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The Study on the Physiological Response in Wearing Sportswear in Two Different Environments

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Abstract : In this study, to find out the physiological reaction of the human body and the sensation of comfort when people are wearing sportswear which is made of waterproof breathable fabrics under general environmental conditons (temperature : 20 ± 1°C, humidity : 60 ± 5%RH, air current : 0.1 m/sec) and rainy environmental conditions (temperature : 20 ± 1°C, humidity : 60± 5%RH, air current : 0.1 m/sec, rainfall : 250 l/hr), we made an experiment with sportswear in an artificial climate chamber and studied the thermal physiological response and subjective sensation. Mean skin temperature of the subjects was low and had a big range of fluctuation in rainy environmental conditions of two condition. Temperature started to increase at the beginning of the exercise, reached the maximum at the 2nd level of the exercise and then started to decline. Rectal temperature showed a slighter increase and bigger range of fluctuation in general conditions than in rainy conditions. Except clothing micro climate in rainy conditions, temperature and humidity and their range of fluctuation around back were higher than those around chest. Humidity was high and had wide range of fluctuation in general conditions. Heart rate was 4.4 beats/min higher in general conditions. In subjective test on rainy conditions, the feeling of discomfort increased due to the raindrops fallen on the skin. Unlike that in general conditions, cold sensation increased and humidity sensation reached to the peak after the exercise. In wearing sportswear made of shape memory breathable waterproof fabric, controlling function over a small amount of heat and water was distinctive while it turned out to be not so comfortable over a large amount of heat and water. Through this, the limitation of shape memory breathable waterproof fabric was recognised.

Key words : sportswear, comfort, rainy environmental conditions, mean skin temperature, rectal temperature, clothing micro climate

INTRODUCTION

Owing to the rapid progress of science in civilization and the change in quality of lifestyle, people have become more and more interested in leisure and sports to improve their health. As a consequence, the conditions for the proper sports environment have varied and people have become more concerned about the functions of sportswear.

There are physical, physiological and psychological conditions for comfortable sportswear. Among those conditions, the movement of heat, moisture and air to maintain body heat balance under the changing weather and during the sports activity is considered to be the main condition.

In other words, comfortable sportswears should control the transmission of heat and moisture according to changeable weather conditions and the motion of the body.

The transmission of heat and moisture, main physiological variables of clothing, should be properly applied according to the weather and environmental conditions and should be able to adopt according to changing weather conditions and the decrease of motion during a break when it is worn for a long time.

As for the condition of the sportswear during a change of weather, under summer hot condition or during severe exercise low conduct effect, fast transportation of moisture and low absorbition of moisture have to be achieved, because sweat loss is high. However, under the cold environment, when sweat loss is low, high conduction effect and good absorbtion of moisture is needed.

Therefore, choosing good material which can adapt according to conditions is very important for the comfort sensation of clothing.

As for the studies on the sensation of comfort according to the change in environment, Kim K. H., and Park K. H (1999) reported that the change of environmental temperature has an effect on physiological change, but the form of the sportswear does not. Midorikawa T. (1995) performed a study on the cooling function of the body when sportswear gets wet in a rain shower and the physiological significance of the material. Jung D. J. (1994) studied body temperature and loss in body weight accord-

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ing to the change of temperature and humidity when working a maximum capacity.

Now, studies about functional material for sportswear have been performed in many different ways. However, most of them were studies at the textile level and environmental conditions were limited as the change of temperature and humidity (Nam, 1994; Umbah,1988; Tanaka, 1986; Yoon, 1984; Mathew, 1969).

In this study, to find out the physiological reaction of the human body and the sensation of comfort when people are wearing sportswear which is made of waterproof breathable fabric under general environmental conditons (temperature : 20± 1°C, humidity : 60± 5%RH, air current : 0.1 m/sec) and rainy environmental conditions (temperature : 20± 1°C, humidity : 60± 5%RH, air current : 0.1 m/sec, rainfall : 250 *l*/hr), we have made sportswear experimented in an artificial climate chamber and studied the thermal physiological features and subjective sensation.

