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Improvement of Working Thermal Environment for Female Office Workers

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Abstract

In office spaces where people frequently enter and leave, the setting of higher outlet air speeds or outlet airflow temperatures is necessary. The direct incidence of cold air emitted from the air conditioner on the body risks causing air-conditioning syndromes such as sensitivity to cold, headaches, and physical listlessness. The purpose of this study is to demonstrate the effect localized heating of the feet has on physiological and psychological reactions in an air-conditioned environment in summer. The improvement of sensational and physiological

temperature by localized warming of the body may contribute to a healthy working environment for female office workers and their safety. The result of heating by means of heat conduction via the sole of the foot was expressed more strongly as a psychological effect than as a whole-body physiological effect. Heating by means of heat conduction via the sole of the foot was a thermal environment factor that compensates for a low temperature in whole-body thermal sensation and whole-body thermal comfort. Applying slight heat conduction by means of heating via the sole of the foot demonstrated the result of improved whole-body thermal sensation and whole-body thermal comfort. Accordingly, heating by means of heat conduction via the sole of the foot increases sole-of-the-foot skin temperature and can be considered to alleviate sensitivity to cold through stimulating the extremities of the body.

Keywords - female, heat conduction, office worker, oversensitivity to cold, thermoregulation

1. Introduction

Air-conditioning facilities of this variety have issues of deterioration of air quality, discomfort owed to the direct effect of the outlet airflow, and vertical temperature distribution. In particular, it is difficult to resolve issues such as disparities in personal thermal sensation with respect to indoor air temperature in an office space when air conditioning is used during the summer. Furthermore, the direct effect of cold air emitted from the air conditioner on the body can chill the body and risk causing air-conditioning syndromes such as sensitivity to cold, headaches, and physical listlessness. In comparison with their male counterparts, female office workers wear less clothing, making it more likely for them to experience physical chill.

In an air-conditioned office space in summer, women can adopt the behavioral thermoregulation of putting on cardigans etc., but this does not greatly contribute to improving the condition of the lower extremities of the body. Accordingly, it is necessary to improve the environment around the body by conveying heat from the environmental side, making it essential to improve the thermal environment using local thermal radiation and heat conduction.

Individual personal space in an office environment is scarce and scope of activity is limited. In addition, if energy conservation is a concern, then it is important that heat transfer to the human body be efficient and from a small apparatus. With thermal radiation, a large surface area or a high surface temperature is necessary, and areas not directly related to the human body must be warmed, leading to wasted energy. Accordingly, the subject of this study is a heat conduction apparatus applying a surface heating element. If an improvement in physical circumstances can be demonstrated by a method whereby part of the body is warmed in isolation while the airspace is cooled, then the sensational and physiological temperature can be improved by heat conduction, which may contribute to a healthy working environment for female office workers, their safety, and a reduction in air conditioning's energy expenditure.

To date, several studies quantitatively discussing heat conduction by contact have been reported with respect to the effect heat conduction from the foot region has on the human body. Muncey and Hutson [1], Missenard [2], Cammerer and Schüle [3], and Olesen [4, 5] deal with the heat conduction from the foot quantitatively. The research of

Choi et al. [6] regarding floor heating spaces deals with the heat conduction between the contact area of a human body in a cross-legged sitting position and the floor quantitatively. Watanabe et al. [7] regarding a “*kotatsu*” heating space deals with heat conduction between a human body in a leg-out sitting position and the floor quantitatively. The research of Kurazumi et al. [8, 9] deals with heat conduction between a human body in a leg-out sitting position and the floor quantitatively. Kurazumi et al. [10] deal with the heat conduction between a human body in standing, chair-seated, “*seiza*” sitting, cross-legged sitting, sideways sitting, both-knees-erect sitting, leg-out sitting, and lateral supine positions and the floor quantitatively.

However, research dealing with the heat balance of the human body is rare. In addition, heating/cooling combining the heating and cooling of the human body has not been studied at all.

Accordingly, the present study focused on heat conduction from the foot region and aimed to demonstrate the effect that local heating of the foot region has on physiological/psychological reactions in a cooled environment in summer.

