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SEASONAL DIFFERENCES OF PHYSIOLOGICAL RESPONSES DURING THE COMBINED CONDITIONS OF HEAT AND NOISE

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1. INTRODUCTION

The purpose of this study is to determine the physiological effects during the combined conditions of heat and noise. It is important to clarify the human responses by physiological analysis, as well as psychophysical methods in order to obtain in-situ evaluation of daily environment that the officers and the habitants usually live in. For this purpose, this study analyzes basic physiological indices and especially discusses the effect of noise and time responses.

2. MATERIALS AND METHODS

Two series of experimental programs were conducted at the experimental chamber of Nagoya Institute of Technology in early summer 1998 and in winter 1999.

2.1 *Subjects*

The subjects of the experiments in summer were ten Japanese healthy male students with normal hearing, ranged in age between 19 and 25 (Mean (SD) = 21.6 (1.9)). Eight of them were also adopted as the subjects of the experiments in winter. Each subject participated voluntarily in all the experimental conditions and was compensated for participating. In the experimental chamber they wore only cotton undershorts with clothing insulation estimated at 0.05 clo, and kept up sedentary posture.

2.2 *Experimental Conditions*

For the experiments in summer, the pre-test room was kept at 27℃ in operative temperature that might give us thermally neutral feelings and 45.9L_{Aeq} under air-conditioning noise level. In the test room, five operative temperature levels (27, 30, 33, 36, 39℃) at each of five noise levels (46.8L_{Aeq}: air-conditioning noise; 59.2, 73.1, 80.0, 95.4L_{Aeq}: traffic noise) constituted twenty-five experimental conditions. Relative humidity and air velocity were controlled at approximately 30-70% and less than 0.15 m/s, respectively, at the occupied zone in the test room and the pre-test room. For the experiments in winter, four cooler operative temperature levels (19, 22, 25, 28℃) were adopted instead of high temperature levels (27, 30, 33, 36, 39℃) and another conditions were similar to those of the experiments in summer.

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2.3 *Experimental Facilities*

Two rooms were built with steel frames and polystyrene foams. Dimensions of the pre-test room on the left of the figure were 2,400mm by 2,700mm with a ceiling height of 2,400mm. Those of the test room on the right of the figure were 3,600mm wide, 3,000mm long and 2,400mm height. The interior surfaces of each room were covered by gray colored (N8.5) curtain to identify the mean radiant temperature with the air temperature. It was possible to separately control the air temperatures of each room by means of the packaged air-conditioner. Traffic noise has been recorded on the bridge over the highway in Nagoya suburb and was presented using the digital audio tape recorder (SONY TCD-D10 PRO II). Noise levels were adjusted by the volume of the amplifier (AIWA S-A22).

2.4 *Measurement*

The ambient dry-bulb and wet-bulb temperatures in each room were measured by a ventilating psychrometer at 700mm above the floor, and the globe temperature was measured by a globe thermometer. Along with these temperatures, the surface temperatures of the walls, floor and ceiling and the vertical distribution of air temperature were continuously monitored and recorded by 0.3mm T-type thermocouples. Mean radiant temperature for calculating the operative temperature (Winslow et al. 1937) was calculated using the surface temperatures of the walls, floor and ceiling and the angle factor (Horikoshi et al. 1978a) between a subject and each surface. The local skin temperatures and the local sensible heat flow rates at the forehead, trunk, hand, upper arm, front thigh, front shin and foot were measured by 0.2mm T-type thermocouples and heat flow meters (EKO MF-9) respectively, and the mean skin temperature was calculated by Hardy-DuBois (1937) weighting factors. Oral temperature was monitored and recorded by 0.2mm T-type thermocouple coated with acrylic. Metabolic rate and heart rate were also continuously measured by aeromonitor (MINATO AE-280S) and electrocardiograph

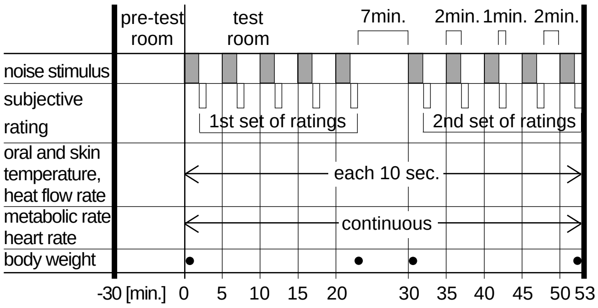

FIG. 1 Time schedule

(NEC San-ei, System 360), respectively. Body weight during experiments was measured by digital balance (METTLER-TOLEDO KCC150) four times a session.