EXPERIMENT

Subjects

Subjects were 4 healthy men and the physical features are in Table 1.

Environmental conditions

This experiment had been conducted in an artificial climate chamber for 2 months from July 1999 to August 1999. In order to exclude physiological changes of subjects, the experiments had been conducted at the same time of the day.

Table 1. Physical characteristics of subjects

Subject	Age (year)	Height (cm)	Weight (kg)	Rohrer[a)] index	Body surface area (m^2)[b)]
A	26	179	68.1	1.184	1.804
B	26	182	72.9	1.210	1.880
C	26	183	63.6	1.038	1.775
D	26	178	67.2	1.192	1.786

Note) a) Rohrer Index=[(W1000/H^3]× 100
b) Body surface area (m^2) =$W^{0.444}$× $H^{0.663}$× 88.83
W : Weight (kg), H : Height (cm)

Table 2. Two environmental conditions established in a climate chamber

	Temperature (°C)	Humidity (% R.H.)	Air current (m/sec)	Rainfall (*l*/hr)
General Condition	20± 1	60± 5	0.1	-
Rainy Condition	20± 1	60± 5	0.1	250

Considering the feature of material of the sportswear, the generally pleasant conditions of spring and fall, and slightly rainy conditions were chosen as environmental conditions and those are described in Table 2.

Experimental garment

The material for the experimental garment was new breathable waterproof fabric invented by the KOLON Co. LTD., and its features are shown in Table 3.

The material is up-to-date, breathable and waterproof having the feature of shape-memory polyurethane which controls the vapor transmission rate according to the glass melting point.

Before exercise, when there is no sweat and heat, stiff molecules block transmission of moisture and thus keep the meter warm. If the temperature and humidity inside the garment go up during exercising molecules move and increase the vapor transmission rate dramatically.

In other words, this material can control the vapor transmission rate according to the environmental conditions and is pleasantly comfortable with only a-third of the mover of the fabric material.

In addition to its softness, it has both a high waterproof and high vapor transmission rate at the same time.

With this material, the experimental garment was made in with the same design as Fig. 1.

We added an detachable hood to general forms of sports wear such as casual jackets hiking, fishing, jogging gear have mash fabric inside to make it a double layer.

Measurements

Mean skin temperature and rectal temperature : The measuring sensor was ϕ0.1 mm JIS T type thermocouple and the data were continuously recored by a Hybric Recorder (HR-2300, Yokogawa Electric CO.).

Skin temperature was measured in 7 points of the body; forehead, forearm, the back of the hand, the back of the

Table 3. Specification of the samples used for the experiments

Coating method	Ground fabric			Thickness (mm)	Weight (g/m^2)
	Fiber	Yarn number (D/F) (Wp× Wf)	Fabric count (Wp× Wf)		
Shape memory polyurethane	N100%	70/24× 160/96	120× 68	0.18	109.6

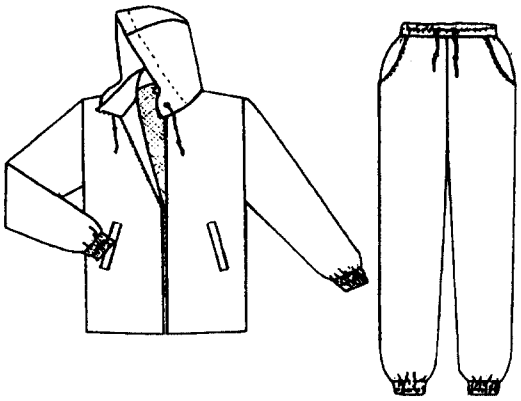

Fig. 1. Design of the sportswear used for the experiments.

foot, trunk, calf and thigh. Rectal temperature was continuously measured as core temperature. Mean skin temperature was calculated by the following equation (Hardy and DuBois, 1938).

$$\text{Mean skin temperature} = 0.07\ T_{head} + 0.35\ T_{trunk} + 0.14\ T_{arms} + 0.05\ T_{hands} + 0.19\ T_{thigh} + 0.13\ T_{leg} + 0.07\ T_{feet}$$

Clothing micro climate : By using a sensitive Hygrometer (CHMT-2, Codix Co.) and Linear recorder (FWR-3701, Graphtec Co.), temperature and humidity between the inner wear and outerwear were measured on the chest and the back for clothing micro climate.

