HUMAN TRANSIENT RESPONSE UNDER LOCAL THERMAL STIMULATION

by

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Human body can operate physiological thermoregulation system when it is exposed to cold or hot environment. Whether it can do the same work when a local part of body is stimulated by different temperatures? The objective of this paper is to prove it. Twelve subjects are recruited to participate in this experiment. After stabilizing in a comfort environment, their palms are stimulated by a pouch of 39, 36, 33, 30, and 27 °C. Subject's skin temperature, heart rate, heat flux of skin, and thermal sensation are recorded. The results indicate that when local part is suffering from harsh temperature, the whole body is doing physiological thermoregulation. Besides, when the local part is stimulated by high temperature and its thermal sensation is warm, the thermal sensation of whole body can be neutral. What is more, human body is more sensitive to cool stimulation than to warm one. The conclusions are significant to reveal and make full use of physiological thermoregulation.

Key words: *human body, physiological parameter, thermal sensation, thermal stimulation*

Introduction

Human beings spend most of their time in building environment. So, the comfortable indoor environment is very important. Because occupants thermal sensations are different between artificial and natural environment, the researches about thermal comfort consist of experimental test in artificial environment and field test in natural environment. In the former research, predicted mean vote [1] is usually used, while in the latter research, thermal adaptive models [2] are effective.

Actually, human has the ability of adaptation to environment by thermoregulatory system which is closely related to thermal comfort. The common methods of thermoregulation are the vasoconstriction, vasodilatation, muscle metabolism by shivering, and skin moisture excretion by sweating [3, 4]. In the quiet condition, 60-70% of the circulatory blood is stored in the vein [5], and is useful for vasoconstriction and vasodilatation.

Nowadays, physiological parameters are widely used to reveal the mechanism of thermal comfort. Mean skin temperature is the most actively physiological parameter in thermal comfort researches [6]. It is calculated by the local skin temperature and weighting factors, such as 4-site [7], 6-site, 7-site, 10-site [8], 21-site [9], and 32-site [10, 11] method. Choi *et al.* [12] thought that high metabolic rate would improve heart rate. So the heart rate has dramatic

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correlation with metabolic rate, and is usually tested in different thermal environments [13]. Li *et al.* [14] and Tan *et al.* [15] did lots of physiological experiments, and they adopted about 10 kinds of physiological parameters, such as skin temperature, core temperature, skin impedance, heart rate, electrocardiograph, electroencephalograph, motor conduction velocity, sensory nerve conduction velocity (SCV), and so on. They proved that SCV was a representative parameter to present the effects of thermal environment on human neural physiological system.

In our experiment, the thermal resistance of skin or its conductive heat flux was sensitive to human thermal sensation. For inanimate materials, such as evaporator wick [16], nanoscale thin films [17], and nanofluid in a tube [18], thermal resistance is equal to temperature difference divided by heat flux, but for human skin, this method should be revised according to physiological thermalregulation. Heat flux is the function of thermal resistance, and can be measured directly. In order to reduce calculation error, heat flux is used in this paper. Besides, skin temperature, heart rate, and thermal sensation are recorded to research the effects of local stimulation on physiological thermoregulation.

Methodology

Climatic chamber

The climatic chamber is located at the College of Environmental and Chemical Engineering, Xi'an Polytechnic University, Xi'an, China. It consists of climatic chamber and control room, and can accurately control environmental parameters, such as air temperature, relative humidity, and air speed. The air temperature can be set between 0 °C and 40 °C, with the accuracy of ±0.3 °C. The relative humidity can be set between 15% and 85%, with the accuracy of ±4%. The air speed is controlled by a frequency converter that can be adjusted from 0 to 50 Hz, and the range of air speed is 0.1-2 m/s.

Subject characteristics

A total of 12 subjects participate in this experiment. The subjects are all graduates between the age of 23 and 27. The height is 1.76 ± 0.07 m, and the weight is 70.1 ± 10.9 kg. Prior to commencing with the experiment, the subjects wear the required clothes. During the experiment, the subjects simulate light activity, such as reading or chatting.

