

Physiological and Subjective Responses in the Elderly When Using Floor Heating and Air Conditioning Systems

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Abstract The purpose of this study was to investigate the effects of a floor heating and air conditioning system on thermal responses of the elderly. Eight elderly men and eight university students sat for 90 minutes in a chair under the following 3 conditions: air conditioning system (A), floor heating system (F) and no heating system (C). The air temperature of sitting head height for condition A was 25°C, and the maximum difference in vertical air temperature was 4°C. The air and floor temperature for condition F were 21 and 29°C, respectively. The air temperature for condition C was 15°C. There were no significant differences in rectal temperature and mean skin temperature between condition A and F. Systolic blood pressure of the elderly men in condition C significantly increased compared to those in condition A and F. No significant differences in systolic blood pressure between condition A and F were found. The percentage of subjects who felt comfortable under condition F was higher than that of those under condition A in both age groups, though the differences between condition F and A was not significant. Relationships between thermal comfort and peripheral (e.g., instep, calf, hand) skin temperature, and the relationship between thermal comfort and leg thermal sensation were significant for both age groups. However, the back and chest skin temperature and back thermal sensation for the elderly, in contrast to that for the young, was not significantly related to thermal comfort. These findings suggested that thermal responses and physiological strain using the floor heating system did not significantly differ from that using the air conditioning system, regardless of the subject age and despite the fact that the air temperature with the floor heating system was lower. An increase in BP for elderly was observed under the condition in which the air temperature was 15°C, and it was suggested that it was necessary for the elderly people to heat the room somehow in winter. Moreover, it is particularly important for elderly people to avoid a decrease in peripheral skin temperature, and maintain awareness of the warmth of

peripheral areas, such as the leg, in order to ensure thermal comfort. *J Physiol Anthropol Appl Human Sci* 23(6): 205–213, 2004 <http://www.jstage.jst.go.jp/browse/jpa>

Keywords: floor heating system, air conditioning system, elderly people, physiological response, subjective response

Introduction

In Japan, many types of heating systems, including oil heaters, air conditioning systems, electric carpets, etc., are used in winter to heat indoor rooms and keep the human body sufficiently warm. Enomoto et al. (1995) showed that the elderly people use several types of heating equipment, and 26.6% of the subjects use air conditioning systems. Ohbuchi et al. (2001) surveyed the relationships between the elderly people's health and heating conditions in indoor rooms in winter, and reported that about half of the subjects used an air conditioning system. Although heating methods used in winter vary, depending on the living area and lifestyle, etc., the air conditioning system is one type of heating equipment in common use. It is reported that many elderly people felt their skin was itchy if they used the heating equipment that emits warm air in winter (Ohbushi et al. 2001). It was found that dry skin was related to itchy skin and to catch a cold (Igarashi et al. 2000). Therefore, for elderly people who tend to stay in the house for a long time, it is possible that an inappropriate thermal environment caused by using heating systems gives rise to not only subjective discomfort but also physical ailments.

Recently, floor heating systems have become popular in Japanese houses. Because a floor heating system, in contrast to other heating equipment such as an oil heater, air conditioning system, etc., does not produce dirty air or emit air at a high velocity, it could be considered a heating method that allows

the elderly to live comfortably and safely. Much research on floor heating has been carried out from different points of view. The comfort range for floor surface temperature and air temperature using floor heating systems has been investigated in many previous studies (Bougaki, 1985; Emura et al., 1992; Choi et al., 1996; Zhang L et al., 1998; Hori et al., 2000). Although Enomoto et al. (1991, 1994) investigated the effects of radiant heating systems on the elderly people, the number of studies is in this area still limited. Floor heating systems are recognized as providing a high comfort level in comparison with other heating systems, because the vertical air temperature difference is small and occupants find it pleasant to receive direct thermal radiation from the heated floor (Watanabe, 2001). However, there are few reports that make a comparison of heating methods as an object of the study. Isoda et al. (1996) compared the floor heating with air conditioning systems, and indicated particular influences of each heating method. However, the subjects were not the elderly but the young in the reports. It is certain that the number of people over 65 has rapidly increased in Japan. It has been an absolute necessity to investigate comfortable and safe living spaces for elderly people. Generally, various physiological functions are depressed because of age. Therefore, it is important to demonstrate the actual efficacy of floor heating systems for elderly people.

