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Review Article

Relationship between Protection against Cold and the Physiological Index during a Cold Environment

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Abstract

A snow cave is a bivouac shelter used in mountain climbing that is widely used as a shelter against the cold during winter. In the outdoors, wind velocity and air temperature have an influence on temperature change. It could stabilize body temperature if it can control the convection of ambient air. This paper could develop a theory focusing on the relation between physiological indexes and the protection against the cold while staying in a snow cave. For

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example, protection against the cold could be thermal insulation underwear, thermal insulation gloves, thermal insulation socks, a steam warmed temperature sheet and a rescue sheet. Measurement items were heart rate, blood pressure, rectal temperature, score of a subjective thermal sensation and the activity of the parasympathetic nervous system. It was clarified that the protection against the cold could be effective for the decrease of the physiological index. These field studies suggest that they would enable the adaptation in the adjustment range of the autonomic nervous system given these protections against the cold.

1. Introduction

Hypothermia-related accidents among mountain climbers occur not only during winter but also during the summer [1]. As stress because of a cold environment increases, body heat radiation increases instead of body heat production, and body temperature could decrease [2-8]. However, when cold-induced stress increases, the association between the autonomic nervous system and the cardiovascular system is disrupted, leading to peripheral circulatory disturbance [2]. Moreover, when body temperature decreases, the sensation of cold increases and is indicated by continuous shivering [2], followed by the sensation of extreme cold at the digits of the hand and foot. Under these conditions, strong shivering would serve as a defense mechanism. However, a person may develop circulatory disorders and disturbances of consciousness.

Therefore, the aim of this study was to develop a theory focusing on the relation between physiological indices related to hypothermia and cold stress and to review reports of studies involving field works while living in a snow cave.

2. Cold environment and the snow cave

The harmonization required for walking would be affected during long exposure to the cold environment. Therefore, this condition could lead to a high risk of falling and sliding without disturbance of the mountain trail. Although the decrease in body temperature accelerates, consciousness orientation becomes impaired without agreement between recognition and retinal imaging [2]. In addition, the consciousness has slowed down to the reaction for changing of the temperature [2]. In the outdoors, wind velocity and air temperature have an influence on temperature change.

The wild-chill index (WCI) is a cold evaluation index based on the combination of temperature and wind velocity [3]. WCI theoretically calculates heat release and air current, and it is often illustrated by using a nomograph [3].

A snow cave is a bivouac shelter used in mountain climbing that is widely used as a shelter against the cold during winter. It could stabilize body temperature if it can control the convection of ambient air. It is not necessarily appropriate to express "to be warm" in a snow cave because the temperature in the snow cave is 2-5℃ lower than that in the open air. However, it is the expression that captured the characteristics of a snow cave without the influence of convection of ambient air.

3. Relation between physiological index and the cold stress

This paper reports the results of the fieldwork using thermally insulated underwear; gloves and socks; a "steam warm temperature sheet," an uncommon use of a thermal insulation aluminum seat as an insulating board; and convection conservation measures of body heat radiation as a progressive conduction interception measure of this radiation [9-18] without protection against cold. Table 1 showed that the physiological parameters and countermeasures as protection against the cold during field work. It is the flow of the study design which is to clarify the relevance of the physiological parameters and additional protection against cold to show the utility of the protection against cold. The paper (study A) showed that heart rate and rectal temperature significantly decreased in response to an extreme change in WCI (Fig. 1) [9].

Table 1 Protection against cold and measurement items of each study item

Study	Protection against cold	Measurment items
A	Nothing	HR, RT
B	IM	HR, RT, SSTS
C	IM, TU	HR, RT, SSTS
D	IM, TU, TG, TS, HSS	HR, RT, SSTS
E	Thermal group; IM, TU, TG, TS, HSS, Control group; IM	HR, RT, SSTS
F	IM, TU, TG, TS, HSS	HR, RT, SSTS, logHF
G	IM, TU, TG, TS, HSS, TIAS	HR, RT, SSTS, BP

IM: insulating material, TU: thermal underwear, TG: thermal gloves, TS: thermal socks
HSS: heat and steam generating sheets, TIAS: thermal insulation aluminum seat
HR: heart rate, RT: rectal temperture, SSTS: subjective scores of thermal sensation, BP: blood pressure

