temperature sensor located at the bottom of the watch, directly under the optical heart rate lens. Measurements are taken every 5 minutes. Only the periods when the sensor is in direct contact with the skin are analyzed, while periods when the watch is not being worn or is positioned on top of a sleeve are excluded.

Our internal pre-validation conducted in real-life settings with 15 subjects demonstrates a strong correlation between skin temperature readings from the Polar Ignite 3 and reference thermometer readings from an iButton device (Pearson's R=0.904, Fig. 1). The reference thermometer was attached just above the Polar Ignite 3 on the wrist, which explains the slightly lower temperatures recorded by the Ignite 3. Furthermore, the temperature sensor accuracy in Polar watches has been verified through measurements conducted in our in-house climate chamber.

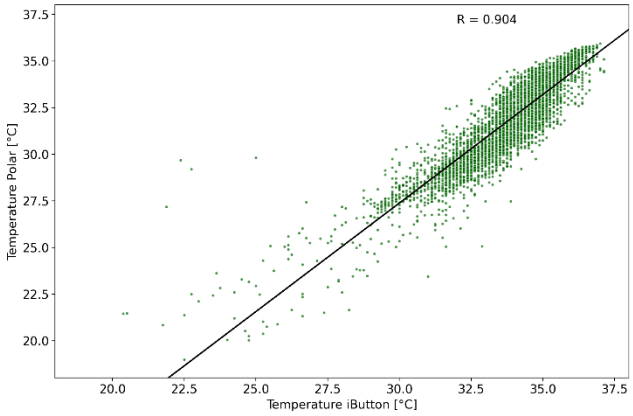

Fig.1. Internal prevalidation results against reference device show that Polar Ignite 3 skin temperature values correlate with a reference thermometer.

4 Polar application

Nightly skin temperature

Nighttime provides the optimal opportunity to obtain an accurate representation of your body's state. During sleep, the environment, that is your bed and bedroom, is typically stable and your body is at rest under the blanket. Skin temperature is automatically tracked during sleep. An aggregate value is calculated as the maximum temperature recorded during sleep and then compared to user's own historical data, specifically the average value of the past 28 days. Variations from that average are displayed and interpreted as falling within the usual range, below the usual level, above or much above the usual level. It is natural for skin temperature to exhibit slight variations from night to night. The usual range is considered to be a variation between -1 and +1 °C or -1.8 – +1.8 °F from the average. If the skin temperature exceeds 2 degrees above the 28-day average, it is categorized as much above the usual level.

Users can view the results for the previous night as well as weekly and monthly trends (Fig. 2). They can observe how much higher or lower their skin temperature was compared to their personal baseline and determine if the nightly skin temperature was within the usual range. The initial result is provided after three nights of data collection.

Elevated temperatures above the usual range can be indicative of various factors, including an impending illness. If you are feeling unwell, it is recommended to verify your temperature using a thermometer. Additionally, skin temperature can be influenced by different phases of the menstrual cycle. On the other hand, lower temperatures below the usual range may be attributed to external factors like room temperature or sleeping with your hand outside the blanket.

In menstruating women, wrist skin temperature can be influenced by the phase of the menstrual cycle. It may be higher than average during the luteal phase and lower during the follicular phase. However, it's important to note that hormonal cycles can vary significantly among individuals, and your temperature patterns are unique to your body. Furthermore, certain types of hormonal birth control may potentially suppress variations in skin temperature.

Fig. 2. Skin temperature views for the last night and one week.

5 Limitations

Various physiological, lifestyle, and environmental factors can influence wrist temperature data. To obtain accurate results, it is important to ensure a proper fit of your Polar watch. If the fit is too loose, it can affect the temperature data. It's worth noting that absolute temperature values are not provided to the user. Skin temperature measurements should not be used for medical or diagnostic purposes. Moreover, skin temperature tracking should not be considered a substitute for using a thermometer.

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