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Effects of Local Cooling on Heat Strain in the Hot Environment -On the Trunk Region-

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Abstract: This study was to determine the effect of cooling part of the trunk without harm for the health. The results provide basic data for the development of clothing which could increase work efficiency and reduce body strain in hot environment. Eight males took part in the study. The experiment was conducted in a climate-chamber controlled with 37±1°C, 50±5%R.H. The trunk was divided into six areas to be cooled: head, neck, chest, abdomen, the upper back, the lower back. According to preceding studies, permissible safety cooling limits of skin temperature, of each part of the trunk for four hours cooling were 25°C on the head, 20°C on the neck, 27°C on the chest, 25°C on the abdomen, 20°C on the upper back, 20°C on the lower back. So cooling temperatures of each region set up temperatures above mentioned. In conclusion, the head, the neck and the upper back cooling could reduce sweating amount, rectal temperature and heart rates and reduce the heat stress of workers exposing in the hot environment by decreased subjective sensations of heat and comfort. Thus, it was concluded that effectiveness of cooling among the trunk was best on the head and the neck.

Keywords : *cooling, hot environment, trunk, cooling efficiency*

Introduction

With the increasing hot workshop recently, governments and academic circles have tried to preserve workers' health. For examples, many farm workers have worked over five hours when they sprayed pesticides in hot,[1,2] and it should make heat-related illness like heat rash and heat stroke.

Mostly, their studies have focused on the method to reduce heat strain in many ways and to find optimum proportions of work and rest, rearrangement of workplace and development of various cooling aids.[3-5] Furthermore, more positive studies were carried out to reduce heat strain in the hot environment through more efficient coolant and cooling system.[6,7]

Clothes protecting against heat has been shown to reduce physiological strain under high temperature and stop the decline of efficiency of labor.[8,9] The cooling vest which is easy to produce and to put on and off in particular and it has been shown to effectively reduce physical strain in the hot environment. However, the weight of the vest, about three to five kilograms, may increase wearer's physical strain or its excessive cooling effect may harm wearer's health, thus it is necessary to reduce the weight and to find out effective cooling parts of the body to keep cooling effect and wearer's health at the same time.

The parts of the human body do not show the same response to cooling under cold weather or artificial cooling under hot environment and the degree of sensitivity of body parts to cooling stimulus varies. For instance, supposing the sweating ratio is one by chest cooling under the hot environment of 39°C, the influence on the sweating ratio of the local cooling of forehead showed 3.3 times, that of the back was 1.2 times, that of abdomen 0.8 times: the order of cooling efficiency was forehead, back, chest and abdomen.[10]

According to preceding studies, permissible safety cooling limits of skin temperature of each part of the body for one-hour cooling was 25°C on the head, 20°C on the neck, 27°C on the chest, 25°C on the abdomen, 20°C on the upper back and 20°C on the lower back.

This study aims are to find out cooling effect and effective cooling part of the trunk without harm for the health and to provide basic data for

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the development of clothing which could increase work efficiency and reduce body strain in the hot environment.

Research Method

Conditions of Environment

Each subject entered an artificial climatic room of 37±1°C, 50±5%R.H. after a rest for more than 30 min in 25°C. The subjects were exposed in 37°C for 4 hours and taken a rest in 30°C for 10 min without cooling packs after 80 and 155 min after cooled. The experiment period lasted from December 2001 to November 2002.

Measurement Items

After a subject took a rest for 10 minutes in a climate-chamber and a cooling packs were attached on the body, the skin temperature and average skin temperature of seven areas (forehead, chest, lower arm, the back of the hand, the fleshy inside of thigh, the calf of the leg, and the top of the foot), rectal temperature, heart rate, and temperature and humidity of inside of clothes were measured for 4 hours at intervals of 1 minute and the subjective sensation was measured at intervals of 15 minutes.

Total sweating amounts for 4 hours was obtained by measuring the weight loss before and after the experiment with a body scale. For the local sweating amount for 4 hours, a filter paper of 12 cm^2 (3 cm × 4 cm) covered with vinyl sheet of which edge sealed with contact tape was attached to the back and the thigh and then the difference in the weight of the filter paper before and after the experiment was measured with a chemical balance.

The subjective sensations such as heat, humidity and comfort were graded according to Winakor's 11 scales (Fig. 1).

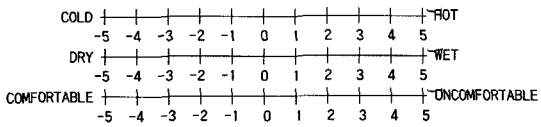

Fig. 1. Subjective sensation (Winakor, 1982).