Body weight loss : Body weight loss was calculated from the weight difference between weights before and after exercise using Multi-range balance (KCC-150, Mettler Co.).

Blood pressure and heart rate : For pulse and blood pressure, the maximum and minimum blood pressure and pulse were measured every 10 minutes using a Blood pressure manometer (HEM-705 CP, Omron Co.).

Subjective Sensation : 5 scale of comfort sensation, 7 scales of humidity sensation, 9 scales of thermal sensation and 4 scales of fatigue sensation were reported every 10 minutes and the scales used are in Table 4.

Experimental protocol

Two hours after lunch, subjects sit for 60 minutes in the preparing room (20°C, 60%RH) to calm down then their weight is taken and they are put on a sensor for mea-

Table 4. The scale vote used to evaluate the sensation response of the subjects

Comfort sensation	Thermal sensation	Humidity sensation	Fatigue sensation
1. comfortable	1. very hot	1. very wet	1. neutral
2. neutral	2. hot	2. wet	2. slightly fatigue
3. slightly uncomfortable	3. warm	3. sightly wet	3. fatigue
4. uncomfortable	4. slightly warm	4. neutral	4. very fatigue
5. very uncomfortable	5. neutral	5. slightly dry	
	6. slightly cool	6. dry	
	7. cool	7. very dry	
	8. cold		
	9. very cold		

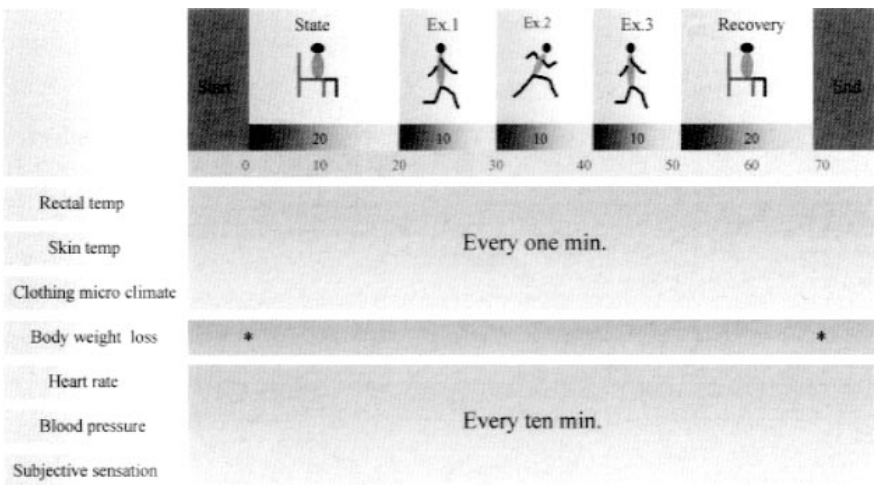

Fig. 2. Experimental schedule.

suring and the experimental garments before they enter the artificial climate chamber which is adjusted to experimental conditions.

The experiment is to minutes long and the interval and the process are stated in Fig. 2. After they enter the artificial climate chamber, they spend 20 minutes for relaxing and then the next 30 minutes for exercising and 20 minutes for recovering.

Taking R.M.R. into consideration was established; normal and strong.

Intensity and time length are like this : 5.5 mile/hr for 10 minutes (Ex.1), 9.5 mile/hr for 10 minutes (Ex.2), 5.5 mile/hr for 10 minutes (Ex.3) on a tread-mill.

RESULTS AND DISCUSSION

Mean skin temperature

Fig. 3 shows mean skin temperature according to the environmental conditions at every level in the experiment. Mean skin temperature in the general environmental condition was 31.71~32.27°C with the range of fluctuation of 0.56°C and mean skin temperature in the rainy environmental condition is 31.60~32.32°C with a gap of 0.72°C.