Subjects who may suffer from skin allergy, fever and other disorders or may be using skin medicinal products that are known to interfere with the evaluation of skin physiology are excluded. The subjects are prohibited from applying lotions, sunscreens, skin-care products, or pharmaceutical products of therapeutic effects at the measurement points during the experiment. They are also prohibited from performing strenuous exercise, and drinking coffee or alcoholic drinks in 24 hours prior to testing. The subjects are briefed on the course of this experiment, and an informed consent is obtained from each participant.

Instruments

Human skin temperature usually includes the local and mean skin temperature. Local skin temperature refers to the skin temperature in the hand, arm, face, trunk, thigh, leg, and foot. It can be measured directly by instrument. Mean skin temperature refers to the skin temperature of whole body, and is calculated by local skin temperature. Similar to skin temperature, the conductive heat flux of skin includes local and mean conductive heat flux. Local conductive heat flux is the conductive heat flux in hand, arm, face, trunk, thigh, leg, and foot. Mean conductive heat flux is calculated by local conductive heat flux.

The skin temperature of whole body (MST) is calculated by:

$$MST = 0.07t_{\text{forehead}} + 0.35t_{\text{chest}} + 0.14t_{\text{forearm}} + 0.05t_{\text{palm}} + 0.19t_{\text{thigh}} + 0.13t_{\text{leg}} + 0.07t_{\text{sole}} \quad (1)$$

where t_{forehead}, t_{chest}, t_{forearm}, t_{palm}, t_{thigh}, t_{leg}, and t_{sole} are local skin temperature in °C of forehead, chest, forearm, palm, thigh, leg, and sole, respectively.

The heat flux of whole body (MCHF) is given by:

$$MCHF = 0.07q_{\text{forehead}} + 0.35q_{\text{chest}} + 0.14q_{\text{forearm}} + 0.05q_{\text{palm}} + 0.19q_{\text{thigh}} + 0.13q_{\text{leg}} + 0.07q_{\text{sole}} \quad (2)$$

where q_{forehead}, q_{chest}, q_{forearm}, q_{palm}, q_{thigh}, q_{leg}, and q_{sole} are local conductive heat flux in W/m^2 of forehead, chest, forearm, palm, thigh, leg, and sole, respectively.

In this experiment, both the skin temperature and heat flux are tested by the multi-channel heat flow meter (HFM-215N) with low heat flow sensors (KM1). The KM1 is designed to be put on the surface of a living body of high sensitivity and high precision. Its outside diameter is 30 mm × 15 mm, and the thickness is 1.7 mm. The heat flow measurement range is 11.6-3480 W/m^2, and the temperature range is –40-150 °C. The accuracy is ±2%.

The heart rate is tested by DMS300-4A, 10 leads ECG. Its sampling frequency is from 256 to 4096 Hz. The sensitivity error is less than 10%.

Experimental procedure

In order to study the effects of local skin stimulation on physiological thermoregulation, the subjects should experience thermal comfort and local stimulation from warm to cool. So, the ambient environment is controlled as 23 °C, 50%, 0.05 m/s, which is comfortable for subject (clothing thermal resistance of 1.0 clo, sedentary). Palm is selected as the local part to be stimulated. Stimulating temperatures are 39, 36, 33, 30, and 27 °C, respectively. After one stimulation at set temperature is finished on one palm, another palm is stimulated by next temperature. For each stimulation, the period is about 20 minute.

Under each stimulation, the subject is physiological parameters, such as skin temperature, heart rate and heat flux are recorded. In order to quantify subject is thermal sensation, the ASHRAE thermal sensation, the ASHRAE thermal sensation vote (TSV) (see [19]) is used, as shown in tab. 1. When the measurement at the stimulation is finished, the stimulation is set to the next temperature value. During the experiment, the subjects are blinded to the experiment.

