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Effects of Wearing Two Different Types of Clothing on the Core Temperature under Conditions Simulating Actual Indoor Life

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The influence of extremities differently insulated by clothing on the core temperature under experimental conditions simulating actual indoor life was studied with six healthy females at the follicular phase of their menstrual cycles in a climatic chamber at ambient temperature (T_a) ranging from 20 to 25°C and 50% R.H. The subjects wore either Type A clothing (covering almost the whole body, 911 g) or Type B (covering mainly the trunk, the upper arms and the thighs, 631 g). Thereafter, they were exposed to various conditions of rest, exercise and change of air temperature from 10:30 to 17:00. Major findings obtained are as follows: 1) A higher rectal temperature (T_{re}) was maintained with Type A than Type B during 30 min of exercise on a treadmill. 2) The decrease rate for T_{re} was greater with Type A than with Type B during recovery. 3) When T_a was lowered from 25 to 20°C, the level of T_{re} was higher and its increase rate was greater with Type B than with Type A. These findings confirmed those obtained in our previous studies, which were carried out under defined experimental conditions, suggesting that the mechanisms functioning with Type A and Type B clothing could also be valid in conditions simulating indoor daily life during the daytime.

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Keywords: rectal temperature, skin temperature, counter-current heat exchange, two types of clothing.

Introduction

The extremities play an important role in human thermoregulatory responses like those in other animals, for example, the ears of a rabbit, tail of a rat and so on.[1] In addition, the core and shell of the human body vary as the air temperature changes, and the ratio is largely dependent on the air temperature.[2]

On the basis of these facts, two types of clothing were taken into account to change the body core-shell ratio in previous studies,[3)-5)] *i.e.*, Type A (covering almost the whole body with clothing) and Type B (mainly covering the trunk, upper arms and thighs with clothing). The results obtained from the previous studies indicated that Type B worn by the subjects could keep the rectal temperature higher than with Type A. In those studies, the experiments were carried out only under restrictively defined conditions. In our everyday life, people would sit on a chair, move from one place to another, encounter temperature changes from cold to warm or from warm to cold, and so on. It remains to be known how the core temperature would react under the environmental conditions of actual life, including such kinds of behaviour as sitting, walking, eating and sleeping. Therefore, it becomes necessary to observe whether or not the same results as those obtained in the previous studies could also be observed in the case of actual life.

In this study, therefore, we attempted to investigate the influence of extremities differently insulated by clothing on the behaviour of the core temperature under experimental conditions simulating indoor life during the daytime.

Materials and methods

Experimental clothing. The clothing used in this

Table 1. Characteristics of the clothing

Body area	Clothing	Fabric
Upper part	brassiere	
	T-shirt[a]	100% cotton
	vest[b]	70% acrylic, 30% wool
Lower part	shorts	
	panty stocking	100% nylon
	trousers[c]	100% absorbent acrylic
	socks[d]	

[a] With long sleeves for both Type A and Type B.
[b] With long sleeves for Type A and sleeveless for Type B. [c] Long trousers for Type A and short trousers to the knee for Type B. [d] Worn only for Type A.

study is described in Table 1. Type A clothing (weight: 911 g) covered the whole body except for the head and hands, and Type B (weight: 631 g) mainly covered the trunk, upper arms and thighs. The Type A and Type B clothing used in this study were determined in a slightly different way when compared with previous studies on the basis of the fact that both types of clothing could be considered as indoors wear.

