Experimental study on the thermal comfort and physiological responses of the elderly in unstable environments

Zixuan Zhang[1], *Yuxin* Wu[1*], *Hong* Liu[2,3**], *Baizhan* Li[2,3], *Risto* Kosonen[4,5]

1 School of Civil Engineering and Architecture, Zhejiang Sci-Tech University, Hangzhou, 310018, Zhejiang, China

2 Joint International Research Laboratory of Green Buildings and Built Environments (Ministry of Education), Chongqing University, Chongqing, 400045, China

3 National Centre for International Research of Low-carbon and Green Buildings (Ministry of Science and Technology), Chongqing University, Chongqing 400045, China

4 Department of Mechanical Engineering, Aalto University, 02150 Espoo, Finland

5 College of Urban Construction, Nanjing Tech University, Nanjing 210009, China

Abstract. In this study, the investigators used comparative experiments in order to study the age differences and the effects of temperature changes on physiological responses. Firstly, This paper analyzed the thermal sensation differences and the trend of changes in the design working conditions in different age groups. The researchers found that the thermal sensation of elderly people was lower than that of young people in the hot environment and higher than that of young people in the cold environment. On this basis, the heart rate changes of the elderly in the dynamic environment and the differences with the young people were studied. The results showed that the heart rate of the elderly and the young people increased with the increase of temperature in the temperature rise condition, but there was no significant difference between the two groups. In the temperature drop condition, the heart rate decreased with the decrease of temperature. Finally, an equation was developed to quantitatively predict heart rate parameters. The equation predicts human heart rate by ambient temperature, and the results show that the least square error of the prediction equation for elderly people is 46, while the average difference between the actual and predicted values is 1.2. Therefore, it is recommended to use the proposed heart rate prediction equation when predicting the healthiness of heart rate in elderly people.

Keywords: thermal comfort; thermal sensation; physiology; age; the elderly

1 Introduction

Modern society is striding towards an ageing society, and how to settle the elderly in their old age has become an urgent problem for human society. Currently being widely used in foreign standards ISO7730 , ASHRAE Srandard55 , EN15251 and other places PMV lacks relevant standards for the elderly [1]. Meanwhile, in studies by Fanger [2] , Rohles and Johnson [3] , Fanger and Langkilde [4] and others, it was noted that there was no significant difference in thermal preference temperature between older and younger people. professor Taylor [5] found that no significant difference in thermal preference temperature emerged between the two age groups of middle-aged and older people. kalmár Professor [6] recruited 20 older people and 20 younger people and found that there were gender differences in heat sensation, but no significant differences emerged between the different age groups. Prof. Natsume [7] and others first found differences in thermal preference temperature between age groups in 2006. Prof. Schellen [8] compared the physiological and psychological responses of two age groups under steady state and temperature drift conditions. The results showed that, under the same conditions, older people felt colder thermally than younger people [9] . However, in studies by Bill [10] and Huang and Chen [11], the opposite result emerged. bill's study showed that despite the many cold tickets, 50% of older people in South Australia did not want to heat their homes in winter, with room temperatures as low as 12°C. In contrast, older people felt slightly warmer when set to the neutral temperature recommended by ASHRAE Standard 55. Huang and Chen found that older people had a narrower range of thermal comfort temperatures than younger people [12]. There were studies about thermal comfort in dynamic thermal environments [13, 14] or thermal environments with temperature ramps [15] using college students, but

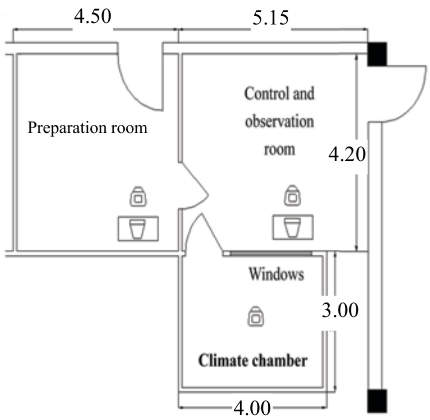
* Corresponding author: wuyuxin1988@foxmail.com;
wuyuxin1988@cqu.edu.cn (Yuxin Wu)
** Corresponding author: liuhong1865@163.com (Hong Liu)

very few study using the elderly as test subjects. Our previous study [16] investigated the thermal adaptation of the elderly in summer. However, the thermal responses of the elderly in thermal environments with temperature ramps still worth to be studied.