Subjects

Subjects were eight healthy men of twenties, aged average 26.6±1.7 years, hight 174.1±3.1 cm, weight 70.6±2.5 kg, and body surface area 1.86± 0.1 m^2. All subjects wore long-sleeved thin cotton T-shirt, string panty, cotton pants, and cotton socks for the experiment.

Cooling Areas and Methods

In this study, the trunk was divided into six areas to be cooled: head, neck, chest, abdomen, the upper back and the lower back.

Two tubes were inserted into the cooling pack in order to keep the temperature of the pack regularly by removing heated water through one tube and providing cold water through the other tube. This way cooling packs maintained on fixed temperature by freezer.

Subjects were covered with cooling packs which made different sizes on each area. The cooling pack for head was produced like a peaked hat and the other packs were squares. The surface area of cooling packs are shown Table 1.

Cooling Temperature by Area

By the use of cooling packs in which cold water was circulated, each area was cooled to permissible safety cooling limits of skin temperature suggested by preceding studies. The cooling temperature of each area was 25°C on the head, 20°C on the neck, 27°C on the chest, 25°C on the abdomen, 20°C on the upper back and 20°C on the lower back.

Statistical Analysis

With the use of statistical package, SAS (Statistical Analysis System), ANOVA was analyzed between each area by subjects and Duncan's multiple range test was carried out for the items of significance on the level of significance, 5%.

Table 1. Surface area of cooling packs (8 persons)

	Head	Neck	Chest	Abdomen	Upper back	Lower back	Whole body
m^2	0.1245	0.0538	0.1426	0.0925	0.1281	0.0862	1.86*
%	6.7	2.9	7.7	5.0	6.9	4.6	33.8

Table 2. Physiological responses during the experiment

	Head	Neck	Chest	Abdomen	Upper back	Lower back	F-value
Total body weight loss (g/4 hr)	$329.0^{a1)}$	477.5^{abc}	500.0^{abc}	558.0^{bc}	350.0^{ab}	538.5^{abc}	1.92^{**}
Local sweat rate in back (mg/12 cm^2/4 hr)	37.09^{c}	26.44^{ab}	21.99^{ab}	21.06^{ab}	17.00^{a}	32.43^{bc}	4.70^{**}
Local sweat rate in thigh (mg/12 cm^2/4 hr)	13.91	10.30	12.76	9.81	11.16	10.98	$2.34^{n.s.}$
T_{re} (°C)	37.30^{a}	37.33^{ab}	37.33^{ab}	37.28^{a}	37.37^{b}	37.29^{a}	3.32^{**}
HR (bpm)	77.56^{a}	81.77^{c}	82.47^{c}	85.37^{d}	81.71^{c}	80.42^{b}	59.22^{***}
Thermal sensation	0.28^{ab}	0.41^{abc}	0.52^{bc}	0.61^{cd}	0.17^{a}	0.59^{cd}	7.10^{***}
Humidity sensation	1.61	1.32	1.42	1.50	1.56	1.50	$7.52^{n.s.}$
Thermal comfort	0.11^{abc}	0.30^{cd}	0.25^{bc}	0.47^{d}	0.03^{a}	0.28^{bc}	35.82^{***}

[1)]Values with different letters within a same row are significantly different by Duncan's multiple range test.
(*; P<.05, **; P<.01, ***; P<.001, n.s.; not significant)

Results

Table 2 shows mean value of physiological responses and significance of each measurement items when 6 areas in trunk were cooled. This results were obtained by statistical analysis through experimental study to distinguish cooling efficiency between body parts.

Sweating Amounts

Fig. 2 shows decrement of total body weight loss on cooled by areas. When the body was not cooled and exposed to hot environment of 37± 1°C for 4 hours, total body weight loss was 689.8 g/4 hr, and the local sweat rate by area was 42.16 mg/12 cm^2/4 hrs on the back and 15.67 mg/12 cm^2/ 4 hrs on the thigh.

The greatest reduction in total body weight loss appeared when the head (52.31%) and the upper back (49.26%) were cooled among other six areas (p<.01). In spite of small cooling area, neck cooling (30.78%) was more effective than chest (27.52%), the lower back (21.94%) and abdomen (19.11%) in reducing sweating.

