〔보 문〕

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Physiological and Psychological Thermal Responses to Local Heating of the Human Body in a Cold Environment

한랭환경하에서 인체의 국소가온 자극이 온열생리 · 감각반응에 미치는 영향

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Abstract

본 연구는 한랭 환경 하에서의 인체의 국소 가온 자극이 생리, 감각반응에 끼치는 영향을 검토했다.

건강한 성인여자 5명을 대상으로, 기온 25℃, 습도 50%의 환경 하에서 균일한 국소 가온을 부하 했을 때 피부온, 고막온, 손가락, 발가락 혈류량, 온냉감, 쾌적감의 반응에 미치는 영향을 검토한 결과는 다음과 같다. 1) 국소가온에 의해 가온 부위 피부온은 유의하게 상승하고 가온 부위에 따라 상승도에는 유의한 차가 보였다. 2) 국소가온에 의해 고막온은 머리의 가온 시에 높은 상승, 전완의 가온 시에 상승하고, 다른 가온 부위에서는 하강의 경향이 보였다. 3) 국소가온에 의해 혈류량의 변화는 3개의 군으로 분류된다. 가온과 함께 손가락 혈류량이 증가하는 군, 발가락 혈류량이 변화하는 군, 양쪽의 혈류량이 적게 변화하는 군으로 나누어진다. 이것은 각 피험자의 평균 피부온 수준 즉 체온조절 수준과 관계 있는 것으로 논할 수 있다. 4) 국소 가온에 의해 각 부위 피부온으로의 파급효과는 머리, 상완의 가온 시에 크지만 대퇴, 하퇴 다리의 가온 시에는 대부분의 부위에서 영향이 보이지는 않았다. 5) 이와 같이 국소 가온에 의한 생리, 감각반응은 가온 부위에 따라 다르고 머리, 상완의 가온 시에는 생리반응이 크고 하퇴, 다리의 가온 시에는 국소의 감각변화가 컸다.

Key words: local heating, thermoregulation, blood flow, tympanic temperature, mean skin temperature; 국소가온, 체온조절, 혈류량, 고막온, 평균피부온

I. Introduction

Humans have adapted to the cold by putting a heavy coat, a shawl, and a bowler or gloves on in the cold environment. Furthermore, humans have tried to make a comfortable residential environment by using an electronic blanket on the bed, lighting a stove, and using radiant heat and the Ondol when clothing was insufficient.

Stevens et al.(1974) reported the difference of local skin temperature in the order of face, trunk, arm, and leg part when the local heating with heat radiation was added. Yutani et al.(1982) showed that the effects of local heating were most conspicious on the back and loin which affected the whole body. They also reported that the leg part was more effective than the arm part on the local heating. Kuji et al.(1984) applied heat to peripheral parts such as hands and feet with a

silicon heater so that they could find the effect of local heating when they heated the dorsum manus and foot at the same time. They also described that heated feet were more effective than heated hands. Lee et al.(1985) used an electronic heating system and reported that arm parts were more easily affected than leg parts by local heating when they heated 5 parts. Also thermal sensations of the whole body had a high relationship with those of the shoulder part. Effects of local heating were closely related to the distributions of cold and heat receptors. Tamura and An(1993) also said that chest local cooling were affected to the whole body but peripheral local cooling were affected to the cooling body part. Tympanic temperature increase was showed at every part cooled.

Further studies of the local heating in the cold environment or thermal neutral zone researched the effects of the local heating on skin temperatures and thermal comfort index but the research of the relationship between tympanic temperature and blood flow rate was rare. It could be an interesting research if we tried to compare the response of tympanic temperature of the local heating with that of the local cooling because a transitory increase was showed from response of tympanic temperature by local cooling in further researches.

The purpose of this study is to find the effect of local heating on tympanic temperature, skin temperature, blood flow, thermal sensation and thermal comfort.

II. Methods

1. Subject and clothing

5 healthy women volunteered for the experiments. (21-36 ages, 161±3.44cm, 54.2±6.65kg). All subjects belonged to the regular prototype according to the body mass index. Subjects were sitting on the chair with brassier and shorts during the experiment.

2. Environment and local heating system

The environmental conditions of the chamber were 25±0.5℃ air temperature, 50±10% RH, and air velocity of less than 20㎝/sec.

