Influences of clothing types on metabolic, thermal and subjective responses in a cool environment

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Abstract

This study was conducted to investigate the effects of two different types of clothing (S-type, short sleeves and knee trousers; L-type, long sleeves and long trousers) on thermal, metabolic and subjective responses according to sex during mild cold exposure (19°C air). The EE of the subjects was higher in the S-type than in the L-type (p < 0.001). We concluded that the EE of the lightly clad subjects in the mild cold environment increased but was not within the range of being a burden on thermal and subjective responses.

Keywords: Clothing insulation; Energy expenditure; Thermoregulation; Mild cold; Thermal comfort; Human

1. Introduction

To investigate sex- and age-related differences or to observe influences of clothing on thermal, metabolic and subjective responses in the cold, many studies have been conducted in cold condition below 15°C, which are expected to induce shivering (Glen et al., 1987; Glickman et al., 1967; Vogelaere et al., 1992). There has been relatively a few interest about the effects of clothing in mild cold above 15°C which does not induce visible shivering. It is well established that the metabolic rate of man increases just like other mammals, during the acute exposure to the severe cold (Dauncey, 1981), but not to mild cold.

Several studies have reported the effects of the mild cold on energy expenditure (EE). Wagner and Horvath (1985b) reported that EE in subjects with minimal clothing at 20°C air during 120 min exposure increased about 4–10%. Warwick and Busby (1990) observed that 24 h EE in normally clothed adults at 20°C air was 5% higher than EE at 28 air. Inoue et al. (1992) reported that EE of young males wearing swimming trunks at 17°C air for 1 h increased about 2–3% while that of old males increased about 10%.

FAO/WHO/United Nations University (1985) have reported that the EE of the subjects which were insulated by clothing or blankets was not affected by mild cold, but Warwick and Busby (1990) concluded that ‘the assumption that mild cold is unlikely to affect the EE of the subjects wearing normal clothes may be incorrect’. There are some discrepancies in the EE of subjects dressing comfortably in mild cold. And these studies observed metabolic responses during the mild cold exposure. The studies did not take influences of clothing types and clothing weight into account. In studies about humans exposed to a cold environment, the experimental garments worn by the subjects were various according to the purpose of study and the intention of the researchers. The subjects generally wore only shorts for men and bra and briefs for women, so-called, ‘minimal clothing’ (Dorothy et al., 1978; Wagner and Horvath, 1985a,b), or ‘shorts and socks’ (Wagner et al., 1974), or ‘light clothing’ (Glen et al., 1987), or ‘normal clothing’ (Buemann et al., 1992; Warwick and
Busby, 1990). We assumed that the differences in clothing type might partly account for the discrepancies in the thermal, metabolic and subjective responses in the cold in these studies.

Based on these previous results, we hypothesized that the EE of subjects dressing lightly in mild cold would increase gradually. Therefore, the purpose of this study was to assess the influences of clothing insulation on energy expenditure, thermoregulation and subjective sensations in man and woman during mild cold exposure.

2. Methods

2.1. Subjects

Fifteen young males and seven females participated as subjects in this study. Their ages and anthropometric data are presented in Table 1. All were healthy and none had undergone either experimental or occupational exposure to cold for at least 1 yr previously. In this study, all subjects submitted written informed consents. For the women subjects, the measurements were done in the week after menstruation to minimize the effects of the menstrual cycle.

2.2. Measurements

During the experimental exposure, skin temperature \(T_{sk}\), rectal temperature \(T_{re}\), heart rate (HR), oxygen consumption \((\text{VO}_2)\), and subjective sensations were monitored. \(T_{sk}\) was measured at 7 sites (forehead, trunk, arm, hand, thigh, leg, foot) using a thermistor (Takara K923 Co., Japan) every 5 min. Mean skin temperature \((\bar{T}_{sk})\) was calculated according to the Hardy and DuBois equation Eq. (1)

\[
\bar{T}_{sk} = 0.07T_{\text{forehead}} + 0.35T_{\text{trunk}} + 0.14T_{\text{forearm}} + 0.05T_{\text{hand}} + 0.19T_{\text{thigh}} + 0.13T_{\text{calf}} + 0.07T_{\text{foot}}
\]

