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Effects of wearing two different forms of garment on thermoregulation in men resting at 10° C

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Summary. We have compared the human thermoregulatory responses and clothing microclimate temperature when the body core-shell ratio was changed by wearing two different forms of garment. Each was worn for 160 min at an ambient temperature of 10° C and a relative humidity of 50% by six healthy males in the supine posture. One garment covered the whole body area except for the face (long-sleeves: L-S), the other covered the central body area alone (half-sleeves: H-S). Major findings are summarized as follows: 1) Rectal temperature was kept higher by H-S than L-S even though L-S showed higher thermal resistance values. 2) The standard deviation of rectal temperature was smaller in H-S. 3) Trunk skin and clothing microclimate temperatures were also kept higher by H-S. We suggest that the reduced level of rectal temperature in L-S might be ascribed to a different pattern of venous return originating in the mechanisms of the counter-current heat exchange system: the venous return from the periphery into the thoracic and abdominal areas being cooler in L-S than in H-S.

Key words: Different forms of garment — Core-shell ratio — Rectal temperature — Counter-current heat exchange system

Introduction

One of the functions of skin blood flow is thermoregulation, and its variability is greater in the distal parts of the limbs than in the proximal parts of the limbs and the trunk (Witzleb 1983). In addition, it is known that the body core-shell ratio is largely influenced by environmental temperature, and that the shell temperature and thickness depend on the ambient temperature (Aschoff 1958). Burton (1955) has demonstrated that the regulation of thermal insulation down the length of the limbs is much more important than that of the gradient from the deep tissues to the skin. Therefore, it is considered that the extremities play important roles in the control of heat loss in human thermoregulation. With these facts in mind it seems necessary to consider the utility of some protective garments against cold in terms of core-shell concepts. To change the core-shell ratio, it seems appropriate to use two forms of garment, one with long sleeves and long trousers, and the other with half sleeves and short trousers. Therefore, we attempted to compare the human thermoregulatory responses of human subjects wearing the two different forms of garment: one covering the whole body area except for the face (long-sleeves: L-S), and the other covering the central body area alone (half-sleeves: H-S).

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Methods and materials

Subjects. Six healthy males volunteered as subjects. Their age was 21.8±5.0 years (mean ±S.E.M.), height 168±1 cm, weight 60.2±1.6 kg, and body surface area (BSA), calculated by the equation BSA $(m^2) = W\ (kg)^{0.444} \times H\ (cm)^{0.663} \times 88.83$ (Fujimoto and Watanabe 1965), was 1.64±0.02 m^2. Figure 1 shows the two different forms of garment worn by the subject, and their characteristics are summarized in Table 1. The garments weighed 2329 g in L-S and 1625 g in H-S. The subjects were first covered with a blanket for 40 min to obtain steady skin temperatures and were then exposed for 120 min. Throughout the experiment they were in a supine posture at an ambient temperature of 10° C and a relative humidity of 50%. All experiments began at 4:00 p.m.

Measurements. Rectal temperature (T_{re}) was measured by a copper-constantan thermocouple inserted to a depth of about

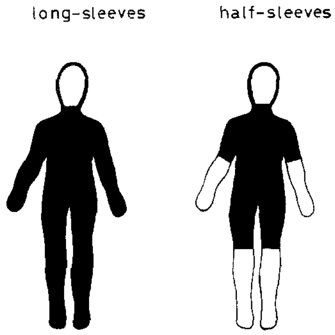

Fig. 1. Areas of the body covered by the garments (shown in black). *Left:* the whole body area except for the face insulated (L-S). *Right:* the central body area alone insulated (H-S)

12 cm. Skin temperatures were measured at 7 sites (head, hand, leg, foot, trunk, arm, thigh) with copper-constantan thermocouples fixed to the skin with thin adhesive surgical tape, and mean skin temperature ($\bar{T}_{sk}$) was calculated according to the Hardy and DuBois equation:

$$\bar{T}_{sk} = 0.07\ T_{head} + 0.05\ T_{hand} + 0.13\ T_{leg} + 0.07\ T_{foot} + 0.35\ T_{trunk} + 0.14\ T_{arm} + 0.19\ T_{thigh}$$

Clothing microclimate temperature between the skin and the innermost garment layer was also measured at chest level with a copper-constantan thermocouple. Body weight loss was recorded by using a Potter Bed Balance (33B type, James Addison Potter Co., USA) with an accuracy of 1 g. Oxygen uptake was obtained by the open circuit method. After the expired air volume was measured with a gas meter (WT-10, Shinagawa Co., Japan), the expired air was analyzed by a magnetic oxygen analyzer (MAG-2, Shimadzu Co., Japan). Oxygen consumption was calculated according to the following equation (Consolazio et al. 1963):

$$\dot{V}_{O_2}\ \text{consumed} = \dot{V}_{STPD} \times (\%O_2\ \text{in inspired air} - \%O_2\ \text{in expired air})/100$$

where $\dot{V}_{O_2}$ is the total volume of oxygen consumed, and $\dot{V}_{STPD}$ is the volume of expired air corrected to STPD.