2.5 *Procedure*

The time schedule of the experiment is shown in Fig. 1. All experiments were conducted in the morning (9:00-12:30) or afternoon (13:30-19:00) from 14 June to 7 July 1998 and from 2 February to 18 1999, but not during an hour after the breakfast or an hour after lunch, to ensure that the subjects' metabolism was stable. Measuring instruments were attached to each subject in the pre-test room. After half an hour for thermal adaptation in the pre-test room, the subjects walked in the test room and sat on the chair. They reported the impression of the exposed environment on the ballot after presenting the noise stimuli during 2 minutes. After 7 minutes, they repeated the ratings for the same exposed condition. However, the second set of ratings for the 19 ℃ condition was not conducted and all subjects were exposed to only one thermal condition a day for preventing the subjects from excessive physical and mental stress. Each combined condition of heat and noise was randomly presented to exclude the order effect.

3. RESULTS

As psychological data was already analyzed in our previous studies (Nagano et al. 2000, 2001), this paper discusses the physiological effects. Fig. 2 through Fig. 4 were derived from the data during exposure time to noise stimuli after 30 minutes, which were on more steady state, in order to clarify the effect of noise. Fig. 5 through Fig. 8 were analyzed results of the data during exposure to noise stimuli in the test room, focused on thermal effects.

3.1 *The Effect of Noise*

Fig. 2 and Fig. 3 show the relationship between the noise level (L_{Aeq}) and the mean value of the mean skin temperature (MST) and the oral temperature, respectively. With rising the ambient temperature, the mean skin temperature rose up to higher level, with little respect to the noise level. The oral temperature was ambiguously affected with the noise level, as well as the temperature level.

