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EXPERIMENTAL STUDIES ON HUMAN REACTION TO COLD

Differences in the vascular hunting reaction to cold according to sex, season, and environmental temperature

BY

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ABSTRACT

The vascular hunting reaction was determined on four groups; swimmers, students, ice-chamber workers, and cool-room workers.

Determination of the vascular hunting reaction is performed as follows: The left middle finger is immersed up to its base in a water bath of O°C. Room temperature is kept at 22~24°C. Then three characteristics of the temperature change of the finger due to immersion in ice water are adopted as parameters of the reaction, and a "resistance index" is drawn from the values of each characteristic. "Resistance index" of ice-chamber workers was the largest, swimmers the second, normal students the third, and that of cool-room workers was the lowest.

In the second place, effects of room temperature and clothing on the vascular hunting reaction to cold were tested under controlled conditions, and variations due to season and sex were compared according to the vascular reaction of the finger to cold. The higher the room temperature and the thicker the clothes, the higher were the characteristics of the skin temperature curve, but the "resistance index" became almost the same value in each state by using a calibration according to the finger temperature before its immersion. There was no sex difference in the vascular hunting reaction. "Resistance index" in winter was less than that in summer.

INTRODUCTION

Previously a study[1] was carried out to know the influence of environmental temperature such as severe or mild cold on workers by examining the vascular hunting reaction and it was found that ice-chamber workers working in a severely cold environment showed a remarkably higher "resistance index" to cold than cool-room workers working in a mild temperature.

Basic studies on the temperature response was performed by Lewis[2]

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and Grant et al.[3], and the local vascular hunting reaction was standardized for determination of resistance or tolerance to cold by Yoshimura et al.[4] There are many factors affecting the development of the reaction, such as the diet[5], experience of cold exposure[1], age[6], season[4], etc. Therefore, actual experimental conditions should be considered for comparison of each datum.

In the present study, the vascular hunting reaction was determined on four groups; swimmers, students, ice-chamber workers, and cool-room workers. A part of the previous data which had been taken from the subjects of almost the same age as the present subjects. In the second place, effects of room temperature and clothing on the vascular hunting reaction to cold were tested under controlled conditions, and finally variations due to season and sex were compared according to the vascular reaction of the finger to cold.

Method

Determination of the vascular hunting reaction has been described elsewhere[1]. In brief, the left middle finger was immersed up to its base for 30 minutes in a well-stirred water bath of 0°C, as illustrated in Fig. 1. Room temperature was kept at 22~24°C.

When a finger is exposed to an extreme cold, the skin temperature falls steeply at first to a certain level when the subject feels coldness or sometimes pain; secondly, the temperature tends to restore with decreasing pain and coldness, sometimes with a warm sensation, and then at last the temperature fluctuates at a fixed level. This is a typical digital vascular response to cold, i.e., the vascular hunting reaction.

Evaluation of the local vascular hunting reaction in the present study

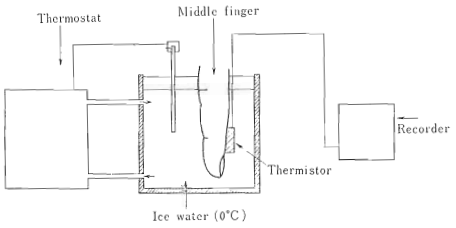

Fig. 1. Measurement of vascular reaction
T.F.R. =Temperature of the first rise after immersion
T.T.R.=Time for first temperature rise after immersion
M.S.T. =Mean skin temperature (values during the first 5 minutes after immersion were rejected)
A.T. =Amplitude of temperature reaction

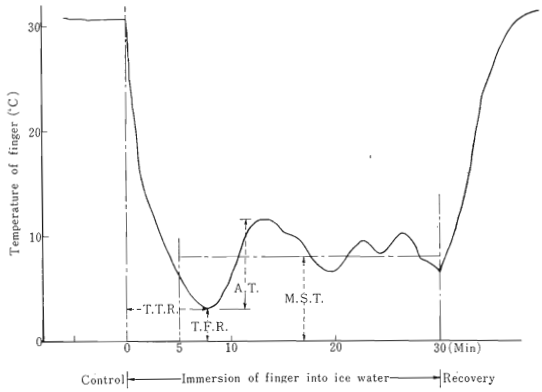

Fig. 2. Characteristics of temperature curve

was performed according to the method of Yoshimura et al.[4]. The following three characteristics of the temperature change due to the immersion of a finger in an ice-water were adopted as parameters of the reaction, as shown in Fig. 2:

