Bull. Tokyo Med. Dent. Univ., 19: 1–18, 1972.

EXPERIMENTAL STUDIES ON HUMAN REACTION TO COLD

—With reference to differences between males and females—

BY

Masatoshi TANAKA*1

ABSTRACT

This study was carried out to find physiological reactions to cold, with reference to difference in the reactions between male and female human subjects. Experiments were made on six each healthy male and female students aged 19 to 25 years, in summer and winter. They wore standardized clothes and lay on a bed for 2 hours in an artificial climate room at about 10°C.

Heat production, skin temperature, sublingual temperature, rectal temperature, urinary 17-Ketosteroids (17-KS), etc., were measured and the following results were obtained.

1. Heat production for females was lower than that for males, and decrease in the mean skin temperature for males due to the cold exposure was bigger than that for females.

2. On the interrelationships between heat production and mean skin temperature, no remarkable difference was noticed in the average values for males between summer and winter, but female students were weak to cold in summer, and contrarily, became stronger in winter. It seems that females have an ability of acclimatization to cold by the seasonal shift.

3. 17-KS for males increased at the cold exposure, but no remarkable change was seen for females in winter.

4. From these evidences, the female subjects may be assumed to have a physiological adaptability to cold. This fact could be related not only to the sexual difference in physical characteristics such as skinfold thickness, etc., but also to that in feature and function of endocrine system.

INTRODUCTION

There have already been many reports on experimental studies on the human reaction to cold, and many questions have been raised about the so-called cold tolerance–What is the cold tolerance? and what is used for the index to that?, etc.

Studies on the cold tolerance and heat tolerance in human beings are

*1 田中正敏: Department of Hygiene (Chief: Prof. H. KITA), School of Medicine, Tokyo Medical and Dental University (Tokyo Ika Shika Daigaku).
Received for publication, November 29, 1971.

carried out at the Department of Human Adaptation, International Biological Program, starting in 1964, and many studies on these problems have been reported by the members of Japanese Human Adaptation Group in Japan.

Eight-hour method[1] or 2-hour method[2] have been suggested for the index, in general. In Japan, various methods have been suggested, such as, indices introduced from the hunting reaction[3,4] or combined parameters of the heat production and the mean skin temperature[5,6].

As regards the characteristic of subjects, there have been a large number of publications dealing with physiological reactions to cold of men, such as fat men, cold-resistant and cold-susceptible men, men from the warm or cold native place, swimmers, etc. However, most of these reports were about males, and a few studies have been made on females, who are generally accepted as having a high tolerance of cold.

In the present study, it was considered that experimental conditions should be comfortable to the subjects, with reference to the basic knowledges already established. Many items for the measurement of indices for cold tolerance were selected as far as possible.

This study was performed to know the human reaction to cold in summer and winter, especially difference in this reaction between males and females.

Method

Six each of healthy male and female students of 19∼25 years of age were subjected to the investigation. Table 1 shows physical status of the subjects. Skinfold thickness indicates total sum for upper arm, back, abdomen, and chest. The experiments were carried out in August, when the subjects seemed to be acclimatized to hot weather, and in February, when they did so to cold climate.

The experimental procedure is described below and schematically shown in Fig. 1. In the anteroom, adjusted to a room temperature of 22∼24°C, instruments for the measurement were attached to the subjects, and measurements of the vascular hunting reaction, skin temperatures, etc., were made (anteroom value). They were then placed in the cold room, adjusted to a room temperature of about 10°C, a wind velocity of about 50 cm/sec, and a humidity of 75∼85%. During the first 30 min, the subjects lay under double blankets wearing a thick underwear and black athletic training clothes (control value). Then they were exposed to cold in the same posture without blankets for 1 hr (exposure value), and then they lay

Table 1. Physical status of the subjects

Subject	Age (yr)	Body height (cm)		Body weight (kg)		Upperarm circum. (cm)		Skinfold thickness (mm)	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Males									
H.N.	24	167.0	166.4	53.0	53.5	25.0	25.7	29.0	29.0
A.I.	25	174.2	173.8	58.0	57.5	26.2	27.0	19.4	21.5
Y.T.	22	163.0	164.2	56.0	58.2	27.0	28.0	23.7	33.5
K.H.	23	175.6	175.4	81.6	86.0	30.0	31.6	60.5	78.5
A.H.	24	157.7	157.2	56.4	58.4	28.0	28.3	34.2	48.0
K.S.	22	168.5	168.0	64.5	63.0	28.0	27.0	51.0	51.0
M.±S.E.		167.7 ±2.5	167.5 ±2.5	61.6 ±3.9	62.8 ±4.4	27.4 ±0.6	27.9 ±0.8	36.3 ±6.0	43.6 ±7.6
Females									
A.M.	21	151.0	150.4	44.9	45.1	25.0	24.8	58.0	62.5
T.T.	19	161.2	160.0	55.6	59.2	24.5	27.0	57.4	71.6
T.Y.	21	158.8	158.9	42.4	43.7	21.0	21.0	50.0	55.0
S.T.	22	155.4	155.4	49.6	47.0	24.0	23.0	60.3	50.0
M.M.	21	161.0	160.9	48.9	51.0	24.5	25.0	56.0	63.1
I.O.	22	158.0	157.1	46.2	46.0	22.5	23.0	62.0	64.5
M.±S.E.		157.6 ±1.4	157.1 ±1.4	47.9 ±1.7	48.7 ±2.1	23.6 ±0.6	24.0 ±0.8	57.3 ±1.6	61.1 ±2.8

again with the blankets for 30 min (recovery value).