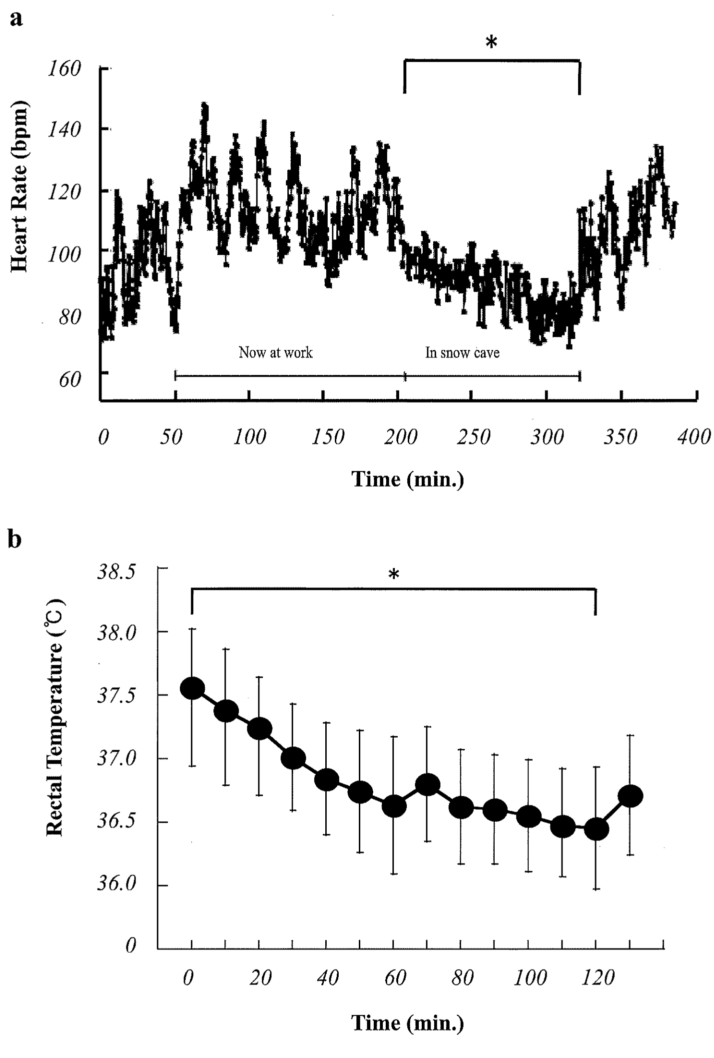

Fig. 1 Changes in the heart rate and the rectal temperature to cold exposure while living in a snow cave (Onodera et al.: *Jpn J Mountain Med* 24(1): 61-63, 2004). Values are mean (SD). Significant difference: *$p<0.05$. a, heart rate; b, rectal temperature.

These results suggest that changes in heart rate and rectal temperature while living in a snow cave are in agreement with physiological effects to cold exposure [9]. In this situation, it could be estimated that rectal temperature progressively decreases, although the impact of hypothermia remains uncertain [9].

Based on these findings, we hypothesized (study B) that decreases in the heart rate, the rectal