where \(T_{re}\) was measured with the thermistor (Takara K923 Co., Japan) every 5 min and a rectal probe was inserted to a depth of 10 cm by the subjects themselves. Metabolic rate (MR) was determined by the open-circuit method. It was computed from the measurements of \(\text{VO}_2\) with a Douglas bag (Fox et al., 1993). Expired gas samples were collected in a Douglas bag for 5 min after a 15 min rest repeatedly, and analyzed by the gasmeter (Sinagawa, Japan) and gas analyzer (NEC San-ei, Respina IH 26, Japan). HR was recorded by telemetry (polar electro sport tester PE 3000) every 5 min. Subcutaneous fat thickness was measured using a caliper and ultrasonic meter (SEIKOSHA SM-206) at three skin sites (male: chest, abdomen, thigh; for female: triceps, subscapular, thigh) by Jackson and Pollack’s equation and body density and percent body fat content were estimated from the fat thickness by the equation of Jackson and Pollack (1978).

Subjects gave reports of subjective thermal sensation and thermal comfort every 60 min (Table 2). They also reported thermal sensation and comfort whenever he or she became aware of a change, and if they felt the sensation of shivering.

2.3. Experimental procedure

The air temperature of the climatic chamber was maintained constant at 19 ± 0.5°C and the relative humidity at 50 ± 5%. This environmental condition is the mild cold often experienced in daily life. We selected our experimental conditions through preliminary experiments. In view of our pretests, young men felt comfortably cool and there was no visible shivering or the sensation of shivering in 19°C air, although piloerection occurred occasionally. Before entering the test chamber, subjects dressed in the experimental clothing weighed themselves (Sartorius Co. F150S Germany, Accuracy 1 g). Subjects dressed in the two
types of clothing four times each, for a total of eight times in separate days (Table 3). The first type of clothing was the S-type (short sleeves and knee trousers, Total clothing weight 533 g), and the second type was the L-type (long sleeves and long trousers, Total clothing weight 1065 g). We would not let subjects participate in our experiments for 2 consecutive days and made them expose to the two types of clothing by turns. During the initial 30 min after entering the controlled chamber, the subjects were equipped for all the physiological measurement. For the last 120 min, they rested in a sitting position on a chair (Fig. 1). All experiments were conducted at the same time of a day and in the same season (June–August) to avoid circadian variation.

2.4. Data analysis

All physiological data are expressed as means (SEM). The differences by clothing types and sex were tested using the two-way ANOVA and subjective data were analyzed by the percentage and χ²-test using the SPSS package. The significance level was set at p < 0.05.

3. Results

Table 4 and Fig. 2 show the values and the percentage change of EE of subjects in the S- and L-type clothing during the mild cold exposure. The EE at 120 min exposure was significantly higher in S-type clothing than in L-type clothing (p < 0.001) but we could not observe significant difference by sex. In the S-type clothing, the heat production was higher by an average of 7.9% (male) and 11.6% (female) at the end of the mild cold exposure than at the beginning of the exposure, whereas it was lower by an average of 15.5% (male) and 16.7% (female) in L-type clothing (Table 4). However, the EE of some subjects (male 5, 9, 15) in S-type clothing showed opposite pattern.

The repeatability of EE measurement was verified by variations of repeated trials in each subject. As indicated, we repeated same trial four times to each subject. Standard deviation among four trials in each subject was 0.00–0.17 kcal/m²/min and these values can be converted into 0.7–18.9% out of mean of four values (Table 4).

The time responses of $T_{re}$ and $T_{sk}$ were shown in Fig. 3. During the mild cold exposure, a slight decrease in $T_{re}$ was observed in both sexes but there were no significant differences related to clothing types and sex. For four conditions, mean $T_{re}$ were maintained from 37.0°C to 37.2°C and the range of mean $\Delta T_{re}$ was 0.3–0.6°C (Table 5). $T_{sk}$ was lower in S-type clothing (male 31.0°C, female 30.8°C) than in L-type clothing (male 32.3°C, female 31.8°C; $P < 0.001$). $T_{sk}$ was significantly lower in female than in male ($p < 0.05$, Fig. 2). During the mild cold exposure, $T_{sk}$ decreased by an average of male 2.0°C (female 1.9°C) and male 1.1°C (female 1.5°C) in the S- and L-type clothing, respectively, and $\Delta T_{sk}$ was greater in S-type than in L-type ($p < 0.001$). $T_{re} - T_{sk}$ was significantly greater in the subjects wearing S-type (male, 6.87°C; female, 7.08°C) than L-type clothing (male, 5.31°C; female, 5.76°C; $p < 0.001$), and so were in females than in males ($p < 0.05$). During the mild cold exposure, most local skin temperatures were maintained or decreased. However, the skin temperature on the chest increased for males in L-type clothing (0.42°C), and skin temperature on the abdomen increased for females in L-type clothing (1.37°C).