Table 1. Define of TSV

3	2	1	0	–1	–2	–3
Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold

Results and analysis

Skin temperature

Skin can perceive the cold and hot stimulus, and sends signal to hypothalamus. Skin temperature is often measured as an essential physiological parameter related with human thermal response. In fig. 1, before stimulation, the mean skin temperature of palm is about 32 °C. Under the stimulation of 39, 36, 33, 30, and 27 °C, the skin temperatures of palm have significant changes. The higher the stimulating temperature is, the longer period the palm needs to stabilize. When the stimulating temperature is 30 and 27 °C, the skin temperatures of palm stabilize at 32.7 and 31 °C, respectively. The palm temperature is higher than stimulating temperature because palm has stored heat at high stimulating temperature (39, 36, 33 °C), and the heat does not release completely at low stimulating temperature (30, 27 °C).

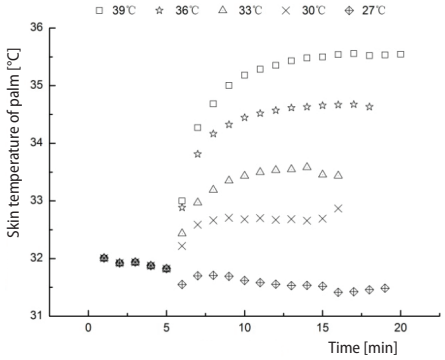

Figure 1. The skin temperature of palm under different stimuli

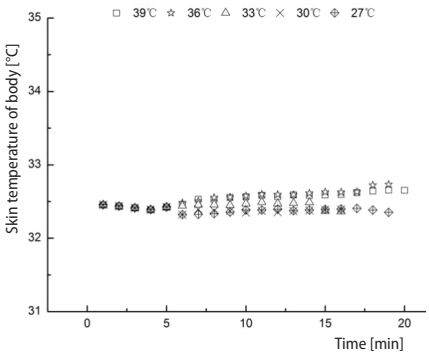

Figure 2. The skin temperature of body under different stimuli

The skin temperatures of whole body are shown in fig. 2. Before the stimulation in palm, the mean skin temperatures of body are about 32.5 °C, while when palm is stimulated from 39 to 27 °C, they change a little, less than 0.5 °C. It means that when local skin is affected by harsh temperature, the physiological parameter of whole body is also impacted. Although it changes slightly, it is proved that the whole body is doing physiological thermoregulation.

Heart rate

High metabolic rate would increase the volume of circulation blood, which would improve heart rate. So, the heart rate has dramatic correlation with metabolic rate, and is usually tested in different thermal environments.

In fig.3, the heart rate is about 76 beats per minute (bpm) before stimulation, and it changes between 73 and 78 after stimulation. When the stimulating temperature is 39 °C, heart rate is a little higher than 76 bpm, while when the stimulating temperature is 36, 33, 30, and 27 °C, heart rate is below 76 bpm. It decreases as the stimulating temperature declines. Therefore, when palm is stimulated by different temperatures, the heart rate is adjusting, and the body is doing physiological thermoregulation.

Heat flux of skin

When skin feels cool or warm, body can regulate its temperature by vasodilatation or vasoconstriction. The blood flow volume under skin increases or decreases, which can change the thermal resistance of skin, and thus the heat flux of skin will alter. So, the heat flux of skin is tested in this experiment.

Figure 4 indicates that the mean heat fluxes of whole body are 46 W/m^2 before stimulation, they decrease a little after stimulation. From 39 to 27 °C, as the difference between ambient temperature and skin temperature increases, the heat flux should rise, but it does not. It decreases a little because when the skin gets the sign of cool, see fig. 6, it uses the physiological thermal regulation, namely vasoconstriction and closed pore to improve the thermal resistance of skin. Thus, the heat flux declines as the stimulating temperature decreases.