2 Methods

2.1 Experimental setup

The experiment was carried out in a climate chamber with the dimensions shown in Figure 1: 4.0 m (L) 3.0 m (W) 2.7 m (H). The air-conditioning system could adjust indoor air temperature (Ta) within the range of –5°C and 40°C, with an accuracy of ±0.30°C, as well as relative humidity 10% and 90% with a precision of ±5%. The subjects remained in the preparation room prior to the experiments, as shown in Fig. 1. The test personnel used the control and observation room to monitor the thermal environment and subjects in the climate chamber.



(a)

(b)

Fig.1. The climate chamber: (a) Plan view; (b) Photo of inside

An Italian Richter LSI instrument was used to quantify environmental factors during the experiment. The measurement was placed within 0.5 m of the subject and set to 0.6 m in height. The subjects' height, weight, and body fat percentage were all measured prior to the experiment.

Throughout the experiment, heart rate was measured continuously using a Polar A300 heart rate band.

2.2 Experimental conditions and procedures

The experiment used the climate chamber to simulate two temperature ramp conditions within the temperature range that common in the hot summer and cold winter (HSCW) climate region [17]: a temperature ramp down condition (34 - 18°C) and a temperature ramp up condition (18 - 34°C). The relative humidity in the climate chamber is maintained at 55%±5%, and the air velocity is set to less than 0.15m/s. During the experiment, all testing subjects wore summer clothing that was typical for the region and the overall thermal resistance of clothing is about 0.55 clo.

Subjects were required to arrive half an hour early for the test to remove the effects of different thermal experiences and familiarize themselves with the questionnaires. During the experiment, the subjects remained seated at an activity intensity of about 1.1 met. The subjects completed the questionnaire every 15 minutes during the 150-minute session, while the testers recorded environmental factors and relevant physiological data.

2.3 Subjects

A gender-balanced total of 32 subjects, with 16 health elderly persons and 16 heath college students, participated in the experiments. The anthropometry information (e.g., height, weight, BMI and BF) of the participants in different age groups was measured in advance by the investigators. Each subject participated in the experiment for one time in each condition. All 32 participants of this study involved in the experiments of both temperatures ramp up and down conditions on two different days, with at least one-week interval to ensure that the earlier test did not affect the latter one. The work carried out complied with the Code of Ethics of the World Medical Association (Declaration of Helsinki) [18] for experiments involving human subjects. The university's ethics committee has approved all experiment protocols.

2.4 Questionnaire and processing method

During the experiment, all subjects evaluated their surrounding thermal environment using some scales representing their instant perceptions, including Thermal Sensation Vote (TSV), and sick symptoms. According to ASHRAE standard 55, seven-point scales were used to assess TSV: -3 cold, -2 cool, -1 slightly cool, 0 neutral, +1 slightly warm, +2 warm, and +3 hot.

The data was collected and analysed in SPSS 22. The subjects' responses with time were presented using mean values and standard deviations. To take the variation/error of the data into account, T test was used to examining the significant difference of mean values between the youth and the elderly. Inter-subject effects tests were used to detect the interactions effect of factors. The levels of significance in this paper were set at p = 0.1, 0.05 and 0.01, respectively.

3 Result

3.1 Thermal sensation

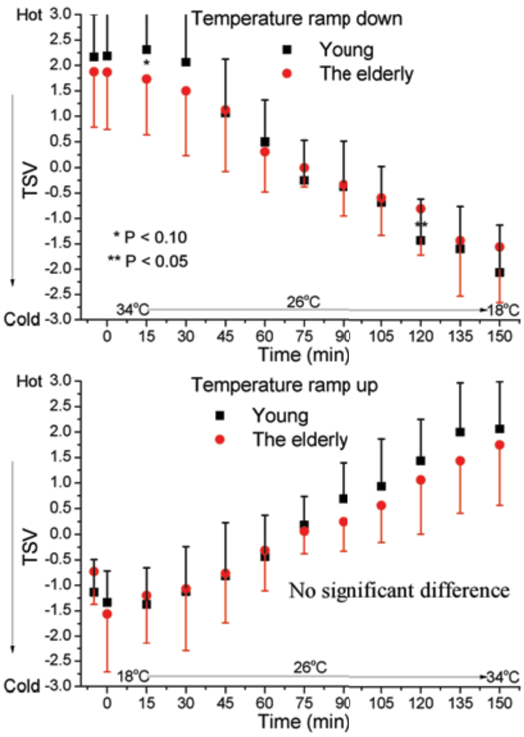


Fig.2. Overall thermal sensation vote with time (mean ± standard deviation)

Fig.2 shows the overall thermal sensation vote with time. Under the temperature drop condition, there was a significant difference between the heat sensation of the elderly and the young people in the 45th minute of the experiment (P<0.1). When the temperature was lowered to 20°C, there was again a significant difference between the thermal sensation of young and old people (P<0.05). The thermal sensation of young people was higher than that of old people with the ambient temperature.