2. Experimental design

The experiment was performed using a cloth booth-type laboratory placed in an artificial climate chamber as shown in Fig. 1. Footprint-shaped sole-of-the-foot heating apparatus comprising a graft carbon heater element was installed in the booth. Aside from the sole-of-the-foot heating section of the heating apparatus, heat-insulating material and thermal radiation shielding sheets were used, with linoleum as the floor covering material. The surface temperature was the same as the air temperature, with the exception of the sole-of-the-foot heating section.

The seat and back of the chair used in the case of a chair-seated position had good breathability. The chair had a low heat capacity and only a small part was in contact with the human body, so with the exception of the part in contact with the floor the human body was considered to be exposed to the air.

The thermal environment conditions were set in a range such that a naked human body at rest would not shiver or sweat ineffectively. Thermal environment conditions were established through a combination of three air temperatures (24°C, 26°C, and 28°C) and five sole-of-the-foot/floor surface temperatures (equal to air temperature, 26°C, 28°C, 30°C, and 32°C). Air velocity and relative humidity were a constant for all conditions (a still condition of current under 0.2 m/s; 60% RH). Because of the necessity to identify the impact on the human body more clearly and to simplify parameters as much as possible, the test subjects wore light clothing consisting of a white T-shirt and shorts. The subjects were in a chair-seated position during the experiment and their state of work was at rest. The subjects maintained a chair-seated position in a state of rest for over 60 minutes in a quiet anterior room with air temperature and relative humidity equivalent to the initial environment setting conditions, and with wall temperature equivalent to air temperature. Thereafter, the subjects promptly moved inside the test booth, assumed the prescribed position in an exposed location, placed their feet on the sole-of-the-foot heating apparatus, and were

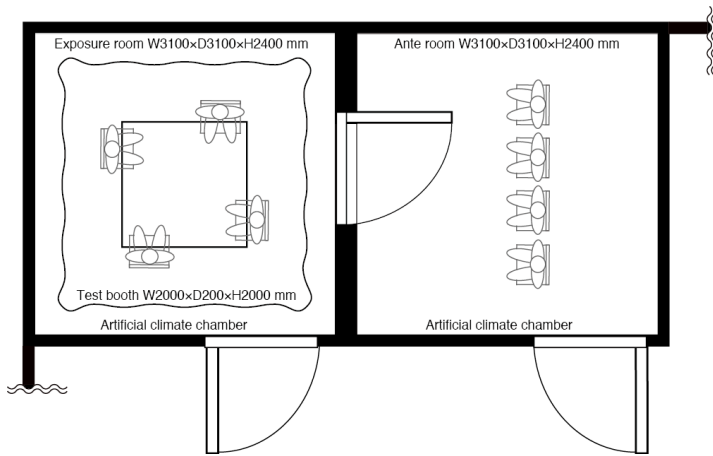


Fig. 1 Experimental artificial climate chamber

exposed to the configured thermal environment conditions for 15 minutes. Exposure time was configured with a concern to avoid moderate-temperature burns.

The subjects were eight healthy adult female university students. Their height was 158.8 ± 6.3 cm and their weight was 50.20 ± 5.73 kg. The subjects had standard physiques according to the Rohrer index and were not unique. In accordance with the Helsinki Declaration [11], the details of the experiment were fully explained to the subjects in advance and their consent to participation in the experiment was obtained.

The measured human body parameters were sublingual temperature, skin temperature, weight loss, skin surface sensible heat flux of the sole-of-the-foot contact section, thermal sensation, and thermal comfort.

The female test subjects wore light clothing: panties, a brassiere, a camisole, a T-shirt, and shorts. Since it was difficult to make the panties, bra, and camisole identical, the subjects wore items they had brought themselves.

The calculation of the mean skin temperature used for the calculation of the heat balance of the human body was performed using a weighting factor that took into account the convective heat transfer area [12]. Furthermore, the chair used in the experiment had good breathability, and so the weighting factor used did not take into account contact with the chair. Then, the calculation of the mean skin temperature used for the physiological response of the human body was performed using a weighting factor that took into account conductive heat transfer area [13].