The heating load pads for local heating which are silicon tubes with a length of 7m(inside diameter 3mm, outside diameter 4.5mm) were stuck to nonwoven fabric(15×20cm; double fabric) and was connected to a motor pump(output volume 7l/min) which circulated the 45℃ hot water with 6.5l/hr flow rate. Insulated aluminium compression fabric was used on the surface of the heating pad to restrict the effects of air temperature. Thermistor sensors were put in silicon tubes to measure the water temperature and the entrance and outlet of the heating pad. The local heating system was used when a stable state after pre-heating was required. Local heating area were as follows: head, neck, chest, back, abdomen, loin, upper arm, lower arm, hand, thigh, lower leg and foot.

3. Experiment process

The experiment was composed of 30 minutes of rest, 30 minutes of local heating and 30 minutes of recovery periods in 25℃ air temperature. Subjects wearing a brassiere and shorts entered the chamber after removing water with a towel. After measuring the body mass, subjects sitting on the chair inserted the rectal temperature sensor to their rectums and then tympanic temperature, skin temperature, blood flow with sensors adhered to the middle finger and toe were recorded during rest, heating and recovery periods. After the measurement, body mass of subjects were measured again.

4. Measurement Index

Tympanic temperature was measured with spring type of high sensual tympanic temperatures on the drum membrane. 13 points of skin temperatures were recorded with a thermistor (Japan Takara co.) every 1 minute. Mean skin temperature was calculated with equations of the 7 points of Hardy & Dubois and the 13 points of Tamura. Blood flow rates were measured on the middle finger and toe by laser doppler type sensor every 1 second. Thermal sensations were also measured by 7 scales of ASHRAE and thermal comfort were measured by 5 scales.

Ⅲ. Results

1. Thermoregulation before local heating and acquired heat load of local heating

In 25~30 minutes of resting period, it could be cold environment from mean tympanic temperature (36.99℃), mean skin temperature(31.81℃) and thermal sensation(a little cool).

Acquired heat load of each part of local heating was calculated with the water velocity and the water temperature differences of the entrance and outlet to the heating pad at 10 minutes and 20 minutes after local heating.

Acquired heat load of each part of local heating was 5.50W ~ 12.24W. The reason why the temperature of the peripheral parts was higher than the trunk parts was because the temperature of the peripheral parts was lower than the trunk parts before local heating.

2. Changes of skin temperature by local heating

Every part of skin temperature was increased from the beginning of local heating and became stable after 10 minutes. The degree of increase by

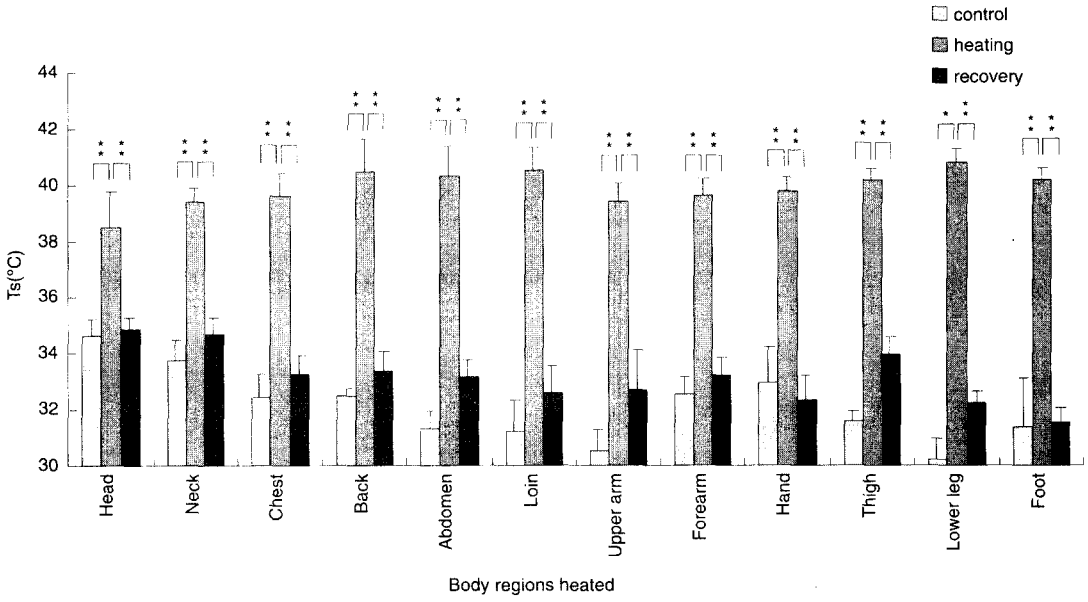

Fig. 1. Mean and standard deviation of skin temperature beneath the heating pad during control, local heating and recovery. Asterisks indicate significant difference(:p<0.01, *:p<0.05) between the two values bridged by the solid line.**