This study, therefore, was conducted to investigate the thermal responses of the elderly and young men to the floor heating and an air conditioning system. Moreover, we examined the age-related characteristics of these responses to suggest appropriate methods of heating for the elderly.

Methods

Subjects

Eight healthy elderly male and eight healthy young male volunteers participated in this study. Their mean age, height, body weight, and BMI are shown in Table 1. There were no significant differences in body weight and BMI between the elderly and young subjects. The elderly male subjects had never suffered from hypertension, heart disease, or cerebral apoplexy, etc. It was confirmed by the medical examination that they were in good health. Each subject gave his written informed consent to participate in this experiment.

Procedures

The study was conducted from October to December 2002. On arrival at the laboratory's pre-room, the subjects wore short pants, a short-sleeved T-shirt, a long-sleeved sweat shirt, and trousers (0.9 clo). After waiting at least 30 minutes in a sitting position in the pre-room where the air temperature was 25°C, the subjects moved to the test room. Each subject sat for 90 minutes in a chair in the test room under the following 3 respective conditions: air-conditioning system (A): a household air conditioning system was used in this experiment; floor heating system (F): the floor surface was

Table 1 Physical characteristics of subjects

	Age**	Height** (cm)	Body weight (kg)	BMI
Elderly (n=8)	69.5±4.1	163.5±4.8	63.9±8.7	23.9±3.2
Young (n=8)	21.9±1.7	171.7±4.2	65.7±7.8	22.3±2.7

Values are means±SD. ** $p<0.01$ indicates significant difference between elderly and young subjects.

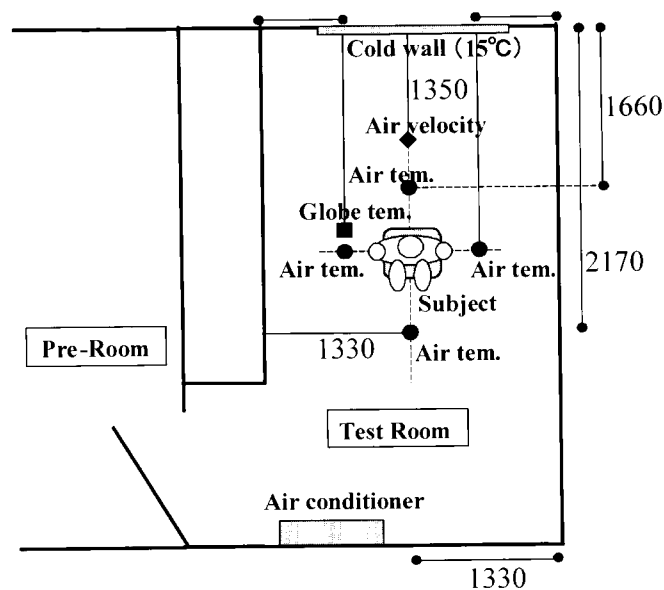


Fig. 1 The plan of the chambers and the measurement points (mm).

Table 2 Thermal conditions in the experimental chambers

	Air temp.	Floor temp.	Wall temp.	RH
Pre-room	25°C	—	—	40%
Test room A	21–25°C	21°C	15°C	40%
F	21°C	29°C	15°C	40%
C	15°C	15°C	15°C	40%

radiantly heated by hot water; and control (C): there was no heating system. Figure 1 shows the plan of the chamber and the measuring points of air temperature, air velocity and relative humidity. Thermal conditions of the air, floor and wall temperatures and relative humidity are shown in Table 2. The floor temperature and the air temperature of sitting head height for condition A was 21 and 25°C, respectively. Namely, the maximum difference in vertical air temperature was 4°C under condition A. The air and floor temperature for condition F were 21 and 29°C, respectively. The air temperature for condition C was 15°C. Figure 2 shows the vertical distribution of air temperature under the 3 conditions. And Table 3 shows the air velocity.

Measurements

Rectal temperature (T_{re}) and skin temperature at 15 local body locations (forehead, chest, abdomen, back, ilium, forearm, back of hand, palm, buttocks, anterior thigh, posterior thigh, shin, calf, instep, sole) were measured with thermistors every minute. Mean skin temperature (\bar{T}_{sk}) was calculated using the Hardy–Dubois formula (1937). Blood pressure (BP) was obtained at the left-upper arm using an automatic tonometer (HEM-737, OMRON, JAPAN) every 10 minutes. Heart rate (HR) was obtained from the electrocardiogram using chest electrodes (Dyna Scope DS-502, FUKUDA DENSHI, JAPAN). HR was computed for three minutes every 30 minutes. Thermal sensation (TS), thermal comfort (TC), and requested changes in the air temperature (RC) were evaluated every 10 minutes. Regarding TS, 8 local body locations (face, abdomen, back, forearm, hand, buttocks, leg, and sole) and whole body were individually evaluated. As shown in Table 4, TS, TC and RC were rated on 9-point, 4-point and 5-point scales, respectively.