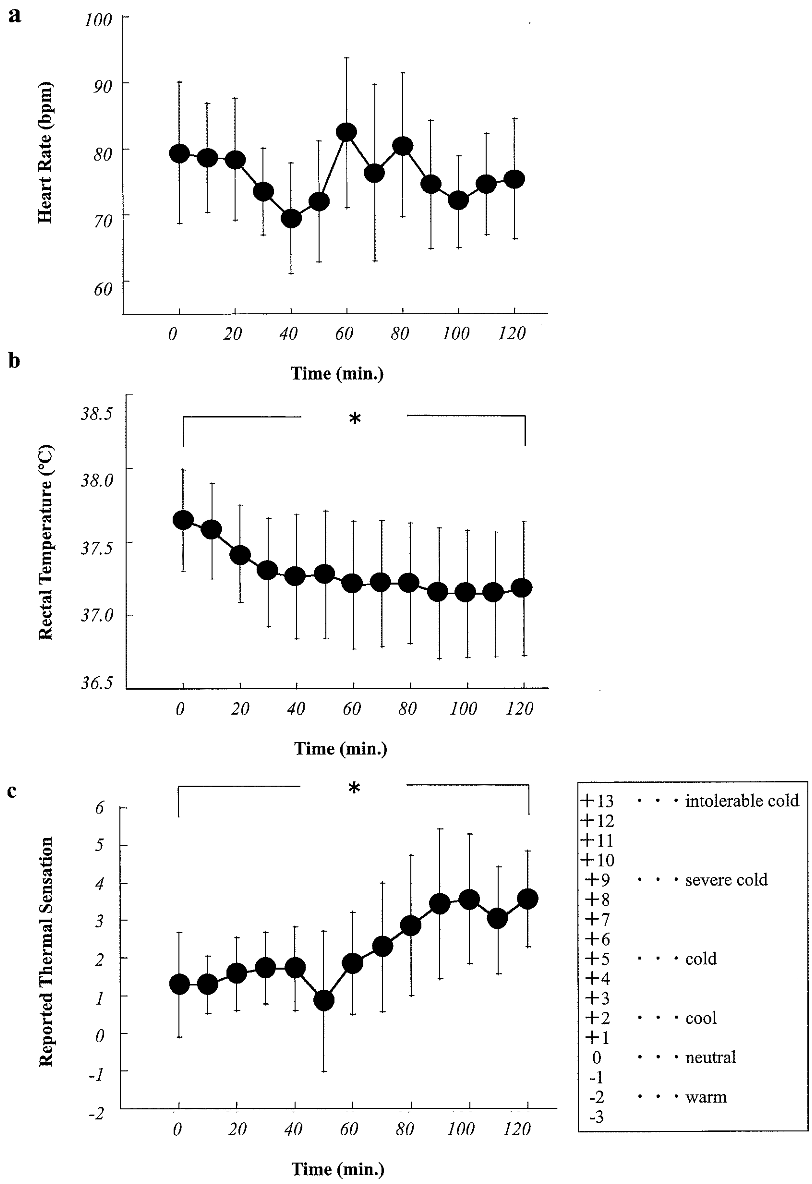

Fig. 2 Changes in the heart rate, the rectal temperature and reported thermal sensation while living in a snow cave by the use of an insulating material (Onodera et al.: *Jpn J Mountain Med* 25(1): 81-83, 2005). Values are mean (SD). Significant difference: *p<0.05. a, heart rate; b, rectal temperature; c, reported thermal sensation.

temperature and reported thermal sensation (SSTS) could be inhibited by the use of an insulating material [10]. Although no change was observed in heart rate [10], rectal temperatures significantly decreased and SSTS were significantly increased (Fig. 2) [10]. The heart rate and the rectal temperature increase, and SSTS decrease when it is a cold environment. These results suggest that using an insulating material is effective in inhibiting a decrease in heart rate while living in a snow cave.

We hypothesized (study C) that decreases in the heart rate, the rectal temperature and SSTS could be inhibited by the use of an insulating material and thermal underwear [11]. Rectal temperature was significantly decreased and SSTS significantly increased (Fig. 3) [11]. Nonetheless, the rate of the decrease was one-fourth of that reported in 2004 [9]. Thus, it was considered that using an insulating material and thermal underwear inhibited the previously observed decreases in heart rate and rectal temperature while

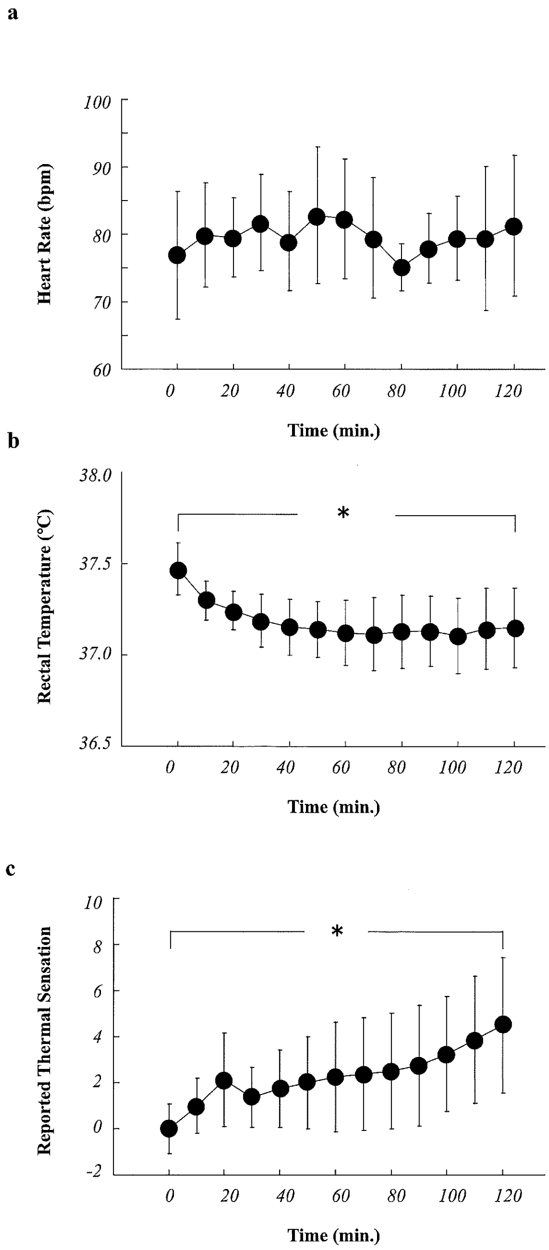

Fig. 3 Changes in the heart rate, the rectal temperature and reported thermal sensation while living in a snow cave by the use of an insulating material and thermal underwear (Onodera et al.: Changes of the rectal temperature, heart rate and scale of a subjective thermal sensation using thermal underwear during a 2 hour stay in snow hole. *Jpn J Mountain Med* 26(1): 65-67, 2006). Values are mean (SD). Significant difference: *$p<0.05$. a, heart rate; b, rectal temperature; c, reported thermal sensation.

