

# Physiological response differences in relation to the body fat of vehicle passengers

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## SUMMARY

It is well known that body fat affects skin temperature due to its insulating feature, which means people could react differently depending on their body fat. Given that the vehicle has a transient thermal environment, the effect of body fat on skin temperatures might be more significant compared to the typical buildings. However, few studies explored this issue. Thus, this study examined the differences in skin temperature depending on the body fat of vehicle passengers. The subject experiments were conducted with middle-aged men in a vehicle which located in a climate chamber. The subjects were divided into normal and overweight groups according to their body fat. In addition, the skin temperatures were measured, and the subjects evaluated their thermal comfort during the experiments. As a result, it was confirmed that there were no significant differences in skin temperature and subjective sensation between the normal and overweight groups in both cooling and heating conditions.

## KEYWORDS

*Body fat, Skin temperature, Thermal sensation, Vehicle*

## 1 INTRODUCTION

Body fat is one of the most significant intrinsic factors affecting skin temperature ( $T_{skin}$ ), representing physiological responses to the thermal environment. It has been confirmed that the adipose tissue has a thermal insulating property that influences individual thermal patterns, and differences in fat thickness lead to  $T_{skin}$  variations (Fernández-Cuevas et al. 2015). It means that people could react differently depending on the body fat, even in an identical environment. Sometimes body mass index (BMI) is used instead of body fat, but it does not represent the body fat correctly. Being overweight does not always mean being overfat; some people have a normal BMI yet a high body fat percentage (Gallagher et al. 2000). Thus, body fat itself needs to be considered in relation to  $T_{skin}$ . Unlike typical buildings, the vehicle has a transient thermal environment, resulting in the passengers' unstable and changeable  $T_{skin}$ . In this case, the degree of influence of individual factors such as body fat on people's responses may be more significant than in the buildings. However, vehicle passengers' body fat and  $T_{skin}$  have rarely been studied together. Therefore, this study aims to examine vehicle passengers'  $T_{skin}$  changes depending on their body fat.

## 2 METHODS

### Experimental conditions

The experiments were conducted in a vehicle parked inside a climate chamber under two conditions: cooling and heating. In the cooling conditions, the climate chamber was set to summer-like conditions and winter-like conditions for heating conditions. The air temperature and solar radiation of the chamber were 40 °C and 830 W/m<sup>2</sup> in cooling conditions and -20 °C and 0 W/m<sup>2</sup> in heating conditions to imitate hot and cold weather, respectively. The natural

sunlight with global radiation was simulated by solar lamps installed at the top of the chamber. Also, the chamber system automatically controlled the relative humidity and air speed to keep the set condition, so the air temperature and solar radiation were maintained identically during the experiments. These settings are generic evaluation environments for vehicle performance evaluation. They are meant to ensure heating and cooling performance regardless of area or climate by securing performance in harsh environments.

Inside the vehicle, the Heating, Ventilation & Air Conditioning (HVAC) system started right after the experiment began. The set temperature of the HVAC system was 23 °C in both conditions, which is a neutral temperature. Then the HVAC system optionally operates the air conditioner or heater depending on the outside temperature to keep the indoor at 23 °C. Also, the system automatically adjusts the other environmental parameters, such as relative humidity and air speed. Consequently, the air conditioner was operated in cooling conditions, and the heater was on in heating conditions. Although the chamber was kept identically during the experiments, the indoor environment of the vehicle changed throughout the experiment due to the operation of the HVAC system. The entire experimental conditions were strictly controlled, so there were no environmental differences between subjects.

### Subjects

Twenty Korean men in the 40-50 age group participated in each condition. According to the report in 2019-2021 by the Korean national police agency, men accounted for about 57.32% of the whole driver's license holders, and in terms of age, the 40-50 age group was about 44.68% out of the whole age group. It shows that most drivers are men and people in the 40-50 age group. However, studies regarding them have rarely been conducted. Therefore, men in the 40-50 age group were selected as subjects in this study. Then the subjects were classified into two groups (normal group and overweight group) depending on their body fat percentage, referring to Gallagher et al. (2000)'s study. According to the study, percentage body fat levels were derived per ethnicity corresponding to the BMI thresholds, and the predicted percentage of body fat for Asians are as follows: <13% are underweight, >24% are overweight in middle-aged men (40-59 years old). The specific information of the subjects is summarized in Table 1. The sample size in the table was the value that invalid data was excluded.