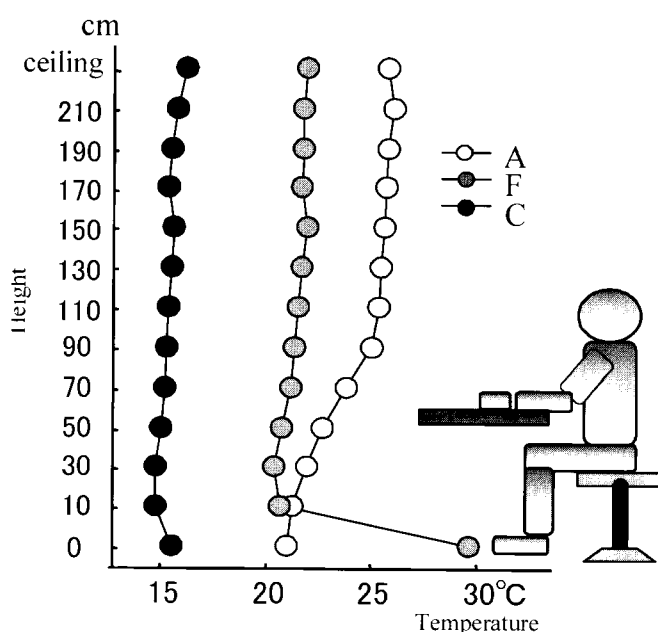


Fig. 2 The vertical distributions of air temperature under the 3 respective heating system conditions.

Table 4 The scale of subjective votes

Thermal sensation	Thermal comfort	Requested changes in the air temperature
9 very cold	4 terribly uncomfortable	7 strongly want to be cooler
8 cold	3 uncomfortable	6 want to be cooler
7 cool	2 slightly uncomfortable	5 somewhat want to be cooler
6 slightly cool	1 comfortable	4 no necessity for change
5 neutral		3 somewhat want to be warmer
4 slightly warm		2 want to be warmer
3 warm		1 strongly want be warmer
2 hot		
1 very hot		

Statistical analysis

Results of physiological and subjective data were analyzed by repeated-measures analysis of variance (ANOVA) using Visual Stat for Windows Release 4.5J Software (Stat Soft, Inc.). For the ANOVA of BP, the factors were age, conditions and time. And for the other data, the factors were age and conditions. A multiple comparison was performed using Fisher's PLSD. The relationship between TC and skin temperature was analyzed using the Pearson's correlation coefficient test. The relationships between TC and TS were analyzed using the Spearman's correlation coefficient by rank test. Differences at $p < 0.05$ were significant for all statistical analyses.

Results

Skin Temperature and Rectal temperature

Figure 3 shows the mean values of local skin temperatures, \bar{T}_{sk} and T_{re} , for the last 10 minutes in the test room. Each local body location skin temperature, except the abdomen and ilium, was significantly affected by the conditions ($p < 0.001$). Most local skin temperatures and \bar{T}_{sk} for condition C were significantly lower than those for conditions A and F. The large differences in skin temperatures between conditions A and F were observed in the arm and leg. The skin temperatures of forearm, back of hand, palm, and anterior thigh for condition A were significantly higher than those for condition F. The skin temperature of instep and sole for condition A were lower than those for condition F. On the other hand, the differences in corporal skin temperature, e.g., chest, back, buttock and so on, between condition A and F were small, and those differences were not significant. \bar{T}_{sk} for condition A and F were 33.1 and 32.4°C, respectively; the difference in \bar{T}_{sk} between condition A and F was very small. Moreover, T_{re} was not significantly

Table 3 The air velocity under 3 heating system conditions

Height	A	F	C
110 cm	0.27 (0.08)	0.04 (0.03)	0.00 (0.00)
70 cm	0.69 (0.04)	0.17 (0.02)	0.00 (0.00)
10 cm	0.28 (0.06)	0.25 (0.09)	0.05 (0.02)

Values are means (SD).

