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Original Article

Effects of Decreasing Air Temperature on Peripheral Thermal Reactions in Males and Females

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Abstract

Objectives: This study was performed to determine the effects of decreasing ambient temperature on peripheral blood flow and body temperature of males and females in a thermal neutral zone for references to the thermal standard of office workers.

Methods: Peripheral blood flows of the hand and feet, and body temperatures and so on of male and female subjects were measured in a climatic chamber. Air temperature was maintained at 28.5°C at the beginning. After this, air temperature was decreased linearly to 21.0°C over a period of 60 minutes. Finally, air temperature was maintained at 21.0°C.

Results: Blood flows and skin temperatures of male and female subjects became similar or showed no significant difference at beginning and the end of the experiment. Skin blood flow of the hand and skin temperatures of the hand and fingers decreased, and these values in females were lower than in males, when air temperature was decreased linearly in a thermal neutral zone. However, there were no remarkable differences between males and females in sublingual and mean skin temperatures during the experiment.

Conclusion: Minimum air temperature at the thermal standard for offices in Japan is 17°C, which may be too low to be comfortable or neutral. Even in a neutral thermal condition, it is better that office workers are provided some protection such as a blanket or clothing, to protect peripheral body parts from cooling in winter, as there are individual differences in physiological thermal reactions.

Key words: blood flow, skin temperature, sex difference, thermal environment, thermal standard

Introduction

The heat and cold stress threshold limit values (TLVs) in Japan are decided by the Japan Society for Occupational Health and the thermal standard of offices is decided by the Ministry of Health, Labor and Welfare. The heat and cold stress TLVs are intended to protect workers from the severest effects of thermal stress and to describe the hot or cold working conditions to which nearly all workers can be repeatedly exposed without adverse health effects. On the other hand, the thermal standard for offices is intended to allow office workers to work safely and comfortably. Ambient temperature at the thermal standard for offices in Japan is 17°C to 28°C, relative humidity is 40% to 70%, and wind velocity is under 0.5 m/sec (1, 2).

Although elderly people and women are generally weak in severe cold or hot zones, it is said that there are no remarkable differences among sex, age, etc. in a thermal neutral zone. Women in light clothing could tolerate a wide range of air temperatures (Ta) in offices, but they would suffer from Raynaud's phenomenon in a cold room. Their comfort zone, in which heat loss and heat production are equal, is wide-ranging compared to that of men. In a cool zone the skin temperature and the average body temperature of women were generally lower than men (3–5).

Although the hands and feet represent about 10% of total body surface, they show the most dramatic changes in blood flow according to the change of ambient temperature. The transfer of body heat to the environment depends on body surface properties and environmental factors. However, equally

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important are subcutaneous insulation, vasculature and blood flow (6–10). Women have lower tissue conductance in cold and higher tissue conductance in heat than do men. This fact indicates a greater variation in the peripheral reaction to climatic stress in women (11).

The vasculature of human skin has a major role in surface heat transfer. However, the vasculature of the skin varies significantly depending on location. Areas such as the pulp of the fingertip and toe have a very large contribution of arteriovenous anastomoses, whose main role is that of thermoregulation in a severe cold or hot zone. Other locations such as the elbow or knee have a mainly nutritive capillary supply. The dorsal aspects of the finger and toe have a vasculature with both components of thermoregulation and nutritive supply. The skin vessels in human fingers dilate severely in response to warm stimulation of the skin or body core thermoreceptors, facilitating heat transfer from the body's core to the environment. At lower temperatures the decrease in blood flow is significant. Thus, blood flow has a primary role in thermoregulation. Reflex control of this blood flow is performed through sympathetic vasoconstrictor nerves and a sympathetic active vasodilator system. The vasoconstrictor system is adrenergic and is found in all regions of the skin. Various factors, known as determinates, of these thermal responses can be assessed, such as sex, age, body build and body composition, physical fitness, diet, etc (5, 12, 13).