HR in all subjects decreased slightly during the mild cold exposure. There were no significant differences in HR related to clothing type but HR was higher during the mild cold exposure. In the S-type clothing, the
in females than in males \( (p < 0.001, \text{Fig. 3}) \). Also, Fig. 3 shows the fluctuation for females in S-type clothing.

During the 120 min exposure, most subjects wearing S-type clothing felt cooler with time and about 80% of subjects reported feeling ‘cold’, ‘cool’ or ‘slightly cool’, whereas over 80% of the subjects in L-type clothing reported feeling ‘slightly warm’ or ‘neutral’. Fig. 3 displays significant differences related to the clothing type in thermal sensation \( (p < 0.05, \text{Fig. 4}) \). Regarding thermal comfort, over 80% of the total subjects of both sexes in L-type clothing stated that they were ‘comfortable’, whereas in S-type clothing, 89.4% of males expressed feeling ‘comfortable’, and 67.8% of females expressed feeling ‘comfortable’. That is, females felt less comfort in the same environment (Fig. 4). None of our subjects reported shivering, although most subjects said they felt cool or cold in S-type clothing.

4. Discussion

Before discussing the EE results in this study, there is a problem to be discussed first. The problem is that the subjects are in a transient state at the beginning of the experiment, which is evidenced by the continued decline in HR. We let our subjects rest on chair for 60 min but their steady-state might was disturbed because of equipping for 30 min. The simple act during initial instrumentation can raise the metabolic rate, so it is virtually impossible for a subject to arrive at an experiment with a metabolic rate. In this study, this point is more important because we focused the effect of clothing weight in the mild cold. So, to validate EE results when we compare the difference of EE by clothing weight, we repeated the same trial four times for each subject and selected the value at the last 120 min exposure instead of the mean of EE for 120 min.
In this study, we observed that the metabolic rate was lower with the heavier clothing than with the lighter clothing. Also, subjects did not express the feeling of shivering and we also could not observe visible shivering. This was due to VO₂ being lower in L-type clothing than in S-type clothing. The absence of a recognizable tremor does not necessarily mean that striated muscles are not responding to the stress of cold (Webster, 1974). Garland (1993) reported that the term 'shivering' includes grades of muscular contraction which range from an increased muscle tone (preshivering tone), via a barely perceptible tremor to a vigorous overt shivering.

First, an increase of muscle tone prior to visible shivering may affect partly increases of EE in subjects wearing S-type clothing. We assumed that the increase of VO₂ measured from the subjects wearing S-type clothing might be due to the following processes. Venous return may be increased by peripheral vasoconstruction and muscle tone prior to visible shivering in mild cold. Increased venous return may heighten filling pressure of blood. Subsequently, stroke volume and cardiac output increase and these affect VO₂ (Landau, 1980; Graham, 1988). Also, EE in S-type clothing increased without increase of HR as well as absence of visible shivering. VO₂ is dependent upon the blood volume and O₂ concentration in blood (Evans, 1994). Blood volume is dependent upon cardiac output and cardiac output is dependent upon HR and stroke volume. Because HR decreased gradually in this study, we can assume that the increase of cardiac output was due to the increase of stroke volume. But as we could not measure directly cardiac output, blood pressure and EMG, it needs to be verified whether lightly clad human's stroke volume increases actually in the mild cold, through further study.