Items of the measurement were the following:

Heat production: Expired air was collected in a Douglas Bag for 10 min. Total volume of the air was measured and gas components of the air was analyzed by gas chromatography. Heat production, calculated from the respiratory quotient and oxygen consumption, was translated into a term relative to the surface area and expressed by kcal/m²•hr.

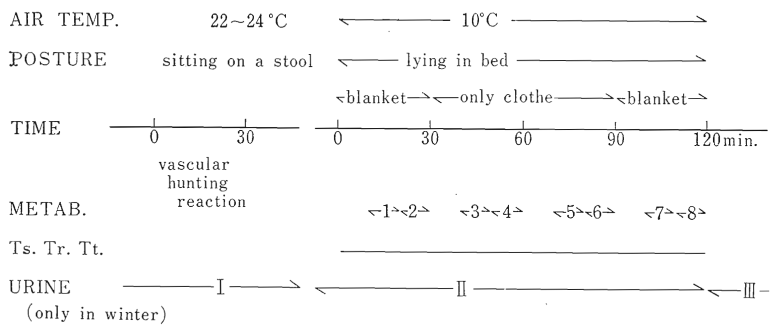

Fig. 1. Schedule of the experiment.

Table 2. Measurement sites and weighting coefficients for calculating the average skin temperature

Site	Weighting coeffi-cients
Forehead	9.8
Chest	16.6
Abdomen	8.1
Hip	8.1
Upper arm	8.2
Lower arm	6.1
Back of hand	5.3
Thigh	17.2
Leg	13.4
Back of foot	7.2
(Total)	100.0
Dorsal surface of the distal left-middle finger and big toe	Special points

Rectal temperature: This was measured with a thermistor at the point 8 cm from the anus and recorded continuously.
Sublingual temperature: This was measured with a thermistor under the tongue.
Skin temperature: Since deviation in skin temperature measurements occurs according to the pressure of fixing thermometer to the skin, a flat tip of the skin thermometer was attached to skin surface by using a kind of stripping tape in round shape and consideration was made to keep it at a constant pressure. Thermistors were placed at 12 points on the body surface, as shown in Table 2, and two of them were selected as special points; distal parts of dorsal surface of the middle finger and the big toe, which are sensitive points concerning regulation of body temperature to cold.

A method for calculating the mean skin temperature was changed from the 10-point system to the 3-point system[7]. The first system has been used chiefly in Japan because the reliability of the true mean value depends on the number of points used. Therefore, the mean skin temperature was calculated by mean of the proportion of the body surface area using the 10-point system according to Research Committee on Physiological Reaction to Climatic Seasonal Change[8], as shown in Table 2.
Urinary examination: Urine volume and urinary 17-Ketosteroids (17-KS) were measured 3 times; before, during, and after cold exposure. On other

days, urine was measured at the same time for control. Measurement of 17-KS was according to Kanbegawa method as modified by Zimmerman method[9].

RESULTS

1. Local skin temperatures and mean skin temperature

The anteroom values of the skin temperature were almost stable and distributed mostly in a range from 28° to 36°C. Fig. 2 shows representative data of one subject. Local skin temperature decreased in the order of the forehead, trunk, and extremities. The control value for the trunk was almost the same or slightly higher than the anteroom values, the control value for the forehead was rather low due to direct exposure, and the temperature of the extremities tended to decrease slightly for 30 min.

As soon as the subjects were exposed to cold without blankets, each of the skin temperatures dropped rapidly, but, there was only a slight difference in the temperature of the trunk between initial and terminal

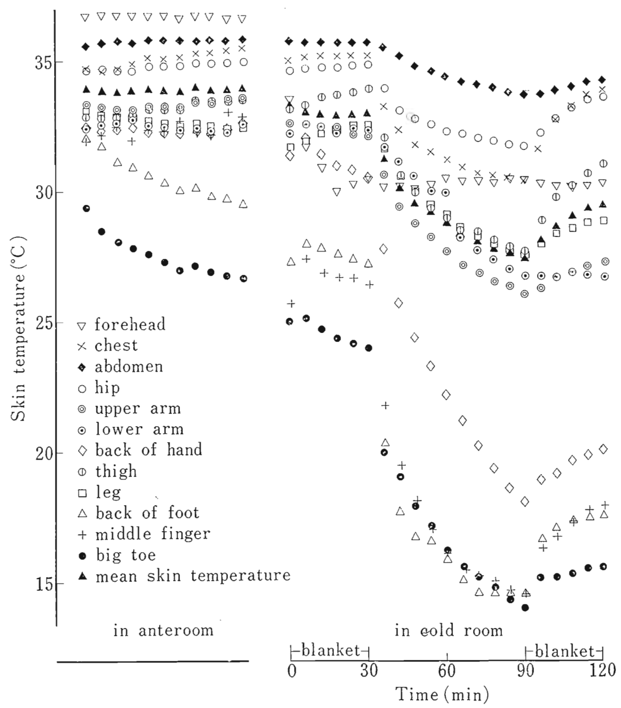

Fig. 2. Time response curves of skin temperatures before, during, and after exposure to cold.