The peripheral parts of females are said to be more sensitive to a cool condition compared to males, but the reaction of peripheral body parts is not clear in transient ambient thermal changes. This study was performed to determine the effects of decreasing air temperature on the peripheral thermal reactions of males and females in the thermal neutral zone for references to thermal standard of office workers.

Subjects and methods

Experiments were carried out in a climatic chamber. Wall, floor and air temperatures, humidity and air velocity were independently controlled in the chamber. Air temperature (Ta) was maintained at 28.5°C for 30 minutes at the beginning. Predicted mean vote (PMV) (4) was +0.5. After this, air temperature was decreased linearly to 21.0°C over a period of 60 minutes. Finally, air temperature was maintained at 21°C for 90 minutes. Then, PMV was −1. Throughout the experiment, air velocity (Va) was maintained at 0.15 m/s, and wall (Twall) and floor (Tfloor) temperatures were maintained at 21°C. These parameters were constantly monitored (14).

The subjects were 6 French males and 6 French females aged from 18–24 years old; average age (±SE) of the males was 21.0±1.09 years old, and that of the females 20.8±0.83 years old. They were students or laboratory staff, that is, sedentary people. They all wore briefs, thin trousers, and thin long-sleeved shirts, socks and rubber-soled shoes. The clothing insulation was 0.6 clo as measured by thermal manikin (Heatman Co., Sweden). Subjects sat on a chair during the experimental procedures. Female subjects participated during the days of menstrual period unless there were specific complaints.

Peripheral blood flows were measured at the non-dominant dorsal hand and the dorsal foot with laser Doppler technique (Perimed Co., Sweden). Skin temperatures were continuously recorded by thermistors (accuracy±0.05°C) at standard locations (chest, non-dominant hand, middle finger, foot, upper arm, thigh and leg) and the mean skin temperature (Tsk) was calculated taking the average of the four locations (chest, upper arm, thigh and leg). Sublingual temperature was measured by an electronic thermometer (Craft Medical A B Co., Sweden). The experiments were carried out from November to January in the winter season.

After hearing an explanation of the details of the present study and having their privacy guaranteed by the authors, all subjects signed an informed consent form. Statistical analysis was done with nonparametric Student's t- test. Significant level is below 0.05.

Results

Skin blood flow of the non-dominant dorsal hand (BFDH) was almost 15 to 25 levels for males and 12 to 20 levels for females at 28.5°C Ta for 30 minutes. Maximum BFDH of male subjects was 22.8±9.3 levels (mean±SE) at the 25th min and

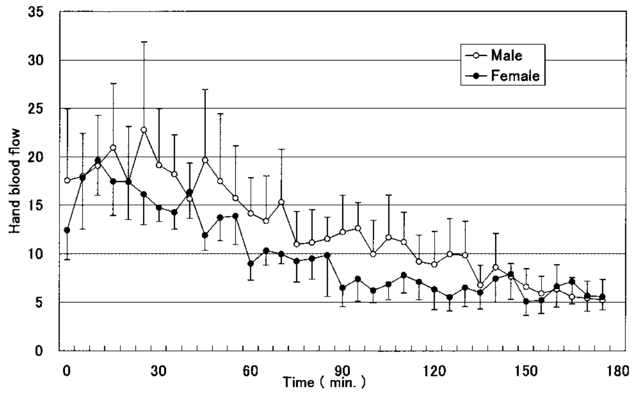

Fig. 1 Time response curves of hand skin blood flow of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors.

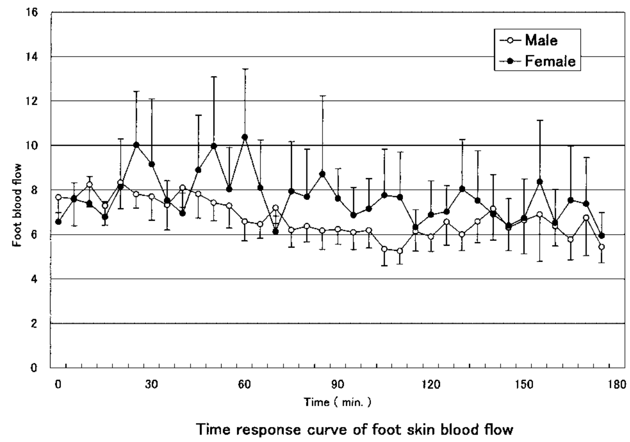

Fig. 2 Time response curves of foot skin blood flow of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors.

