A physiological chamber experiment to explore human thermal adaption on the seasonal scale

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Abstract. In the theory of thermal adaption, it’s usually believed that people can adapt to the thermal environment actively from three aspects: physiology, psychology and behaviour. The purpose of this study is to explore whether there is some thermal physiological adaption on the seasonal scale. A chamber experiment was designed and conducted twice at spring and early summer with the time interval of 1 month. There were totally four experimental conditions in each experiment, including 16 °C, 22 °C, 28 °C and 34 °C. We measured four physiological parameters of 18 recruited subjects, including in skin temperature, blood flow, moisture evaporation amount and metabolic rate. At the same time, some of the subjective thermal evaluation was collected. It was a tracing experiment in which the same individual was asked to participate in the experiment twice. So, some comparison on physiological parameters and thermal comfort evaluations at different season could be explored to illustrate the characteristics of thermal adaption. We found that there was some obvious difference on the moisture evaporation and the blood flow after one-month adaption, and the thermal comfort vote in the same temperature also had some variation. This study is meaningful for further understanding the mechanism of thermal adaption.

1. Introduction

Adaptive thermal comfort model which emphasises the active regulated ability of human body in the interactive relationship between human and environment was popularly discussed since it proposed in 1990s [1]. Human can interact with the environment by three adaptive way from the aspects of physiology, phycology, and behaviour [2]. Based on the concept of adaption, the comfortable temperature range is not changing narrower without any obvious improvement on human perception [3], but wider because of the applying of human active adjustment which has a huge energy saving potential [4]. However, the mechanism of thermal adaption is not clear, and the understanding of the adaptation generation is not comprehensive. In the previous chamber study, some research [5] focused on human thermal perception of a steady environment, but less of them discussed about thermal adaption in chamber. Though physiological adaption usually used to describe the difference on preferred temperature, none of the study proved it by measurement in chamber or on human. To illustrate the laws of adaptive phenomenon on the seasonal scale is of vital importance for further understanding of thermal adaptation. The purpose of this study is to explore the laws of physiological adaption on the seasonal scale. A chamber experiment was designed to do some comparison at different season with the time interval of one-month. It is meaningful for further understanding the mechanism of thermal adaption.

2. Methodologies

This experiment was carried out in a climate chamber in Beijing China. Eighteen subjects were recruited to participate in this experiment. They are all college male students with the average age of 22. To illustrate the difference before and after one month, the same subjects were asked to participate the experiment twice. The experimental procedure was shown in Figure 1. There were totally four experimental conditions in each experiment, including 16 °C, 22 °C, 28 °C and 34 °C, which were...
selected considering that the adaptive differences were more obvious in some non-neutral environment. Subjects were asked to change into the unified clothes (trousers with short sleeves, 0.56 clo) and adapt to the temperature for 20 min firstly, then they needed to fill in the questionnaires each 10 min with some physiological measurement at the same time. We mainly focused on four physiological parameters in this study, included in skin temperature, blood flow, moisture evaporation amount and metabolic rate. The skin temperature was measured by thermocouple with the accuracy of ±0.1 °C in seven-point method. The blood flow was of the right middle finger which was measured by Doppler flowmeter. The moisture evaporation amount was calculated by the human weight difference tested of high precision electronic balances before and after each experiment. And the metabolic rate was measured by an exercise physiology system which could determine the respiratory gas composition. Subjects were asked to answer some questions every 10 min during the experimental process. The subjective thermal evaluation questions were TSV and TCV with their scales shown in Table 1 [6].

| Questions         | Scales                                      |
|-------------------|---------------------------------------------|
| Thermal sensation | Very cold (-3), cold (-2), a little cold (-1), neutral (0), a little hot (1), hot (2), very hot (3) |
| Thermal comfort   | Very uncomfortable (-3), uncomfortable (-2), slightly uncomfortable (-1), slightly comfortable (1), comfortable (2), very comfortable (3) |

There were two groups of experiment. Group A was carried out in April which climate was the last winter and early spring; Group B was carried out in May which climate was the early summer. The average temperature difference was about 10 °C. One-month interval was between these two experimental groups. The outdoor temperatures were shown in Figure 2. One highlight of was that this study was a tracing experiment because the same individual was asked to participate in twice experiments with one-month interval. By comparing the differences of the same subjects before and after, the influences of differences between individuals on the results could be effectively avoided.
3. Results
In this experiment, we compared the results of two groups to see whether there was some adaptive phenomenon in human’s sensation of thermal environment on a seasonal scale.

3.1. Comparison of objective parameters
The four parameters: skin temperature, blood flow, moisture evaporation amount and metabolic rate were the main physiological parameters we selected which could describe the relationship between human body and surrounding environment.