Subjects and procedure. Six healthy females at the follicular phase of their menstrual cycles volunteered as subjects. Their age was 21.8±0.7 years (mean±S.E.M.), height 161.3±1.3 cm, and weight 52.6±1.2 kg. Each subject entered a room controlled to ambient temperature (T_a) 20°C and 50% R.H. at 10:00. After putting on either of two types of clothing, the subject was exposed to various conditions in six periods. First, T_a of 20°C for about 1 hr (I), and then T_a of 25°C for 40 min (II). Thereafter, the subject walked on a treadmill at 2.4 km/hr on the level for 30 min from 12:30 to 13:00 (III), and as soon as the exercise was finished, the subject rested sitting on a comfortable chair for 1 hr from 13:00 to 14:00 (IV). After the subject had eaten lunch—some sandwiches and a glass of milk—at 14:00, she had free time until 15:30 (V). Thereafter, she experienced a change of T_a from 25 to 20°C in about 20 min and remained at 20°C again until 17:00 (VI). Throughout the experiment, the subject was not allowed to take a nap, although being instructed to sit on a comfortable chair during periods II, IV and VI. During periods I and V, she was allowed to engage in normal activities such as book reading and writing. The subject was asked to give a subjective rating of the general thermal comfort and thermal sensations in the trunk, hands and feet, respectively, at the end of each period.

Measurements. The measurements started at 10:30, the rectal temperature (T_{re}) being continuously measured by a thermistor probe and recorded on a chart recorder. Skin temperatures of the head, chest, thigh, leg, foot, arm and hand were measured every minute by copper-constantan thermocouples fixed to the skin with thin adhesive surgical tape and were also recorded on the chart recorder. The mean skin temperature ($\bar{T}_{sk}$) was calculated according to the Hardy and DuBois equation,[6] $\bar{T}_{sk}=0.07\,T_{head}+0.05\,T_{hand}+0.13\,T_{leg}+0.07\,T_{foot}+0.35\,T_{trunk}+0.14\,T_{arm}+0.19\,T_{thigh}$. The clothing microclimatic humidity between the chest skin and innermost garment layer was continuously measured in order to check whether the subject sweated or not, especially when walking on the treadmill.

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

Results

The results of T_{re} obtained throughout the whole experimental period from 10:30 to 17:00 are shown in Fig. 1. As can be seen, there was a tendency for T_{re} in Type B clothing to be higher than in Type A, especially when sitting at rest during periods II and VI, although not significantly so. We mainly analyzed the behaviour

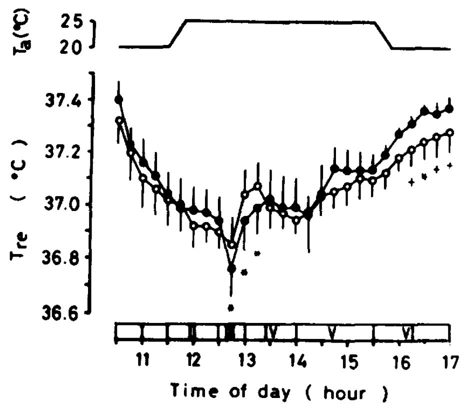

Fig. 1. Comparison of the mean rectal temperatures between Type A (open circles) and Type B clothing (closed circles) during the experimental period

Roman numericals indicate each period of different conditions for the experiment. Values are means ± S.E.M. + $p<0.1$; * $p<0.05$.