that of female subjects was 16.1±3.1 levels. These values decreased during the negative thermal transient toward 21°C Ta. Blood flow of females especially decreased greatly for the first 90 min, after that it kept to 5 to 8 levels (Fig. 1). BFDH of females was lower than that of males during the transient toward 21°C Ta. At the end of the experiment BFDH of male and female subjects became similar and lower, being about 5 levels.

Skin blood flow of the left dorsal foot (BFDF) was lower than BFDH at 28.5°C Ta. BFDF of males was almost constant during the experiment 5 to 8 levels, although it tended to decrease for the first 110 min. BFDF of females were somewhat changeable and tended to be higher than males, showing no significant difference (Fig. 2).

Sublingual temperature was 36.84±0.09°C at 28.5°C Ta at the initial stage, and tended to decrease on exposing to 21°C Ta. And sublingual temperature was 36.67±0.11°C at 21°C Ta at the final stage. There were no significant differences between sublingual temperatures of female and male subjects.

Mean skin temperatures (Tsk) kept to rather high levels for the first 30 min, with no significant difference between male and female subjects. Maximum Tsk of male subjects was 33.3±0.7°C and that of female subjects was 33.5±0.4°C at the 30th min. Following this, the Tsk decreased gradually, being 32.0°C at the 110th min and the Tsk of males tended to be lower than that of females during the transient toward 21°C Ta. The Tsk of males and females kept to constant levels at 31.4 and 31.3°C, respectively, at the final stage (Fig. 3).

At 28.5°C Ta, the finger skin temperature (Tf) was about 35°C for males and 34°C for females, showing no significant sex difference. When Tf decreased during the negative thermal transient toward 21°C Ta, Tf of females decreased rapidly and greatly compared to males and there were significant differences between the values of male and female subjects from the 75th to the 115th min (P<0.05). These values became almost stable after 120 min for females and after 160 min for males. Towards the end of the experiment, these differences between male and female subjects became rather smaller at 25 and 24°C, respectively, at the final stage (Fig. 4).

At 28.5°C Ta, hand skin temperatures (Th) reached about 34°C. When Th started to decrease gradually during the negative thermal transient toward 21°C Ta, the values were lower in females compared to males. There were significant differences between male and female subjects from the 75th to the 130th

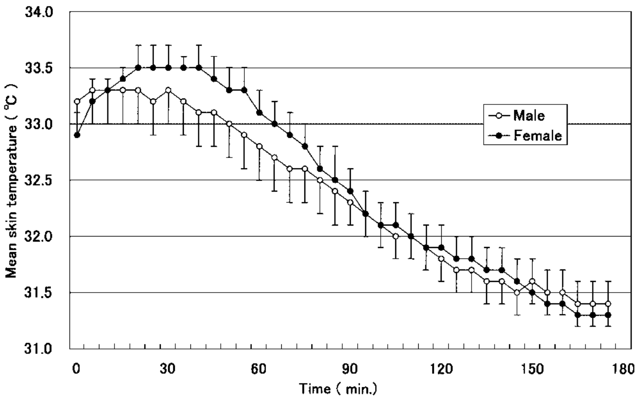

Fig. 3 Time response curves of mean skin temperatures of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors.