The subjects wore the same clothes for the experiments. The clothes were set to represent the typical indoor clothes in summer and winter. In cooling conditions, clothes consisted of a short-sleeved T-shirt, long cotton pants, socks, and sneakers, and the clothing insulation was 0.51 clo. The clothes in heating conditions were a long-sleeved T-shirt, jeans, socks, sneakers, and jackets, and they were 0.85 clo.

Table 1. The specific information of the subjects

Conditions	Body fat classification	Sample size	Age	Height (cm)	Weight (kg)	Body fat (%)
Cooling	Normal	7	47.64	172.36	79.59	28.98
	Overweight	11	47.14	172	73.17	20.43
Heating	Normal	6	45.83	176.03	80.15	21.12
	Overweight	8	48.14	170.88	80.35	29.49

## Measurements

The environmental parameters near the subject were measured to examine the change in the indoor environment during the experiment. Installation of the sensors might negatively affect the subject during the experiment, so the parameters were measured separately after the whole experiment was finished. The HVAC manikin (Thermetrics, Seattle, USA, Fig.1(a)) was seated on the driver's seat the same as the subject for the measurement under the same conditions and period as the experiments. It has 60 measuring points throughout the body and measures the ambient temperature ( $T_a$ ), relative humidity (RH), air speed, and radiant heat flux.

As the physiological response, the local  $T_{skin}$  was measured at 10-second intervals during the experiments by TSK 7+1 (accuracy  $\pm 0.1$  °C, eight-channel, Songkitopia, Korea, Fig.1(b)) at 16 body parts as shown in Fig.1(c). Then the mean skin temperature (MST) was calculated using local  $T_{skin}$  by the Hardy&Dubois formula (Hardy et al. 1938).



Figure 1. Instruments for the measurement. a) HVAC manikin for environmental parameters measurement, b) Sensors for  $T_{skin}$  measurement, c) Body parts where the  $T_{skin}$  sensors were attached

Along with the physiological response, psychological responses were also collected. The subjects evaluated their whole-body and local thermal sensation and comfort at 5-minute intervals during the experiments. Local body parts for the evaluation were the same as the 16 body parts where  $T_{skin}$  was measured. A 9-point scale for thermal sensation and a centrally separated 10-point scale for thermal comfort were used (Fig.2).

Body part	Thermal sensation									
(e.g.) Right Upper Arm	-4	-3	-2	-1	0	1	2	3	4	
	Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot	
	Thermal comfort									
	-4	-3	-2	-1	-0	0	1	2	3	4
	Very uncomfortable	Uncomfortable		Just uncomfortable	Just comfortable	Comfortable		Very comfortable		

Figure 2. Scales for thermal sensation and thermal comfort evaluation

## Experimental procedure

The whole procedure is described in Fig.3. The same procedure was applied to all subjects in both conditions. 1) Preparation: After the subjects changed into experimental clothes and

measured their weight, height, and body fat, the Tskin sensors were attached to 16 body parts. 2) Stabilization: They stayed in a room set at neutral temperature for 20 min to stabilize their thermal state and metabolism. 3) Experiment: They entered the vehicle parked inside the climate chamber, and the experiment was started. Each experiment lasted 60 min, and the subjects evaluated their thermal sensation and comfort every 5 minutes.

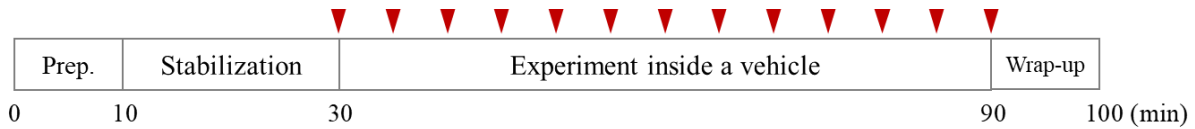


Figure 3. Experimental procedure (Red triangles: time to thermal comfort evaluation)