m/sec

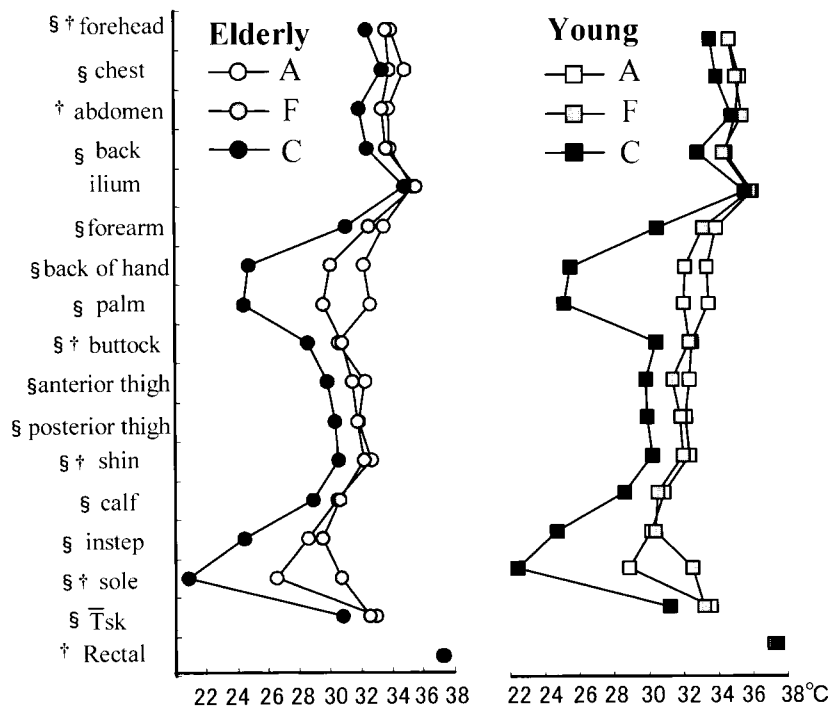


Fig. 3 Mean values of skin temperature and rectal temperature for the last 10 min in the test room. Values on the left are for the elderly, those on the right for the young. Values are means for all 8 subjects. $^{\circ}$ $p < 0.05$ indicates significant main effect (condition) with ANOVA. † $p < 0.05$ indicates a significant main effect (age) with ANOVA.

affected by the conditions. Some local skin temperatures and T_{re} were significantly affected by age, though most location skin temperatures showed no significant effects for age; overall, there was no definite correlation of body temperature with age.

Figure 4 shows the mean values of the differences in temperature between \bar{T}_{sk} and peripheral skin temperature (back of the hand and instep) for the last 10 minutes in the test room. The temperature differences between \bar{T}_{sk} and hand, and \bar{T}_{sk} and instep were significantly affected by the conditions (hand: $F(2,42)=222.1$, $p < 0.001$, instep: $F(2,42)=100.4$, $p < 0.001$). The temperature difference between \bar{T}_{sk} and hand for condition F was larger than that for condition A, and the values of the elderly and young were 1.1 and 2.8°C on average, respectively. On the other hand, regarding the instep, the temperature difference for condition A was larger than that for condition F, and the values of the elderly and young were 3.4 and 4.4°C on average, respectively. In contrast, the temperature difference between \bar{T}_{sk} and instep for condition F were less than 3°C in both age groups.

Blood Pressure and Heart Rate

Figure 5 shows the changes in systolic blood pressure (SBP). SBP was significantly affected by the interaction between age and time ($F(10,42)=9.0$, $p < 0.01$). SBP for the elderly subjects increased while sitting in the test room, and the increase was significantly larger than the value for the young subjects. There was also significant interaction between the condition and time ($F(20,42)=2.3$, $p < 0.05$). The largest

increases in SBP while sitting in the test room were observed under condition C. SBP in the pre-room for the elderly under condition C was 113.1 mmHg on average, and this value was similar to that for the young. But the differences in SBP between the elderly and the young expanded with time. The increase in SBP during sitting in the test room was 29.8 mmHg on average for the elderly, whereas, in contrast, the value for the young during this period was 3.5 mmHg on average. There was no significant difference in SBP between conditions A and F; the similar changes were indicated in the two groups.

No significant effects of the condition and age were shown in the changes in HR.