1. Temperature of the first rise following the immersion (T.F.R.).
2. Time of the first temperature rise following the immersion. (T.T.R.).
3. Mean skin temperature (M.S.T.); values during the first 5 minutes following the immersion are excluded from the mean.

Resistance index (R.I.) was drawn from the values of each characteristic and calibrated by the finger temperature before the immersion (control) according to the Nagasaki University method[7]. Thus, the strongest resistance was estimated as a maximum index of 9 and the weakest, 3.

Results

1. Influence of Environmental Temperature

Yoshimura et al.[6] reported the effect of age that the maximum reactivity was found at ages of 25~29 years (R.I. 7.13) and the reactivity generally decreased as the age became younger or older. In the present study, 29 healthy males of 21~35 years of age were subjected to the investigation. They consisted of four groups such as 5 excellent swimmers who have been training in swimming all seasons for about 5 years, 15 healthy students as control group, 5 ice-chamber workers working in a room kept at −20 to −25°C, and 4 workers working in a room kept at 15~18°C.

Data in the present study were assembled in a period from the beginning of March to the same of April. The subjects were dressed in everyday

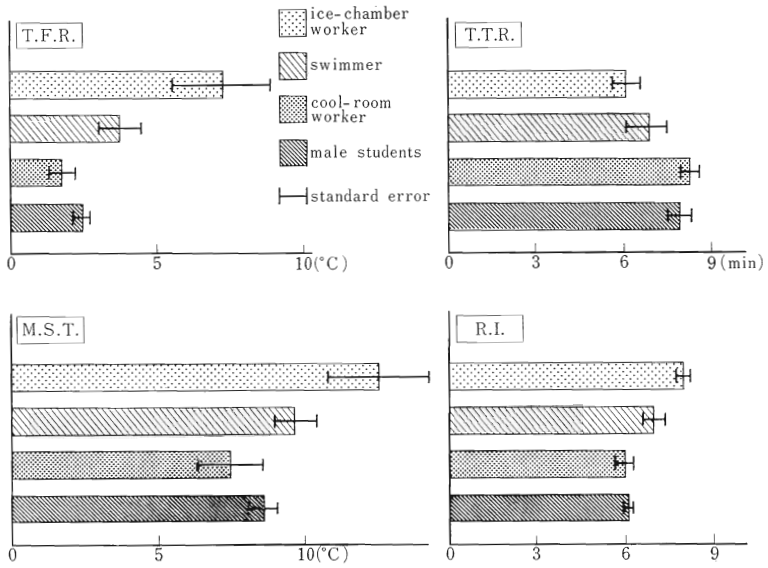

Fig. 3. Comparison of T.F.R., T.T.R., M.S.T., and R.I. of each group

clothes and tested in range of 22~24°C of room temperature throughout the experiment.

Fig. 3 presents averages (±standard error) of the characteristics of the temperature curve and R.I. For T.F.R. and M.S.T., the ice-chamber workers was the shortest, the swimmers second, the control third, and the cool-room workers the longest.

Each average and range of individual R.I. for the four groups were as follows: the swimmers, 7.00 and 6~8; the control, 6.13 and 5~7; the ice-chamber workers, 8.00 and 7~9; and the cool-room workers, 6.0 and 5~7. There are significant difference in R.I. between ice-chamber workers and the control, and between the ice-chamber workers and cool-room workers ($P<1\%$), and also between the swimmers and the control ($P<5\%$). On the contrary, there is no significant difference between the swimmers and ice-chamber workers, the control and cool-room workers, and the swimmers and cool-room workers.