Table 1. Significant differences of skin temperature change beneath the heating pad among body regions heated. Upper right show t-values of the change by heating and lower left values show recovery

Body region heated	Effect of heating											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Head		2.61+	3.85*	5.37**	4.16*	3.63*	4.38*	2.99*	2.43+	8.05**	10.63**	3.29*
2 Neck	1.76		1.89	3.53*	3.67*	3.99*	5.89**	1.72	1.09	6.55**	7.02**	2.82*
3 Chest	3.93*	2.17+		3.87*	2.63+	1.94	2.02	0.07	0.23	3.82*	2.48+	1.47
4 Back	3.41*	2.49+	1.34		1.07	1.13	0.83	1.12	1.17	0.99	3.15*	0.49
5 Abdomen	3.56*	3.38*	1.79	0.12		0.14	0.44	5.77**	4.53*	0.82	2.13+	0.74
6 Loin	3.07*	3.34*	1.26	0.62	0.51		0.63	1.84	1.58	0.71	1.01	0.39
7 Upper arm	2.66+	2.96*	0.33	0.38	0.62	1.95		2.92*	1.93	0.49	2.11	0.13
8 Forearm	3.20*	3.81*	0.13	0.69	1.89	1.56	0.46		0.26	2.43+	7.84**	3.74*
9 Thigh	3.35*	3.02*	1.82	0.22	0.76	0.36	0.66	1.70		1.99	5.79**	2.59+
10 Lower leg	3.77*	2.63*	0.20	1.81	1.59	1.48	0.46	0.23	1.58		4.94**	0.23
11 Hand	8.67**	8.39*	6.06**	1.58	3.18*	0.69	2.06	5.81**	2.32+	4.84**		2.06
12 Foot	5.48**	9.02**	3.24*	1.33	2.73+	0.68	2.99*	7.59**	1.96	3.91*	0.35	
heated	1	2	3	4	5	6	7	8	9	10	11	12
	Effect of recovery											

**: p<0.01, *:p<0.05, +:p<0.1

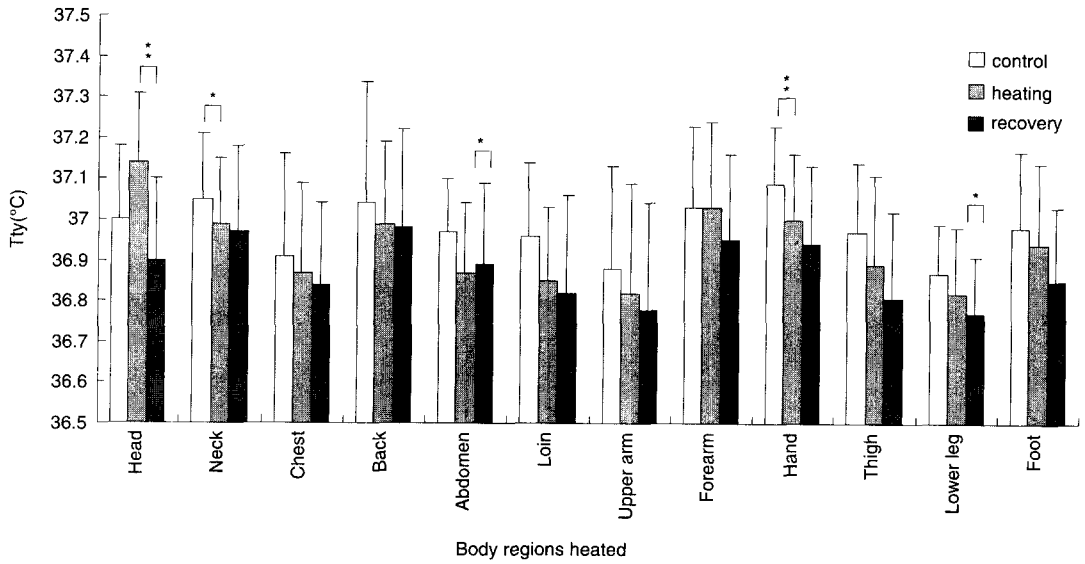

Fig. 2. Mean and standard deviation of tymapnic temperature beneath the heating pad during control, local heating and recovery. Asterisks indicate significant difference(:p<0.01, *:p<0.05) between the two values bridged by the solid line.**

local heating were higher on the lower leg, loin and lower arms with 8.90℃ ~10.67℃ than on the thigh and foot with 8.47℃ ~8.53℃. The hand, neck and head showed 4.19℃ ~6.86℃ increase by local heating.