### 3 RESULTS

#### The indoor environment during the experiments

The HVAC manikin was used to measure the environmental parameters under the same conditions as the experiments. Sixteen points were selected among its 60 measuring points, and the average was calculated to check the environment around the subject. Those 16 points were the same as where the Tskin sensors were attached. Fig.4 shows the change of Ta (Fig.4(a)) and RH (Fig.4(b)) during the experiment in each condition. Ta decreased fast at the beginning of the experiment in cooling conditions. It was about 40.3 °C initially and decreased to about 26.5 °C as the air conditioner was operated. In heating conditions, Ta gradually increased from -14.3 °C to 23.2 °C for the first 30 min and became 27.2 °C at the end. Ta was similar in both conditions at the end of the experiments because the set temperature of the HVAC system was the same. The system was set to 23 °C, but the measured Ta was higher than that.

RH was under 20 % in cooling conditions. In contrast, RH in heating conditions was about 43 % at the beginning. Then it continuously decreased as Ta increased and reached 4.8 %. RH was relatively unstable because other parameters than Ta were automatically adjusted to keep the set temperature.

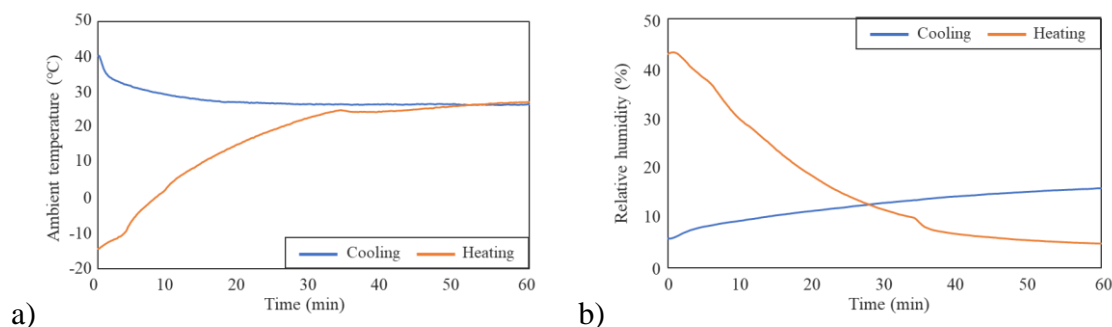


Figure 4. The indoor environmental parameters measured by the HVAC manikin. a) Ambient temperature (Ta), b) Relative humidity (RH)

#### Body fat of the subjects

Subjects were divided into two groups: normal and overweight, according to the predicted percentage of body fat for Asians (Gallagher et al. 2000). The body fat of whole subjects in each group is described in Fig.5. the overweight group has a significantly higher body fat percentage than the normal group in both conditions ( $p \leq 0.01$ ).

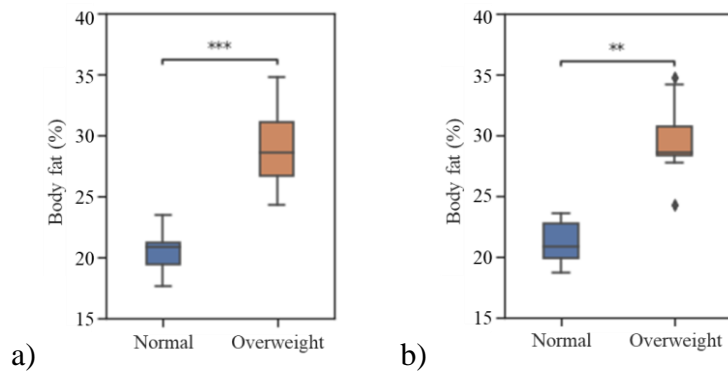


Figure 5. The body fat of subjects in each group. a) In cooling conditions, b) In heating conditions (\*\*  $p \leq 0.01$ , \*\*\*  $p \leq 0.001$ )

### Skin temperature changes in each body fat group

Figure 6 shows the average local  $T_{skin}$  and MST change in cooling conditions. Mann Whitney U Test was carried out to examine if there are statistically significant  $T_{skin}$  differences between the groups. The time when the significant differences ( $p < 0.05$ ) were found was marked in yellow shades.

