EVALUATION OF PSYCHOLOGICAL AND PHYSIOLOGICAL RESPONSES UNDER GRADUAL CHANGE OF THERMAL CONDITIONS WITH AIM TO CREATE INDEX TO EVALUATE THERMAL COMFORT OF CLOTHES

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ABSTRACT

Temperature and humidity at the periphery of the human body is a direct factor that influences thermal comfort. This paper describes the evaluation of thermal comfort through measurement of the physiological and psycho-logical responses to changes in the microclimate surrounding the human body. We investigated the validity of considering the results of physiological response and psychological response separately in the evaluation of thermal comfort. The temperature and humidity was changed using 2 patterns: from neutral to hot, and from hot to neutral. We measured peripheral blood flow as the physiological response and sensory test as the psychological response to changes in the microclimate. The threshold of physiology and psychology were deduced from the data of peripheral blood flow and sensory test, and the physiological thresh-old was higher than the psychological threshold. The result of our study indicates that establishing a thermal comfortable index reflecting the results of psychological and physiological responses to clothing climate is needed.

Keywords: Psychophysiological response, Thermal comfort, Clothing comfort

1 INTRODUCTION

This study aims to suggest an index to describe thermal comfort in the microclimate within clothing. Our previous paper reported that the thermal comfort is different depending on the direction of the climate change through the measurement of physio-logical and psychological responses (Uemae & Kamijo, 2010). There is a tendency that people easily get a feeling of discomfort in human's thermal comfort sensation in the case of "from neutral to hot" for the temperature and humidity around the human body, comparing with the case of "from hot to neutral". On the other hand, people easily get a comfortable feeling in the case of "from hot to neutral", comparing with the case of "from neutral to hot". Therefore, we concluded that it is necessary to con-sider the change direction of the thermal environment to propose the evaluation index of thermal comfort in the microclimate within clothing.

In this paper, we would like to discuss differences between physiological response and psychological response for thermal stressors. Previous studies have demonstrated that that human being has two perception abilities. One is unconscious, another is conscious (Horiba et al., 2000). In the thermal comfort sensation, although we do not feel the thermal sensation, physiological responses react when given thermal stimulus. The challenge of this paper was to show psychological and physiological responses to a gradually changing thermal stimulus presented to the body in the experimental approach. From these results, we discuss the necessity to consider a thermal comfort assessment index from the point of view of both psychological responses and physiological responses.

2 EXPERIMENT

2.1 Environmental setting

The experiment was conducted in a thermo-hygrostat chamber in which the temperature and humidity can be controlled freely. The participants sat down on a chair in the centre of the chamber. Figure 1 shows the size of the chamber and participant position in it. This chamber has a down flow system to circulate air set to a certain temperature and humidity. The heat exchange between the human body and the environment consists of conduction, radiation and convection. In this study, only heat exchange with the air near the skin is considered as thermal stimulation. In this experiment, conduction is negligible, because the clothes worn by participants are only short pants and underwear. We confirmed that the wind velocity near the skin is weak by using an anemometer (KANOMAX JAPAN INC.). We measured the wind velocity at a height of 60cm at the centre of the floor of the experimental chamber. The measured results are shown in Table 1. The wind velocity was small enough to ignore convection, based on comparing the threshold value as the thermal condition in the microclimate within clothing reported in the previous research (Harada & Morishita, 1997).

Table 1. The results of wind velocity in working environmental chamber

		Measurement		
	Report	Ave	Max	Min
Wind velocity (m/sec)	0.25 ± 0.15	0.03	0.23	0.01

