THERMAL COMFORT AND THERMOREGULATION FOR ELDERLY PEOPLE TAKING LIGHT EXERCISE

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ABSTRACT
This paper presents the results of subjective experiments on the thermal comfort requirements of elderly people taking light exercises. The experiments were conducted in a climatic test chamber. Eighty elderly subjects were exposed to four conditions, two thermal conditions (23 °C under 60 %rh and 27 °C under 60%rh) combined with two exercise conditions. The duration of the experiment for each subject was 180 minutes. The results showed that the exercises increased the mean skin temperature and the metabolic rate. However, evaporative water loss did not significantly increase with the increase of the metabolic rate. The exercises also increased Thermal Sensation Vote. Generally the elderly subjects felt the experimental conditions were warmer than PMV which was determined from the measured metabolic rate.

INDEX TERMS
Thermal comfort, Elderly people, Subjective evaluation, Physiological responses

INTRODUCTION
It has been suggested that the elderly prefer warmer environments due to the fact that their basal metabolic rate decreases with age. However, it is also said that ageing is associated with a lower evaporative heat loss which can cancel out the effect of the lower basal metabolic rate on preferred temperature. Previous studies have shown no differences in neutral temperature or preferred temperature between the younger subjects and the elderly, e.g. studies using Danish subjects (Fanger, 1970), Japanese female subjects (Ohnaka, Tochihara, Tsuzuki et al., 1993), and Australian male subjects (Taylor, Allsopp and Parkes, 1995). The latter two showed no age differences in temperatures preferred by the subjects, although physiological responses were different. Thus, in order to see the elderly subjects’ thermal comfort it is necessary to measure physiological response as well as subjective response.

Our previous study suggested that the elderly subjects’ evaluation was not appropriate and unreliable (Tsuzuki, Ohfuku, Mizuno et al., 2001). It was also found that there was little difference in evaporative water loss between the younger and the older subjects although the metabolic rate for the elderly group was almost 70% that of the young group. In this study the elderly subjects took light exercises to increase their metabolic rates so that the relationship between thermophysiological responses and thermal comfort can be better clarified.

METHODS
Test chamber
The experiments were carried out in a climatic chamber, 5.0m x 4.5m x 2.7m, at the National Institute of Bioscience and Human-technology, Tsukuba, Japan in July and in September, 2000. Two environmental conditions (23 °C/60%Rh, 27 °C/60%Rh) and two exercise
conditions (16 steps per minute and 32 steps per 2 minutes) were evaluated. Air velocity was maintained at less than 0.2 m/s and mean radiant temperatures were kept equal to the ambient temperatures by cloth curtains covering the walls.

**Subjects**

Eighty elderly people whose physical characteristics are shown in Table 1 were recruited. The subjects underwent medical examinations to show their health.

<table>
<thead>
<tr>
<th>Table 1. Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
</tbody>
</table>

*1 Body surface area (m²) = 0.008883 x Height ∧ 0.663 x Weight ∧ 0.444

*2 Average (Standard deviation)

**Procedure**

Figure 1 shows the procedure of the experiment. The duration of the experiment for each subject was 180 minutes. In the first 30 minutes, the subject listened to an explanation of the experiment, changed their clothes and were set up with individual thermistor sensors. Clothing for the experiment consisted of cotton sweatshirts, sweatpants and calf-length socks; the Clo-value was estimated at 0.7 clo. Subjects were sedentarily talking and/or reading magazines except while doing the exercises. A set of exercises included getting up from his/her seat and moving up onto a step (15 cm in height) and down 16 times per minute. Two exercise conditions were adopted; lighter one was 1 set x 6 repetitions (6 sets in total) and the other was 2 sets x 6 repetitions (12 sets in total). Both had 10 minute intervals. Four subjects participated in the experiment at the same time.

Skin temperatures were taken every 30 seconds at eight extremities of the body (forehead, abdomen, back, forearm, hand, thigh, calf and foot) using thermistor sensors taped to the skin. Mean skin temperature (\( T_{sk} \)) was calculated according to the following equation (Hardy and DuBois, 1938):

\[
T_{sk} = 0.07 \times T_{\text{forehead}} + 0.175 \times T_{\text{abdomen}} + 0.175 \times T_{\text{back}} + 0.14 \times T_{\text{arm}} + 0.05 \times T_{\text{hand}} + 0.19 \times T_{\text{thigh}} + 0.13 \times T_{\text{calf}} + 0.07 \times T_{\text{foot}}
\]

(1)

where \( T_{\text{forehead}} \) to \( T_{\text{foot}} \) are the temperatures measured at eight sites.