During the whole experiment, the skin temperature of human body was recorded continuously used the seven-points method. The mean skin temperature can be calculated based on the following equation (1) [7]. The comparison of the two groups’ mean skin temperature was shown in Figure 3. It was found that the mean skin temperature has a positive relationship with the temperature. In the conditions of 22 and 28 °C which were close to neutral, the mean skin temperature of the two groups were nearly the same. But there was some discrepancy between the mean skin temperature of Group A and Group B in the conditions of 16 and 34 °C. T-test was used to illustrate the significance of difference here. P values of conditions 16°C and 34 °C were 0.05 and 0.006, respectively. It seemed that the skin temperature was lower when human adapt to a relatively higher outdoor temperature, while the difference was not obvious.

\[
T_{sk-m} = 0.07 \times T_{head} + 0.35 \times T_{trunk} + 0.14 \times T_{left\_lower\_arm} + 0.05 \times T_{left\_hand} + 0.19 \times T_{left\_thigh} + 0.13 \times T_{left\_leg} + 0.07 \times T_{left\_foot}
\]

(1)

Where \(T_{sk-m}\) is the mean skin temperature; \(T_x\) is the skin temperature of body part “x”.

![Figure 3. Mean skin temperature of the two groups at different experimental conditions](image)

The metabolic rate comparison of the two groups was shown in Figure 4. The differences of this parameter in two groups were not significant. The metabolic rate was generally stable at about 1.0 met. It meant the metabolic rate could not reflect the adaption in a steady environment.
Figure 4. Metabolic rate of the two groups at different experimental conditions

Figure 5 shows the comparison of blood flow. Blood flow is an important parameter which can reflect the ability of adaption by vasoconstriction and vasodilatation. It varied in a large range when temperature changed. In the comparison of two groups, we found that the blood flow had some obvious differences when the temperature near to neutral, which represented that some differenced happened in human regulation ability. But in the extremely cold or hot condition, the difference of blood flow was not obvious which meant that there is little difference in human regulatory capacity at extreme temperatures. And P values of conditions 22°C and 28 °C were 0.0001 and 0.02, respectively, which meant there were significate differences between these two groups in the conditions of 22°C and 28 °C.

Figure 5. Blood flow of the two groups at different experimental conditions

Figure 6 shows the comparison of moisture evaporation amount of the two groups. Moisture evaporation amount is an indicator of human sweat regulating ability in hot environment. The difference with the P value of 0.04 in the 34 °C condition between Group A and Group B reflected that the sweat ability could be intensified when experienced higher outdoor temperature for one month. It meant that human body adapted to the environment and prepared for the coming higher temperature in summer.
Figure 6. Moisture evaporation amount of the two groups at different experimental conditions

3.2. Comparison of subjective evaluations
The thermal evaluations before and after one month were also compared. The differences of thermal sensation and thermal comfort between Group A and Group B could represent the degree of thermal adaption.

Figure 7 shows the comparison of thermal sensation in different temperatures. T test was used here, and P value of each condition was above 0.05, which meant that there was no significant difference between the two groups. They both obeyed the tendency that increased following the increasing temperature. We could say that human thermal sensation of a specific steady temperature was relatively stable.

Figure 7. TSV of the two groups at different experimental conditions

However, it was found that there were some differences in thermal comfort feelings, as shown in Figure 8. When people experienced higher outdoor temperature, their thermal comfort vote would deviate. It meant that they had adapted to the warmer environment and felt more comfortable in the same temperature compared with the data in Group A. The similar phenomenon was observed in the cold side. P values of these two extreme conditions were both lower than 0.05. It seemed that the physiological adaption had no effects on human thermal sensation but changed the thermal comfort perception.
Figure 8. TCV of the two groups at different experimental conditions

4. Discussion
How long would it take for human to adapt to a climate change? In this study, it proved that the thermal adaption on the seasonal scale was existed. Though the differences of skin temperature and the metabolic rate were not obvious, the blood flow and the moisture evaporation amount could be used as the typical physiological parameters which represented the adaption. Also, we found some variations on thermal comfort feelings. Even if there were no obvious changes on the sensation of hot and cold, the comfortable perception of the same temperature changed. Thermal history was a considerable factor which related to human thermal perception. It should be deliberated in the construction of indoor thermal environment. The expression of human thermal adaptive ability was suitable in a specific temperature range. It could be evident in the temperature near to neutral. For some extreme temperature deviated neutral, there was little difference on the results of thermal adaption but it may had differences on the regulation process for response to temperature changes.

Indeed, there were some limitations of this study which should be considered further. This experiment was only referred to the conditions that the adaptive time length of one month. Maybe in a longer adaption time, the observations of physiological parameters and thermal evaluations were different from the above results. However, this individual tracing experiment offered more details of thermal adaption on the seasonal scale which could help for the understanding of thermal adaptive mechanism and for the instruction of indoor environment construction.

5. Conclusion
This study focused on the comparisons of physiological parameters and subjective thermal evaluations before and after one-month adaption. We found that thermal physiological adaption on the seasonal scale was existed. Blood flow and moisture evaporation amount can be used as the indicators of thermal adaption. And the differences of subjective feeling can be reflected on thermal comfort vote. If people have adapted to a higher outdoor temperature, their physiological regulation ability change, and their comfortable temperature shift toward warmer side. These study help to further understand the thermal adaptation mechanism and offer some theoretical support for adaptive thermal comfort researches.

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