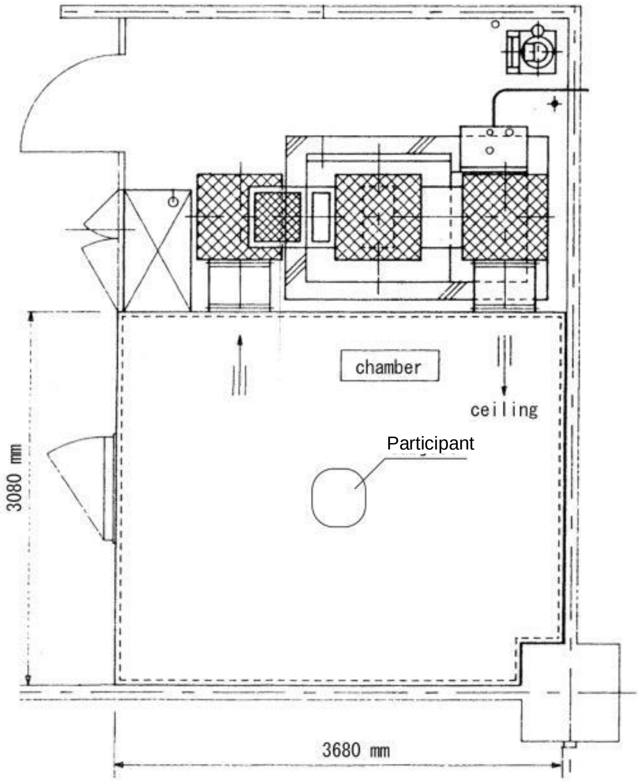


Fig.1. The chamber and participant position

2.2 Experimental setting

Table 2 shows the twelve experimental environment patterns. The experiment setting consists of changes in temperature and humidity, and the change of direction was set in two patterns: one from neutral thermal condition to high thermal one, and the other from high thermal condition to neutral one. The temperature was increased (or de-creased) by 2 degrees Celsius every 30 minutes. The humidity was increased (or de-creased) by 10%RH every 30 minutes. Patterns A and C are a pair of settings with opposite temperature change directions. Patterns B and D are a pair of settings with opposite humidity change directions. For Patterns A and C, during the experiment of temperature change, humidity was controlled at a constant level of one of three humidities (30%RH, 50%RH, or 80%RH), and for Patterns B and D, during the experiment of humidity change, temperature was controlled at a constant level of one of three temperatures (28°C, 32°C, or 36°C). In this paper, we would like to discuss the four patterns of thermal change.

Table 2. Settings of experiment environment

Direction	Variable	Setting of Variation							Constant		Ex No.	Pattern
		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7				
to High	Temperature	28℃	30℃	32℃	34℃	36℃	38℃	40℃	Humidity	30%RH	Ex1	A
		26℃	28℃	30℃	32℃	34℃	36℃			50%RH	Ex2	
		24℃	26℃	28℃	30℃					80%RH	Ex3	
to Neutral		40℃	38℃	36℃	34℃	32℃	30℃	28℃		30%RH	Ex4	B
		36℃	34℃	32℃	30℃	28℃	26℃			50%RH	Ex5	
		30℃	28℃	26℃	24℃					80%RH	Ex6	
to High	Humidity	30%RH	40%RH	50%RH	60%RH	70%RH	80%RH		Temperature	28℃	Ex7	C
										32℃	Ex8	
										36℃	Ex9	
to Neutral		80%RH	70%RH	60%RH	50%RH	40%RH	30%RH			28℃	Ex10	D
										32℃	Ex11	
										36℃	Ex12	
	Experimental time (min)	0～30	30～60	60～90	90～120	120～150	150～180	180～210				

2.3 Procedure

All participants were started from Step 1 shown in Table 2. Figure 2 shows the experimental procedure of Ex3 shown in the table as an example of the experiment. The total experimental time of Ex3 was 120 minutes from Step 1 to Step 4. The humidity was controlled to a constant 80%RH, and the temperature was increased 2 degrees Celsius every 30 minutes. The participant was sitting down on the chair for 30 minutes in every step. The sensory test, electrocardiogram (ECG), peripheral blood flow (BF), and temperature and humidity near the skin (ambient to body) were measured during the time from minute 25 to 30 in every step.