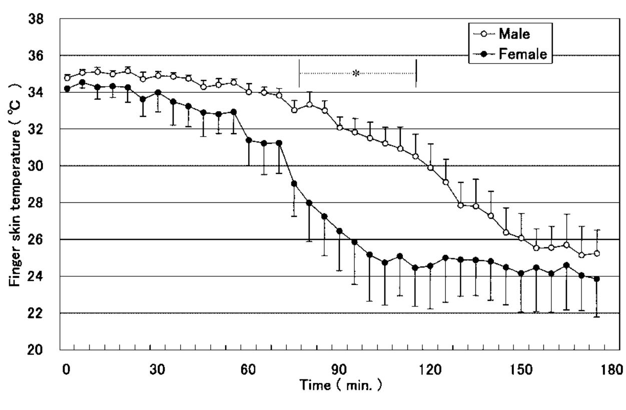

Fig. 4 Time response curves of finger skin temperatures of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors. * indicate significant differences between male and female at each time (p < 0.05).

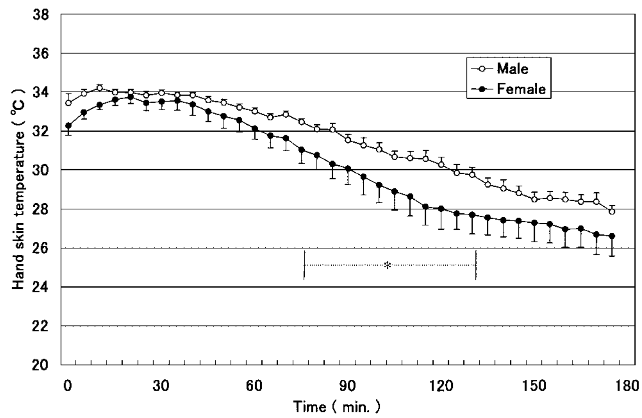

Fig. 5 Time response curves of hand skin temperatures of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors. * indicate significant differences between male and female at each time (p < 0.05).

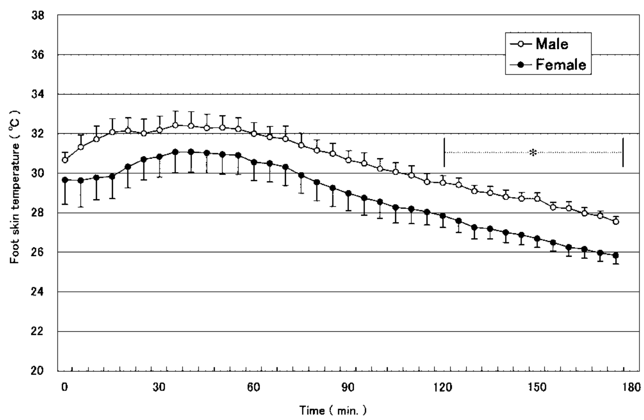

Fig. 6 Time response curves of foot skin temperatures of females and males.
Each point is the average value of the subjects and vertical lines indicate standard errors. * indicate significant differences between male and female at each time (p < 0.05).

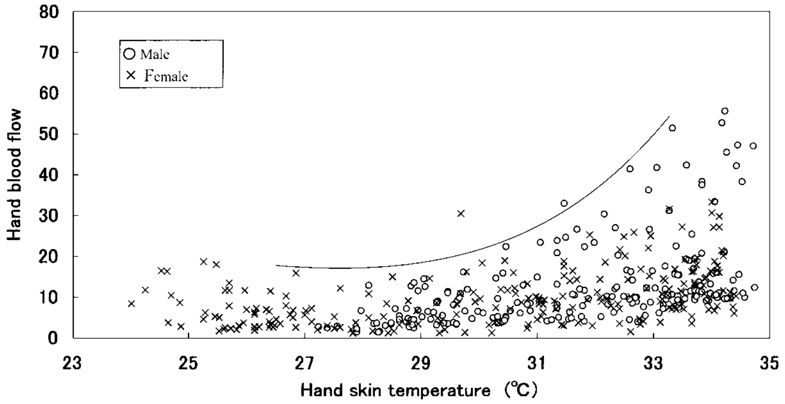

Fig. 7 Relationship between hand skin blood flow and hand skin temperature during the experiment.