Skin temperature went up till the 2nd level of exercise and declined from the 3rd level of exercise through the recovering period. The hike in skin temperature in the 2nd level of exercise was because the increase in quantity of motion created a lot of heat in the human body as time went on. The decline in skin temperature of the 3rd level of exercise appears to be due to the evaporation of sweat resulting in cooling down and decline in the body temperature as the intensity of the exercise slowed down.

This decline occurs more clearly in the rainy condition. Also mean skin temperature at the beginning of the experiment in the rainy condition appeared lower than in the general condition, which is thought to be because the skin temperature is affected by the temperature of the outer surroundings and raindrops on the skin lowered the skin temperature.

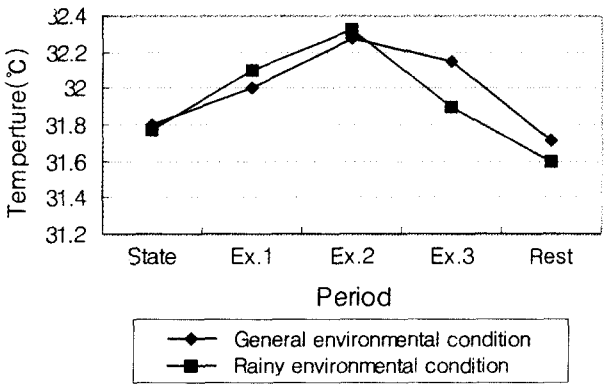

Fig. 3. A comparison of two different conditions mean skin temperature.

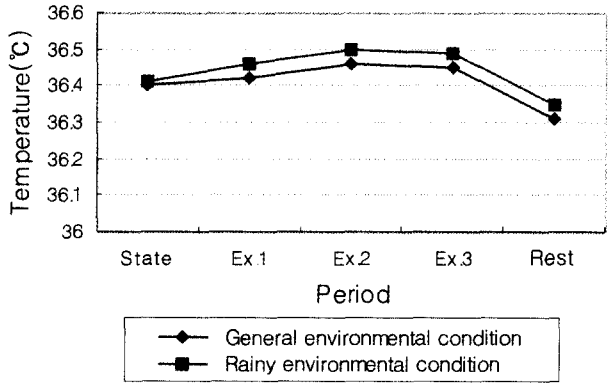

Fig. 4. A comparison of two different conditions rectal temperature.

Rectal temperature

Rectal temperatures according to the conditions are shown in Fig. 4.

The main trend was the increase in temperature till the 2nd level of exercise, a decrease from the 3rd level of exercise and a sharp drop in the recovering period. When exercising, heat generation from body is high and body temperature goes up because of the excited temperature controlling nucleus. Yet, the increase in temperature caries according to the intensity and petit of time of exercise and environmental conditions. Rectal temperature in this experiment also shows the increase realtime to the intensity of exercise.

Rectal temperature in the general environmental condition was 36.32~36.46°C with fluctuation range of 0.14°C. The rectal temperature in rainy conditions was 36.34~36.50°C with the fluctuation range of 0.16°C. The difference between the two conditions was 0.034°C and smaller increase was shown in rainy condition.

Clothing micro climate

Temperature within clothing : Fig. 5 shows temperatures within clothing according to the parts and the level of the experiment. Temperature within clothing around chest was 28.40~29.26°C in general conditions and the range of fluctuation through the entire experiment was about 0.86°C. Temperature within clothing around the chest in rainy conditions was 30.36~32.07°C and the range of fluctuation through the entire experiment was about. 1.7°C. At the 1st level of exercise the temperature went up declined at the 2nd level and went up again at the 3rd. The inner temperature around the back was 29.50~31.17°C in general conditions and the range of fluctuation through the entire experiment was about 1.67°C. The