Subjective responses

Figure 6 shows TS at body locations and whole body after the subjects sat for 90 minutes. TS for all body locations and the whole body were significantly affected by the conditions. TS values for the leg and for the sole under condition F were significantly warmer than those for condition A (sole $p < 0.001$, leg $p < 0.01$). There was no distinct difference in TS between the elderly and young subjects.

TC and RC after the subjects sat for 90 minutes were significantly affected under the conditions (TC $p < 0.05$, RC $p < 0.05$). There were no significant differences in TC and RC between condition A and condition F. Though there was no significant difference between condition A and F, the number of subjects who felt comfortable and made no requests for the change in the air temperature for condition F was larger than that for condition A. No significant difference in TC and RC

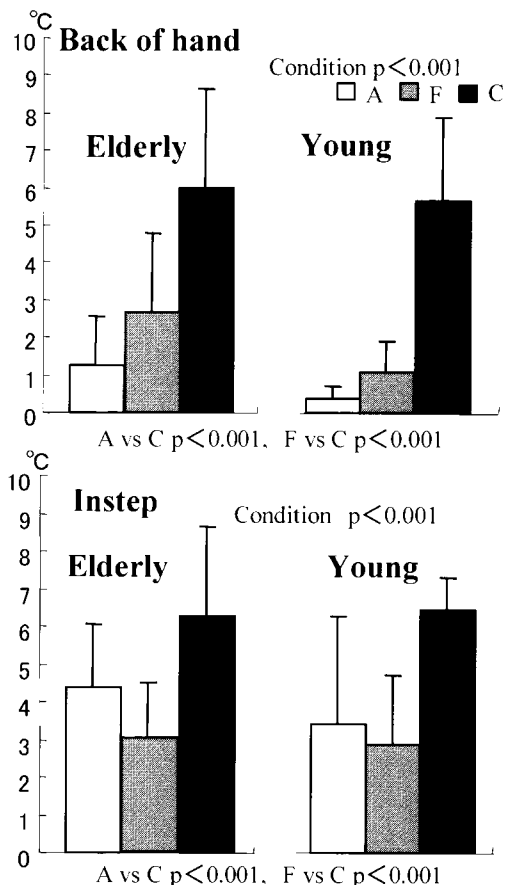


Fig. 4 Mean values of differences between mean skin temperature and back of hand (upper) & instep (lower) temperatures for last 10min in the test room. Values are means±SD for 8 subjects. A significant main effect (condition) was shown for both the back of the hand and the instep with ANOVA. Significant differences between C and A & F ($p < 0.001$) were shown for both the back of the hand and the instep.

was seen between the young and elderly subjects.

Figure 7 shows the relationship of TC and skin temperature (back and instep), and Figure 8 shows the relationship of TC and TS (back and leg) after the subjects sat for 90 minutes. In the young subjects, the relationship between TC and skin temperature at both back and instep were significant (back $r = -0.65$ $p < 0.001$, instep $r = -0.61$ $p < 0.001$). Likewise, the other local body (i.e., face, chest, hand, and calf) skin temperatures were significantly connected with TC. Namely, both peripheral and corporal skin temperature showed the great influences on TC in the young subjects. On the other hand, for the elderly subjects, a significant relationship between TC and instep skin temperature was shown ($r = -0.75$ $p < 0.001$), but there was no significant relationship between TC and back skin temperature. The other peripheral (i.e., hand and calf) skin temperatures had a significant relationship to TC in the elderly subjects (hand $r = 0.64$ $p < 0.001$, calf $r = -0.60$ $p < 0.01$), but the chest skin temperature did not. Namely, there was no correlation of corporal skin temperature with TC in the elderly subjects. The relationship between TC and TS showed a

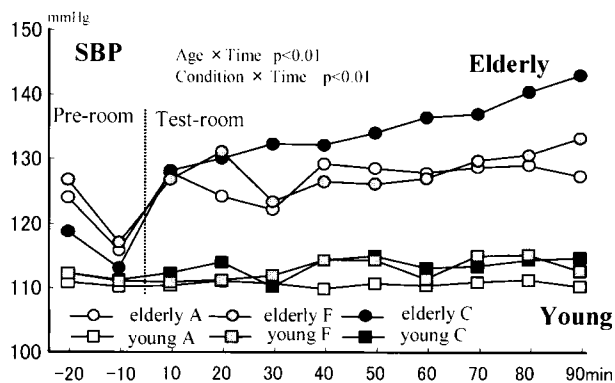


Fig. 5 Systolic blood pressure under the six conditions. Values are means for 8 subjects. Significant interactions (age×time, condition×time) were shown with ANOVA.