Calculations. The thermal resistance (I_{cl}) of the two different forms of garment was calculated according to the formula proposed by Winslow and Herrington (1949). Thermal conductance could be obtained using the following formula, assuming that heat flows from the body core to the body shell.

$$K1 = (M - E \mp S)/A(T_{re} - \bar{T}_{sk})$$
$$K2 = (M - E \mp S)/A(\bar{T}_{sk} - T_a)$$
$$K3 = (M - E \mp S)/A(T_{re} - T_a)$$

where,
K1: Internal thermal conductance ($W \cdot m^{-2} \cdot {}^\circ C^{-1}$)
K2: External thermal conductance ($W \cdot m^{-2} \cdot {}^\circ C^{-1}$)
K3: Total conductance ($W \cdot m^{-2} \cdot {}^\circ C^{-1}$)
M: Metabolic heat production (W)
E: Evaporative heat loss (W)
S: Heat storage (W)
A: Body surface area (m^2)
T_{re}: Rectal temperature (°C)
$\bar{T}_{sk}$: Mean skin temperature (°C)
T_a: Ambient temperature (°C)

Data analysis. All data were analyzed by the paired *t* test.

Table 1. Characteristics of garments

Form	Body area	Garment	Type	Fabric
		shirt	long sleeves	cotton 50%, polyester 50%
		training wear	long sleeves	absorbent acrylic 100%
	Upper part	vest	no sleeves	acrylic 70%, wool 30%
		jacket	long sleeves	nylon 100%, down 100%, polyester 100%
		hood	attached to the jacket	nylon 100%
L-S		gloves	for skiing	
		shorts		cotton 100%
	Lower part	trousers	short	acrylic 50%, polyester 50%
		training wear	long	absorbent acrylic 100%
		socks	ankle high	cotton, acrylic
		socks	knee high	wool, nylon
		shirt	half sleeves	cotton 50%, polyester 50%
		training wear	half sleeves	absorbent acrylic 100%
	Upper part	vest	no sleeves	acrylic 70%, wool 30%
		jacket	no sleeves	nylon 100%, down 100%, polyester 100%
H-S		hood	attached to the jacket	nylon 100%
	Lower part	shorts		cotton 100%
		trousers	short	acrylic 50%, polyester 50%
		training wear	short	absorbent acrylic 100%

Table 2. Means ± standard deviations of the thermal resistance of clothing (I_{cl}), total thermal conductance, body weight loss, oxygen consumption ($\dot{V}_{O_2}$), and temperatures in L-S and H-S in six subjects

	L-S	H-S
I_{cl} (clo)	2.0 (0.3)	1.3 (0.2)**
Total thermal conductance ($W \cdot m^{-2} \cdot °C^{-1}$)	1.7 (0.2)	1.9 (0.2)
Body weight loss ($g \cdot m^{-2}$)	8.3 (1.8)	7.1 (2.2)
$\dot{V}_{O_2}$ ($ml \cdot min^{-1}$)	209.2 (13.4)	219.9 (15.9)
Tre (°C)	36.6 (0.4)	37.1 (0.1)+
Fall of Tre (°C)	0.7 (0.3)	0.5 (0.3)
$\bar{T}_{sk}$ (°C)	31.1 (0.8)	28.2 (0.7)**
Trunk skin temperature (°C)	34.9 (0.4)	35.3 (0.5)**
Clothing microclimate temperature (°C)	32.0 (0.4)	32.6 (0.4)*

Values were obtained during the last 30 min period
+ $p<0.1$, * $p<0.05$, ** $p<0.01$, as compared with L-S

Results

The physiological parameters obtained in our present study are summarized in Table 2. The thermal resistance of the garments was significantly higher in L-S than in H-S ($p<0.01$). However, there was no significant difference between the two forms of garment in total thermal conductance. On the other hand, internal and external thermal conductance were 8.3±0.7 and 2.2±0.2 $W \cdot m^{-2} \cdot °C^{-1}$ in L-S and 5.7±0.6 and 2.8±0.4 $W \cdot m^{-2} \cdot °C^{-1}$ in H-S. These values differed significantly between L-S and H-S ($p<0.01$).