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The heart rate (HR) and blood pressure was measured at 60 minute intervals. Expired gas was collected in a Douglas bag for 5 minutes twice during the experiment. The metabolic rate was determined by measuring O₂ consumption, CO₂ production and expired gas volume. The body mass was measured every hour with an accuracy of +/-1g and the evaporative water loss (EWL) was determined from the change in body mass as a factor of time and body surface area.

The subjects orally evaluated the thermal conditions using the categories shown in Figure 2 (SHASE, 1981) at 30 minute intervals.

RESULTS

Physiological responses

Figure 3 and Figure 4 show the time course of the tympanic temperature and that of mean skin temperature respectively. The results of the four conditions in this study are illustrated as well as the results for the conditions without exercise in our previous study (Tsuzuki, Ohfuku, Mizuno, et al., 2001). The upward and downward bars in Figure 3 show the standard deviation. Tympanic temperature was not influenced by the strength of the exercise. Mean skin temperatures at 23°C conditions showed differences between 0, 6 and 12 sets of exercises. Although the skin temperature in the case of no exercise decreased with time, the skin temperature in the case of 12-set exercises was kept at constant value. However, 27°C conditions did not show obvious differences. Therefore, skin temperatures at hand and calf are presented in Figures 5 and 6. The response of calf skin temperature was a complete contrast to hand skin temperature. Skin temperature of the hand decreased while doing and that of the calf increased. In other words, hand skin temperature was mainly affected by air convection due to body movement and calf skin temperature was affected by the increment of blood flow.
Fluctuations of skin temperature while doing exercises also can be explained by the convection and blood flow. Thus the effect of the exercises on skin temperature was not so simple but produced opposite results on skin temperatures on different parts of body.

Figure 7 and Figure 8 show the result of metabolic rate and that of evaporative water loss (EWL) respectively. The white bar shows “before doing exercises” and the shaded and black bars show means “after doing half of 6 and 12 sets of exercises”. No significant difference in the metabolic rate can be found between female and male because of large individual differences. Although the exercises increased the metabolic rate, the mean metabolic rate was still low, less than 50W/m$^2$. On the other hand, the exercise had no influence on EWL that increased with the increasing ambient temperature. The standard deviation indicated in upward bars are very large.

Subjective responses
Figure 9 shows the time course of mean Thermal Sensation. The results of our previous study are also illustrated. The previous study without exercise showed that Thermal Sensation decreased with elapsed time for both 27°C and 23°C.

Table 2 shows the results of analysis of variance. The upper table indicating the result of 3-way analysis of variance using data at 60 and 90 minutes after starting the experiments.
(non-exercise time) shows no difference between the previous and the present data under the same condition. This fact means the present data can be compared with the previous data, although the subjects were different. The lower table indicating the result of 2-way variance using data at 150 minutes, just after doing exercise shows that and that the exercise increased Thermal Sensation significantly.

Table 2. ANOVA

<table>
<thead>
<tr>
<th>Factor</th>
<th>Sum of sq.</th>
<th>D.F.</th>
<th>Mean sq.</th>
<th>F</th>
<th>P</th>
<th>L.S.</th>
</tr>
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<tr>
<td>A*</td>
<td>48.57</td>
<td>1</td>
<td>48.57</td>
<td>31.17</td>
<td>0.000</td>
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</tr>
<tr>
<td>B*</td>
<td>0.362</td>
<td>1</td>
<td>0.362</td>
<td>0.232</td>
<td>0.630</td>
<td>-</td>
</tr>
<tr>
<td>C*</td>
<td>12.88</td>
<td>1</td>
<td>12.88</td>
<td>8.269</td>
<td>0.004</td>
<td>1%</td>
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<tr>
<td>AxB</td>
<td>0.142</td>
<td>1</td>
<td>0.142</td>
<td>0.091</td>
<td>0.763</td>
<td>-</td>
</tr>
<tr>
<td>AxC</td>
<td>1.251</td>
<td>1</td>
<td>1.251</td>
<td>0.803</td>
<td>0.371</td>
<td>-</td>
</tr>
<tr>
<td>BxC</td>
<td>1.185</td>
<td>1</td>
<td>1.185</td>
<td>0.760</td>
<td>0.384</td>
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<tr>
<td>AxBxC</td>
<td>0.801</td>
<td>1</td>
<td>0.801</td>
<td>0.514</td>
<td>0.474</td>
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<tr>
<td>residual</td>
<td>327.2</td>
<td>210</td>
<td>1.558</td>
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<tr>
<td>Total</td>
<td>392.4</td>
<td>217</td>
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<table>
<thead>
<tr>
<th>Factor</th>
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<th>P</th>
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<tbody>
<tr>
<td>X*</td>
<td>54.18</td>
<td>2</td>
<td>27.09</td>
<td>18.61</td>
<td>0.000</td>
<td>1%</td>
</tr>
<tr>
<td>Y*</td>
<td>30.01</td>
<td>1</td>
<td>30.01</td>
<td>20.61</td>
<td>0.000</td>
<td>1%</td>
</tr>
<tr>
<td>X x Y</td>
<td>5.849</td>
<td>2</td>
<td>2.924</td>
<td>2.008</td>
<td>0.139</td>
<td>-</td>
</tr>
<tr>
<td>residual</td>
<td>161.6</td>
<td>111</td>
<td>1.456</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>251.7</td>
<td>116</td>
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</tbody>
</table>