Second, the reason the EE was higher with S-type clothing than L-type clothing may be due to the involvement of non-shivering thermogenesis (NST) as well as the increase of muscle tone. Usually, NST is regarded as thermogenesis substituted for shivering after cold adaptation. How is it possible that NST is elicited to its full extent before shivering is evoked? Under the condition of severe cold stress, NST is additional to shivering thermogenesis. But under the condition of moderate cold, NST can substitute shivering thermogenesis altogether (Webster, 1974; Bruck, 1970; Dauncey, 1981). In this study, the EE of subjects was 14% and 16% higher in S-type clothing than in L-type clothing for male and female, respectively. In addition, in the S-type clothing, the heat production increased by an average of 7.9% (male) and 11.6% (female) for 120 min exposure. Nakayama (1980) reported that the increase of heat production by NST was in the range of up to 10–40%, whereas Wagner and Horvath (1985b) have observed that %ΔM of the subjects in minimal clothing at 20°C air was below 10%. Dauncey (1981) found that 24 h EE in mild cold (22°C) increased by an average of 7% (2–12%). It seems that NST in mild cold exists and its contribution to metabolic responses varies with air temperature and the clothing worn.

In this study, the mean EE of the subjects in S-type clothing increased gradually but the EE of some subjects decreased gradually (Table 4). Because mean body fat (%) was less in subjects with decreased EE (male 5, 9, 15) than in the rest of subjects (p<0.001), we can assume that the differences of metabolic response in mild cold would be related to individual body fat (%). Some authors observed the decrease of heat production when cold exposure has been repeated after training (Shephard, 1987). Therefore, in case of evaluating the changes of the EE of subjects exposed to the cold, authors should take individual variations into considerations, including body fat (%) and physical fitness, etc.

In addition, our observation that the mean EE of subjects in L-type clothing decreased demonstrates that the heat production of the subjects wearing comfortably was not stimulated by mild cold. FAO/WHO/United Nations University (1985) reported that mild cold is unlikely to affect the EE of the subjects kept insulated by clothing or blankets, but Warwick and Busby (1990) found that 24 h EE was 5% higher at 20°C air than at 28°C for normally clothed subjects. De Boer et al. (1988) also found a lower EE in a group of normally clothed men housed at 24.5°C air compared with another group housed at 21°C air. Because our subjects were exposed to mild cold in an only sitting position for 2 h, not active for 24 h, we cannot directly compare this study with
other works. But our study supports the results from the FAO. As there are conflicting findings as to whether heat production in subjects dressed comfortably increases in the mild cold, more studies are required.

Generally, $T_{re}$ shows a slight initial increase in response to cold exposure. But in this study nobody showed the initial increase in $T_{re}$. During the 120 min cold exposure, both $T_{re}$ wearing S- and L-type clothing slowly decreased over time without any initial increase and all $\Delta T_{re}$ in four groups were below 1°C. Initial increase of $T_{re}$ is the positive thermoregulatory action caused by the thermogenic response that occurs rapidly in the cold environment where shivering takes place (Bittel et al., 1988). In this study, the absence of initial increase and the drop of $T_{re}$ within the zone of thermal neutrality show that the subjects in S-type clothing did not feel cold enough to cause the shivering. In light of the fact that $T_{re}$ dropped within the zone of thermal

![Fig. 3. Changes of $T_{sk}$, $T_{re}$ and HR during the 120 min exposure in the 19°C air. (**p < 0.001, Significant differences between S- and L-type. Results were expressed as mean and SD. Variation bars means the standard deviation of inter-subject.)](image)