The local sweating amount which was measured on the back was the most reduced on the cooled the upper back (59.68%), abdomen (50.05%) and chest (47.84%). It was the least on the head cooling (12.03%)(p<.01). The local sweat rate on the thigh was reduced by 11.23% on the head cooling, 34.27% on the neck cooling, 18.57% on the chest cooling, 37.40% on the abdomen cooling, 28.78% on the upper back cooling and 29.93% on the lower back cooling. But it showed no difference of significance between areas. Fig. 3 shows decrement of local sweating rates on the back and the thigh when 6 areas were cooled.

Rectal Temperature

The rectal temperature increased to 37.99°C in 37°C when there were no cooling of body areas.

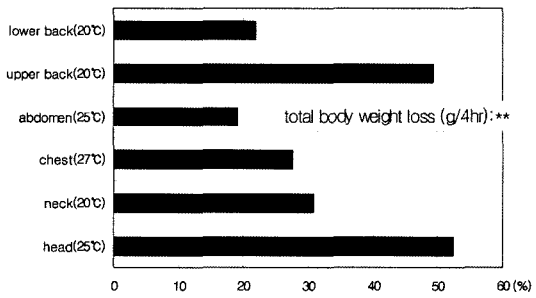

Fig. 2. Decrement of total body weight loss by local cooling.

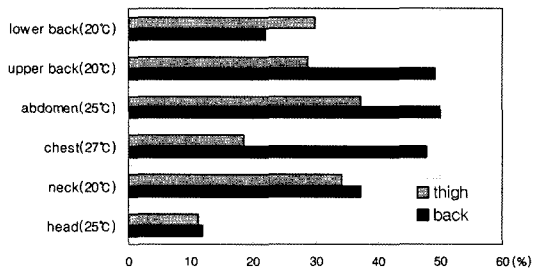

Fig. 3. Decrement of local sweating rate on the back and the thigh by local cooling.

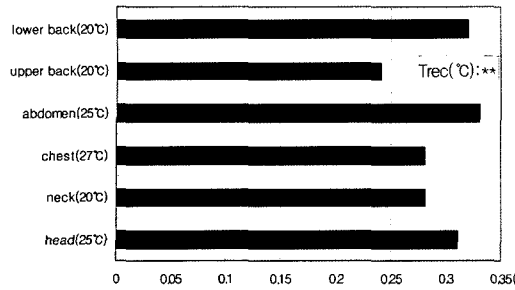

Fig. 4. Decrement of rectal temperature by local cooling.

Fig. 4 shows decrement of rectal temperature when 6 areas were cooled. The rectal temperature showed difference of significance between areas.

The upper back cooling (0.24°C) among other six areas cooling, showed the least reduction in rectal temperature item ($p<.001$), and the reductions were shown in the order of chest (0.28°C), neck (0.28°C), head (0.31°C), the lower back (0.32°C) and abdomen (0.33°C).

Heart Rate

Heart rate increased to 86.01 bpm in a climate-chamber of 37°C when there was no cooling of body area. Fig. 5 shows decrement of heart rate when 6 areas were cooled.

Head cooling (7.88 bpm) among other six areas cooling, showed the greatest reduction in heart rate ($p<.001$), and then the reduction was shown in the order of the upper back (5.02 bpm), the lower back (3.73 bpm), neck (3.67 bpm), chest (2.97 bpm), and abdomen (0.07 bpm).

The cooling on the head and the upper back came into the excellent effects on decrement of heart rate and the result was similar to the case of total body weight loss.

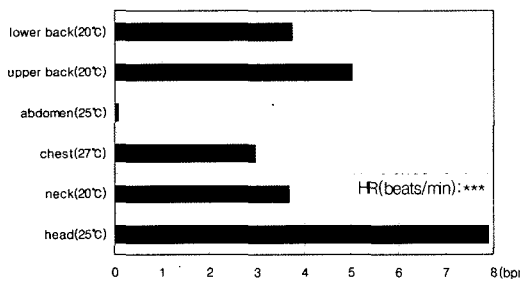

Fig. 5. Decrement of heart rate by local cooling.

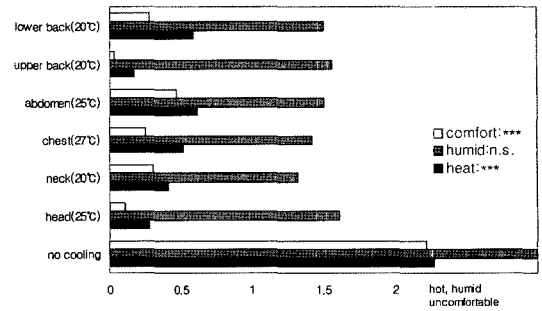

Fig. 6. Subjective Sensation by local cooling.