Thermal sensation

The TSV is used in this experiment to reflect human psychological response. Figure 5 shows the local thermal sensation of palm. Before stimulation, the TSV of palm are about 0, and the local thermal sensation is neutral. When the stimulating temperatures are 39, 36, 33, 30,

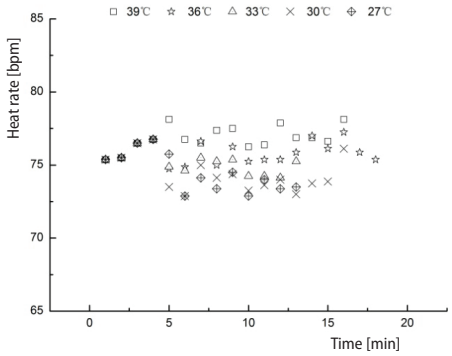

Figure 3. Heart rate under different stimuli

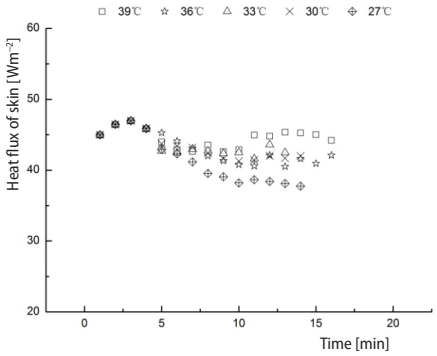

Figure 4. Heat flux of whole body under different stimuli

and 27 °C, the TSV of palm after stability are 1.6, 1.3, 0.6, 0, and –1.0, respectively, changing from warm to slightly cool.

Figure 6 presents the thermal sensation of whole body. In different stimulating temperatures, TSV of whole body change between 0 and –0.7. They are less sensitive than TSV of palm. Besides, under the stimulating temperature of 39 and 36 °C, the thermal sensation of whole body is nearly neutral, which means that although local skin is suffering from high temperature, the whole body can still feel comfortable. Under the stimulating temperature of 33, 30, and 27 °C, the whole body feels slightly cool because it satisfied with the high temperature stimulating (39 and 36 °C), and any stimulating temperature lower than those temperature is processed into cool by the receptor under skin. Another reason is that the cold receptors under skin are more than hot ones, and thus human is more sensitive to low temperature than to high temperature.

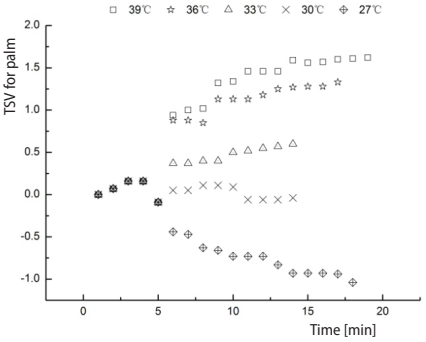

Figure 5. The TSV of palm under different stimuli

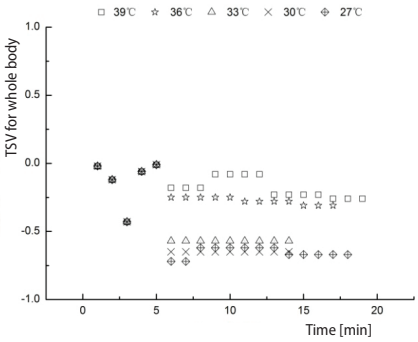

Figure 6. The TSV of whole body under different stimuli

Conclusions

When palm is stimulated by 39, 36, 33, 30, and 27 °C, human physiological parameters and thermal sensation have corresponding responses. This research proves that the local part is more sensitive to the stimulation than the whole body both in skin temperature and thermal sensation, and the higher the stimulating temperature is, the longer time the palm needs to stabilize.

The physiological parameters prove that when local skin is affected by harsh temperature, the whole body is doing physiological thermoregulation, although it has a weak variation.

The thermal sensation data indicate that when palm is stimulated by high temperature, the thermal sensation of this part has great variation, but the thermal sensation of whole body is stable. That is to say when local skin is transitorily suffering from high temperature, the whole body can keep feeling comfortable.

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