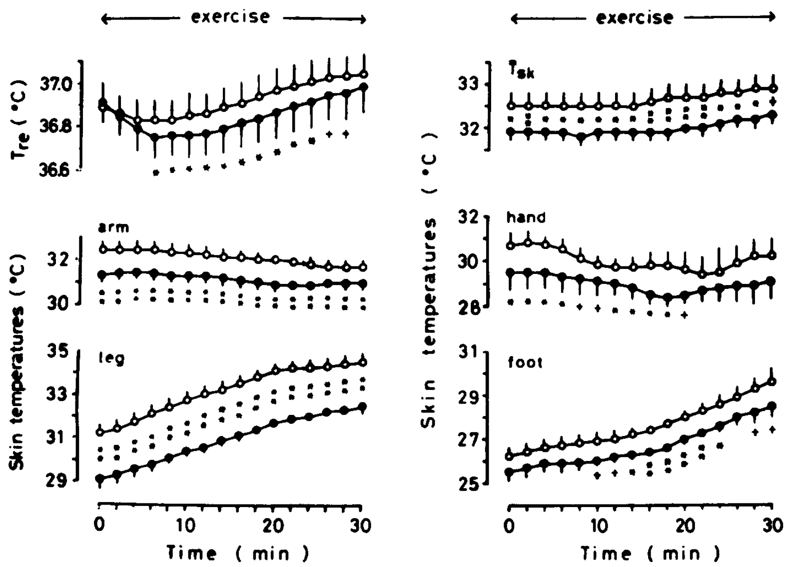

Fig. 2. Comparison of T_{re}, $\bar{T}_{sk}$ and the extremity skin temperatures of the arm, hand, leg and foot between Type A (open circles) and Type B clothing (closed circles) during exercise

Values are means ± S.E.M. $^{+}p<0.1$; $^{*}p<0.05$; $^{**}p<0.01$.

of T_{re} during periods III, IV and VI, because T_{re} did not become stable after gradually falling during period II, and might have been interfered with due to voluntary activity during periods I and V.

Figure 2 shows the temporal changes of the rectal and skin temperatures during the 30 min exercise on the treadmill (III). The subject did not seem to sweat during the exercise, judging from the behaviour of the clothing microclimatic humidity. As is shown during the initial stage of exercise within 10 min, T_{re} fell to greater extent in Type B clothing than in Type A, and thereafter, rose in both types of clothing.

It should be noticed that the skin temperatures of the leg and foot increased gradually in both Type A and Type B clothing, while those of the arm and hand hardly changed. In addition, the rectal and skin temperatures remained significantly higher in Type A than in Type B clothing.

Figure 3 shows the temporal changes of the rectal and skin temperatures during the 60 min recovery period after exercise (IV). There did not exist significant differences in the level of T_{re} between the two types of clothing, but the decrease rate of T_{re} in Type A was greater than that in Type B during the recovery after exercise. It was noticeable that the skin temperature of the leg gradually decreased in both types of clothing, while those of the arm, hand and foot either increased or remained constant. $\bar{T}_{sk}$ and the extremity skin temperatures were significantly higher in Type A than in Type B clothing, and the change rates of $\bar{T}_{sk}$, and of the arm and foot skin temperatures were significantly greater in Type A clothing.

Figure 4 shows the temporal changes of the rectal and skin temperatures during and after the fall of T_a from 25 to 20°C (VI). As can be seen clearly, it was notable that T_{re} increased, while the skin temperature decreased either during or after the fall of T_a. The level of T_{re} and its change rate were significantly higher in Type B than in Type A clothing. $\bar{T}_{sk}$, and the skin temperatures in the arm, leg and foot were significantly higher in Type A clothing than in Type B. The decrease rate of the leg skin temperature was greater in Type B clothing than in Type A. T_{re} during the last 30 min at T_a of 20°C was 37.3±0.1°C (mean±S.E.M.) in Type B clothing and 37.2±0.0 in Type A, being maintained higher in Type B compared with Type A, although not with high significance (see Fig. 1).

Figure 5 shows the thermal comfort and thermal sensation of the whole body which the subjects felt throughout the complete experiment. From the beginning of measurement, the subjects felt more uncomfortable, although only slightly, in