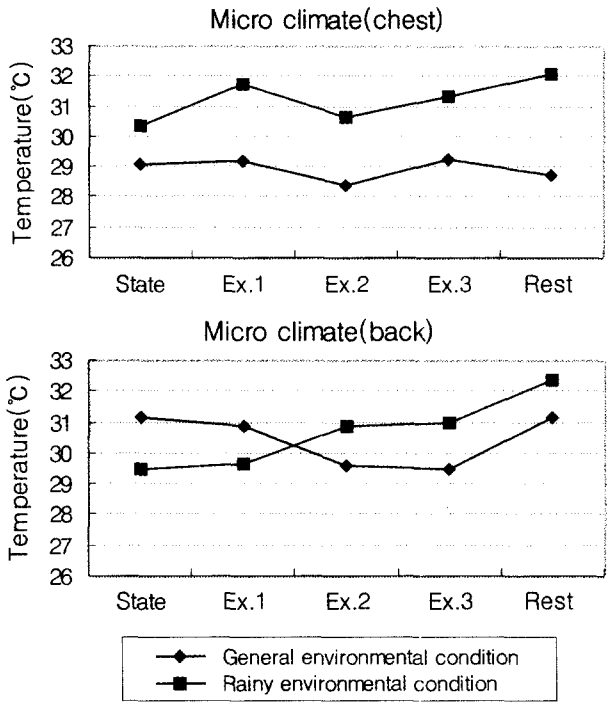

Fig. 5. A comparison of two different conditions on temperature within clothing at chest (upper) and back (lower).

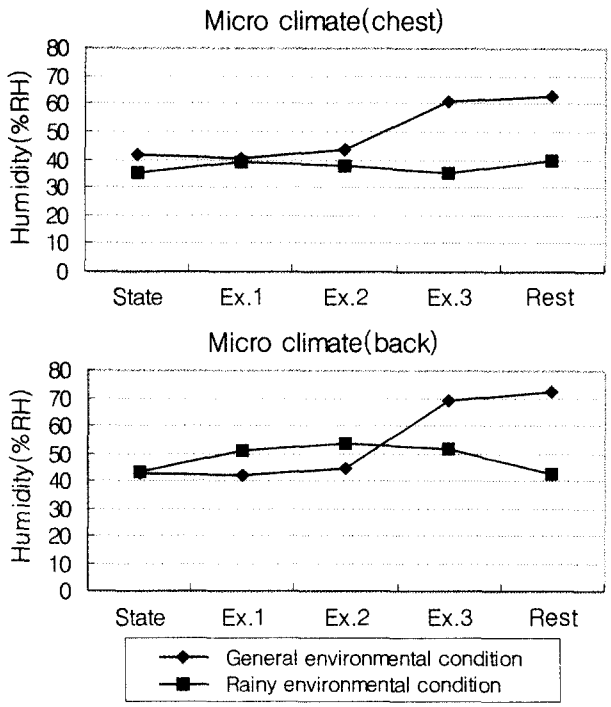

Fig. 6. A comparison of two different conditions on humidity within clothing at chest (upper) and back (lower).

inner temperature went down during the exercise levels and went up during break. The inner temperature in rainy condition was 29.45~32.38°C and the range of fluctuation was 2.93°C which was quite distinctive unlike in general condition, the temperature went up after the average exercise. Compared to the environmental conditions, inner temperature in rainy conditions was 30.94°C, which is 1.25°C higher that of general conditions and the range of fluctuation in rainy conditions was larger than that of environmental conditions.

In general conditions the inner temperature of the chest area was higher than that of the back area by 1.54°C and the fluctuation range of the chest area was bigger than that of the back area. Unlike in the general condition, in rainy condition the temperature around the chest was 0.56 higher.

Humidity within clothing : Fig. 6 shows inner humidities according to the level of experiment. Inner humidity around the chest in general conditions went down at the 1st level of exercise, which we believed to be because of the non-moving air layer during the relaxation period started to move as the exercise started and caused convection current phenomena.

The humidity within clothing in general conditions was 40.50~62.5%RH and its range of fluctuation was 22%RH. In rainy conditions the humidity within clothing was 35.05~39.37%RH and its range of fluctuation was 4.32%RH. The humidity within clothing around the back in general conditions was 41.97~2.5%RH and its range of fluctuation through the entire experiment was about 30%RH. It was 42.75~53.40%RH in rainy conditions and its range of fluctuation was 10.65% RH. It tended to be high at the 2nd level of exercise and lowest during the recovering period.