In the case of MST, the change patterns were similar, and there were no significant differences between normal and overweight groups. As the air conditioner was operated, MST decreased at first and then increased again after the middle of the experiment. MST of the overweight group decreased faster than that of the normal group. MST increased again in the overweight group after decreasing for 7 min, while the normal group's MST decreased for 10 min longer than the overweight group (a total of 17 min).

Regarding local  $T_{skin}$ , the two groups also had similar change patterns. Compared to the overweight group, the normal group had higher  $T_{skin}$  in all body parts except for the hands, left thigh, left foot, and chest, but the differences were insignificant. Significant differences were only found in the upper arms, back, and head only in the beginning of the experiments (0-20 min).

However, the degree of change was different depending on the body fat. For example, the  $T_{skin}$  of hands was similar at 10 min (about 34 °C). After that, the  $T_{skin}$  of the normal group decreased more, becoming a 0.5-0.7 °C lower  $T_{skin}$  than the overweight group. In the case of the abdomen, the  $T_{skin}$  of the overweight group changed more highly than the normal group. The  $T_{skin}$  of the normal group was 34.4 °C at 0 min and 35 °C at 60 min. In the overweight group, it was 33.6 °C at the beginning, lower than the normal group. However, it rose significantly afterward, reaching 35 °C at the end, the same as the normal group.

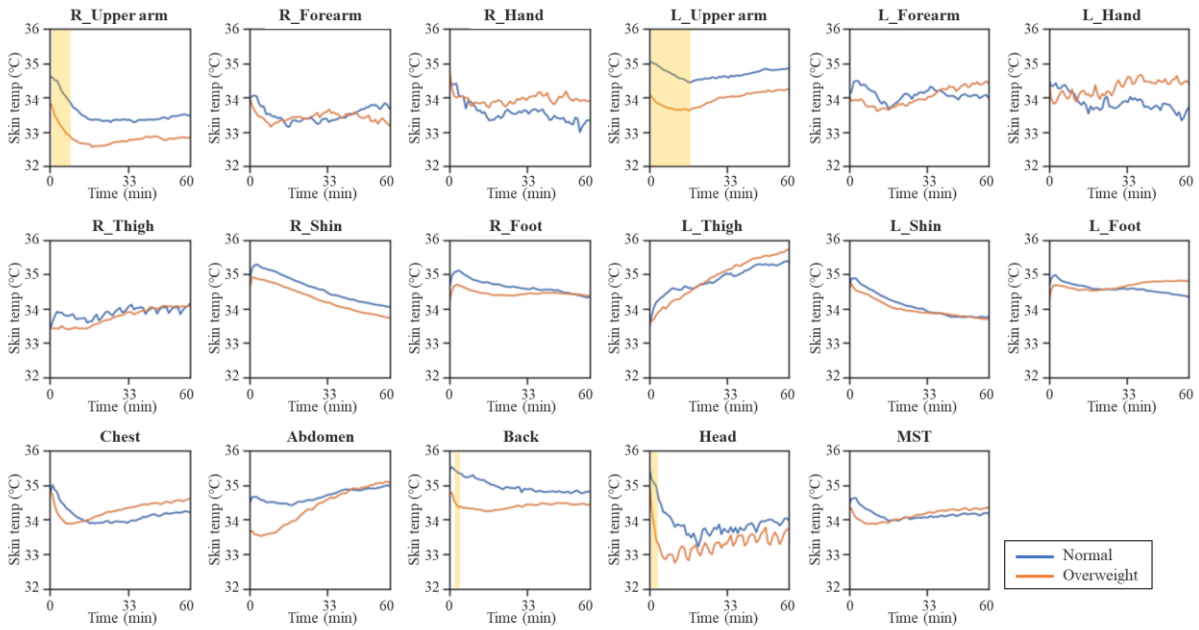


Figure 6. The average local T<sub>skin</sub> and MST change in cooling conditions (Blue lines are the normal group, and orange lines are the overweight group. The yellow shade is when significant differences ( $p < 0.05$ ) were found between the groups.)