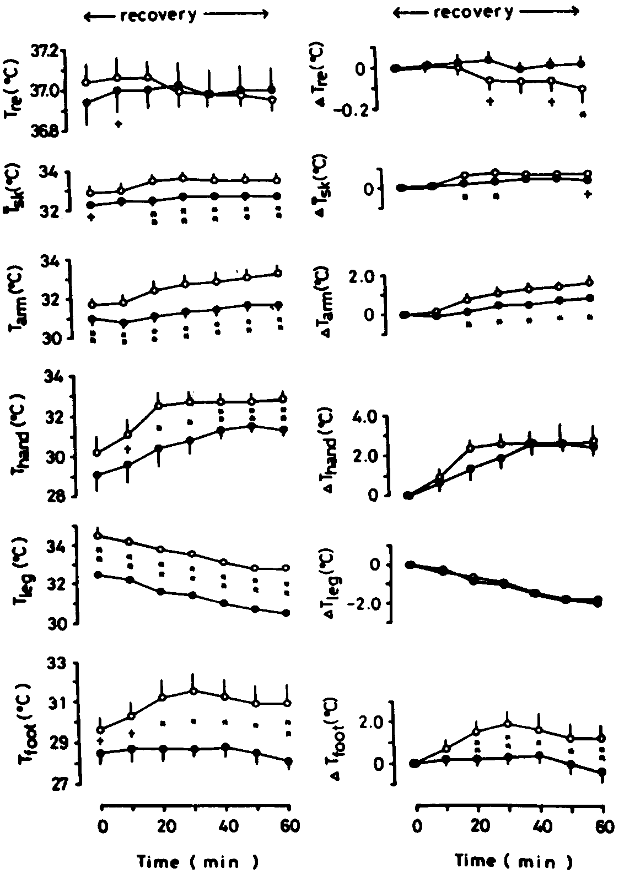

Fig. 3. Comparison of the level (left) and the change rates (right) of T_{re}, T_{sk} and the extremity skin temperatures of the arm, hand, leg and foot between Type A (open circles) and Type B clothing (closed circles) during recovery after exercise

Values are means $\pm$ S.E.M. $^{+}p<0.1$; $^{*}p<0.05$; $^{**}p<0.01$.

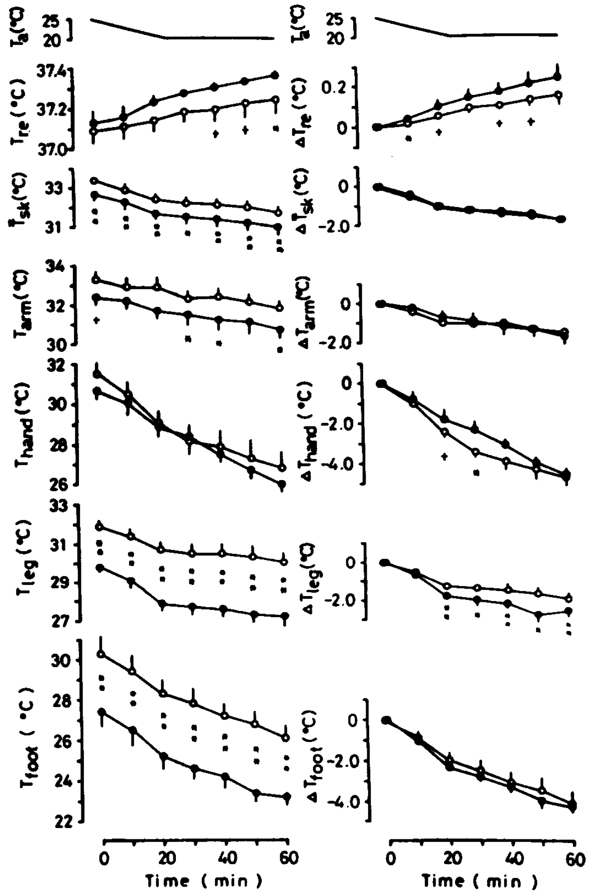

Fig. 4. Comparison of the level (left) and the change rates (right) of T_{re}, T_{sk} and the extremity skin temperatures of the arm, hand, leg and foot between Type A (open circles) and Type B clothing (closed circles) after the fall of T_a from 25 to 20°C

Values are means $\pm$ S.E.M. $^{+}p<0.1$; $^{*}p<0.05$; $^{**}p<0.01$.