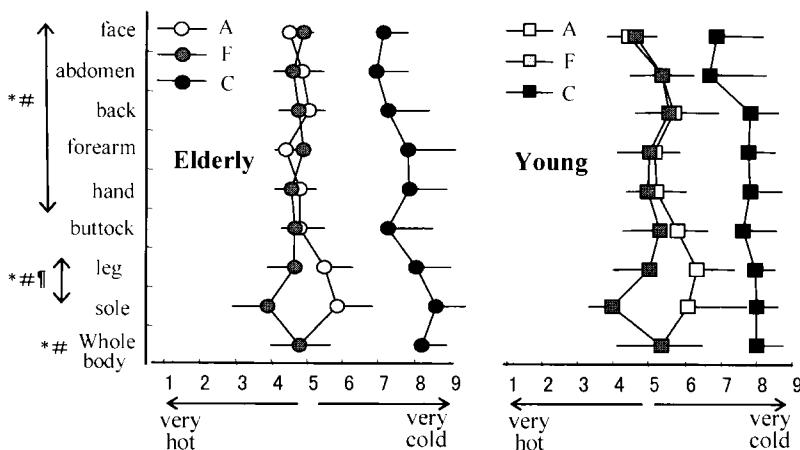


Fig. 6 Thermal sensation at each site and for the whole body after subjects had been sitting for 90 min. Values on the left are for the elderly, those on the right for the young. Values are means±SD for each of the 8 subjects. Significant main effects (condition) were shown at all locations and for the whole body with ANOVA * $p < 0.05$ indicates a significant difference between A and C. # $p < 0.05$ indicates a significant difference between F and C. * $p < 0.05$ indicates a significant difference between A and F.

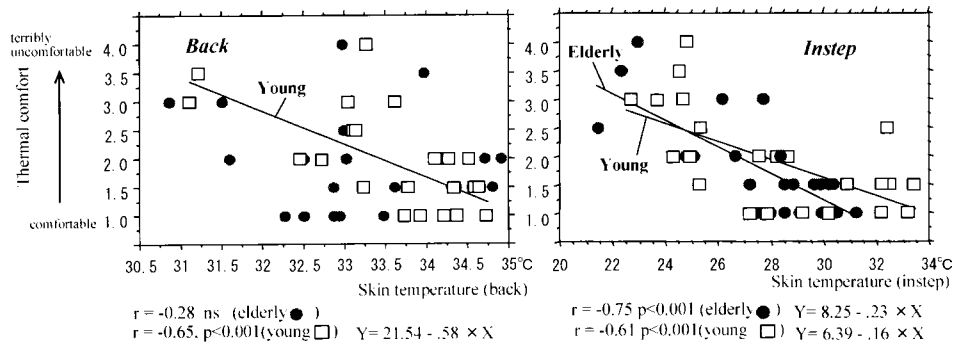


Fig. 7 Relationships between thermal comfort and skin temperature (back and instep).

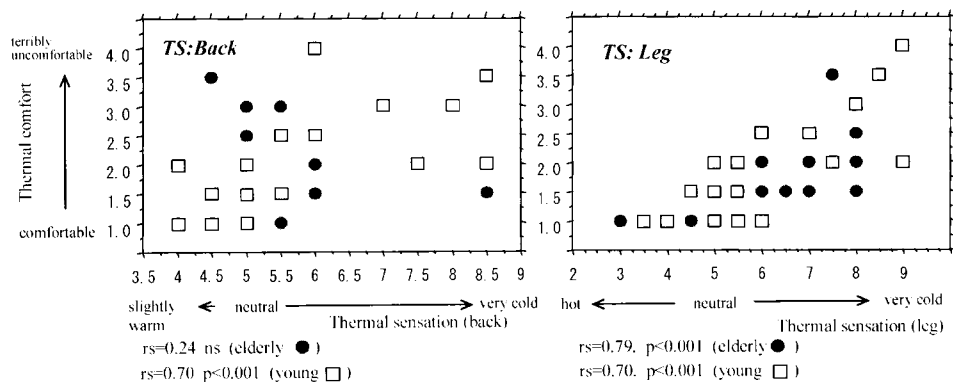


Fig. 8 Relationships between thermal comfort and thermal sensation (back and leg).

tendency similar to that between TC and skin temperature. Specifically, for the young subjects, TC was significantly affected by both leg and back TS (leg $r_s = 0.70$, $p < 0.01$, back $r_s = 0.70$, $p < 0.01$). For the elderly subjects, the leg of TS was significantly connected to TC ($r_s = 0.79$, $p < 0.001$), whereas the back of TS was not.