With a focus on heat conduction, air temperature, air velocity, humidity, and thermal radiation were assigned as thermal environment stimuli for the thermal environment parameters of the present study. In any investigation of the impact heat conduction has on the human body the relationship between the thermal environment and physiological/psychological reactions can be more clearly identified by taking into account the effect of skin temperature on conduction heat conversion [9, 10, 14, 15].

Furthermore, the sensational and physiological temperature index ETF has been verified as a thermal environment index that comprehensively expresses the effect of air temperature, air velocity, thermal radiation, humidity, and heat conduction [16]. Accordingly, we performed our investigation according to the theoretically proposed and verified sensational and physiological temperature index ETF [16, 17] that enables the evaluation of these environmental stimuli. ETF was calculated from thermal environment measurement values, the skin temperature of the human body, and clothing quantity. As regards the coefficients used in the calculation of ETF, the values of Kurazumi et al. [18] were adopted for the convective heat transfer area, the radiant heat transfer area, and the conductive heat transfer area for the human body. Hendler et al.'s value of 0.98 [19] found from the reflectance of skin in electromagnetic waves of wavelength $3\mu\text{m}$ or more was used for the emissivity of the human body. The value of Tsuchikawa et al. [20] was used for the angle factor of the human body. The values of Kurazumi et al. [21] were used for the radiant heat transfer coefficient and convective heat transfer coefficient of the human body. For the calculation of the latent heat loss of the human body, the moisture heat loss was found by multiplying the vaporization heat by the loss of body weight. The vaporization heat of water, which relates to the calculation of vaporization heat, was used as a function of mean skin temperature. Then, mean skin temperature taking into account conductive heat transfer area was used as the evaluation axis for the physiological response of the human body. Furthermore, the reported values of whole-body thermal sensation and whole-body thermal comfort were the target of investigation for the physiological response of the human body.

3. Results and discussion

Fig. 2 shows the relationship between ETF and mean skin temperature. The figure shows the tendency for mean skin temperature to increase with ETF. The figure also shows the tendency for mean skin temperature to decrease the more the experimental conditions involve a greater heat acquisition owed to heat conduction via the sole of the foot at the same ETF. For roughly the same ETF, this is a thermal environment condition whereby the result of heat conduction owed to heating the sole of the foot is added to the air temperature. Accordingly, the effect of air temperature is probably more strongly expressed in mean skin temperature as a whole-body physiological reaction than the effect of heating by means of heat conduction via the sole of the foot.

Focusing on the regression line for the indicator of heating by means of heat conduction via the sole of the foot, we found that mean skin temperature for around the same ETF shows a tendency to be higher when there is no heating via the sole of the foot. Mean skin temperature also shows the tendency to increase slightly with greater heat acquisition owed to heating via the sole of the foot. However, this tendency is not shown in the case of an air temperature of 24°C . Accordingly, when air temperature is low enough for heat loss from the human body to become excessive, the slight effect in increasing mean skin temperature by heating owed to heat conduction via the sole of the foot may not be desirable.

An inspection of the parallelism of the regression line for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p > 0.10$