2. *Influences of Clothing and Room Temperature*

In investigation of the local vascular hunting reaction, the laboratory room temperature is one of the most important factors influencing the characteristics. Moreover, as the everyday clothes are changeable according to difference in sex and season, the private climatic temperature might strongly affect the vascular reaction.

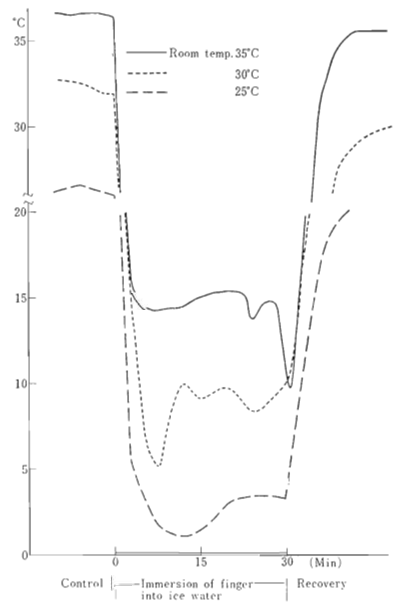

Fig. 4. Vascular hunting reaction according to room temperature

Fig. 4 presents a typical tracing of the hunting reaction of one of the subjects recorded at different room temperatures. Three healthy laboratory men of 30~35 years of age were subjected to the investigation. The finger temperature before the immersion (control) was apparently affected by the room temperature, and the finger temperature was slightly higher than the room temperature. Values of the characteristics at each room temperature were as follows:

At 35°C: the control value, 36°C; T.F.R., 12.3°C; T.T.R., 5 min 30 sec; M.S.T., 16.64°C. At 30°C: the control value, 34.9°C; T.F.R., 11.8°C; T.T.R., 6 min 30 sec; M.S.T., 14.01°C. At 25°C: the control value, 28.0°C; T.F.R., 5.0°C, T.T.R., 9 min 00 sec; M.S.T., 8.4°C. R.I. was 8 for every room temperature.

In the second place, the reaction was compared between subjects in the nude and with clothes at a room temperature of 25°C. In the nude: the control value, 21.0°C; T.F.R., 1.1°C; T.T.R., 12 min 00 sec; M.S.T., 2.51°C; R.I., 6. In light clothe, trousers, and undershirt: the control value 34.0°C; T.F.R., 4.4°C; T.T.R., 4 min 30 sec; M.S.T., 9.01°C; R.I., 6. In thick clothes: the control value, 34.6°C, T.F.R., 7°C; T.T.R., 5 min 00 sec; M.S.T., 10.05°C; R.I., 7.

R.I., which was calibrated from the control value, was almost the same value for every case. However, the characteristics of the temperature curve were different from each other.