Discussion

Many researchers have carried out studies on floor heating systems and determined the thermal comfort zone of air and floor temperatures (Bougaki, 1985; Emura et al., 1992; Choi et al., 1996; Zhang L et al., 1998; Hori et al., 1997; Hori et al., 2000). According to previous studies, the comfort ranges for floor and air temperatures differed slightly depending on the experimental condition. Hori et al. (1997) studied the effects of floor heating systems under the condition in which the young subjects were sitting in the chair and wearing standard winter clothes (1.0 clo). Their findings showed that the optimum temperature for the floor surface was within 25–32°C, and that for the air was within 23–25°C. There have also been several studies on the thermal effect of posture on the human body situated on a heated floor (Kim B et al., 1990; Narumi et al., 1996; Kurazumi et al., 1999). The Japanese typically spend the time in their living rooms in different postures (e.g., sitting in a chair, sitting or lying directly on the floor). These studies garnered valuable results showing that the effects of floor

heating systems on the human body were different depending on the posture. Few reports, however, compared the physiological and psychological responses to various heating methods. So the investigation into the effects of floor heating system on the elderly people is as yet insufficient. Therefore, the aim of the study was to investigate the thermal responses of the elderly and young men when using floor heating and air conditioning systems, respectively.

Significant differences in skin temperature at some body locations between conditions A and F were verified, though no distinct differences were observed in \bar{T}_{sk} and T_{re} (Fig. 3), and no significant differences between conditions A and F were indicated in BP and HR (Fig. 4). These findings suggest that the thermal response and physiological strain under the condition of a floor heating system did not significantly differ from those under the condition of an air conditioning system, although the air temperature of condition F was lower than that of condition A by 4°C.

There were also no significant differences between conditions A and F in thermal comfort and requests for the change in air temperature after the subjects sat for 90 minutes. However, the number of subjects who felt comfortable and made no requests for the changes in air temperature in condition F was larger than that of those in condition A. These subjective results suggested that a floor heating system was preferred over an air conditioning system, even if air temperature for the floor heating system was lower. It is

confirmed by a previous study that mean skin temperature ranges from 33 to 34°C when people feel neither hot nor cold (Osada, 1978). In this experiment, the mean skin temperatures of the elderly and young subjects, respectively, in condition A were slightly over 33°C, and therefore in the range of temperature indicated. It is generally considered that people cannot feel neutral when their peripheral skin temperature is very high or low, even if \bar{T}_{sk} falls within the range in which people typically feel neutral. It was also a requirement when people feel neither hot nor cold that the differences between peripheral skin temperatures and \bar{T}_{sk} are within +1.5~–3.0°C (Osada, 1978). As shown in Fig. 4, the difference between peripheral (instep and hand) and \bar{T}_{sk} were less than 3°C in condition F. The differences in temperature between \bar{T}_{sk} and instep in condition A were larger than that for condition F, and the values were over 3°C. Therefore, it was found that these large differences in skin temperatures among body locations caused thermal discomfort under condition A. Thermal sensations at the leg as well as the sole for condition F were significantly warmer than those for condition A (Fig. 7). The air temperature for condition F was lower than that for condition A by 4°C. However, the small difference in skin temperature among the body locations and the overall warmth of entire leg apparently due to thermal radiation from the heated floor might have contributed to make subjects comfortable in condition F.

We measured various items during the experiment, and only the changes in BP were significantly affected by the difference in age ($p < 0.01$). In particular, under condition C where the air temperature was 15°C, a remarkable increase in BP was found for the elderly whereas BP in the young did not change. Similar changes in BP due to cold exposure were shown in previous studies. Collins et al. (1985) studied the blood pressure of the young and elderly subjects wearing nightclothes, and found that an air temperature of 15°C was the minimum level at which the elderly should live safely in their houses. It is known that an increase in BP due to cold exposure was caused by cutaneous vasoconstriction and an increase in stroke volume (Miwa et al., 1999). Therefore, the elderly receive more physical strain than the young in an unheated room condition. The thermal condition for condition C in this study is not a rare case in Japanese houses, according to previous surveys (Sato et al., 1996; Igarashi et al., 2000). The air temperature might be 15°C or lower in winter depending on the living area. These results for BP also suggested that it is necessary for elderly people, even those who do not suffer from hypertension, to heat any room being used in winter, so that they can spend time in it without putting strain on the heart. However, no physiological marker, except BP, was significantly affected by the difference in age. Some peculiar thermoregulatory functions in elderly people in response to cold exposure have been verified in previous studies (Wagner et al., 1974; Tochiara et al., 1993). For example, it is known that the capacity for cutaneous vasodilation in the extremities to prevent heat loss during cold

