

A study on the relationship between changes in skin temperature and the amount of activity using a wearable device

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SUMMARY

Skin temperature is one of the major predictor of thermal comfort. There are many studies on the relationship between indoor temperature and skin temperature, but studies considering metabolic rate together are insufficient. This study explored changes in people's activity amount, skin temperature, and thermal sensation for 24 hours using a wearable device. The amount of metabolic rate and sweating were calculated from these data. As the metabolic rate increased, the sweating tended to increase, and the skin temperature decreased. In addition, the amount of sweating in the cooling season was higher than in the heating season, and there was a significant difference in the regression line of skin temperature and the metabolic rate among seasons.

KEYWORDS

Physiological signal, Metabolic rate, Wearable device, Thermal comfort, Season

1 INTRODUCTION

Thermal comfort is essential not only for the satisfaction and health of the occupants, but also in terms of energy. Recently, many studies have been conducted to predict thermal comfort using physiological signals. Among the various physiological signals, skin temperature is one of major factors in predicting an individual's thermal sensation.

A study on the difference in skin temperature showed that the wrist skin temperature differed by more than 1°C depending on the season. The higher the outside temperature, the higher the skin temperature. (Kim & Chun, 2022) However, the personal thermal sensation expressed by skin temperature may vary depending on the metabolic rate and external environmental factors, and discussion on this is insufficient.

Meanwhile, several studies have shown that heart rate and metabolic rate(MR) are closely related. First, Revel et al. presented a methodology to integrate the continuous estimation of metabolic rate in a monitoring tool for the indoor thermal comfort. This method was reported to regulate real-time metabolic rate uncertainties within 7% in a range of 0.7–3.4 met. Ceesay et al. (1989) validated a modified heart rate (HR) method for predicting total energy consumption (TEE) using a whole-body calorimeter (CAL). The study in Malchaire (2017) linearly simplified the relationship between heart rate and metabolic rate. Through this, the metabolic rate or degree of activity can be estimated based on the heart rate, or the heart rate itself can be an indicator of the metabolic rate.

With the recent development of wearable devices, real-time physiological signals can be collected, and many studies on predicting thermal comfort using wearable devices have been conducted. In addition, wearable devices make it easier to study individual thermal comfort prediction models in the field.

In this study, the effect of metabolic rate on skin temperature is discussed using heart rate. It compares skin temperature according to heart rate by season and improves understanding of the factors affected by skin temperature based on physiological signals collected through wearable devices. In addition, people experience various spaces in their daily life, going back and forth between indoors and outdoors. Therefore, the results obtained in laboratory experiments may differ from those obtained in everyday life. Therefore, we have chosen a field experiment instead of a laboratory experiment.

2 METHODS

2.1 Data collection and analysis

This experiment was conducted in March, May, and July 2022, and physiological signals and thermal subjective responses were collected from 9 subjects in March, 10 in May, and 9 in July. As a result, a total of 1949 datasets were created. External environmental conditions are summarized in Table 1 based on data provided by the Korea Meteorological Administration. July is the hottest and humid weather with the highest outside temperature and relative humidity.

Table 1. Outdoor environment information

	Outdoor temperature(°C)	Relative humidity (%)
March	7.7 ± 0.5	71.6 ± 1
May	20.1 ± 0.5 -	56.5 ± 3.7
July	29.2 ± 0.4	72.3 ± 3.7

Choi and Loftness (2012) showed that skin temperature can be used as a thermal index and that the wrist is the most responsive body part to the overall thermal feeling. Therefore, the wrist-type wearable device, E4 wristband (Empatica Inc.), is used in this study.



Figure 1. Empatica E4 wristband

The E4 wristband is equipped with an infrared thermopile sensor, a Photoplethysmography (PPG) sensor, a three-axis accelerometer, and an Electrodermal Activity (EDA) sensor to identify skin temperature, heart rate, three-axis acceleration data, and skin conductivity. C. McCarthy (2016)'s study on the validity of the E4 wristband verified the accuracy of the E4 data. More than 85% of the data obtained in E4 matched the existing device's data.