2.4 Participants

The participants were 16 healthy males (Table 3). Each participant experienced an experiment of pair settings of “from neutral to hot” and “from hot to neutral” for temperature changes. The experiment was conducted for 2 days: On the first day, the participant experienced the experiment of pattern A, and then experienced pattern B at the same time on another day, because humans have a circadian rhythm (Iriki, 2003). For example, “Ex1 and Ex4” were carried out as a pair of experiment settings. These 12 experiment settings shown in Table 2 had carried out 6 times in 2 years, because it is well-known that the human body has seasonal variations about thermal sensation and thermal physiological responses (Ishigaki, Matsubara, Gonda, & Horikoshi, 2001; Sato, Yamano, Nakanishi, & Nakajima, 1998; Tsuzuki, Isoda, & Yanase, 1991). Since the experiments were carried out a total of 72 times, there were 6 participants' data for each experiment setting. For all participants, we carried out informed consent, and we conducted the experiments after all of participants gave their consent to the meaning of this study.

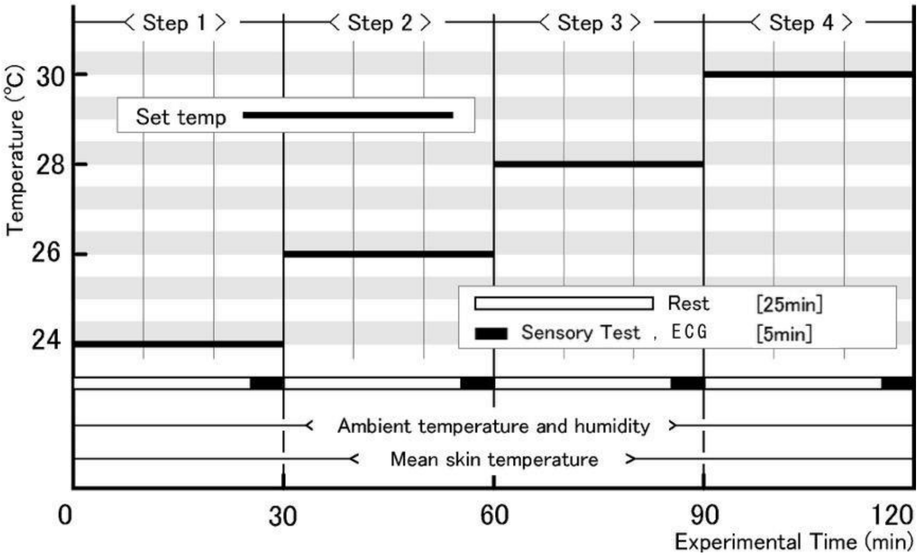


Fig. 2. Experimental procedure of Ex3

Table 3. Characteristics of participants

Participants	Age	Height (cm)	Weight (Kg)	BMI	Body fat (%)
Ave	22.0	173.6	60.9	20.2	13.9
SD	1.2	6.8	6.5	1.8	3.8

N = 16

2.5 Measurement Items

Ambient temperature and humidity near the skin

In our study, ambient temperature and humidity near the skin were measured in order to consider psychological/physiological responses to thermal stimuli from the air near the skin. The temperature and humidity sensors were placed at the positions marked with ■ shown in Figure 3. The sensors were placed in positions of 2cm away from skin at 3 parts: chest, back, and leg. We obtained the average from the 3 measured data as the result. Temperature and humidity were recorded to the data logger (Thermo Recorder TR-72, T&D Inc.) via temperature and humidity sensors (TR-3110) at a 1/20Hz sampling frequency.