Compared to the environmental conditions, average humidy within clothing in general conditions was 51.98%RH and was 9.185%RH higher than that of rainy conditions which was on average 42.80%RH. The range of fluctuation in general conditions was also larger.

The inner humidity around the chest was 4.2%RH higher than that of the back area in general conditions. In rainy conditions that of the back area was higher than that of the chest area by 11.05%RH.

Body weight loss

As for the means to radiate heat, there are two main routes; One is the circulating adaption which increases the amount of blood stream below the skin by expanding the blood vessels. The other is the cooling effect of evaporator by increasing sweat. This kind of perspiration is the means to evaporate heat to keep the body temperature balanced after the body temperature increases and is also important to control the moisture balance of the body. In the case of exercising for a long time, a lot of body mois-

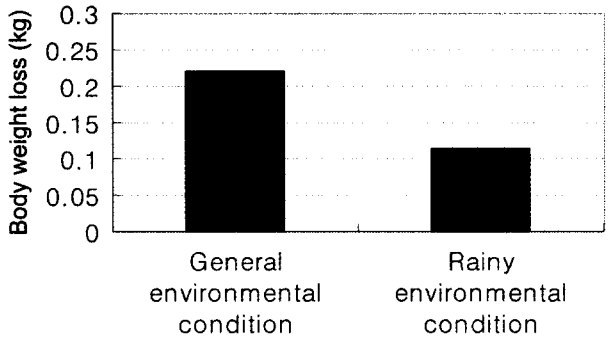

Fig. 7. A comparison of two different conditions on body weight loss.

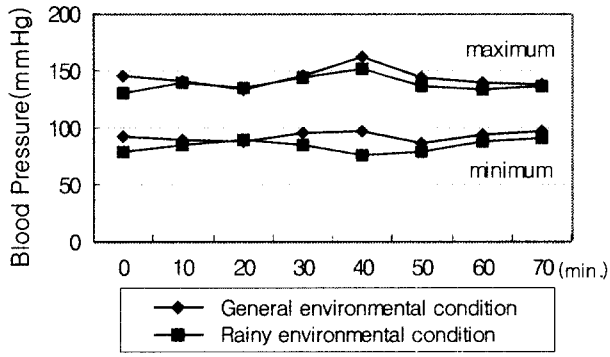

Fig. 8. A comparison of two different conditions on blood pressure.

ture loss and unbalance cause the increase of body temperature.

Therefore it could reduce discomfort if sportswear could absorb or transmit and evaporate sweat efficiently.

As seen in Fig. 7, body weight loss general conditions was 0.2 kg and was 0.11 kg in rainy conditions.

Blood pressure and pulse rate

Changes in blood pressure in 2 kinds of to environmental conditions are shown in Fig. 8. The increase in blood pressure during exercise can be seen according to increase rate of body temperature. In this experiment blood pressure tends to increase in proportion to the intensity of the exercise.

The harder the exercise is, the more the blood pressure increases. This is because blood pressure is mostly determined by the amount of blood heart rate and the strength of resistance of peripheral blood vessels and the demand for blood from heart contraction is high when exercising. Although the maximum blood pressure is proportionate to the intensity of the exercise, the minimum blood pressure was not greatly affected by it.

The change of blood pressure in each level of experiment tends to be opposite of the change of temperature

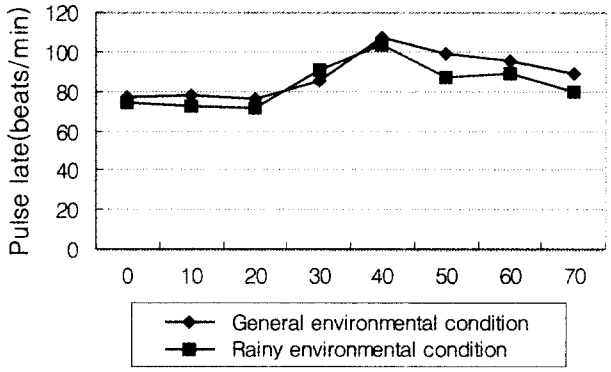

Fig. 9. A comparison of two different conditions on pulse late.

within clothing. This is identical with the previous result that blood pressure drops when surrounding temperature increases. Average blood pressure in general conditions was 109.33 mmHg and was 102.36 mmHg in rainy conditions.