As shown in Figure 2, a 7-point scale was used for the thermal sensation assessment according to the ASHRAE standard, and a 7-point scale was used for the thermal comfort evaluation. The thermal evaluation was recommended to respond as much as possible once every 15 minutes during a day.

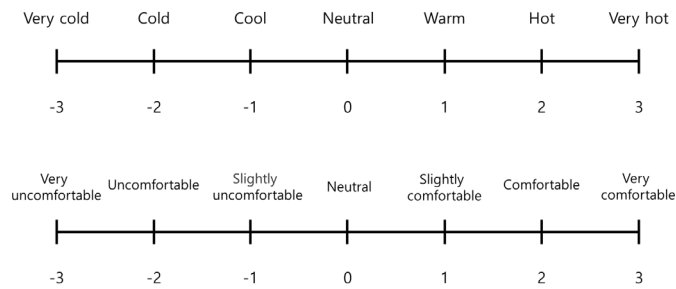


Figure 2. Thermal sensation scales and thermal comfort scales.

Subjects were encouraged to live their daily lives with wearable devices on their wrists, and experiments were conducted for one day except for sleep time. The following Table 2 shows the information on physiological signals collected through the E4 wristband.

Table 2. Characteristic of E4 wristband sensors.

Parameter	Sampling Frequency	Range
EDA sensor	4 Hz	0.01 – 100 μ S
PPG sensor	64 Hz	-
Infrared thermophile	4 Hz	-40 - 115 $^{\circ}$ C

Skin temperature and heart rate data were used for analysis after excluding outliers, and subjective responses were used for analysis except for items with less than 10 responses when divided by month.

2.2 Metabolic rate and heart rate

Heart rate can be used as an indicator of metabolic rate. Several studies have explained the linear relationship between the metabolic and heart rates. A study by Malchaire and Palella (2017) proposed a formula for heart rate and metabolic rate, including variables such as age, height, and weight. Although it is difficult to say that the heart rate represents only metabolic rate, it was determined that the metabolic rate could be expressed as the heart rate based on these previous studies.

The heart rate also reflects not only the metabolic rate but also thermal sensation. When it gets hot, more blood, which should be sent to the muscles during exercise, goes to the skin to control body temperature. In addition, the amount of blood returned to the heart decreases because a lot of water is discharged through sweat. As a result, the amount of blood emitted from the heart decreases, so the body's heart rate increases to compensate for it.

2.3 EDA and sweating.

Electrodermal activity is a measure of electrical activity on the skin's surface or originating from the skin. The conductivity of the skin surface is due to how much sweat the body is producing. (Bailey, 2017). Therefore, skin conductivity may be an indicator of sweating.

3 RESULTS

3.1 Thermal sensation vote and skin temperature

In Figure 3, the change in wrist skin temperature according to TSV in March, May, and July can be confirmed. On average, the skin temperature tends to increase from March to July. However, when the TSV was 3 (“very hot”) in July, the average skin temperature decreased. In addition, monthly TSV and skin temperature showed significant differences. (Table.3)

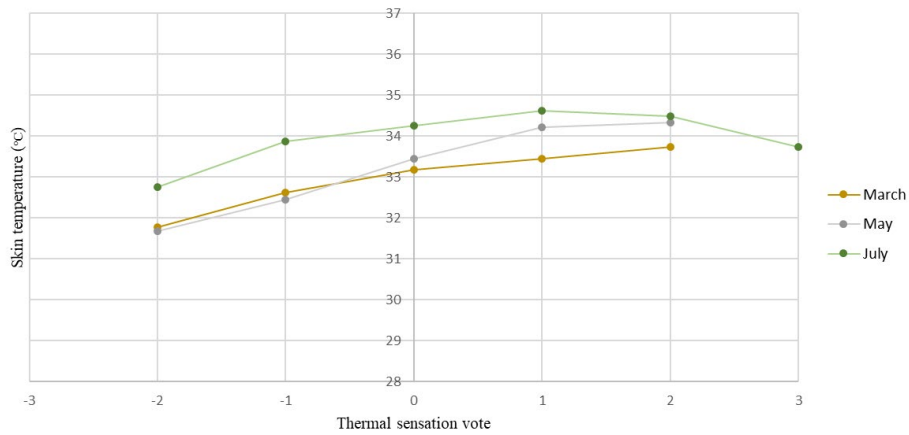


Figure 3. Thermal sensation vote(TSV) and skin temperature.