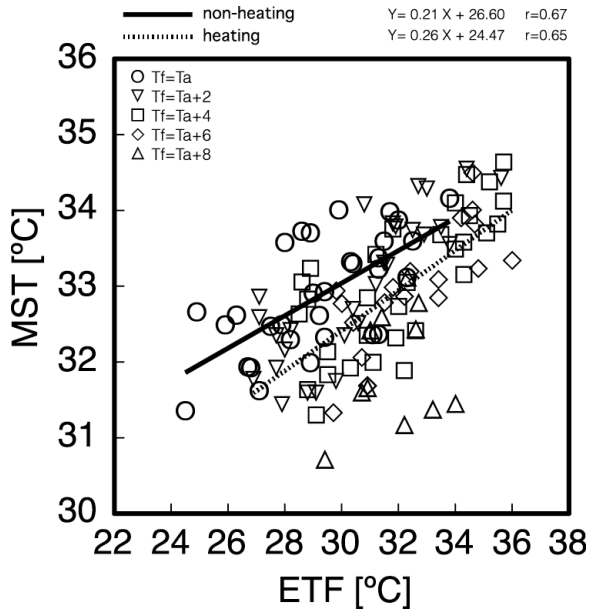


Fig. 2 Relationship between ETF and mean skin temperature

($F(3, 116) = 0.642$, $p = 0.425$), indicating no significant difference in the parallelism of regression. An inspection of the homogeneity of the regression line for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p < 0.01$ ($t(116) = -3.27$, $p = 0.001$), indicating a significant difference in the homogeneity of the regression line. Consequently, it seems improbable that the effect of heating by means of heat conduction via the sole of the foot is expressed in the mean skin temperature within the scope of results for ETF in this experiment.

Kurazumi et al. [22] performed an experiment to demonstrate the effect a thermal environment comprising air temperature and floor surface temperature has on each means of heat transfer for the human body according to difference in position. They showed that an evaluation of the thermal environment including the result of heat conduction is essential for body positions in which the contact surface ratio exceeds 2.5% when there is a large difference between the floor surface temperature and the contact area skin temperature. In the present study also, a change in mean skin temperature is demonstrated as owed to floor heating, and an evaluation of the thermal environment incorporating the effect of heat conduction can be considered essential.

Consequently, heating owed to heat conduction via the sole of the foot has the result of increasing mean skin temperature. However, the effect of air temperature is probably more strongly expressed in mean skin temperature than the effect of heating by means of heat conduction via the sole of the foot.

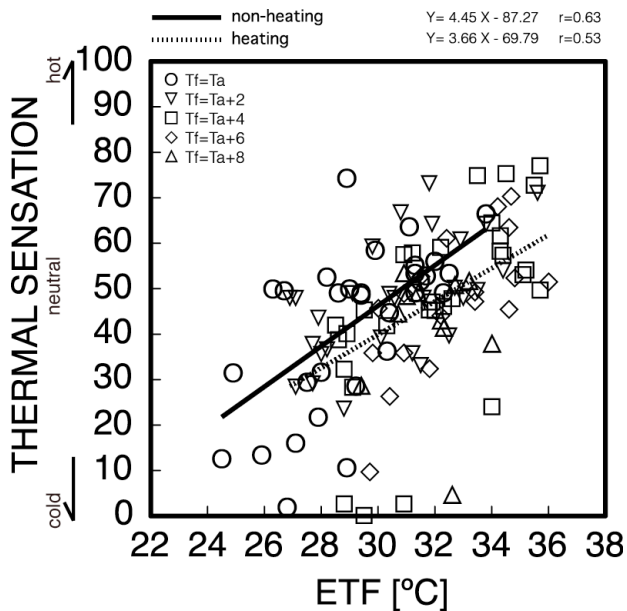


Fig. 3 Relationship between ETF and whole body thermal sensation

Fig. 3 shows the relationship between ETF and whole-body thermal sensation. The figure shows the tendency for whole-body thermal sensation to move towards the hot end as ETF increases. The figure also shows the tendency for whole-body thermal sensation to move towards the cold end the more the experimental conditions involve a greater heat acquisition owed to heat conduction via the sole of the foot at about the same ETF.

Focusing on the regression line for the indicator of heating by means of heat conduction via the sole of the foot, we saw a tendency for whole-body thermal sensation for around the same ETF to move toward the hot end when there is no heating via the sole of the foot. Whole-body thermal sensation also shows the tendency to move toward the hot end for greater heat acquisition owed to heating via the sole of the foot. Accordingly, like the relationship between ETF and mean skin temperature, the effect of air temperature is probably more strongly expressed in whole-body thermal sensation as a whole-body physiological reaction than the effect of heating by means of heat conduction via the sole of the foot.