Type B clothing than in Type A. Each subject felt cooler in Type B than in Type A immediately before the rise of T_a, and warmer in Type A than in Type B immediately after exercise. When the local thermal sensations of the trunk, hand and foot were evaluated by the subjects at the end of each period, there was a consistent tendency to feel cooler only in the case of the foot in Type B clothing than in Type A. When the subjects were asked at the end of the whole experiment about which type of clothing they preferred, four out of six subjects preferred Type A and the other two preferred Type B.

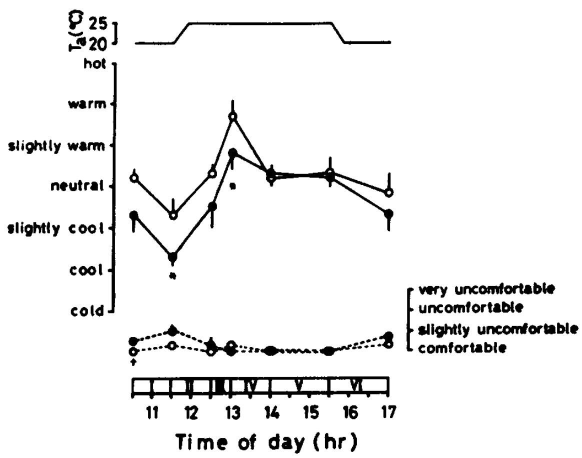

Fig. 5. Comparison of the thermal comfort (solid lines) and thermal sensation (dashed lines) between Type A (open circles) and Type B clothing (closed circles)

Discussion

With the results obtained in the previous studies through some experiments[3)-5)] carried out in a climatic chamber under the defined conditions, it is of great significance to consider the applications to actual life. In this study, some experimental schedules were designed to include rest, light exercise, and changes of room temperature which would be encountered in everyday life.

During exercise, the rise of T_{re} in unclothed men resulted from the decreased dry heat loss due to a consistent fall of skin temperature which was proportional to the intensity of exercise.[7)8)] In the previous study,[4)] the initial fall of some local skin temperatures during exercise was found to be greater in Type B clothing than in Type A. In this study, however, there was almost no fall in the skin temperatures (Fig. 2), which might have been due to the intensity of exercise in this study not being as strong as that in the previous study. Furthermore, vasoconstriction seemed to occur consistently during walking at least in the both arm and hand. However, in exercising part of the body, *i.e.*, the legs and feet, vasoconstriction was likely to have been hidden by the heat produced in the muscles.

Although T_{re} increased during exercise in both Type A and Type B clothing, its increase rate was smaller in Type B (Fig. 2). This is consistent with the findings obtained in the previous study. These phenomena could be explained by the legs and feet being fully covered with Type A clothing, while only lightly covered with Type B. It is known that the convective heat transfer coefficient is greater during exercise than during rest.[9)]

It is conceivable that the convective heat transfer coefficient might be greater in lightly covered legs and feet than in fully covered legs and feet, since air with a faster velocity would flow near the skin surface of the lightly covered legs and feet with Type B clothing than of the fully covered legs and feet with Type A. As the change rates of the extremity skin temperatures were identical between Type A and Type B, a higher convective heat transfer coefficient in the legs and feet might be one probable factor for T_{re} to have dropped temporarily in Type B clothing shortly after the start of exercise, and to have shown lower increase rates in Type B during the 30 min exercise.

Although the level of T_{re} was not different between Type A and Type B during recovery after exercise, its change rates were steeper with Type A (Fig. 3). This is also in agreement with the findings obtained in the previous study.[4)] Contrary to expectation, T_{re} was identical between the two clothing conditions. This is inconsistent with the findings reported in the previous study that T_{re} remained higher in Type B clothing than in Type A. This discrepancy could be explained by the facts that the clothing was different between the two studies because of the higher T_a in this study than T_a of 20°C in the previous study.[4)] Smaller differences of the extremity skin temperatures between the two types of clothing, and the higher T_a in this study might have made the mechanisms for counter-current heat exchange difficult to function effectively.