3.2 EDA and skin temperature

Figure 4 shows all skin temperatures and EDA during the experimental period, and EDA increased rapidly when the skin temperature was between 30°C and 35°C. When the skin temperature rises due to increased body temperature, the human body tries to control body temperature by discharging sweat to control body temperature. Therefore, it can be said that the increased skin conductivity when the skin temperature rises is due to sweating for body temperature control. At this time, the skin temperature may decrease due to the evaporation of sweat, but it is difficult to confirm in the following graph.

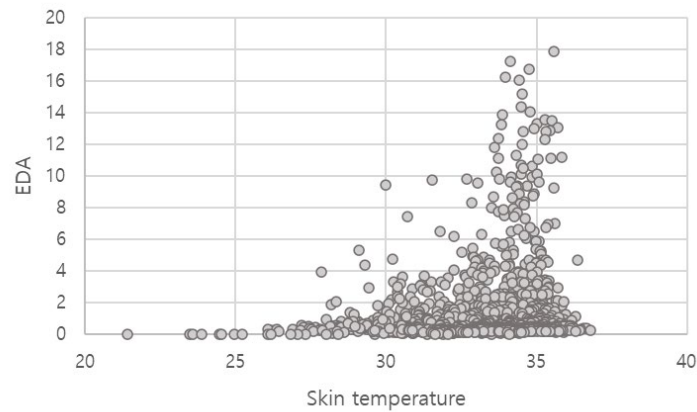


Figure 4. EDA and skin temperature

3.3 Heart rate and skin temperature

Table 3 shows the Pearson correlation analysis results of monthly skin temperature and heart rate. There was no significant correlation between skin temperature and heart rate in March, but there was a significant correlation in May and July.

Table 3. Pearson Correlation Analysis for Skin Temperature, TSV, and HR.

		TSV	HR
Skin temperature	March	0.315**	0.07
	May	0.387**	-0.139**
	July	0.149**	-0.12**

Figure 5 shows the relationship between skin temperature and metabolic rate. First of all, in July, when the outdoor temperature is the highest, unlike other months, there is a part where the skin temperature decreases when the metabolic rate increases. In figure 4(d), the skin temperature drops sharply from 35 °C to 30 °C between the heart rate of 90-110 bpm. It can be thought that the temperature of the skin decreases because the heat on the surface of the skin is released with sweat.