Figure 2 shows the time course of changes in mean rectal temperature during the 160 min exposure: there was a rapid decrease during the first 40 min when the subjects were covered with the blanket, and as soon as the subjects were uncovered the rectal temperature remained at a relatively constant level in both L-S and H-S. Although the rectal temperatures between the two forms of garment were not significantly different during the first 40 min of exposure ($p>0.1$), they were higher in H-S during the 40–160 min period ($p<0.1$), while the standard deviation was smaller in H-S throughout the entire 160 min period of exposure. The average fall in rectal temperature

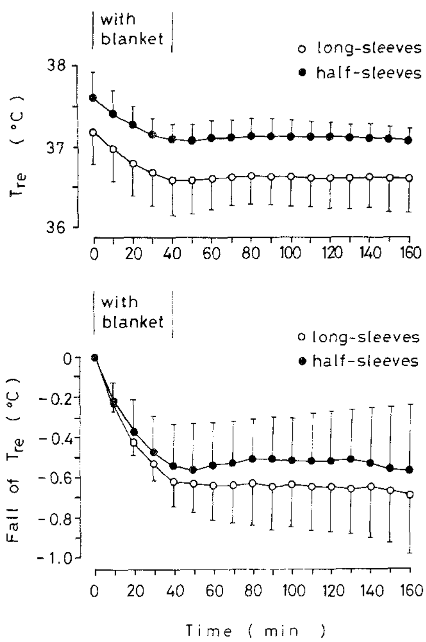

Fig. 2. A comparison of mean rectal temperature between L-S *(open circles)* and H-S *(closed circles)* during the 160 min exposure. Top: mean values. Bottom: fall in rectal temperature. Values represented as means ±SD every 10 min

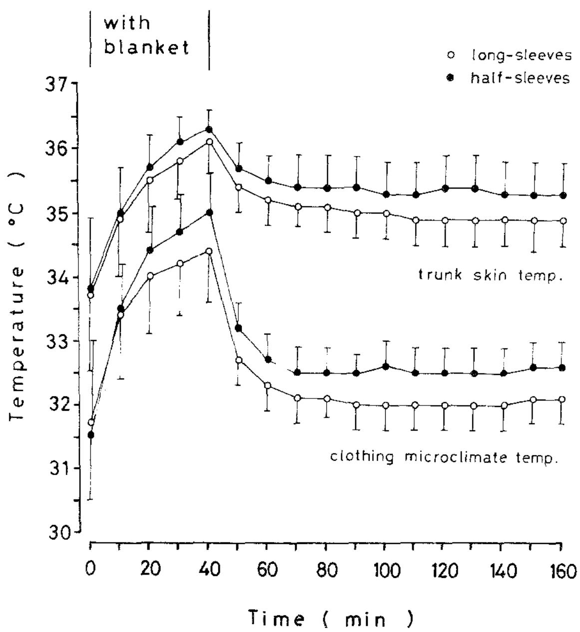

Fig. 3. A comparison of mean skin and clothing microclimate temperatures at the chest between L-S *(open circles)* and H-S *(closed circles)* during the 160 min exposure. Values represented as means ±SD every 10 min