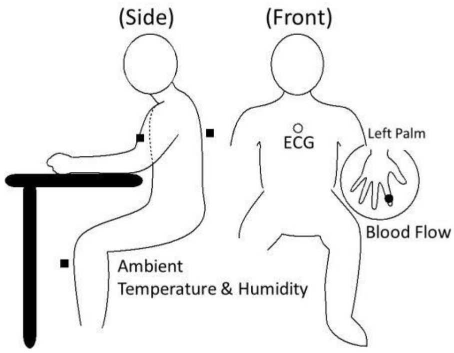


Fig. 3. Sensor positions of temperature, humidity, ECG and Blood flow

Heart Rate

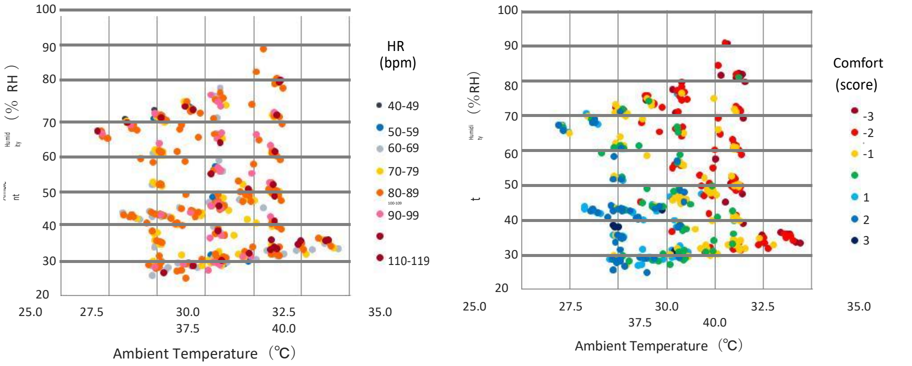
It is well-known that the index of autonomic nerve activity is effective to evaluate stress by thermal stimuli (Sokejima & Kagamimori, 1998). In particular, heart rate (HR) is the most popular index to evaluate thermal stress. Electrocardiogram (ECG) was derived from the precordial leads with the MP 100 (BIOPAC SYSTEMS Inc.) system at 100Hz sampling frequency. We calculated the average of HR in each thermal environment setting.

Sensory test

Participant evaluated thermal comfort sensation every 30 minutes in each thermal environment setting by using the semantic differential method of a 7-point equal-interval ordinal scale: +3 = very comfortable, +2 = comfortable, +1 = slightly comfortable, 0 = neither, -1 = slightly uncomfortable, -2 = uncomfortable, -3 = very un-comfortable.
There are two kinds of thermal comfort: positive and negative directions. Negative thermal comfort means no uncomfortable feeling with hot or cold. The comfort in this study means the negative thermal comfort (Miyata, 1998).

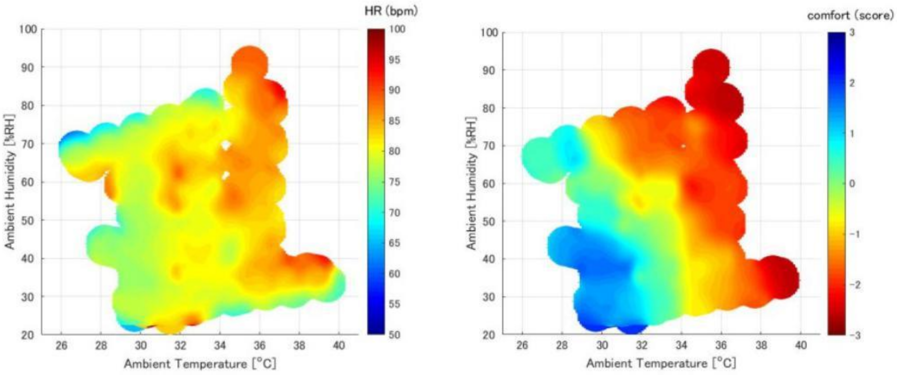
3 Results

The scatter diagrams of Figure 4 shows HR and thermal comfort sensation with respect to temperature and humidity, respectively. Figure 5 shows the data of Figure 4 interpolated and smoothed. An ellipse with a diameter of 1 degree Celsius and 5% RH was set on the temperature and humidity axis. The average value of the HR data contained in the ellipse was obtained in the temperature and humidity range where the data existed. In Table 4, the temperature and humidity range is divided by a grid of 2 degrees Celsius and 10% RH, and the average value of the grid where two or more HR and thermal comfort sensation data exists is shown. The difference between psychological response and physiological response can be seen by comparing the two diagrams.