The local T<sub>skin</sub> and MST in heating conditions are described in Fig. 7. In heating conditions, local T<sub>skin</sub> and MST changed similarly between the groups. Except for the right upper arm and left hand, local T<sub>skin</sub> was higher in the normal group compared to the overweight group in all body parts. However, the significant differences were only found in the right upper arm and left hand for less than 7 min. The head's T<sub>skin</sub> of both groups changed the most among the body parts. It was about 28.5 °C, rising to 33.2 °C at the end. Since the head was exposed without being covered with clothes, it was low at the beginning, when the T<sub>a</sub> was below 0 °C, then rose as the T<sub>a</sub> increased.

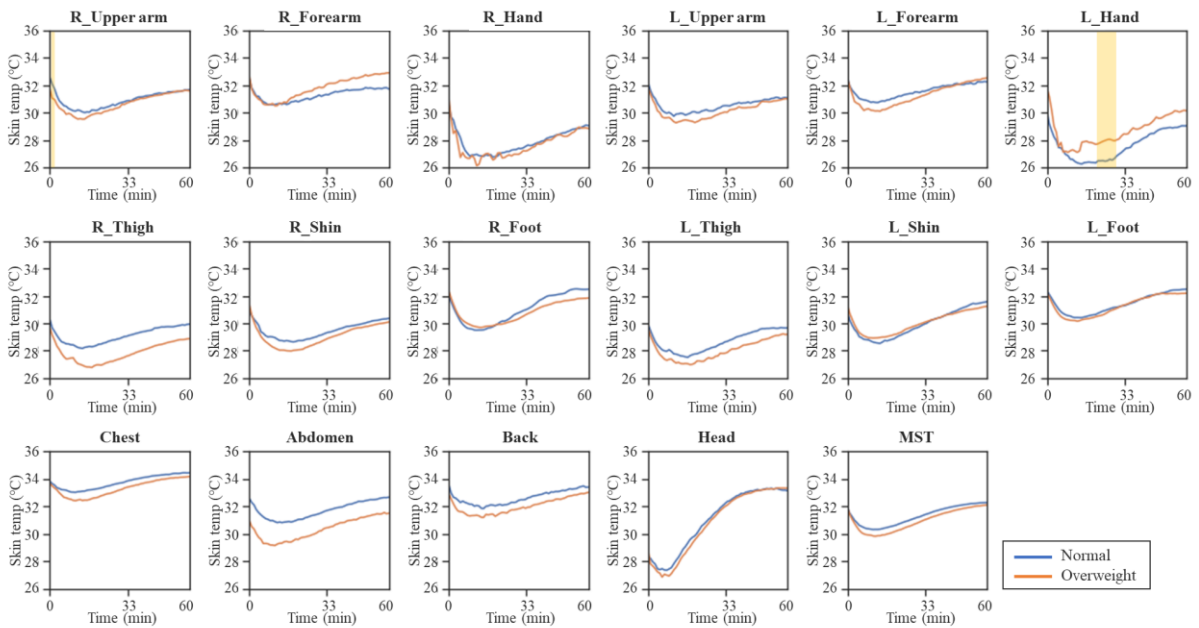


Figure 7. The average local T<sub>skin</sub> and MST change in heating conditions (Blue lines are the normal group, and orange lines are the overweight group. The yellow shade is when significant differences ( $p < 0.05$ ) were found between the groups.)

Along with the physiological responses, the whole-body thermal sensation was also compared to investigate the differences in the psychological responses depending on the body fat. Figure 8 shows the average whole-body thermal sensation votes in each group. Same as the T<sub>skin</sub>, the thermal sensation was almost identical between the group in both conditions without any statistically significant differences.

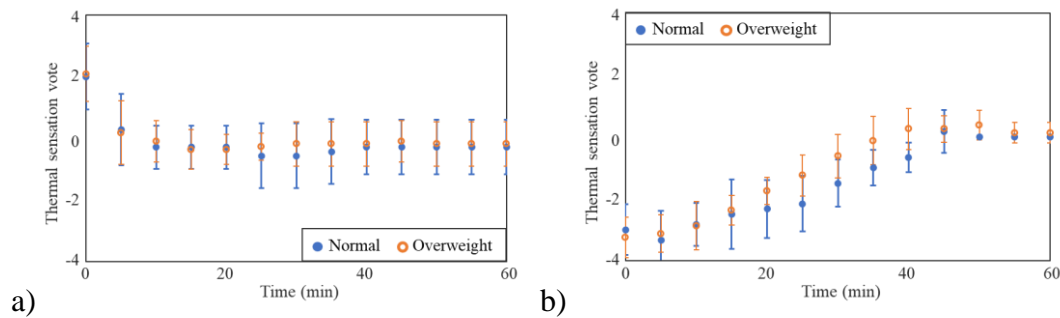


Figure 8. The average whole-body thermal sensation. a) In cooling conditions, b) In heating conditions