Fig. 1 shows the means of each skin

temperature on rest, heating and recovery periods of the last 5 minutes. All parts except for the lower leg were significantly different among the rest, heating and recovery periods($p<0.01$). lower leg was significantly different among the rest, heating and recovery periods($p<0.05$). The upper right in Table 1 shows increase rates among the body parts. Because the increase rates were high by lower leg heating, there were significant differences on the head, neck, lower arm, hand and thigh($p<0.01$) and on the back, chest and abdomen($p<0.05$). On the otherhand, on the head and neck which showed lower increase rates showed differences with similar responses. The lower part in Table 1 shows the comparison of the skin temperature decrease rates from the heating to recovery period. There were much differences between the foot and lower leg which showed large decrease rates and the head and neck which showed small decrease rates.

3. Changes of tympanic temperature

Tympanic temperature showed different reponses according to the heating parts. Tympanic temperature was significantly increased with 0.13℃ in the head heated but was stable and decreased in other parts heated. Fig. 2 showed the tympanic temperature differences among the rest, heating and recovery periods with the averages of last 5 minutes of each period. In general, there were no significant differences. However, there were significant differences on the neck and hands($p<0.01$) and on the abdomen and lower leg($p<0.05$) with the differences in the rest and heating periods.

4. Changes of blood flow

Blood flow was measured on the middle finger and toe. The amount of blood flow of the middle finger was more than that of the toe.

Table 2 shows the changes of blood flow in heating and recovery period by subjects and measured parts. The responses of each subject by local heating would be divided into 3 different groups. The blood flow changes of the middle

Table 2. Change of blood flow

Subject	HB				JM				KS				SS				KA			
Site measured	Finger		Toe		Finger		Toe		Finger		Toe		Finger		Toe		Finger		Toe	
Phase region heated	H	R	H	R	H	R	H	R	H	R	H	R	H	R	H	R	H	R	H	R
Head	↑	↓	—	—	↑	↓	↑	—	—	—	—	—	—	—	↑	↓	—	—	—	↓
Neck	—	↓	—	—	↑	↓	—	—	—	—	↑	↓	↓	↑	↑	↓	—	↓	—	↓
Chest	↑	↓	—	—	↑	↓	—	—	—	—	—	—	↓	—	↑	↓	—	—	↑	↓
Back	↑	↓	—	—	↑	↓	↑	↓	—	—	↑	↓	↓	—	—	↑	—	—	—	↓
Abdomen	↑	↓	↑	↓	↑	↓	—	↓	↓	—	↑	↓	—	—	↑	↓	↓	↑	—	↓
Loin	↑	↓	—	—	↓	↓	—	—	—	↓	↑	↓	—	—	↑	↓	—	↓	—	—
Upper arm	↑	↓	—	—	↑	↓	—	↓	—	—	↑	↓	↑	—	↑	↓	—	↓	↑	↓
Forearm	↑	↓	—	—	↑	—	—	—	—	—	↑	—	↓	↑	↑	—	↓	—	—	—
Thigh	—	↓	—	↓	—	↓	—	—	—	—	—	↓	—	—	—	↓	—	↓	—	↓
Lower leg	↑	↓	↑	—	↑	↓	↑	—	↑	↓	—	—	↓	—	↑	—	—	—	—	—
Hand	↑	↓	—	—	↑	↓	—	—	—	—	↑	↓	—	—	—	—	—	↓	—	—
Foot	—	↓	↑	—	—	—	↑	↓	—	—	—	↓	—	—	↑	↓	—	—	—	↓