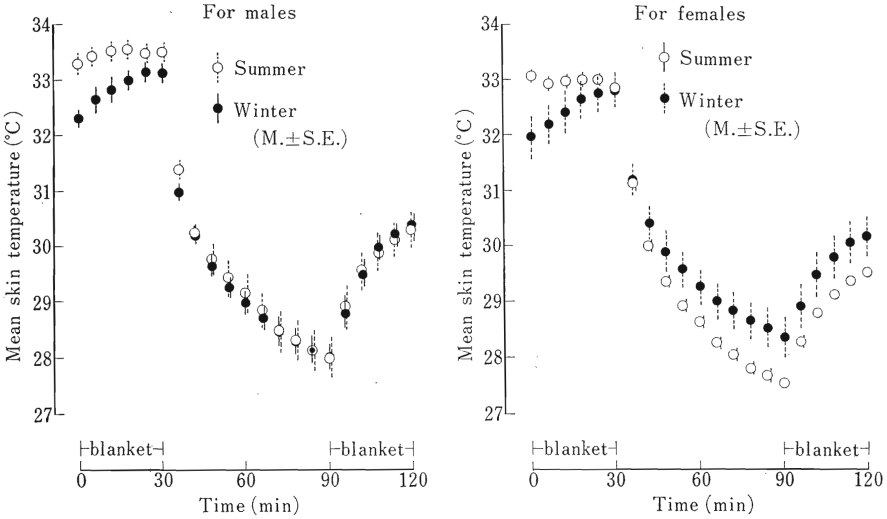

Fig. 3. Time response curves of mean skin temperature average values in summer and winter.

periods of the cold exposure, and rate of the drop was remarkably high in the extremities, especially in the back of the foot, the big toe, and the middle finger. The temperature of the big toe became lower than 15°C, thus, spread of the temperatures became big. There was a spread of about 20°C in the individual measurements. When the blankets were worn again, all the skin temperatures increased, but the rate of increase was not so large and was unstable. The rate of increase was the highest in the finger, 4°C/30 min, and the smallest in the big toe, 2°C/30 min.

Change in mean skin temperature had the same pattern for each skin temperature change. The anteroom values were almost the same for the two sexes, but the values in winter were rather lower than in summer; difference between them was about 1°C. One hour after exposure to cold, one male subject got rather high value difference in winter, while in one female subject, rather low in winter. The average values for males in both summer and winter were almost the same in the terminal period of the exposure to cold, but those for females in winter was higher than those in summer; difference between them was about 1°C as shown in Fig. 3.

Table 3 shows individual differences in the mean skin temperatures between the control period and terminal period of exposure to cold. The difference in summer was bigger than that in winter in both sexes and this difference was statistically significant ($P<0.5\%$). The difference for females in winter was the smallest among all the average values.

Table 3. Differences in mean skin temperature between control period and terminal period of exposure to cold

Subject	Summer	Winter
Males		
H.N.	5.25	4.65
A.I.	4.54	4.21
Y.T.	4.92	5.50
K.H.	7.03	5.77
A.H.	5.41	5.14
K.S.	5.48	5.04
M.±S.E.	5.44±0.32	5.05±0.21
Females		
A.M.	5.56	4.22
T.T.	5.13	4.44
T.Y.	5.37	4.38
S.T.	5.07	4.11
M.M.	5.12	4.94
I.O.	5.40	4.36
M.±S.E.	5.28±0.07	4.41±0.11

2. Rectal and sublingual temperatures

Fig. 4 shows average changes in the rectal temperature for males in summer and winter. Patterns of the curves in summer and winter were similar. The temperature level in winter was lower than that in summer, but the rate of drop in winter was smaller than that in summer. Therefore, the difference between the temperature levels became smaller in the terminal period of the experiment.

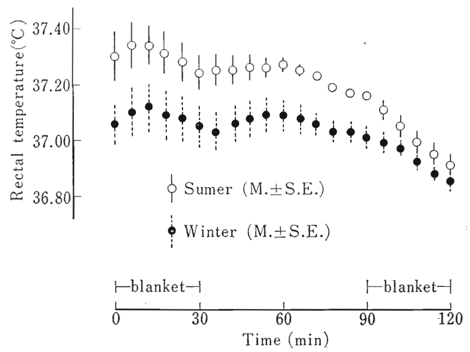

Fig. 4. Time response curves of rectal temperature, average values for males in summer and winter.

Sublingual temperature was lower than the rectal temperature in males at all times. In summer, the sublingual temperature showed a rapid drop after exposure to cold but, in the recovery period with blankets, the sublingual temperature tended to become constant and then increased slightly. On the contrary, the rectal temperature was still decreasing in the same process.