#### 4 DISCUSSION

There were no significant differences in local T<sub>skin</sub> between the normal and overweight groups in cooling conditions. According to Miller Jr et al. (1958)'s study, it can be attributed to the lack of insulating effect of subcutaneous fat in short-term heat stress. The study found that the rectal temperature and heart rate of normal and obese people identically changed when exposed to the same heat load for 90 min.

As in cooling conditions, significant differences depending on the body fat were not found in heating conditions. The normal and overweight groups had similar local T<sub>skin</sub> during the experiments, and similar findings were obtained in the previous study. Lean and overweight subjects had similar local T<sub>skin</sub> and heat production under an hour of mild cold exposure. The T<sub>skin</sub> of overweight subjects was significantly low only at the trunk (Ooijen et al., 2006). The two studies commonly show no differences between the overweight and other groups. In general, additional heat production occurs in people who are not overweight, so the skin temperature rises higher than in overweight people. Also, the adipose tissue acts as an insulator, hindering heat transfer between the body and the surroundings, decreasing T<sub>skin</sub>. Thus, usually, there are apparent differences in cold responses according to body fat (Salamunes et al. 2017). However, such differences did not appear in this study. The reason can be assumed that the differences in body fat were relatively small between the normal and overweight subjects compared to the comparison between lean and overweight people. If the lean subjects are added, those differences might be found.

#### 5 CONCLUSIONS

In this study, subject experiments were conducted in the vehicle with skin temperature measurement to investigate whether skin temperatures change differently depending on the body fat. The results demonstrated that people had similar skin temperatures regardless of body fat. This study is significant in terms that it is one of the few studies that examine the skin temperature and body fat of vehicle passengers together. However, it also has several

limitations. The lean people were excluded from the analysis, and the classification criteria need to be updated to reflect the people's current status correctly. Also, only the overall body fat was considered. More improved results might be obtained if the body fat distribution is known.

## **ACKNOWLEDGEMENT**

This work was supported by the Technology Innovation Program (Development of human thermal comfort model for passengers in an electric vehicle) (20011377) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)

## **6 REFERENCES**

- Fernández-Cuevas, I., Marins, J. C. B., Lastras, J. A., Carmona, P. M. G., Cano, S. P., García-Concepción, M. Á., & Sillero-Quintana, M. (2015). Classification of factors influencing the use of infrared thermography in humans: A review. *Infrared Physics & Technology*, 71, 28-55.
- Gallagher, D., Heymsfield, S. B., Heo, M., Jebb, S. A., Murgatroyd, P. R., & Sakamoto, Y. (2000). Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. *The American journal of clinical nutrition*, 72(3), 694-701.
- Hardy, J. D., Milhorat, A. T., DuBois, E. F., & Soderstrom, G. F. (1938). The Effect of Exercise and Chills on Heat Loss from the Nude Body: Three Figures. *The Journal of Nutrition*, 16(5), 477-492.
- Miller Jr, A. T., & Blyth, C. S. (1958). Lack of insulating effect of body fat during exposure to internal and external heat loads. *Journal of Applied Physiology*, 12(1), 17-19.
- Ooijen, A. M. C. V., Westerterp, K. R., Wouters, L., Schoffelen, P. F., Van Steenhoven, A. A., & van Lichtenbelt, W. D. M. (2006). Heat production and body temperature during cooling and rewarming in overweight and lean men. *Obesity*, 14(11), 1914-1920.
- Salamunes, A. C. C., Stadnik, A. M. W., & Neves, E. B. (2017). The effect of body fat percentage and body fat distribution on skin surface temperature with infrared thermography. *Journal of thermal biology*, 66, 1-9.