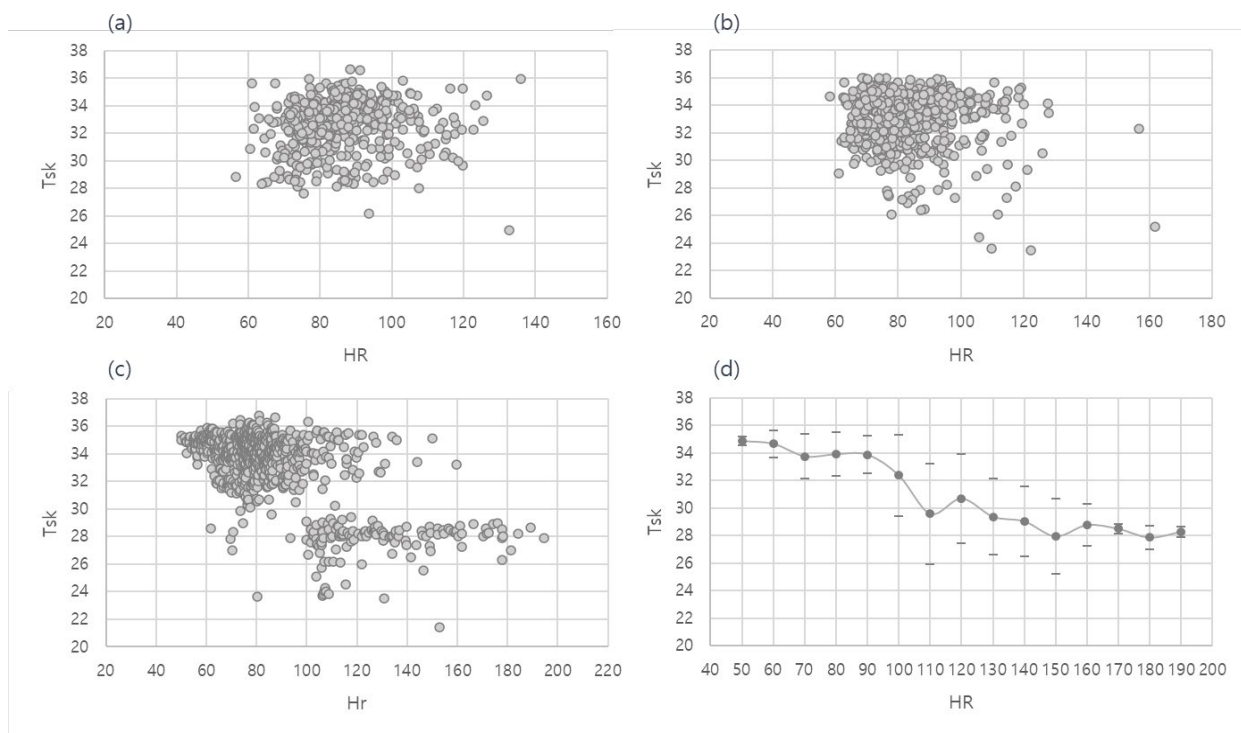


Figure 5. Heart rate(HR) and skin temperature(T_{sk}). (March (a), May (b), July(c), July. Mean(SD) (d))

4 DISCUSSION

4.1 Metabolic rate and sweating.

In a study by Gerrett (2013), skin wetness and skin conductivity were measured in four body parts, and both were significantly higher when they were running than when they were walking. It can be seen that both sweating and skin conductivity increase when the amount of activity is high. Therefore, both sweating and skin conductivity increase when the activity is high, and when the activity level is high, skin conductivity means sweating.

Even when it is cold, the metabolic rate increases due to muscle tremors, but it is hard to say that the amount of sweating increases. However, when it is hot, there is a high possibility of sweating. Therefore, if the metabolic rate increases to a certain level in July, when the outside temperature is high, sweating occurs, and the increase in EDA can also confirm the occurrence of sweating.

4.2 Metabolic rate and skin temperature

According to Fanger (1970), the neutral skin temperature decreases as the activity increases while the body's core temperature rises. In a study by Kuhnén and Jessen (1988), when the skin temperature is above 25-30°C, the skin temperature increases as the metabolic rate decreases, but when the skin temperature is below 25-30°C, the metabolic rate stagnates or decreases further. This shows that the relationship between skin temperature and the metabolic rate does not directly reproduce the temperature-response curve of the skin cold receptor, but rather reflects the complex interactions of several factors.

This can be applied equally to field experiments using wearable devices, and in July, when the temperature and humidity are high, the higher the heart rate, the higher the likelihood of sweating. (Figure 5) Therefore, sweating can be checked using both HR and EDA, and it suggests that changes in skin temperature caused by sweating should be considered when predicting thermal sensation through skin temperature in field experiments using wearable devices.

5 CONCLUSIONS

In this study, a study was conducted on how metabolism affects skin temperature according to season. In particular, in the season when the outside temperature is high, the increase in heart rate and the sweat seems to affect on lowering the skin temperature. Therefore, when the metabolic rate rises rapidly, sweating occurs for thermoregulation due to increased core temperature, and skin temperature decreases slightly. Understanding these body mechanisms is expected to produce more accurate results when using skin temperature as a predictor of thermal comfort. In addition, this study can provide insight into how physiological signals through wearable devices can be used by performing measurements in everyday life, not in the laboratory.

However, there are several limitations to this study. First, since the experiment was conducted with fewer subjects, it is necessary to prove the research results through more subjects in the future. In addition, since the metabolic rate was estimated and used only with the heart rate without accurately calculating the metabolic rate, some errors may occur here. Finally, as a limitation of field research, it may have been affected by other uncontrolled factors such as clothing.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (RS-2023-00208588)

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