An inspection of the parallelism of the regression lines for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p > 0.10$ ($F(3, 116) = 0.986$, $p = 0.323$), indicating no significant difference in the parallelism of regression. An inspection of the homogeneity of the regression lines for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p < 0.05$

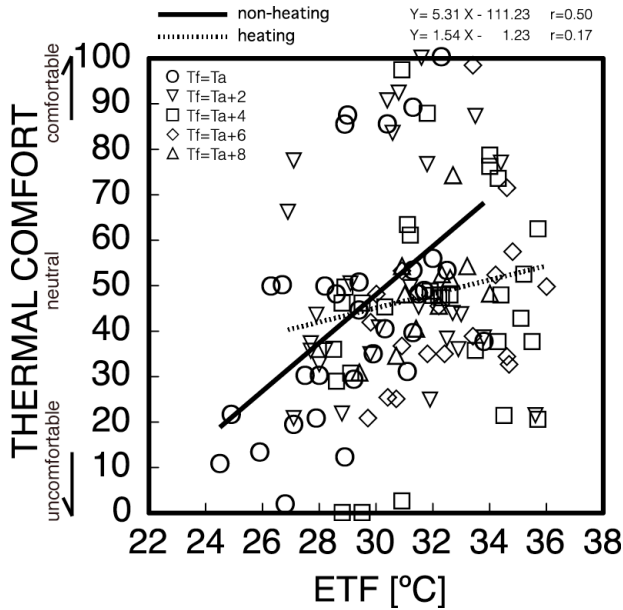


Fig. 4 Relationship between ETF and whole body thermal comfort

($t(116) = -1.990$, $p = 0.049$), indicating a significant difference in the homogeneity of the regression lines.

The above suggests that heating by means of heat conduction via the sole of the foot may work to move whole-body thermal sensation toward the hot end.

Fig. 4 shows the relationship between ETF and whole-body thermal comfort. The figure shows the tendency for whole-body thermal comfort to move towards the comfortable end as ETF increases. Focusing on the regression line for the indicator of heating by means of heat conduction via the sole of the foot, we found that cases where there is heating by means of heat conduction via the sole of the foot tend to be more comfortable when ETF is lower than 29°C, and cases where there is no heating by means of heat conduction via the sole of the foot tend to be more comfortable when ETF is around 29°C or higher. Accordingly, when the body is in a cool condition, heating by means of heat conduction via the sole of the foot works to move whole-body thermal comfort toward the comfortable end. However, when the body is in a warm condition, heating by means of heat conduction via the sole of the foot may work to move whole-body thermal comfort toward the uncomfortable end. Kuno et al. [23] proposed a two-dimensional thermal sensation model by which comfort differs depending on whether the body is cold or warm when the thermal balance of the body is in transition, even with the same thermal environment stimuli. In the present study also, which is a human subject experiment, the same phenomenon was observed for an ETF of around 29°C.

An inspection of the parallelism of the regression line for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p < 0.10$ ($F(3, 116) = 3.832$, $p = 0.053$), indicating a significant difference in the parallelism of regression. An inspection of the homogeneity of the regression lines for the indicator of heating by means of heat conduction via the sole of the foot gave the result $p > 0.10$ ($t(116) = -1.280$, $p = 0.2052$), indicating no significant difference in the homogeneity of the regression lines. Accordingly, the effect of heating by means of heat conduction via the sole of the foot may be expressed in the whole-body thermal comfort, given the scope of results for ETF in this experiment.

Accordingly, heating by heat conduction via the sole of the foot may be a thermal environment factor for whole-body thermal sensation that compensates for a low air temperature by way of a psychological reaction, similarly to the relationship between ETF and thermal sensation.

4. Conclusion

Measures to prevent sensitivity to cold of the extremities of the body are important for female office workers, who have the potential to be exposed to an air-conditioned environment in light clothes for long periods in summer. Accordingly, we demonstrated the effect localized heating of the feet has on physiological and psychological reactions in an air-conditioned environment in summer. The effect of air temperature was demonstrated to be more strongly expressed in mean skin temperature than the effect of heating by heat conduction via the sole of the foot. The result of heating by means of heat conduction via the sole of the foot was demonstrated to be more strongly expressed as a psychological effect than as a whole-body physiological effect.

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