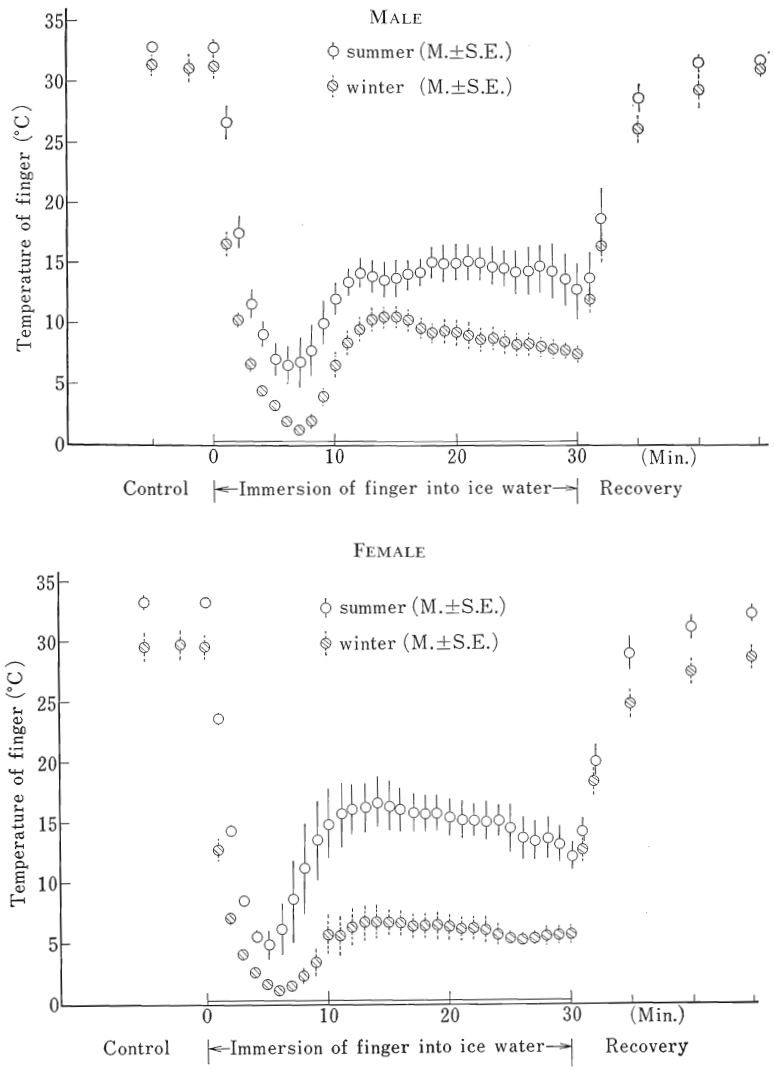

Fig. 5. Vascular hunting reaction

Finger temperature of two groups during the experiment. Each time interval is 1 minute. Each point is the average value of 6 subjects from male students (5 subjects in winter due to measuring instruments trouble). Vertical lines and broken lines indicate standard errors.

3. *Variations due to Sex and Season*

Six each of healthy male and female students of 19~25 years of age were subjected to the investigation. Throughout the investigation they were dressed in the same clothes in an ambient temperature of 22~24°C,

Table 1. Characteristics of temperature curve of each subject

Subject		Summer						
		Control Value (°C)	T.F.R. (°C)	T.T.R. (min sec)	M.S.T. (°C)	A.T. (°C)	R.I.	M.S.T./ A.T.
Male	H.N.	32.45	11.5	3 30	12.23	3.5	9	3.49
	A.I.	32.50	2.3	7 00	9.90	12.4	6	0.79
	Y.T.	34.10	9.0	7 00	13.23	3.8	8	3.48
	K.H.	33.40	1.7	7 30	8.65	9.9	6	0.87
	A.H.	32.00	7.4	5 00	17.36	9.9	9	1.75
	K.S.	33.60	2.1	7 20	16.56	18.6	7	0.86
M. ±S.E.		33.01± 0.30	5.67± 1.56	6′17″± 37″	12.99± 1.30	9.68± 2.31	7.5± 0.5	1.88± 0.53
Female	A.M.	31.20	1.4	7 30	6.28	6.8	6	0.92
	T.T.	34.60	3.6	5 30	18.50	19.4	7	0.95
	T.Y.	34.35	7.3	4 15	18.57	13.9	8	1.34
	S.T.	34.65	6.3	4 10	16.01	15.7	8	1.02
	M.M.	33.15	1.5	7 00	12.05	14.2	7	0.85
	I.O.	32.85	1.7	6 35	12.37	14.9	7	0.82
M. ±S.E.		33.47± 0.50	3.63± 0.97	5′50″± 31″	13.96± 1.67	14.18± 1.67	7.2± 0.3	0.98± 0.08