D.F.: Degrees of freedom  
L.S.: Level of significance  
*1 A. Temperature (23°C vs 27°C)  
*2 B. Previous data vs present data  
*3 C. Elapsed time (30min. vs 90 min.)  
*4 X. Strength of exercise (0set vs 6sets vs 12sets)  
*5 Y. Temperature (23°C vs 27°C)

However, our previous study also showed that the elderly subjects did not feel cool or cold sensations at 23°C, in comparison to the young subjects. Figure 10 shows the relationship between Predicted Mean Vote (PMV) proposed by Fanger (Fanger, 1970) calculated by using the metabolic rate measured and Thermal Sensation. The arrows show the changes in PMV and Thermal Sensation due to the exercise. The exercise, which increased the metabolic rates, consequently increased PMV and also Thermal Sensation. Thermal Sensations for all conditions were higher than PMV. Figure 11 shows the relationship between Thermal Sensation and Comfort Sensation before doing exercise. The most comfortable condition for the subjects is less than zero of Thermal Sensation.

DISCUSSION

The exercises in this experiment could increase not the evaporative water loss but the metabolic rate of subjects. However, the effect of the number of sets of exercises on the
metabolic rate was not obvious and the increment was insufficient. According to the estimation presented by Aren et al. (Aren, Xu, Miura, \textit{et al.}, 1998), the exercises correspond to 10.1 W/m$^2$ for female and 10.3 W/m$^2$ for male in the 6-set case and double in the 12-set case, but our results show 9.5 W/m$^2$ for female and 7.7 W/m$^2$ for male in the 6-set case and 5.3 W/m$^2$ for male and 8.7 W/m$^2$ for female in the 12-set case. This discrepancy should be explained by the difficulty in dealing with the Douglas bag.

In the case of the 12-set exercises under 23$^\circ$C, lower metabolic rate and higher evaporative water loss was observed, therefore it was expected that the subjects would feel cold at 23$^\circ$C conditions. Actually PMV calculated was “cold”. Against this expectation, the subjects’ Thermal Sensation was nearly zero (neutral) and their Comfort Sensation was higher than neutral and that of 27$^\circ$C. As mentioned in our previous study (Tsuzuki, Ohfuku, Mizuno, \textit{et al.}, 2001), the elderly subjects felt neither cold nor discomfort even in the condition that their heat balance appeared to be minus.

CONCLUSION AND IMPLICATIONS

In order to identify thermophysiological responses (metabolic rate and evaporative water loss) and thermal sensation for the elderly subjects, experimental studies were carried out under moderate thermal conditions. The exercises increased the mean skin temperature and the metabolic rate apparently. However the increments in the metabolic rates obtained from measured O$_2$ consumption, CO$_2$ production and expired gas volume were smaller than the estimation from the body weight and the height of the step. Moreover the metabolic rate under the sedentary condition was low at all. The exercise did not increase the evaporative water loss significantly. In total, the exercise could increase PMV, but PMV was lower than Thermal Sensation by the elderly subjects who tended not to feel cold and discomfort. For the elderly people a warmer environment considering their lower metabolic rate should be provided.

ACKNOWLEDGEMENTS

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REFERENCES