↑ : Increase , ↓ : Decrease, —: No change, H: Heating phase, R: recovery phase

Table 3. Effect of local heating on the skin temperature of the other regions and mean skin temperature

body region / skin heated temperature	Head	Trunk					Upper extremity			Lower extremity		
	Head	Chest	Abdomen	neck	Back	Loin	Upper arm	Fore arm	Hand	Thigh	Lower leg	Feet
Forehead	4.19	−0.19	−0.14	−0.02	−0.11	−0.06	0.05	−0.02	−0.06	−0.04	−0.04	−0.03
Cheek	1.57	−0.17	−0.21	−0.11	−0.32	0.29	0.57	0.31	−0.13	0.24	0.03	0.03
Chest	−0.11	7.15	0.16	0.49	−0.11	−0.03	−0.08	−0.02	−0.01	−0.22	−011	−0.09
Abdomen	−0.16	−0.24	8.99	−0.01	−0.03	−0.23	0.00	−0.18	−0.08	−0.15	−0.28	−0.16
Pst.neck	0.40	0.11	−0.25	5.63	0.10	−0.11	0.01	−0.07	0.00	−0.35	−0.05	−0.11
Infrascapula	0.18	−0.23	−0.21	0.09	8.05	−0.16	−0.03	−0.22	−0.25	−0.40	−0.37	−0.20
Loin	−0.75	−0.97	−0.99	−0.52	−0.53	9.14	−0.34	−0.74	−0.61	−0.46	−0.47	−0.66
Lat.upper arm	−0.57	−0.62	−0.72	−0.71	−0.85	−0.55	8.90	−0.64	−0.35	−0.61	−0.63	−0.36
Ant.forearm	−0.57	−0.47	−0.40	0.01	−0.53	−0.57	−0.25	7.07	1.93	−0.38	−0.69	−0.77
Hand	−0.46	−0.44	−0.05	0.29	−0.46	−0.30	0.02	0.27	6.86	−0.33	−0.91	−0.82
Ant.thigh	−0.37	−0.49	−0.42	−0.30	−0.43	−0.37	−0.38	−0.42	−0.28	8.53	−0.33	−0.40
Ant.leg	−0.89	−0.96	−0.96	−0.79	−0.67	−0.77	−0.82	−0.76	−0.81	−0.89	10.67	−0.73
Foot	−1.35	−0.97	−0.92	−0.08	−0.83	−1.15	−0.60	−0.31	−0.06	−0.89	−1.02	8.47
Ts(℃)	0.37	−0.16	−0.49	−0.45	−0.43	−0.42	−0.27	−0.31	−0.14	0.45	−0.41	−0.28
Tty(℃)	0.13	−0.06	−0.05	−0.10	−0.14	−0.15	−0.07	0.02	−0.09	−0.09	−0.05	−0.04
Thermal sen.	−0.50	1.10	0.60	0.90	0.60	1.60	1.00	0.00	0.30	−0.30	0.50	0.40

All the parts which has minus values are marked with mesh.

finger were showed in subject HB and JM by all body parts heated except the foot. In other words, the blood flow of the middle finger was increased at heating period and was decreased at recovery period. However, the blood flow of the toe was high at that time. Subject KS and SS showed low blood flow of the middle finger and high blood flow of the toe. In the heating period, blood flow of the middle finger was increased and decreased in the recovery period. Subject KA showed small changes of the blood flow of the middle finger and toe.

5. Skin temperatures of each body part

Table 3 shows the skin temperature changes of each body part by local heating. There were increased skin temperature on the head, trunk and upper arms by local heating. Comparing by heating parts, the trunk skin temperature was much more increased by head and upper arm heated. There were no heating effects through the whole body part by the thigh, lower leg and foot heated.

IV. Discussion

The regular local heating was added to the subjects wearing a brassiere and shorts under 25℃, 50% RH. The environment of 25℃, and 50% RH was applicable to under the thermal comfort zone which was equal to the physical cooling area and also a slightly cold environment. This environmental condition reached the limit considering the endurance time of the subjects, normality of physical reponses and non-cold causing range by the repetitions of local heating.

As the results of 12 body parts heated, nobody sweated but had red skin on the heating part after local heating. It could be caused by the expansion

of the capillary vessel. The decrease rates of the skin temperatures of peripheral parts was higher than those of the trunk part. Carson and Hsieh (1965) reported that the skin blood flow was regular in every part of the human body at the beginning of the cold exposure, but there were differences the body parts as the time passed. The decrease rates of the skin temperature were lower on the head and trunk and those of skin temperature were higher on the peripheral parts because of the tension of vessel contraction.

Tympanic temperature by local heating was incredibly increased on head heated but was decreased on other parts heated. The research of Tamura and Ann(1993) reported increase of tympanic temperature under the local cooling of any part. However, we could not find the same results in this study. Increasing tympanic temperature was due to the blood flow of the brain which was heated by local heating. Decreasing tympanic temperature was showed by shoulder local heating in the hot environment. In this study, selected cooling of brain temperature was not showed under the cold environment because of the set point of brain temperature.