Subject		Winter						
		Control Value (°C)	T.F.R. (°C)	T.T.R. (min sec)	M.S.T. (°C)	A.T. (°C)	R.I.	M.S.T./ A.T.
Male	H.N.	31.8	1.0	6 30	9.04	10.7	6	0.84
	A.I.	25.5	1.3	7 00	5.07	6.9	7	0.74
	Y.T.	—	—	—	—	—	—	—
	K.H.	32.9	1.4	8 30	5.90	7.0	6	0.84
	A.H.	32.4	1.8	7 30	7.22	9.2	6	0.78
	K.S.	33.4	1.7	7 30	10.28	12.6	6	0.82
M. ±S.E.		31.20± 1.30	1.44± 0.13	7′20″± 18″	7.50± 0.86	9.28± 0.98	6.2± 0.2	0.80± 0.02
Female	A.M.	30.8	1.9	7 00	3.75	2.7	6	1.39
	T.T.	31.3	0.9	7 30	5.42	6.4	6	0.85
	T.Y.	32.9	1.0	6 00	9.33	12.2	6	0.76
	S.T.	31.3	1.2	6 00	6.73	8.9	6	0.76
	M.M.	25.7	0.4	9 00	2.74	4.2	6	0.65
	I.O.	25.2	0.4	9 00	3.12	3.9	6	0.80
M. ±S.E.		29.53± 1.21	0.97± 0.21	7′25″± 30″	5.18± 0.94	6.38± 1.34	6.0± 0	0.87± 0.10

that is, wearing an underwear and training clothes. Data in this part were assembled in August when the subjects seemed to be acclimatized to hot climate, and in February when they did the same to cold climate.

Fig. 5 shows average (± standard error) of the finger temperatures measured at 60-sec intervals for each sex and season. Skin temperature of the finger fell steeply following immersion of the finger into ice-water of 0°C, then the finger temperature tended to restore in an oscillating manner, and fluctuated at a fixed level. Similar pattern was found in every case.

The curve in summer developed at a higher level than that in winter. The curves for both sexes showed almost the same pattern. The control values were different in summer and winter, that is, higher in summer than in winter. Accordingly, R. I. was calibrated by the control value in order to evaluate the seasonal variation. Table 1 shows characteristics of the temperature curve for each subject. T.F.R. and M.S.T. in winter were lower than those in summer. T.T.R. was longer in winter. R.I. in summer were 7.5 for males and 7.2 for females, and R.I. in winter, 6.2 for males and 6.0 for females. Thus, all the value in winter were lower than those in summer. Concerning variations due to sex, the above mentioned values are slightly higher in both seasons for males than those for female. Variations due to season are larger than those due to sex.

Averages of the amplitude of the temperature reaction (A.T.) in summer were 9.68°C for males and 14.18°C for females, and distribution range for individual values was rather wide; 3.5~19.4°C. In winter, the averages were 9.28°C for males and 6.38°C for females. The average for females was smaller in winter. The range for individuals was from 2.7° to 12.6°C. An index M.S.T./A.T. was 1.88 in average for males in summer and 0.98 for females. In winter, the index was lower than that in summer for all the subjects except for one female subject.

Discussion

Frostbite occurs often in extremites by exposure to cold and it is important to measure the vascular reaction or tolerance to cold it those parts.

Wilson et al.[8] stated that "the time to freeze exposed finger skin was measured at varied wind speeds and varied cold ambient temperatures. Some exposures resulted in freezing, some in cold-induced vasodilation (CIVD). Air temperature is the main factor in determining whether freezing or CIVD occurs at windchill indices predicting risk for freezing".

Iida[9] reported that the individual variation of R.I. was closely correlated with difference in their resitsance to frostbite.

Ambient temperature in living or working has, it is said, a great deal of effect on human physical reaction. Hirai et al.[10] examined the vascular reaction of a finger to cold in female divers and students, and stated that "the vascular reaction of a finger to cold was higher in the divers than in students. The mean skin temperature of the finger in ice water and grade of the first rise of the temperature hunting reaction were higher in divers than in the students."

Comparison among the four groups in the present experiment, i.e., first-class swimmers, ice-chamber and cool-room workers, and male students showed that R.I. of the ice-chamber workers was the highest, swimmers the second, students the third, and cool-room workers the lowest. This fact means that the acclimatized ambient temperature has a great effect on the resistance to cold.

In the experiments at varying room temperatures in the nude, the higher the room temperature was, the higher were M.S.T. and T.F.R., and the shorter was the value of T.T.R. For varying thickness of clothes, a similar trend was observed, but R.I. in all the experiments was almost the same for all the individuals. Since R.I. was calibrated by the control value, effects of clothes and experimental room temperature proved to be negligible and R.I. of an individual at that time became constant.