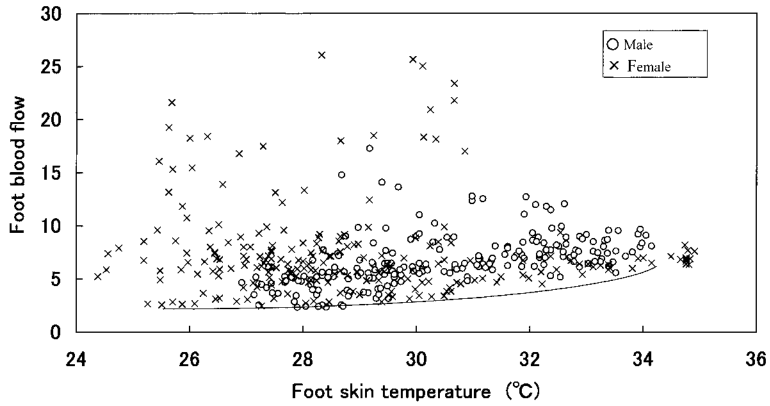

Fig. 8 Relationship between foot skin blood and foot skin temperature during the experiment.

min. Hand skin temperature at the 120th min, when the difference in Th of males and females was the greatest, was 30.6°C in males and 28.1°C in females, showing significant difference. Hand skin temperature was 27.8°C in males and 26.6°C in females at the end of the experiment, with no significant difference (Fig. 5).

At 28.5°C Ta, foot skin temperatures (Tfs) increased gradually and reached maximum values at the 35th min, that is, 32.4±1.8°C for males and 31.1±2.6 °C for females. Foot skin temperatures of males were generally higher than those of females. Foot skin temperature decreased gradually during the negative thermal transient toward 21°C Ta, and the values after 120 min were significantly different between male and female subjects. Foot skin temperature decreased to 27.5°C for males and 25.8°C for females at the end of the experiment (Fig. 6).

Fig. 7 shows the relationship between hand skin blood flow and hand skin temperature. When hand skin temperature reached over 30°C, maximum hand skin blood flow started to increase. Below 30°C of the hand skin temperature, maximum blood flow volume was below 20 levels. Although the relationship between hand blood flow and hand skin temperature of females showed tendencies similar to the relationship between those of males, blood flows were smaller, almost below 30 levels.

Fig. 8 shows the relationship between foot skin blood flow and foot skin temperature. When foot skin temperature reached over 29°C, minimum blood flow volume of the foot started to increase. There were no remarkable differences in the relationship between minimum foot blood flow and foot skin temperature of females and males.

Discussion

Sensible heat loss describes the flow of heat down temperature gradients from the sites of metabolic heat production in humans to the environment by convection, conduction and radiation. In the present experiment, wall and floor temperatures were maintained at 21°C, and air temperature was 28.5°C at the beginning and 21°C at the end of the experiment in a neutral thermal zone. Under such experimental conditions, heat flow from the foot depended greatly on conduction to the floor. And heat flow from the hand depended greatly on convection and radiation. Such thermal condition would occur in an ordinary office room. Wall or floor temperatures do not change so much compared to room air temperature.

In human thermal interaction with the environment, some variability exists due to individual influences such as health condition, acclimatization to thermal stress, race, aging, sex difference, etc (3,4,11,15,16,17,19,20). Women have a lower tissue conductance in cold and a higher tissue conductance in heat than do men. This fact indicates a greater variation in the peripheral reaction to thermal stress in women (11). There are some differences in the physiological responses to thermal condition between female and male. In hot atmospheres, several differences have been observed in the reactions of the sexes with regard to energy production and conductance, circulatory adjustments, and sweating responses. When male and female subjects were exposed for 2 hours to increasing heat, the sweat rates were significantly higher in males than in females (15).

To determine the tolerance of humans to cold, subjects are exposed to cold and their physiological reactions are examined. Carlson (16) proposed an index for cold tolerance based on the relationship between decrease in skin temperature and increase in heat production during cold exposure. This was based on the fact that decrement of skin temperature decreases heat radiation due to vasoconstriction of skin vessels, and increases the heat production. Tanaka (17) examined the responses of females and males during exposure to 10°C air temperature for 2 hours in summer and winter, and females were weaker to cold in summer due to the relationship between heat production and mean skin temperature, and contrarily became stronger in winter, although no remarkable differences were noticed in the average values for males between summer and winter. Therefore, there are some differences in males and females on thermal reaction according to season.