Subjects could be divided into a group changing the blood flow of the middle finger and a group changing the blood flow of the toe by local heating. In any case, the blood flow on the middle finger was much more than that on the toe and Nagasaka et al.(1987, 1989, 1990) also reported the same results. In this study, blood flow of the middle finger and toe were different according to the subjects. It was caused by the shifted thermoregulation level even though all subjects were exposed to the same environment.

Comparing the local heating area, increased trunk temperature was showed at heating on the head and upper arm but there were no effects of local heating at heating on the thigh, lower leg and foot. Researches of local heating and local cooling of Stevens et al.(1974), Yutani et al.(1982), Lee et al.(1985) and Tamura and An(1993) reported that the effects of local heating and local cooling on skin temperatures and thermal sensations were showed in the order of the trunk, arm parts and then leg parts. Tamura(1995) reported that cold spot density were high in the order of the face, trunk, neck, upper peripheral part and lower peripheral part and also hot spot density were high on the face, back neck and then lower arm and low on the lower leg. Local thermal sensations were largely changed at heating on the lower leg and foot because heat acquisitive volume by local heating was great and the skin temperatures before local heating were also low. Effects of local heating in cold environments of this study had similar results with the results of Yutani et al.(1982) and Kuji et

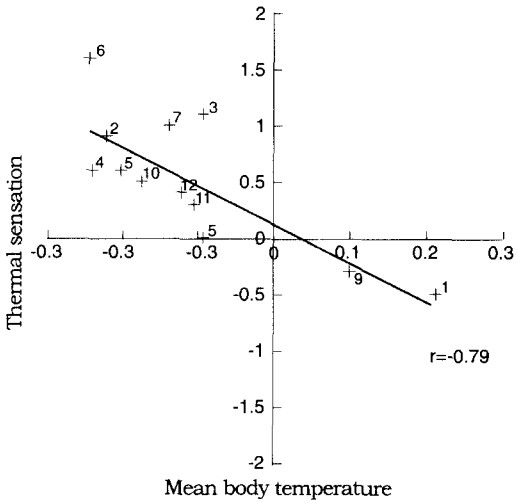

Fig. 3. Correlation between changes of the mean body temperature and changes of thermal sensation by local heating

1: Head	**2: Neck**	**3: Chest**
4: Back	**5: Abdomen**	**6: Loin**
7: Upper arm	**8: Forearm**	**9: Thigh**
10: Lower leg	**11: Hand**	**12: Foot**

al.(1984).

There were significant negative correlations between thermal sensations and mean skin temperature(-0.70) and between thermal sensations and tympanic temperature(-0.67). Researching the relationship between the thermal sensation and mean skin temperature, Fig. 3 shows the relationship between the changes of mean skin temperatures and those of thermal sensations. There were high negative correlations between the changes of mean skin temperature and those of thermal sensations($r=-0.79$). Vokac et al.(1971) reported the high correlations between local thermal sensation and local skin temperatures. They also reported that the thermal sensations were more correlated to mean temperature than to mean skin temperature. Those results were inconsistent with this study.

V. Conclusion

We measured the local skin temperature, tympanic temperature, the blood flow of the middle finger and toe, thermal sensation and thermal comforts of 5 healthy female subjects when the head, neck, back, chest, abdomen, loin, upper arm, lower arm, hand, thigh, lower leg and foot were locally heated with the same degree of $25\pm 0.5^{\circ}C$ and $50\pm 10\%$ RH.

1) Heated local skin temperatures were significantly increased but the increase rates were significantly different due to the heated parts of the subjects.

2) Tympanic temperature was incredibly increased when the head was heated. It was increased when the lower arm was heated, but it was decreased when the other body parts were heated.

3) The blood flow could be divided into 3 different groups such as the first group which the finger blood flow was increased, the second group which the toe blood flow was increased and the third group which the finger and toe blood flow showed small changes by local heating. The blood flow changes by local heating were related to mean skin temperature level of each subject that is anindex of thermoregulation level.

4) The effects of local heating on the skin temperature of each part were showed when the head and upper arm were heated and were not showed when the thigh, lower leg and foot were heated.

5) Physiological and sensational responses to local heating were different according to the heated parts. Physiological responses were showed when the head and upper arm were heated and sensational responses were showed when the lower leg and foot were heated.

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