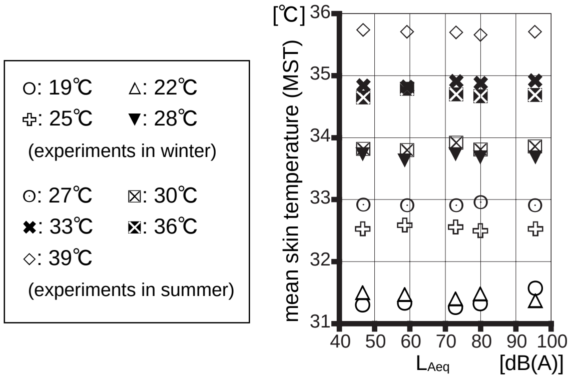

FIG. 2 Relationship between L_{Aeq} and MST

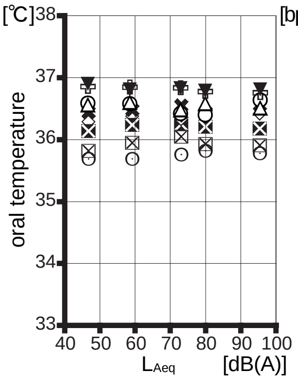

FIG. 3 Relationship between L_{Aeq} and oral temperature

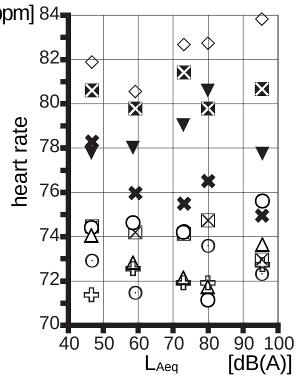

FIG. 4 Relationship between L_{Aeq} and heart rate

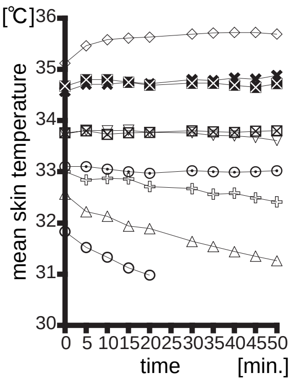

FIG. 5 Changes with exposure time in mean skin temperature

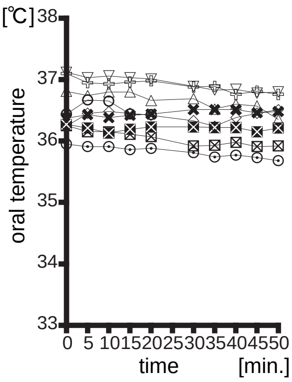

FIG. 6 Changes with exposure time in oral temperature

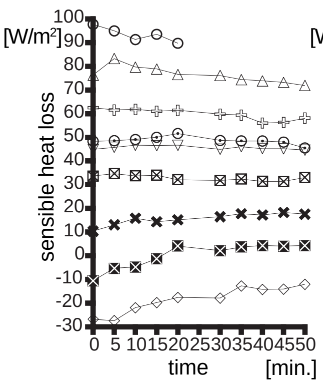

FIG. 7 Changes with exposure time in sensible heat loss

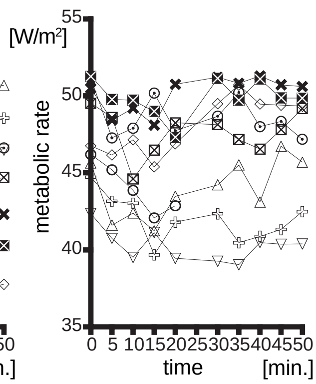

FIG. 8 Changes with exposure time in metabolic rate

Fig. 4 shows the relationship between the noise level and the heart rate. Temperature and noise had little effect on the heart rate.

3.2 *Time series responses*

Fig. 5 and Fig. 6 show the time series results of the mean skin temperature and the oral temperature, respectively. Mean skin temperature fell gradually with time in 19, 22 and 25℃ conditions, and was stable in another hotter conditions. For all conditions, oral temperature was stable at 36-37℃.

Fig. 7 shows the time series results of the sensible heat loss. Sensible heat rate fell down gradually for 19 and 22℃ conditions. The changes in mean skin temperature were consistently similar to the changes in sensible heat loss at the 19-22℃ conditions. However, the subjects did not gain sensible heat at 36℃ condition after 20 minutes, though the ambient temperatures were higher than mean skin temperatures under 36 and 39℃ conditions.

Fig. 8 shows the time series results of the metabolic rates. At 19 to 28℃ conditions of the winter experiments, metabolic rates were 40 to 45 W/m^2, whereas 45 to 50 W/m^2 at 27 to 39℃ conditions of the summer experiments.

Fig. 9 shows variation in human heat balance with ambient temperature. Positive and negative sides on the ordinate represent heat gain and loss, respectively. The value was calculated using the data during exposure to noise stimuli after 30 minutes except 19℃ condition. Each heat rate was derived from equations written in appendix.

As shown in Fig. 9, with rising the ambient temperature, the radiative and convective heat loss decreased to zero level, and they changed to heat gain where the air temperature was higher than the mean skin temperature. Evaporative heat loss was constantly about 20W/m^2 in winter. Whereas in summer, evaporative loss was higher with rising the ambient temperature. In thermally neutral conditions, which are 27℃ in summer and 28℃ in winter, there is no difference between two seasons in radiative, convective and evaporative heat losses. However, metabolic rates in summer were 5 to 10W/m^2 larger than in winter. In winter, metabolic rate was lower with rising the ambient temperature. Heat balance rate was constantly about 20W/m^2 in summer. In the neutral condition, heat balance rates in summer were 5 to 10W/m^2 lower than in winter.