Under the temperature rise condition, the thermal sensation of the elderly in the cooler environment was higher than that of the young people in the first 60 minutes of the experiment. In the ambient temperature of about 24℃, the thermal sensation of young people was gradually higher than that of old people.

In both conditions, the thermal sensation of the elderly in the hot environment was lower than that of the young people, while in the cold environment, the thermal sensation of the young people was lower than that of the elderly. The TSV voting of the elderly in the 0th minute under the temperature rise condition produced an anomaly, which may be due to the fact that the ambient temperature of the preparation room was designed to be 26°C. The elderly with weaker regulation ability suddenly entered the room with an ambient temperature of 18°C and was affected by the thermal experience thus producing a lower thermal sensation.

3.2 Heart rate

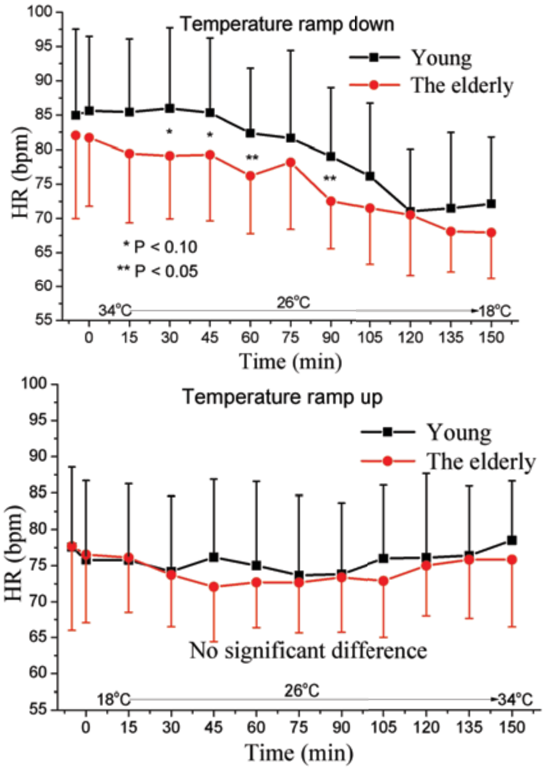


Fig. 3. Heart rate with time

Fig. 3 shows the trend of heart rate changes in both age groups. As shown in the figure, human heart rate decreases with the decrease of ambient temperature. Meanwhile, the heart rate of the elderly was lower than that of the young. In the temperature-decreasing condition, the heart rate of the elderly was significantly lower than that of the young people in the partial-heat condition (P<0.05), but there was no significant difference between the two groups in the temperature-raising condition.

4 Discussion

4.1 The relationships between TSV and skin temperatures

The slope ratios of the linear fitting of the TSV as a function of skin temperatures was close between different age groups when temperature ramp up, which indicated that the elderly feel less warm (Fig.) mainly due to the lower skin temperatures than the young person when air temperature ramp up. While, the elderly was less sensitive to skin temperature changes when air temperature ramp down, which means the elderly have higher health risk in cold environments due to the dysesthesia to physiological cold stress.

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4.2 The effect of time and air temperature on heart rate

From Fig. , it can be deduced that the heart rate (HR) was related to both time and air temperature. Because the heart rate would be decrease with time due to getting more rest with time and the air temperature effect the body functions of vasoconstriction and angiectasis which related to the heart rate. Thus, a new equation to predict HR as functions of resting time (t, min) and air temperature (Ta, °C) is built to calculate the constant values a, b and c:

$$\textit{Predicted HR} = a * t + b * Ta + c \tag{1}$$

The least-square method is used to fit the sets of data (HR, t, Ta):

$$\min(\delta) = \sum_{1}^{n}(\textit{Acutal HR} - \textit{Predicted HR})^2 = \sum_{1}^{n}(\textit{Actual HR} - f(t, Ta))^2 \tag{2}$$

A value set of a, b and c with a minimal deviation from all data points is desired. To minimize the least square error, a program was running in MATLAB 7.0 to derive the values of a, b and c. The results showed the least square errors are 137 and 46 for the young and elderly, respectively. And the average differences between actual and predicted HR are 2.2 and 1.2 for the young and elderly, respectively. The expression equations are shown as follows:

The young:

$$\textit{Predicted HR} = -0.05t + 0.5Ta + 70; R2=0.86 \tag{3}$$

The elderly:

$$\textit{Predicted HR} = -0.04t + 0.4Ta + 67; R2=0.86 \tag{4}$$

($t < 180$ min, $18°C < Ta < 34°C$)

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