In summer, the pattern of sublingual temperature curves was the same in both sexes, but the control values for females were slightly higher than those for males. The values became lower after exposure to cold, as shown in Fig. 5. Anteroom values of the sublingual temperature of both sexes in winter were lower than those in summer, as shown in Fig. 6. The control values were not yet stabilized for 30 min. After exposure to cold, the temperature gradually decreased, but the rate of drop was less than that in summer. Therefore, the difference was assumed to be not so much influenced by exposure to cold. The individual variations were rather big, especially for females. The response curves of both sexes almost coincided with each other about one hour after the cold exposure, the rate of increase by wearing the blankets again was very low for males, and the averaged temperature during the recovery period for males was about 3°C lower

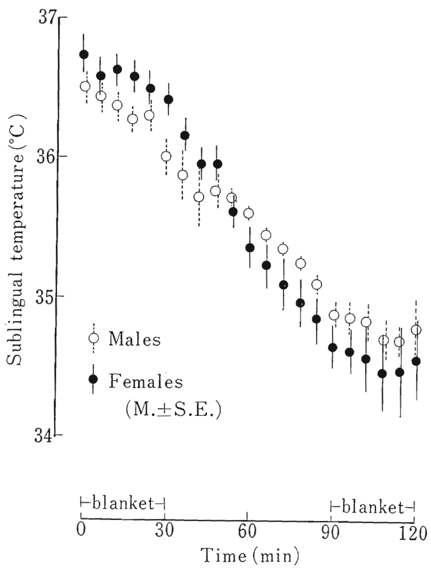

Fig. 5. Time response curves of sublingual temperature in summer, average values for males and females.

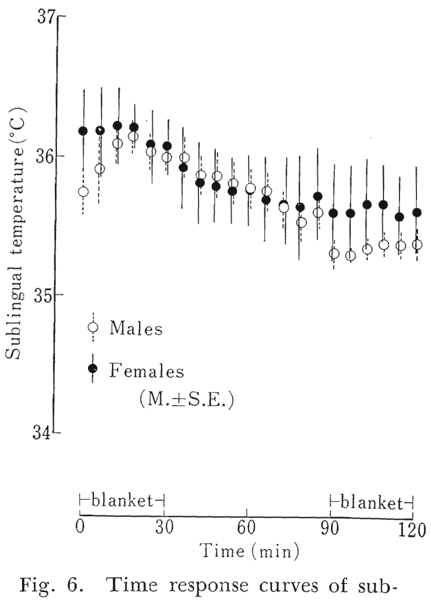

Fig. 6. Time response curves of sublingual temperature in winter, average values for males and females.

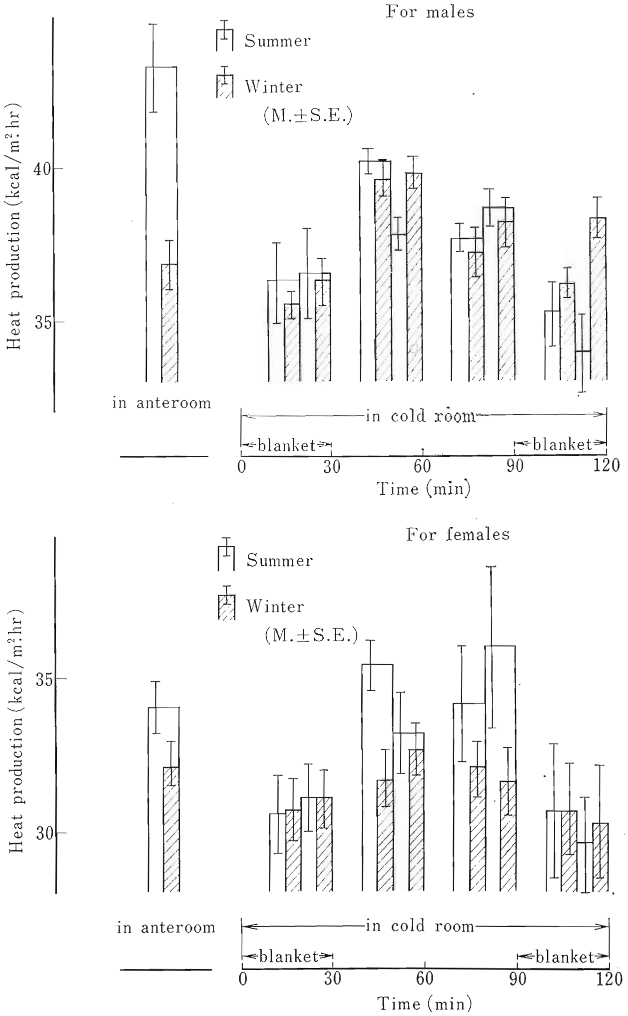

Fig. 7. Heat production.

than for females.

3. Heat production

Fig. 7 shows average (±standard error) of the heat production for each sex and season. The anteroom values in summer were 43.34 kcal/m²•hr for males and 34.00 kcal/m²•hr for females on the average. The value for females was 20% less than that for males. The value for the male individuals ranged from 38.6 to 48.8 kcal/m²•hr, and for the females from 30.7 to 36.7 kcal/m²•hr. The anteroom values in winter were 36.82 kcal/m²•hr for males and 32.13 kcal/m²•hr for females on the average. The value for females was 13% lower than that for males. The range of values for the male individuals was from 40.5 to 33.7 kcal/m²•hr and that for females was from 27.5 to 35.6 kcal/m²•hr.