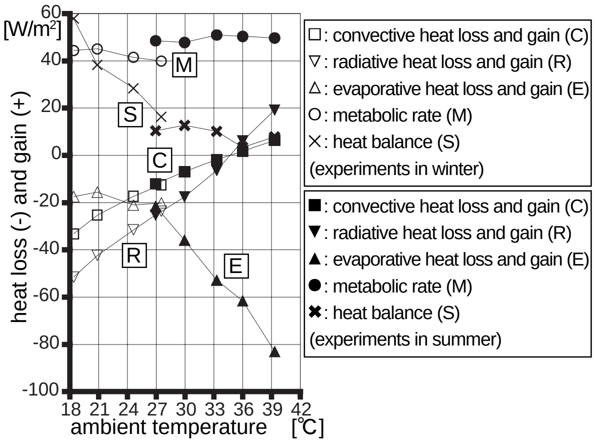

FIG. 9 Heat loss and gain, and heat balance of the human body with ambient temperature

4. DISCUSSION

As shown in Fig. 2 through Fig. 4, it is obvious that noise does not affect measured physiological responses. Thus, time response result in each thermal condition is discussed on thermal effect, with no relation to auditory condition.

It is suggested that over 30℃ conditions, the human body regulated to enlarge latent heat loss through evaporation instead of sensible heat diffusion from skin, as a result of evaporative heat loss.

It is a great interest that there exist seasonal differences on metabolic rates. Ogawa et al. (1975) showed that metabolic rates in winter were higher than in summer, and Yoshimura et al. (1966) showed that there was no seasonal difference on basal metabolism of Canadians living in Japan. However, Gonda et al. (1999) and Ishigaki et al. (2001) showed metabolic rates in summer were higher than in winter. Thus, the findings of this study support recent studies for Japanese subjects, but not the previous studies conducted several decades before for Canadian and Japanese. It may probably be due to a change of diet and controlled temperature in dwellings between generations and nations. Further work is required to clarify the seasonal effects on metabolic rates.

APPENDIX

Convective heat loss C [W/m^2] is shown to be:

$$C = h_c F_{cl} (t_s - t_a)$$
$$F_{cl} = 1/(1 + 0.155(h_c + h_r) I_{clo})$$

where

h_c =convective heat transfer coefficient in W/m^2℃
F_{cl} =intrinsic thermal efficiency in dimensionless
t_s =mean skin temperature in ℃
t_a =ambient temperature in ℃
h_r =radiative heat transfer coefficient in W/m^2℃
I_{clo} =clothing insulation, 0.05 clo, estimated by Hanada's method (1983)

For estimating h_c, following formula proposed by Ishigaki et al. (1991), which was a function of the difference between t_s and t_a, was adopted.

$$h_c = 1.16 \Delta T^{0.33}$$

The coefficient h_r and radiative heat loss R [W/m^2] are derived from equations as follows:

$$h_r = \frac{\sigma \varepsilon_s \varepsilon_w \left[\left(t_s + 273.15 \right)^4 - \left(t_r + 273.15 \right)^4 \right] F_{eff}}{\left(t_s - t_r \right)}$$

$$R = h_r F_{cl} \left(t_s - t_r \right)$$

where

σ =Stefan-Boltzmann constant, 5.67×10^{-8} W/(m^2・K^4)
ε_s =average emissivity of body surface, 0.98
ε_w =average emissivity of enclosing surface, 0.95
F_{eff} =effective radiation area factor, 0.80, estimated by Horikoshi et al. (1978b)

Evaporative heat loss E [W/m^2] is shown to be:

$$E = m\lambda / A_s$$

where

m =body weight loss in kg/h
λ =heat of vaporization of water, 2430 kJ/kg
A_s =Body surface area in m^2

Following formula for body surface area is suggested by Kurazumi et al. (1994).

$$A_s = 100.315 \times 10^{-4} \times W^{0.383} H^{0.693}$$

where

W =body mass in kg
H =body height in cm

Metabolic rate M [W/m^2] is referred to Gagge and Nishi (1977) as follows:

$$M = \left(0.23RQ + 0.77 \right) \times 5.873 \times \left(60 \times V_{O_2} \right) / A_s$$

where

RQ =respiratory quotient in dimensionless
V_{O_2} =volumetric rate of oxygen consumption in lit/min

These two values, RQ and V_{O_2} are measured by the aeromonitor directly. And then, rate of heating or cooling by the body S [W/m^2] is shown to be:

$$S = M - \left(C + R + E \right)$$

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