Subjective Sensation

In spite of having cooling pack on each area, all subjects complained about the stress caused by the exposure to hot environment. Subjects felt less hot and comparatively pleasant when the head and the upper back were cooled, and they felt most hot and unpleasant when the abdomen and the lower back were cooled. Fig. 6 shows the comparisons of subjective sensation when 6 areas were cooled.

Though each area has difference size, skin temperature and clothing microclimate was not greatly influenced by the cooling size.

The result of the study showed that head, neck and the upper back cooling were considered to reduce the heat stress of subjects caused by the exposure to hot environment by reducing sweating rate, core temperature and heart rate and increasing subjective sensation of heat and comfort.

Discussion

In spite of their small cooling areas, head and neck compared to other areas showed excellent cooling effects in sweating amounts, core temperature and heart rate. We have known that core temperature and heart rate are physiological response index to evaluate burden of human body.[11] The same result has also been shown in other researches.[12-16]

Chest cooling requires attention in particular because it could cause heart attack. Cooling vest dropped the skin temperature on the chest to 30.67°C and maintenance of low chest skin temperature may be dangerous for health.[17] A study showed that thermal sensation and thermal comfort were better when the skin temperature on the chest was 32.6°C than when it was 31.1°C. Therefore

excessive cooling of chest should be avoided in order to increase comfort and safety.[18]

However, it was not possible to compare skin temperature of the chest (27°C) between this study and Nishihara (32.6°C),[18] to find out proper cooling temperature because local sensation of heat and cold was between "neutral" and "cool" in this study while it was "cool" or "cold" in Nishihara's study and experiment temperature was different.

When neck or chest was cooled with cold water of 8.3°C in 39.5°C, cooling effects of the two areas were similar that rectal temperature was dropped by 0.5°C and sweating amount was decreased by 16~22%.[19]

This study also showed no difference between areas: neck and chest cooling reduced rectal temperature and heart rate by 0.28°C, 3.67 bpm and 0.28°C, 2.97 bpm.

Given the fact that the chest cooling size was as 2.7 times as that of neck, however, the cooling efficiency of neck was much better.

The sensitivity to cold stimulus of abdomen has been evaluated to be excellent, next to face and palm, and some preceding studies suggested that the density of cold spot on the abdomen was high for this reason.[17,20] And change in local skin temperature of head and trunk of the body had a greatest influence on sweating ratio[15] and they had higher density of cold spot than face, lower arm, the back of the hand, hips, the calf of the leg, the top of the foot and the sole of the foot.[17]

In this study, abdomen cooling showed the least decrement in heart rate among the trunk areas and some subjects complained about the discomfort of coldness.

The upper of back cooling except head showed greatest decrement in heart rate and sweat rate. Therefore, the upper of back cooling is most effective and safe among the trunk areas. This result was same the preceding studies that showed the influence of the skin temperature of the back and the upper arm[21] or the back and the chest[16] on the sensation of heat was greater than any other area's cooling. All of these studies reported that the back cooling was effective.

The experiments were repeated two times considering that subject number was eight. The experimental errors are generally small in the study about humans response because sweat rate, rectal temperature, heart rate and clothing microclimate that can understand delicate change of physiological response are measured. But succeeding study that can confirm this result is needed.

Summary and Conclusion

This study was to determine the effects of cooling parts of the trunk without harm for the health and to provide basic data for the development of clothing which could stop excessive cooling and reduce body strain in the hot environment. Eight male adults took part in the study, conducted in a climate-chamber controlled with an ambient temperature of 37±1°C and a relative humidity of 50±5%RH. The trunk was divided into six areas to be cooled: head, neck, chest, abdomen, the upper back and the lower back.

According to preceding studies, permissible safety cooling limits of skin temperature, of each part of the trunk for four hours cooling were 25°C on the head, 20°C on the neck, 27°C on the chest, 25°C on the abdomen, 20°C on the upper back, 20°C on the lower back. These were the reason that cooling skin temperature of each region were carried out above mentioned temperatures.

In conclusion, for all small cooling sizes, the head and the neck cooling could reduce sweating amount, rectal temperature and heart rates and reduce the heat stress of workers exposing in the hot environment by decreased subjective sensations of heat and comfort. Thus, it was concluded that effectiveness of cooling among the trunk was best on the head, the neck and the upper back.

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