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Physiological response to typical temperature step-changes in winter of China

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ABSTRACT

This study mainly explored human health and thermal comfort associated physiological response to temperature step-changes in winter. Several physiological parameters, including blood pressure, blood oxygen saturation (SPO_2), skin temperature and electrocardiograph (ECG), were measured to exam human reactions to temperature alterations of different intensities and directions. Three temperature step-change conditions (S10: 20 °C; 10 °C; 20 °C, S20: 20 °C; 0 °C; 20 °C, S40: 20 °C; −20 °C; 20 °C) were developed with 18 healthy subjects recruited. Statistical analysis shows that blood pressure is sensitive to temperature steps since significance is detected for values before and after step-changes in all three conditions. The increase in systolic pressure after sudden cooling in the large down-step (S40) reached 18 mm Hg, around fourfold and twice that in small (S10) and medium steps (S20), respectively. Besides, systolic pressure appears to be more responsive than diastolic pressure. Instant change in skin temperature caused by down-step is remarkably larger than that by up-steps. More than 45 min were demanded for skin temperature to become stable after 15 min' exposure in −20 °C. In S20 and S40, the ration of LF (low frequency power) to HF (high frequency power) of ECG underwent remarkable decrease after sudden cooling, and vice versa.

1. Introduction

People always encounter temperature alteration in daily life; for example, moving between air-conditioned indoor and outdoor, getting on or off planes, etc. Temperature step is determined by both the indoor and outdoor thermal levels; it influences both thermal comfort and human health. From the perspective of physiology, temperature step-change affects human health mainly in two ways. For one thing, long-term exposure to such man-made stable environment are supposed to weaken human thermal regulation ability [1–4]. Furthermore, the large temperature gap produced by the neutral indoor temperature will in turn pose great physiological stress on the weakening thermal regulation system [2,4–6].

There already exist some experimental studies concerning effect of temperature alterations on human health. It is reported that people with long-term exposure to air-conditioned environment are more likely to suffer from heat stroke when transferring between indoor and outdoor [7,8]. Cao carried out a field study and concluded that the rates of discomforts in air-conditioned groups were significantly higher than people who didn't use air-conditioning [4]. Some other studies also found that big difference between indoor and outdoor temperatures was the main reason for the Sick Building Syndrome [9–11]. However, most of them were focused on the summer condition while little attention was paid to the winter case, especially in severe cold area where the temperature gap can be pretty large. For instance, in the winter of Northeast China, the outdoor temperature is always as low as −20 °C while the indoor environment is around 20 °C, resulting in a temperature gap up to 40 °C or larger.

By now an increasing number of studies on transient thermal environments have used physiological parameters to probe into thermal comfort [2,5,7,12–16]. It is believed that using physiological mechanism in studies to explore effect of temperature alterations on human health is also of great importance. Physiological parameters including blood pressure, oxygen saturation, skin temperature and electrocardiograph which are associated with thermal comfort and health [2,17–19] are investigated in this study.

Blood pressure is closely related to human thermoregulation and health. Ambient temperature down-step will cause vasoconstriction followed by immediate blood pressure rise which may not only lead to health discomforts but also serious health issues, like cardiac infarction or stroke. Blood pressure (BP) is usually expressed as two numbers. Systolic pressure (SBP, the maximum

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value) measures the pressure in the arteries when the heart beats while diastolic pressure (DBP, the minimum number) represent the pressure in the arteries between heartbeats [20].

Blood oxygen saturation (SPO_2) is the percentage of hemoglobin binding sites in the bloodstream occupied by oxygen and it can reflect effect of stressors on human respiratory system. The change of air temperature is a typical kind of thermal stimulus, so we included this parameter to explore its influence on human respiration. The standard unit of oxygen saturation is percent (%) and oxygen saturation is commonly measured by pulse oximetry.

Skin is a mediator for body to keep thermal balance with the ambience and it is sensitive to the change of air temperature [16,17,21]. There are large numbers of cold and warm thermoreceptors which are connected to neurons located in the anterior hypothalamus in skin. Any factors that may cause vasoconstriction or vasodilatation will affect skin temperature. In warm environments, skin temperature increases and become more uniform, leading to the decreased skin temperature gap among local body parts. By contrast, in cold ambience, less blood flow towards extremities followed by larger local temperature difference.