The anteroom values for both sexes in winter were smaller than those in summer; the value in winter was 15% and 5% less than that in summer for each male and female group. The difference was much smaller for the females. Although there were large individual variations among the subjects, a common pattern consisted of three phases in which the control value was lower than the anteroom value, the level of the values increased during exposure to cold without blankets, and the recovery values tended to decrease.

The control values for males were 36.3 and 36.6 kcal/m²•hr in summer and 35.6 and 36.4 kcal/m²•hr in winter, and for females 30.6 and 31.0 kcal/m²•hr in summer and 30.7 and 31.1 kcal/m²•hr in winter. Although there were similar changes in the values in summer and winter, the control values were almost constant for each season, but the values for females were about 15% lower than those for males. The seasonal difference in the values was not so remarkable for males, but, the level of values for females in winter was generally lower than that in summer (8%).

4. Urine examination

Fig. 8 shows the result of measurements of urine volume as an average

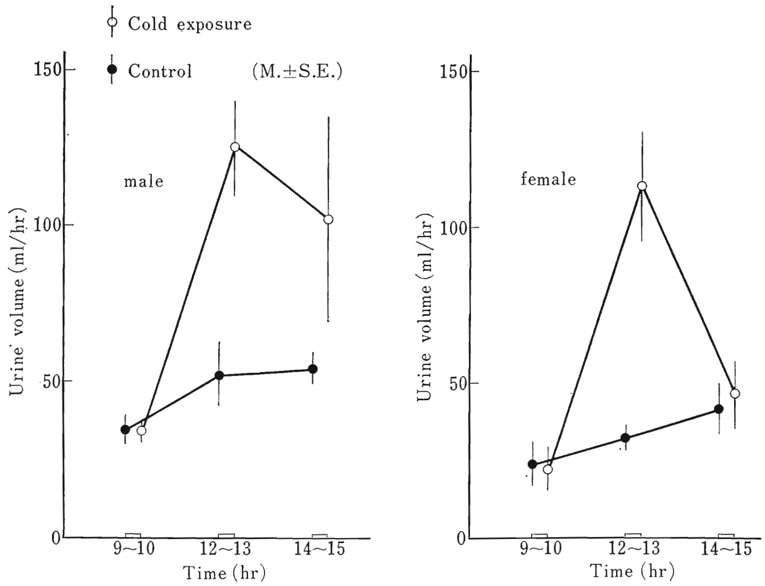

Fig. 8. Changes in urine volume by cold exposure avarages for six each of male and female subjects.

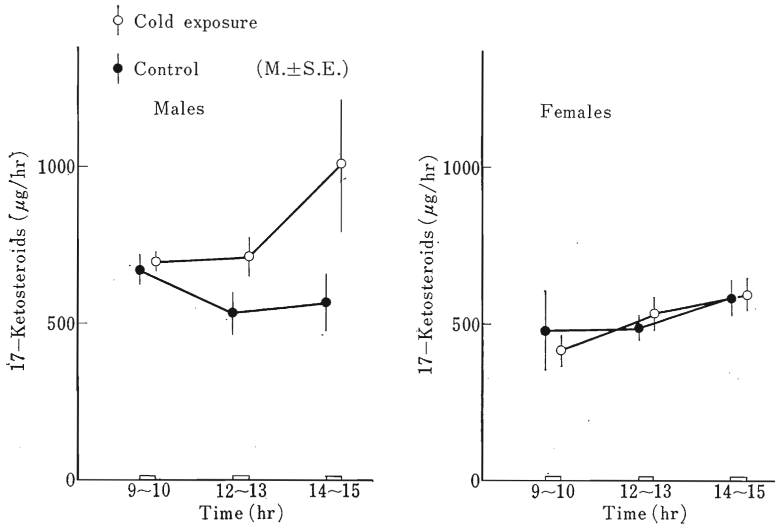

Fig. 9. Changes in urinary excretion of 17-ketosteroid by cold exposure averages for six each of male and female subjects.

of six each of male and female subjects. The average values before exposure to cold were 35.9 ml/hr for males and 21.9 ml/hr for females. Range of individual values was rather wide; from 30 to 47.9 ml/hr for males and 7.5 to 59.9 ml/hr for females, respectively. The averaged values during cold exposure were 3.5 times in males and 5.2 times in females more than those before the cold exposure. For the male subjects, the value was still higher after the exposure to cold compared to the control value. On the contrary, the value before the exposure for females was almost the same as the recovery value and the control values.

Fig. 9 shows changes in the urinary 17-KS by exposure to cold as an average for six each of male and female subjects. The values before exposure to cold did not differ so much from all the control values. During and after exposure to cold, the averaged values for females were higher than the control values, but the difference was not big. In contrast, the increased values during and after the exposure for males was remarkable in comparison with the anteroom value, especially in the latter case, and the difference was significant ($p<5\%$). On the other hand, the range of male individual values was considerably wide, from 456 to 2053 μg/hr after exposure to cold, and their average was 1007 μg/hr.