Hardy et al. (3) examined responses of nude females and males during exposure to air temperatures between 22°C and 35°C and reported that heat production in most of the females was 14–20% lower than that of males in the neutral condition (30°C–32°C Ta). Neutral thermal condition is different according to clothing. Neutral ambient temperature when nude is about 30°C Ta, and in general offices is 17°C to 28°C Ta (1). Mean skin temperature is one of the most important parameters of human thermal interaction with the environment. It is a condition for thermal comfort that mean skin temperature is 33°C–34°C while resting, regardless of clothing condition (4). Mean skin temperature over 35°C is uncomfortably warm and below 31°C is uncomfortably cool (18), and hand skin temperature below 20°C and foot skin temperature below 23°C are reported as uncomfortable cool. In the present experiment, mean skin temperatures were 33.5°C to 31.3°C and minimum hand skin temperature and minimum foot temperature were 26.6°C and 25.8°C, respectively. Therefore the present thermal experimental condition was thought to be comfortable or neutral. However, the skin temperatures of females tended to be lower than those of males at 21°C Ta at the final stage, and were near the lower limits of the neutral thermal zone.

In a thermal neutral condition, thermal sensation, body temperature, heat production, blood flow and so on were measured as an index of comfort or evaluation of thermal environment. The microvasculature of human skin has an especially important part in surface heat transfer (8). Helmut et al. (19) studied leg blood flow responses to graded intrafemoral artery infusions of endothelium vasodilator substance in groups of men and women. Women exhibited blood flow increment in response to the endothelium-dependent vasodilator methacholine chloride more so than men. Therefore, skin blood flow is thought to be most important for evaluation of thermal environment in a neutral thermal zone.

In experiments by Fanger et al. (4), the males preferred a warmer environment than the females among the Danish subjects in the experiment. On the other hand, the females preferred a warmer environment than the males among the American subjects. No good reason has been found for believing that a possible sex-conditioned difference in preferred temperature should be dependent on national-geographic location. The difference is too small to be of engineering significance. In a comfort study involving 420 subjects in standard clothing (0.6 clo), small differences were observed between the sexes, the males preferring a slightly warmer temperature at one activity level and a slightly cooler one at another activity level than the females. Comfort differences between the sexes, which might be observed in practice, are due to differences in clothing. Females seem to be more sensitive to a deviation from the optimum, assessing a given deviation as more uncomfortable than males would assess it (4).

At the thermal neutral condition of 28.5°C Ta as shown in the present experiment, finger skin temperatures and skin blood flows of the hand of male and female subjects were similar. After this, finger skin temperatures and skin blood flows of the hand of females decreased rapidly and greatly compared to males during the negative thermal transient toward 21°C Ta, and these values of male and female subjects became similar again at 21°C Ta at the end of the experiment. That is, there were no remarkable differences between males and females at a stable state of neutral thermal environment. However, the thermal physiological responses of peripheral body parts of the females were affected more than those of males at the transient thermal condition, although there were no remarkable differences between male and female in sublingual and mean skin temperatures, as the index of thermal condition of the whole body.

The threshold limit values for office workers are intended to allow workers to work safely and comfortably. Minimum air temperature at the thermal standard for offices in Japan is 17°C, which is too low to be comfortable or neutral. Minimum air temperature must be raised several degrees centigrade. Office workers complain about the thermal condition of offices, and there are many female office workers complaining of cooling disorders. At the thermal transient state, females showed overreaction in thermal reactions at the peripheral body parts, the hand and the finger as shown in the present study. Even in a neutral thermal condition, it is better that office workers are provided some protection, such as a blanket or clothing to protect the peripheral body parts from cooling in winter.

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