Another important physiological parameter that will explored in this study is electrocardiograph (ECG) because of its association with thermal comfort degree and stress reaction [17]. Autonomic nervous system is in control of cardiac automaticity. The sympathetic system affects heart rate by the release of epinephrine and norepinephrine, and the parasympathetic system does that by the release of acetylcholine through the vagus nerve [22]. The vagal and sympathetic activities interact with each other. The spectral analysis of heart rate variability (HRV) which is the variation in the time interval between heartbeats can provide an overview of the modulatory effects of neural mechanisms. Low frequency (LF: 0.04–0.15 Hz) and high frequency (HF: 0.15–0.4 Hz) are typical bands analyzed by frequency domain methods for short-term ECG recordings [17]. It has been evidenced that LF is a marker of sympathetic modulation especially when expressing it in normalized units [23] while HF is related with parasympathetic nerve system [22,23]. Additionally, their ration, namely LF/HF, is usually acknowledged as an indicator of the interaction between LF and HF.

The purpose of this study is to quantify human physiological responses to temperature step-changes typically encountered in winter, aiming to provide some information for the design of transient thermal environment. Effect of temperature step of different intensities as well as opposite directions were analyzed. Besides, sensitive physiological parameters in transient thermal environments were identified.

2. Materials and methods

2.1. Conditions

The experiment was carried out in Qiqihaer (47.38° N, 123.92° E), a typical city in severe cold zone of China. In January of 2016 when this experiment was implemented, the monthly mean temperature was −19 °C with the mean low and high temperature of −24 °C and −14 °C, respectively.

Three step-change conditions of different intensities and directions (S10: 20 °C; 10 °C; 20 °C, S20: 20 °C; 0 °C; 20 °C, and S40: 20 °C; −20 °C; 20 °C) were developed to simulate situations that are common in daily life. The warm room was set at 20 °C which is the typical indoor temperature in heating area. Low temperatures of 10 °C and 0 °C were designed to represent thermal levels in non-heating room and the outdoor situation in hot-summer and cold-winter zone, respectively. −20 °C is the common outdoor temperature in winter of severe cold area. Instruments for environmental measurement are summarized in Table 1. The monitoring site is located at the center of the each room. The air temperature and relative humidity were recorded every 10 s by data loggers at 0.1 m and 1.1 m height. The air velocity was also measured. As shown in Table 2, all temperature levels were kept around the nominal values. Relative humidity was within the range from 20% to 25% in warm room and from 40% to 55% in cool ambience. Velocity of the air was less than 0.1 m/s. Direct solar radiation on subjects was avoided.

2.2. Participants

Eighteen subjects (mean ± S.D. of age: 30 ± 3 years, height: 168.1 ± 5.7 cm, weight: 66.9 ± 9.6 kg, BMI: 23.6 ± 2.8 kg/cm^2) were recruited, 9 males and 9 females. They were born and raised in severe cold area of China. Instead of standardized clothing, subjects were asked to wear similar clothes during the experiment. We recorded and calculated the dressing based on Ref [24]. Results show that subjects' clothing insulation are generally the same. In the warm environment (20 °C), their clothing insulation was about 1.2 clo, namely underwear with long legs and sleeves, sweater, trousers, socks, shoes. When moving to cold environment (10 °C, 0 °C and −10 °C), subjects would put on their down jackets (about 0.5clo) just as they do in real life, leading to the clothing insulation up to approximate 1.7 clo. All protocols were approved by the university's ethics committee. Verbal and written informed consents were obtained from each subject prior to the participation. All subjects were normotensive and not currently taking prescription

Table 1
Instrumentation information.

Measurement	Instrument	Specification
Physical measurements		
Air temperature	TR-72, T&D CO., Japan	Accuracy: ±0.3 °C Range: 0 °C–50 °C
Air temperature	Pyrobutton-L, OPULUS Ltd., USA	Accuracy: ± 0.2 °C Range: −40 °C–85 °C
Relative humidity	TR-72, T&D CO., Japan	Accuracy: ±5% Range: 10%–95%
Air velocity	TESTO 425, TESTO AG, German	Accuracy: ±(0.03 m/s +5% measured value) Range: 0 m/s–20 m/s
Physiological measurements		
Blood pressure	TKBP-H01, dftaihua Ltd, China	Accuracy: ±1 mmHg Range: 0 mmHg–300 mmHg
Oxygen saturation	Prince-100H, Healforce Instrument,China	Accuracy: ±2% Range: 35%–100%
Skin temperature	Pyrobutton-L, OPULUS Ltd., USA	Accuracy: ± 0.2 °C Range: −40 °C–85 °C
ECG	CCS-103, Careshine Electronic Technology Ltd., China	