Discussion

To determine the tolerance of human beings to cold, it is chiefly carried out that subjects are exposed to cold and their physical or biochemical reactions are examined. There are many parameters for measuring these reactions; heat production, skin temperature, body core temperature, blood pressure, respiration rate, pulse rate, blood cell count, urinary constituent, peripheral circulation, etc. The experimental conditions are changeable according to space, ambient temperature, clothing, etc. It is important that the measuring conditions for the subject should be easy and accurate.

Carlson[10] and Ogata et al. proposed a useful index for the cold tolerance from the interrelationship of decrease in the skin temperature ($\triangle$T) and increase in the heat production ($\triangle$H) during the cold exposure to keep the body temperature in cold. This is based on the fact that decrement of skin temperatures decreases heat radiation according to vasoconstriction of the skin vessels and increases the heat production. Accordingly, subjects who are weak to cold have a high index value $\triangle H/\triangle T$ or $\triangle H/H_0 \cdot \triangle T$ (H_0 is the control value for heat production).

Concerning the ambient temperature for this index, Osada et al.[6] stated that 10°C is preferable to 5°C from psychological and physiological points of view, and Sasaki et al.[5] mentioned the heavy load of 5°C from a comparison of rectal temperature changes at 5°C and 10°C (in clothes). Ōsumi[11] reported that differences in the reaction to cold determining the cold tolerance between the cold-resistant and cold-suceptible men were not so remarkable for 10°C in the nude, for 15°C in the nude, and for 5°C in clothes, although shivering was observed in all the cases. Yurugi et al.[12] reported that at the terminal period of 60-minute exposure to 5°C in clothes, decrease in the mean skin temperature was 4.7°C and increase in the heat production was 17.5 cal/m^2•hr, on the average. Furthermore, Osada et al.[6] stated that the heat production increased 15.7% in summer and 26.6% in winter, and there were no remarkable difference in the mean skin temperature between summer and winter at 10°C in clothes, in supine posture, and for the control in sitting posture for the exposure.

In the present study, variations in the response during the cold exposure were divided into certain response patterns. Comparison between the control value and the value at the terminal periods (40~50 and 50~60 min after entry into the cold room) showed an increase in the heat production of 6.1% (2.23 kcal/m^2•hr) in summer and 6.2% in winter for males and 16.8% (5.2 kcal/m^2•hr) in summer and 2.0% in winter for females. These ratios of increase were smaller than those by Osada and Yurugi. This may be chiefly ascribed to the experimental temperature of 10°C and the supine posture throughout the experiment.

Hardy et al.[14] examined responses of seven women (21~35 years old) and two men (33 and 54 years old) in the nude by exposure to temperatures between 22° and 35°C, and reported that the heat production of men was constant throughout the temperature range and that of women showed a marked fall at about 27°C. In a range of 30~32°C, under the standard condition, heat production in most of the women was 14~20% lower than that of the men. Although the experimental conditions differed in studies by the author and by Hardy et al., all heat production measurements for the anteroom, control, and exposure values for females were lower than those for males, and actually the former two were 13~20% and 15%. Heat production for both sexes in the anteroom was higher in summer than in winter; 15% for males and 5% for females. Concerning the vascular hunting reaction, as concurrently done on the same subjects and previously reported[15], magnitude of the reaction was high in summer and low in winter. From the observations in the anteroom, it is thought that both heat production and hunting reaction may have a common characteristic, the higher the heat production, the higher the resistance index. Appreciable correlation existed between them (r=0.43).

In the present study, the recovery values of the heat production were generally lower than the exposure values and control values in many cases. The last determination increased again in winter for males. This may be ascribed to the urinating motivation and behavior of some subjects occasionally encountered in the recovery period.

Some papers[6,13] reported that there was no seasonal change in the mean skin temperature but, in the present study, the rate of decrease in summer was bigger than that in winter, especially for males. Development of a change in the mean skin temperature was similar to that of the skin temperature change of the thigh for two sexes. Fig. 10 shows a relationship between decreases in the mean skin temperature and increases in the heat production described above. There are marked differences in the lines for female subjects and their tangents are big in summer. In winter, the differences are small, and the tangents for females are significantly smaller in winter than in summer ($P<10\%$). The tangents for males in winter are high rather than in summer, but this difference is not significant. The biggest averaged tangent is seen in the female subjects in summer, and the smallest one is also in the females in winter.