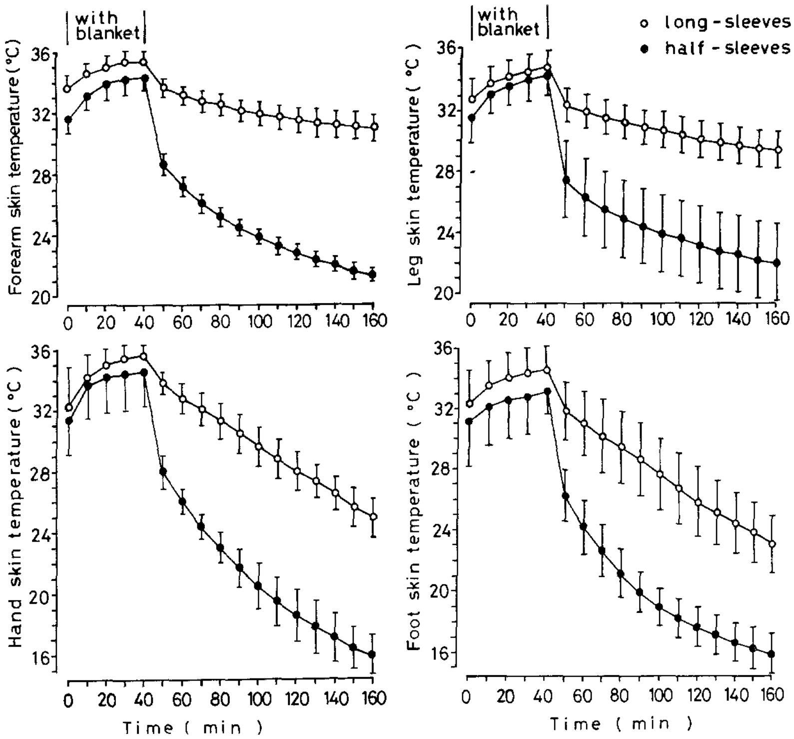

Fig. 4. A comparision of the skin temperatures in the extremities between L-S *(open circles)* and H-S *(closed circles)* during the 160 min exposure. Top left: forearm skin temperature. Top right: leg skin temperature. *Bottom left:* hand skin temperature. *Bottom right:* foot skin temperature. Values represented as means ±SD every 10 min

seemed steeper in L-S (Fig. 2, lower part), although there was no significant difference.

Figure 3 shows the time course of changes in mean trunk skin and clothing microclimate temperatures. Both temperatures rose during the first 40 min due to covering the body with the blanket, but significant difference was not found between the two forms of garment. As soon as the subjects were uncovered, both temperatures began to fall in similar way, but the slope of the decrease was steeper in the clothing microclimate temperature. Thereafter, they remained at relatively constant levels, as had the rectal temperature. Both the trunk skin and clothing microclimate temperatures were significantly higher in H-S than in L-S during the uncovered period at 40–160 min ($p<0.01$ and $p<0.05$ respectively).

Figure 4 shows the skin temperature in the extremities. Significant differences were not found during the first 40 min with the blanket, but when the subjects were uncovered all skin temperatures in the forearm, hand, leg, and foot were significantly higher in L-S ($p<0.01$).

Discussion

Our major findings are summarized as follows: 1) Rectal temperature was higher in H-S than in L-S even though L-S showed a higher I_{cl} value (Fig. 2, Table 2). The standard deviation of rectal temperature was smaller in H-S (Fig. 2). 3) Trunk skin and clothing microclimate temperatures were also higher in H-S (Fig. 3). What mechanisms could explain these findings?

Van Someren et al. (1982) demonstrated that when the hands and feet were cooled in water at 12° C during immersion of the human body in water at 29° C, core temperature ceased to fall and then rose slightly; however when the hands and feet were returned to water at 29° C, the fall in core temperature was resumed. Although our present results were obtained in air, a similar phenomenon was observed: rectal temperature was higher in H-S under the influence of greater cooling in the extremities.

As metabolic heat production and evaporative heat loss did not differ between L-S and H-S (Table 2), it is presumed that dry heat loss from the human body through the garments to the surroundings also might not be different between the two clothing conditions, judging from the thermal balance equation. Therefore, the finding that rectal temperature was kept at a lower level in L-S should not be ascribed to the heat imbalance between heat production and heat loss in L-S. In fact rectal temperature was maintained constant in L-S although at a lower level than in H-S. L-S conditions reduced the shell/core ratio, as edvidenced by the finding that skin temperatures were significantly higher in the forearm, hand, leg, and foot in L-S than in H-S (Fig. 4). Furthermore, internal thermal conductance was significantly higher in L-S, suggesting that the amount of heat flow from deep to superficial tissues was greater than in H-S. Thus, the intensity of vasomotor response was different between the two forms of garment, and blood flow in the extremities was more diminished in H-S, since more vasoconstriction occurred in H-S than in L-S.

From these facts, it might be suggested that the mechanisms of the counter-current heat exchange system (Bazett 1949) might be responsible for such different levels of rectal temperature between the two clothing conditions. Venous blood would return preferentially near the surface of the arms and legs in L-S, and the temperature of venous blood returning from the periphery to the thorax and abdomen might be a little cooler than the core temperature even near the entrance to the thorax and abdomen. Thus the cooled venous blood returning into the thoracic and abdominal areas could result in the lower core temperature found in L-S. In contrast, in H-S the venous return would pass mainly around the limb arteries, and heat could be given off from the artery to the veins; as a result, the temperature in the veins would increase to the level of core temperature at the entrance to thorax and abdomen, and the venous return would not lower the core temperature.

Trunk skin and clothing microclimate temperatures were significantly lower in L-S (Fig. 3). The lower trunk skin temperature in L-S might reflect the decreased level of core temperature to some extent (Aschoff 1972). As the innermost clothing microclimate temperature at the chest is highly correlated with trunk skin temperature throughout all seasons (Natsume et al. 1987), it seems to reflect the lowered level of trunk skin temperature.

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