(a) HR (b) Thermal comfort sensation

Fig. 4. Scatter diagrams of HR and thermal comfort with respect to ambient temperature and humidity



(a) HR (b) Thermal comfort sensation

Fig. 5. Maps of HR and thermal comfort with respect to ambient temperature and humidity

Table 4. Results of HR and thermal comfort with respect to ambient temperature and humidity

(a) HR

Humidity (%RH)	26≤ t< 28	28≤ t< 30	30≤ t< 32	32≤ t< 34	34≤ t< 36	36≤ t< 38	38≤ t< 40
85≤ h< 95							
75≤ h< 85			82	79		88	
65≤ h< 75	78	77	80	81	86	[illegible]	
55≤ h< 65		76	81	81	85	84	
45≤ h< 55		72	78	81	83	83	
25≤ h< 35		77	79	79	[illegible]	82	[illegible]
35≤ h< 45		75	80	81	85	86	92

HR (bpm): 90-95, 85-90, 80-85, 75-80, 70-75

(b) Thermal comfort sensation

Humidity (%RH)	26≤ t< 28	28≤ t< 30	30≤ t< 32	32≤ t< 34	34≤ t< 36	36≤ t< 38	38≤ t< 40
85≤ h< 95					−3		
75≤ h< 85			−2	−2	−3	−3	
65≤ h< 75	1	[illegible]	−1	−2	−1	−2	
55≤ h< 65		[illegible]	0	−1	−2	−2	
45≤ h< 55		0	0	0	−2	−2	
25≤ h< 35		2	1	0	−1	−2	−2
35≤ h< 45		1	1	0	−1	−1	−3

comfort (score): 3, 2, 1, 0, −1, −2, −3

HR increased as the temperature near the skin increased and was not affected by humidity change. The thermal comfort sensation was uncomfortable as the temperature and a humidity near the skin were higher. This result indicated that the thermal com-fort sensation was affected by both temperature and humidity. We obtained different results between psychological response and physiological response by the thermal stimuli near the skin for temperature and humidity.

4 Discussion

Comparing the results of HR and thermal comfort, we confirmed that physiological responses and psychological responses change differently with changes in temperature and humidity near the skin. We considered that the reason is that autonomous body temperature control is performed by the function of the body's homeostasis maintenance mechanism when the temperature near the skin is high. In order to encourage heat dissipation and prevent body temperature from rising, heat is transferred to the periphery by increasing the flow of blood. Since HR is one of the physiological responses controlled by the autonomic nerve system, HR became higher. However, since humidity changes do not affect human body temperature, it is not a trigger to promote autonomous body temperature regulation, so humidity changes did not affect the change of HR as much. On the other hand, the thermal comfort sensation is quite responsive to changes in humidity and temperature. It is well-known that rising skin surface temperature causes perspiration. We surmised that to feel sweat induced the uncomfortable feeling. The detailed reasons are subjects for future research. From these results, it was suggested that indices for evaluating thermal comfort in clothes should include indices of both physiological responses and psychological responses.

5 Conclusions

With reference to the creation of indices for evaluating thermal comfort in clothes, we examined how the psychological index and the physiological index respond to gradually changing thermal stimulus presented to the body. The conclusions are shown below.

The changes of HR as a physiological index were greatly affected by changing temperature, and were hardly affected by changing humidity. That is because HR is the result of autonomous temperature regulation trying to maintain homeostasis of body temperature. The thermal comfort sensation as a psychological index was affected by both changing temperature and changing humidity. We concluded that it is necessary to include both psychological indices and physiological indices as indices for evaluating thermal comfort in clothes.

In the future, it is necessary to create the clothing thermal comfort assessment models composed of physiological index and psychological index, in order to design garments with excellent thermal comfort.

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