Hardy et al.[14] reported that the rectal temperature response to cold showed the same pattern for men and women, and that the decrease in the temperature became slightly small in the lower range of the ambient temperature. Although measurements of rectal temperature were carried out only for male subjects in the present study, the values in the anteroom were

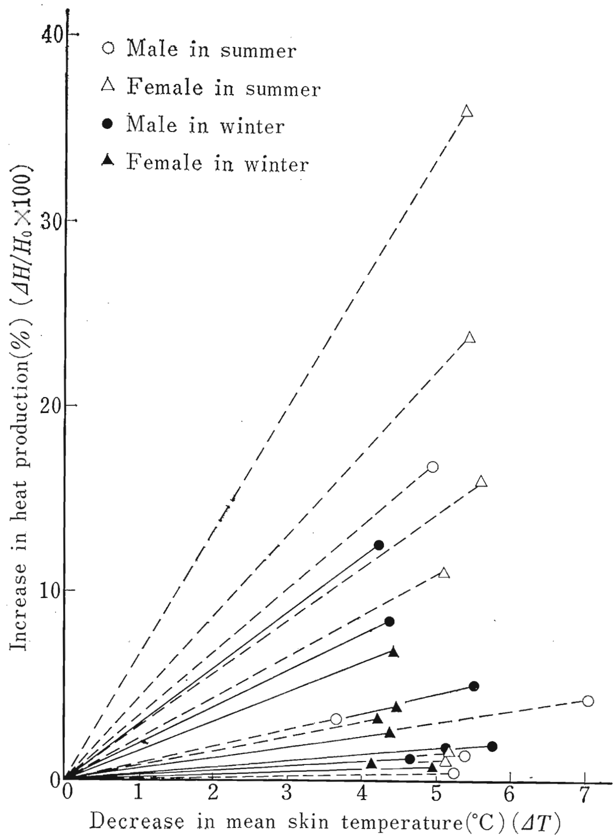

Fig. 10. Relationship between percentage increase in heat production and decrease in skin temperature during exposure to cold, both in summer and winter.
H_0 is the average of two control values, H is the average of two terminal values under cold exposure ($\triangle H = H - H_0$) and ΔT is the difference between the terminal value and the control value.

lower in winter and the grade of drop in the temperature was also smaller in winter, as shown in Fig. 4. The same tendency was noted in the sublingual temperature. The sublingual temperature is often used as a representative of the core temperature, however, in the present study the recovery value of the sublingual temperature tended to increase and its response pattern was not similar to that of the rectal temperature, but was rather similar to that of the mean skin temperature. Under the temperature condition of 10°C, the sublingual temperature might range between the rectal and mean skin temperatures.

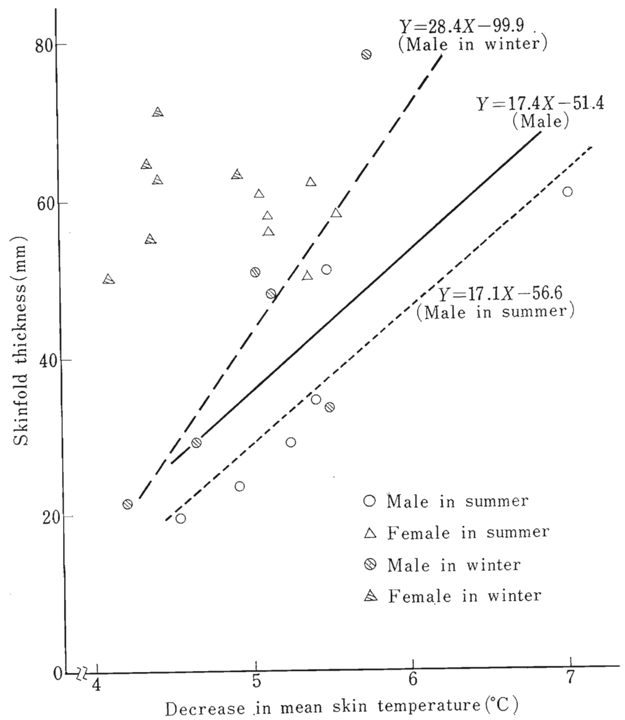

Fig. 11. Relation of skinfold thickness to decrease of mean skin temperature.
Skinfold thickness is the sum of the thickness in back, upper arm, abdomen, and chest.

Sasagawa[16] reported that correlation coefficients between the skinfold thickness and the body conductance at 10°C for male subjects in the nude were −0.55 in summer and −0.52 in winter. Sasaki[5] reported that there was a good relationship between the skinfold thickness and the decrease in the mean skin temperature in male subjects in clothes at 10°C. Wyndham et al.[17] reported that the mean skin temperature of a very fat man was lower than that of a normal man, and the difference of about 10°C between them in the critical temperature for the heat production change can be seen as a quantitative measure of the influence of greater insulation of the fat man in metabolic reaction to cold. Fig. 11 shows relationship between the skinfold thickness and decrease in the mean skin temperature. Correlation coefficient for the male subjects is 0.70 (Y=17.4X−51.4, solid line); 0.78 (Y=28.4X−99.9, broken line) in winter and 0.90 (Y=17.1X−56.6, dotted line) in summer. The correlation coefficient for male subjects was high, but there was no appreciable correlation for the female subjects who had thick skinfold thickness. These findings might suggest various factors other than the physical status for females.

In the experiment by Osada et al.[6] described above, urinary excretion of 17-hydroxycorticosteroids (17-OHCS), adrenaline, and noradrenaline was measured concurrently with other measurements at 10°C and 5°C. It was reported that noradrenaline and adrenaline increased by exposure to cold and the urinary 17-OHCS excretion before the cold exposure was higher in winter than in summer but the increase in 17-OHCS during the exposure was not influenced either by the season or by the exposed temperature. In the study by Hardy et al.[14] a woman, treated with sex hormones for the therapy of amenorrhea, showed a different pattern of heat production compared to other female subjects.