### Table 5
Summary of physiological responses at the end of 120 min exposure and change for 120 min

<table>
<thead>
<tr>
<th>Sex</th>
<th>Clothing</th>
<th>$T_{re}$</th>
<th>$\Delta T_{re}$</th>
<th>$T_{sk}$</th>
<th>$\Delta T_{sk}$</th>
<th>$T_{he} - T_{sk}$</th>
<th>$T_{head}$</th>
<th>$T_{ab}$</th>
<th>$T_{chest}$</th>
<th>$T_{cho}$</th>
<th>HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>S-type</td>
<td>36.9</td>
<td>-0.56</td>
<td>30.0</td>
<td>-1.95</td>
<td>6.87</td>
<td>34.1</td>
<td>32.1</td>
<td>26.8</td>
<td>32.1</td>
<td>28.9</td>
</tr>
<tr>
<td></td>
<td>L-type</td>
<td>37.0</td>
<td>-0.49</td>
<td>31.7</td>
<td>-1.07</td>
<td>5.31</td>
<td>34.3</td>
<td>32.3</td>
<td>28.8</td>
<td>33.2</td>
<td>31.0</td>
</tr>
<tr>
<td>F</td>
<td>S-type</td>
<td>37.0</td>
<td>-0.43</td>
<td>29.9</td>
<td>-1.89</td>
<td>7.08</td>
<td>32.3</td>
<td>32.0</td>
<td>24.9</td>
<td>32.2</td>
<td>29.9</td>
</tr>
<tr>
<td></td>
<td>L-type</td>
<td>37.1</td>
<td>-0.33</td>
<td>31.1</td>
<td>-1.49</td>
<td>6.04</td>
<td>33.2</td>
<td>34.8</td>
<td>27.0</td>
<td>33.2</td>
<td>31.7</td>
</tr>
</tbody>
</table>

$a$ $\Delta = $ value at 120 min—value at 0 min.

$b$ HR $=$ mean for 120 min.
neutrality, we assume that the drop of $T_{rc}$ in the case of comfortably dressed subjects in the cold temperature is an effective bio response that tries to minimize the EE and maintain the body temperature.

During the 120 min cold exposure, $T_{sk}$ in four groups were maintained in the range of 29.9–31.7°C and those coming under the $T_{sk}$ felt from ‘unpleasantly cool’ to ‘comfortably cool’ (Woodson, 1987). $T_{sk}$ was significantly lower in S-type than in L-type clothing. The lower $T_{sk}$ in the subjects wearing S-type clothing was due to more decreases of $T_{sk}$ in peripheral regions than in the trunk of the body. Also, $T_{sk}$ was significantly lower in females than in males and reason for sex difference of thermoregulation in the cold air was usually cited as difference of body fat (%). Haymes and wells (1986) reported that these differences come from the fact that females have more body fat than males. Females have a lower skin temperature because of higher body fat, and synchronously have a lower metabolic rate due to the lower lean body mass directly related to EE. In this study, mean body fat (%) was 11% for males and 16% for females and $T_{sk}$ was significantly lower in females than in males. But we could not observe the sex difference in EE. It may be due to more involvement of various factors like endocrine functions, actual lean body mass, nutritional state, etc., as well as body fat (%), in metabolic responses than in skin temperature responses.

HR decreased gradually during the 120 min exposure and it seems that the steep decreases for initial 10 min were attributed to the influences of initial instrumenta- tion before experiment. The slow and slight decrease in HR in both clothing types for 110 min can be explained by the fact that HR drops by the action of reflex vagal stimulation when the body temperature drops and the peripheral blood vessels contract (Fleisher et al., 1996). But there is some disagreement among the previous studies. That is, HR for resting men decreased gradually in the cold (Fleisher et al., 1996; Vogelaere et al., 1992), conversely, there were some studies in which it increased (Wagner and Horvath, 1985b; Inoue et al. 1992). Considering that Fleisher et al. (1996) reported that the increase of HR in the cold was related to shivering, it seems that HR responses in the cold may be inverted by the severity of the cold. Under our experimental conditions, though clothing types did not influence HR noticeably, HR in females was higher than in male for 2 h, and females, in the case of S-type clothing showed HR fluctuations. This result implies that females were more sensitive to cardiovascular responses than males in the mild cold even with the same clothes.

In this study, as was expected, all the subjects felt cooler in S-type clothing than in L-type clothing. And about 80% of the subjects in S-type responded ‘cold’, ‘cool’, or ‘slightly cool’. However, we can predict that they may feel less cool in actual daily life at 19°C air
5. Conclusion

This study showed that the EE of the subjects was higher with the lighter clothing than with the heavier clothing during the mild cold exposure and male subjects were satisfied thermally with the environment. Since the EE was affected by clothing thermal insulation in mild cold, clothing thermal insulation should be taken into consideration when authors conduct studies about the EE of subjects exposed to mild cold. Additional findings related to sex difference in this study are that (1) the increase rate of the EE in females was greater than in males, (2) $T_{re} - T_{sk}$ in females was greater than in males, (3) females showed more unstable fluctuations in HR, and (4) females felt more uncomfortable than males to the same cool environment.

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References


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