Fig. 6 shows a correlation coefficient between T.T.R. and T.F.R. and Table 2 shows correlation coefficients between each of the items. Correla-

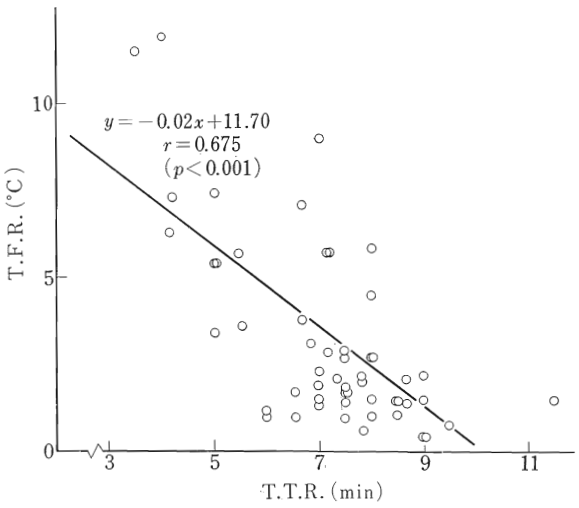

Fig. 6. Temperature of the first rise after immersion (T.F.R.) to time of the first temperature rise after immersion (T.T.R.)

Table 2. Correlation coefficients between each item

Correlation coefficients / Significancy	T.T.R.	T.F.R.	M.S.T.	R.I.	M.S.T./A.T.
T. T. R.		0.68	0.60	0.71	0.48
T. F. R.	P<0.001		0.62	0.86	0.86
M. S. T.	P<0.001	P<0.001		0.70	0.34
R. I.	P<0.001	P<0.001	P<0.001		0.72
M.S.T./A.T.	P<0.001	P<0.001	P<0.02	P<0.001	

tion coefficients between T.T.R. and M.S.T./R.I. (P<0.1%), and between M.S.T. and M.S.T./A.T. (P<2%) were rather lower. Those between other items were rather high and over about 0.6(P<0.1%).

The index M.S.T./A.T. for both the ice-chamber workers and swimmers was larger than 1. For the male the index in summer was 1.88 and M.S.T./A.T. in winter was smaller than that in summer for both sexes. This fact shows that the level of M.S.T. is larger than the range of A.T. in subjects who had a large value of R.I.

Comparison between the male and female subjects showed that T.F.R. of the males was higher than that of the females in both seasons, there being no remarkable difference between the sexes for M.S.T. and T.T.R. R.I. for both sexes was higher in summer than that in winter. In summer, R.I. of the females was 0.3 less than that of the males and 0.2 in average in winter. These differences concerning sex were not statistically significant.

Yoshimura et al.[4] reported monthly changes in the reactivity of the left middle finger in three subjects, and mentioned that "resistance indices changed remarkably with progress of months except those of one subject in which changes were slight. Such changes of indices were probably due to seasonal change in environmental temperature,—" In their paper, R.I. was reported as being the greatest in summer and the smallest in winter.

In the present study, T.T.R. in summer was shorter than that in winter and T.F.R. and M.S.T. in summer were higher. R.I. in summer was 7.5 for men and 7.2 for women in average and that in winter was 6.2 for men and 6.0 for women. R.I. in winter tended to be smaller than that in sum-

mer, and for the females R.I. in winter was significantly less than that in summer ($P<1\%$).

Conclusion

R.I. for the digital vascular response to cold was determined in four groups in accordance with their severe or mild ambient temperatures. R.I. of the ice-chamber workers was the highest, swimmers the second, normal students the third, and that of the cool-room workers the lowest. This fact means that the acclimatized ambient temperature in living or working has a great effect on the local vascular resistance to cold.

There were remarkable differences in the vascular hunting reaction to cold according to conditions of the experimented room temperatures and, the thicker the clothes, the higher were the characteristics of the skin temperature curve (T.F.R., T.T.R., and M.S.T.). However, acute effects of clothing and room temperature on R.I. became negligible by using the calibration method of Nagasaki University.

There was no sex difference in the vascular hunting reaction but there was a remarkable difference in the results in summer and in winter; R.I. in winter was less than that in summer.

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