In the present study, from endocrinological point of view, urine volume and urinary 17-KS were measured. It has been said that variation in the urine volume was brought about by physical conditions and volume of water intake. On the other hand, there are diurnal variation and different patterns of 17-KS for individual subjects[9]. In the present study, each subject was restricted to a certain volume of drinking water and the urine volume was measured at the same time on other days as a control. The urine volume for males was very much influenced by the cold during and even after the cold exposure. For females, the volume increased transiently during the exposure to cold but returned to the control level after the exposure, as shown in Fig. 8. Urinary 17-KS during the exposure to cold rather increased in comparison to the control and remarkably increased after the exposure. It could be said that exposure to cold had a great effect on the urination and excretion of 17-KS for a long time. On the contrary, for females, rate of 17-KS was small.

The female subjects had a marked body characteristics such as the thick skinfold in spite of their lower body weight and smaller height. According to the relationship between heat production and mean skin temperature, a distinct tendency for acclimatization to season can be noticed for females. Although the endocrinological role of 17-KS in the acclimatization has been left unsolved, it could be suggested that the physical as well as endocrine status of females might play some important role in the physiological response to the acute cold stress.

Acknowledgement

Grateful acknowledgement is made to Professor H. Kita for his cordial guidance and to Dr. M. Asano, Department of Physiological Hygiene, Institute of Public Health, for his kind advice and correction of the English manuscript, and Assistant Professor Dr. T. Kubota, Department of Hygiene, for his kind advice. The author's deep gratitude is also due to Dr. S. Ōno, Department of Clothing, Japan Women's University, Dr. K. Nakamura, Department of Public Health, and the colleagues in the Department of Hygiene for their great assistance for this study.

This work was supported in part by a Grant-in Aid for Scientific Research from the Ministry of Education.

An outline of this paper was read at the 25th International Congress of Physiological Sciences in Munich, 1971.

References

1) Hammel, H. T., et al.: Thermal and metabolic responses of the Australian aborigine exposed to moderate cold in summer. J. Appl. Physiol., 14: 605–615, 1959.

2) Wyndham, C. H., et al.: Physiological reactions of Caucasian and Bantu males in acute exposure to cold. J. Appl. Physiol., 19: 583–592, 1964.

3) Yoshimura, H., and Iida, T.: Studies on the reactivity of skin vessels to extreme cold. Part 1. A point test on the resistance against frost bite. Japan. J. Physiol., 147–159, 1950.

4) Hirai, K., et al.: Studies on effect of heat content on the vascular hunting reaction to cold, and the reaction of women divers. (in Japanese, with English abstract). J. Physiol. Soc. Japan, 30: 12–21, 1968.

5) Sasaki, T., et al.: Evaluation of whole body tolerance to moderate cold. (in Japanese). Bull. Inst. Consit. Med. Kumamoto Univ., 20: 83–94, 1969.

6) Osada, Y., et al.: Studies on the test procedure of the whole body tolerance to cold in man. (in Japanese, with English abstract). Bull. Inst. Publ. Health, 18: 41–56, 1969.

7) Teichner, W. H.: Assessment of mean body surface temperature. J. Appl. Physiol., 12: 169–176, 1958.

8) Research Committee on Physiological Reaction to Climatic Seasonal Change: Seasonal variations of skin temperature distribution of Japanese male adults (in Japanese). Nisshin Igaku (Japan. J. Med. Progr.), 39: 121–133, 1952.

9) Sawabe, Y.: Biometeorological studies on 17-Ketosteroid excretion (in Japanese, with English abstract). Japan. J. Hyg., 25: 393–407, 1970.

10) Carlson, L. D., and Hsieh, A. C. L.: Cold: The physiology of human survival. Academic Press, London and New York, 1965, pp. 15–51.

11) Ōsumi, K.: Jintai no taikansei ni kansuru jikkenteki kenkyu (Experimental study about human cold tolerance). (in Japanese). Japan. J. Nat. Health, 30: 72–86, 1961.

12) Yurugi, R., et al.: Inter- and intra-individual variance of a test for whole-body tolerance to cold. (in Japanese, with English abstract). Rep. Aeromed. Lab., 9: 113–121, 1968.

13) Girling, F.: Seasonal changes in the physiological response of men to an acute cold stress. Can. J. Physiol. Pharmacol., 45: 13–27, 1967.

14) Hardy, J. D., and Du Bois, E. F.: Differences between men and women in their response to heat and cold. Proc. Nat. Acad. Sci., 26: 389–398, 1940.

15) Tanaka, M.: Experimental studies on human reaction to cold: Differences in the

vascular hunting reaction to cold according to sex, season, and environmental temperature. Bull. Tokyo. Med. Dent. Univ., 18: 269–280, 1971.

16) Sasagawa, S., et al.: Jintai no taikansei ni kansuru jikkenteki kenkyu (Experimental study about human cold tolerance). (in Japanese). Japan. J. Nat. Health, 30: 104–115, 1961.

17) Wyndham, C. H., et al.: Reactions to cold. J. Appl. Physiol., 19: 282–287, 1967.