The finding that T_{re} fell more rapidly in Type A clothing during recovery irrespective of the higher thermal insulation of Type A could be explained by the different vasomotor activities between Type A and Type B. The skin temperatures of the arm and foot rose during recovery to a greater extent in Type A, which might have helped to accelerate the fall of T_{re} in Type A by increasing the dry heat loss from the arms and feet, even if these parts were covered by clothing, since the degree of dry heat loss is often larger from a hand covered by gloves compared with that from a bare hand.[10)] The skin temperatures of the extremities exclusive of the leg increased or remianed constant during recovery. This might suggest that the vasoconstrictor tone induced by exercise diminished to some extent, resulting in an increased cutaneous heat flow. The fact that leg skin temperature decreased during recovery could be mainly explained from the assumption that the increased conductive heat flow from the underlying muscles during exercise might have diminished during recovery after the exercise had ceased.

The level of T_{re} was higher in Type B clothing than in Type A during the final 30 min period after the fall of T_a from 25 to 20°C. This is compatible with the results obtained in the previous studies,[3)-5)] which was explained then in terms of the difference of function in counter-current heat exchange between the arterial and venous blood in both types of clothing. In other words, more blood volume was put into the cutaneous veins close to the skin surface in Type A clothing than in Type B, and consequently, the venous return might have been more cooled, which could have resulted in the lower rectal temperature in Type A.[11] This suggests, therefore, that the counter-current heat exchange system in Type A clothing might have functioned less effectively compared with that in Type B. On the other hand, the finding that the increase rate of T_{re} was greater in Type B clothing compated with Type A (Fig. 4) seems to be ascribable to the higher decrease rate of the leg skin temperature in Type B.

In addition, the major factor which affected the general thermal sensation seemed to be almost always the local thermal sensation in the foot, judging from the subject's cooler feeling in the foot in the case of Type B. This suggests that the thermal sensation in the foot is of significance in evaluating the thermal sensation of the whole body.

All data obtained in this study confirmed the findings obtained in the previous studies,[3)-5)] suggesting that the mechanisms functioning with Type A and Type B clothing could also be valid in conditions simulating indoor daily life duirng the daytime: that is, T_{re} reacted more positively in Type B clothing to T_a cooling from 25 to 20°C, and the extent of increase in T_{re} during exercise and that of the decrease in T_{re} during recovery were each smaller in Type B.

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日中の実際の室内生活をシミュレートした条件下での２種の異なった型の衣服着用が中核温に与える影響

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平成元年１月23日受理

本研究は，異なった２種の衣服を着用し四肢末梢部を異なって絶縁することが，室内日常生活をシミュレートした実験条件で生活を送るヒトの中核温にどのように影響を与えるかを観察するために行われた．６人の健康な女子学生が被験者として奉仕した．実験室の温度は20～25℃，相対湿度は50％に保たれた．被験者は Type A（ほぼ体の全域を被覆する衣服，911 g），Type B（軀幹部，上腕，大腿を被覆する衣服，631 g）のいずれかを着用し，安静，歩行，室温の変化の種々の条件下で午前10時30分より午後５時まで実験室で生活した．主要な知見が次のようにまとめられる．

1）直腸温はトレッドミル上の30分間の歩行中，Type B より Type A において高く維持された．

2）歩行後の回復時，直腸温の下降速度は，Type B より Type A で大きかった．

3）室温が 25℃ から 20℃ へ下降したとき，直腸温のレベルとその上昇速度は Type A よりも Type B においてそれぞれ高く，大きかった．

これらの知見は厳密に規制した実験条件で得られたわれわれの従来の研究結果を確認するものであり，Type A と Type B の間で作用する異なった機構が日中の室内日常生活をシミュレートした実験条件でも有効であることを示唆している．

キーワード：直腸温，皮膚温，対向流熱交換，２種の衣服型．