The change of pulse rate according to different environmental conditions are shown in Fig. 9. Pulse rate is the measure which evaluate the intensity of the exercise, wearing conditions, different postures and effects of other elements. The increase in pulse rate is in proportion to the intensity of the exercise and the temperature of the environment. This experiment also proved that pulse rate increases in proportion to the amount of the exercise. Pulse rate was 88.0 beats/min in general conditions and 83.6 beats/min in rainy conditions.

Subjective sense

Comfort sensation: Subjects feel comfort sensation when the enviroment is in a proper conditions and they do not feel and burden to their body and are not mentally tense. I wearing sportswear comfort sensation is created when thermal comfort, soft feeling of the garment, humidity sensation and breathability of the material, and other things are achieved.

In general conditions, comfortable sensation was achieved from the beginning of the exercise, but after the exercise recovering comfort was not performed so well. In rainy conditions, during the relaxing period comfortable sensations went up to the level of "being uncomfortable" as time went on. Subjects also reported that they feel uncomfortable owing to the duration and intensity of the exercise and the raindrops on the skin.

Thermal sensation : The change of thermal sensation in both conditions was similar to mean skin temperature, which showed correlation between them. Thermal sensation in rainy conditions was marked even "being cold". The results in rainy conditions was the opposite of those in general conditions as cold feelings were added after the

exercise in rainy conditions.

Humidity sensation : The results of humidity sensation according to the environmental conditions and the levels of the experiments were similar to those of inner humidity. This indicates that subjective humidity sensation is related to inner humidity. In rainy conditions, after starting exercise, subjects reported "very wet" and this high humidity sensation lasted till the recovering period.

Fatigue sensation : There was not distinctive difference in fatigue sensation and it developed from "slightly fatigue" to "fatigue" as the intensity of the exercise got greater.

CONCLUSIONS

A sportswear was specially made with shape memory breathable waterproof fabric for this study. It was experimented in an artificial weather chamber in the two different conditions: general environmental conditions and rainy environmental conditions. In this experiment, thermal physiological response of human body and subjective sensation were observed, compared and studied. The results acquired in this experiment are as follows.

1. Mean skin temperature was low and had a big range of fluctuation in rainy environmental conditions. Temperature started to increase at the beginning of the exercise, reached the maximum at the 2nd level of the exercise and then started to decline.

2. Rectal temperature showed a slighter increase and bigger range of fluctuation in general conditions than in rainy conditions.

3. As for clothing micro climate. the ranges of fluctuation in temperature and humidity around chest were bigger than those around back in both conditions. Except temperature within clothing in rainy conditions, temperature and humidity within clothing and their range of fluctuation around back were higher than those around chest. Humidity within clothing was high and had wide range of fluctuation in general conditions.

4. Body weight loss in general conditions was higher by 0.11 kg.

5. Maximum blood pressure increased in proportion to the intensity of the exercise, while minimum blood pressure was not greatly affected. The change in blood pressure was the reverse of the change in inner temperature. Average blood pressure in general conditions was 6.9 mmHg higher. Pulse rate in general conditions was 4.4 beats/min higher.

6. In subjective test in rainy conditions, the feeling of discomfort increased due to the raindrops fallen on the skin. Unlike that in general conditions, cold sensation increased and humidity sensation reached the peak after the exercise.

7. In wearing sportswear made of shape memory breathable waterproof material, controlling function over a small amount of heat and water was distinctive while it turned out to be not so comfortable over a large amount of heat and water. Through this, the limitation of shape memory breathable waterproof material was recognised.

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