exposure decays in old age. Furthermore, the heat losses due to the increase of cutaneous blood flow in the elderly occurred later than those in the young. However, in this experiment, under condition C as well as A and F, there was no definite correlation of body temperature with the difference in age.

Many studies have been conducted on the effect of age on the range of temperature at which people feel comfortable. Fanger (1970) and Rohels (1972) showed that there was no obvious difference in the comfort range of temperature between the elderly and young people. Tochiara (1993) indicated that elderly people did not feel as cold as young people immediately after cold exposure, and that their sensitivities to cold decays compared to that of the young. Furthermore, it was shown that the sensitivity of the change to air temperature declines with age (Collings, 1981). In this study, we found that age has no great influence on the subjective responses to any heating system conditions. However, as shown in Figs. 7 and 8, some interesting results were obtained. Namely, the relationships between TC and skin temperature, and that between TC and TS, were different for the elderly subjects and young subjects. Specifically, for the young subjects, the thermal comfort was directly reflected in skin temperatures and thermal sensations at most body locations, including the corporal body. On the other hand, for the elderly subjects, significant relationships were indicated between TC and peripheral (i.e. instep, calf, and hand) skin temperature, and the relationship between TC and leg thermal sensation was also significant. However, in the group of the elderly subjects, back and chest skin temperature and back thermal sensation had no significant relation to TC. Namely, for the elderly, corporal body skin temperature and thermal sensations are not related to thermal comfort. It was confirmed that ensuring the warmth of peripheral parts rather than that of the corporal body was important to obtain thermal comfort for elderly subjects.

The air and floor temperatures for condition A were determined by simulating a condominium; therefore, the floor temperature was not especially low in this study. These experimental conditions might produce findings that the thermal responses for condition F did not differ greatly from those for condition A. However, the vertical air temperature difference in a room where an air conditioning system is running in a detached house is actually larger than 4°C (the condition in this study) (Hasegawa et al., 1985; Igarashi et al., 2000). Thus, a thermal environment in which the floor and lower space air temperatures are very low might cause a great decrease in the temperature of the occupant's leg skin. This study did not show that for elderly people, the floor heating system is a heating method evidently superior to an air conditioning system, though we did find that the decrease in peripheral skin temperature and awareness of the coldness of the leg directly reflected thermal comfort for the elderly. This finding might be one piece of evidence that a floor heating system is a relatively more suitable heating method for the elderly in terms of obtaining efficient thermal comfort, because

the floor heating system can produce stable warmth of the leg with relative ease.

In conclusion, thermal response and physiological strain under the condition of the floor heating system did not significantly differ from that under the condition of the air conditioning system, regardless of the subject age and despite the fact that the air temperature using the floor heating system was lower than that using the air conditioning system. An increase in BP for the elderly subjects was observed under the condition in which the air temperature was 15°C. This finding suggested that it was necessary for elderly people to heat indoor rooms by some heating system in winter. Moreover, it is particularly important for elderly people to avoid a decrease in peripheral skin temperature, and maintain an awareness of the warmth of peripheral areas, such as the legs, in order to ensure thermal comfort.

Acknowledgments The authors wish to thank the subjects for their participation. In addition, we thank Ms. Chikako Ogawara and Ms. Yujin Sunwoo, Kyushu Institute of Design, and Ms. Madoka Kushibe and Ms. Akiko Yamamoto, Fukuoka Women's University, for their invaluable assistance. We would like to express our gratitude to Mr. Hiromitsu Ito and Mr. Shiro Yoshitake, Saibu Gas Co., Ltd., for their technical support. We also wish to acknowledge Dr. Yumi Kaji of Yame Rehabilitation Hospital for making a medical check of the subjects. This study was supported in part by a Grant-in-Aid for the 21st Century COE Program.

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Received: June 7, 2004

Accepted: September 24, 2004

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