living in a snow cave, although the increase in SSTS was unchanged.

We hypothesized (study D) that the increase in SSTS could be inhibited by the use of an insulating material, thermal underwear, thermal gloves, thermal socks, and heat- and steam-generating sheets [12]. Adding these protections against cold to equipment, increase of heart rate and rectal temperature were inhibited. SSTS was significantly increased until 50 minutes thereafter, and the score remained relatively unchanged (Fig. 4). These results indicate that those are completely effective in preventing coldness in a snow cave.

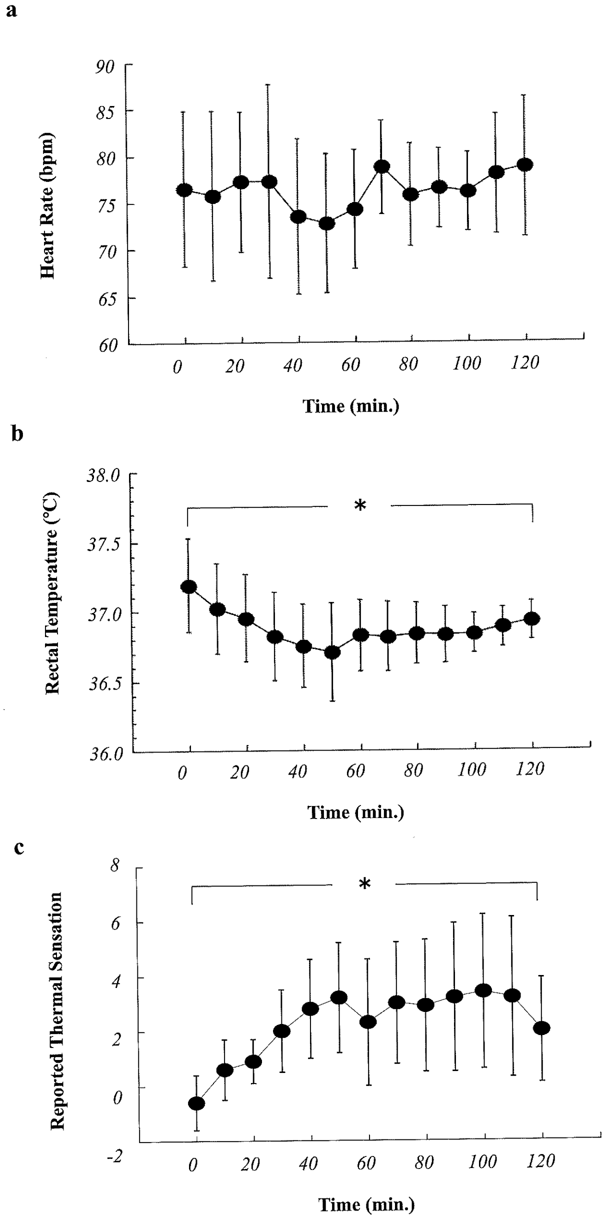

Fig. 4 Changes in the heart rate, the rectal temperature and reported thermal sensation while living in a snow cave by the use of an insulating material, thermal underwear, thermal gloves, thermal socks and heat-and steam-generating sheets (Onodera et al.: *Jpn J Mountain Med* 27(1): 91-94, 2007). Values are mean (SD). Significant difference: $^{*}p<0.05$. a, heart rate; b, rectal temperature; c, reported thermal sensation.

To verify these data, a comparison of thermal and control conditions was performed (study E), which showed that the mean SSTS was significantly increased under controlled conditions (Fig. 5) [13]. There were no changes in the other indices under either condition. These data suggest that using a thermal countermeasure may be effective in inhibiting physiological indices.

We hypothesized (study F) that changes in SSTS correlated with decreased autonomic nervous system activities [14]. The sympathetic nerve activity increased while SSTS increased. The other, parasympathetic nerve activity increased while SSTS decreased. SSTS significantly increased, and the parasympathetic

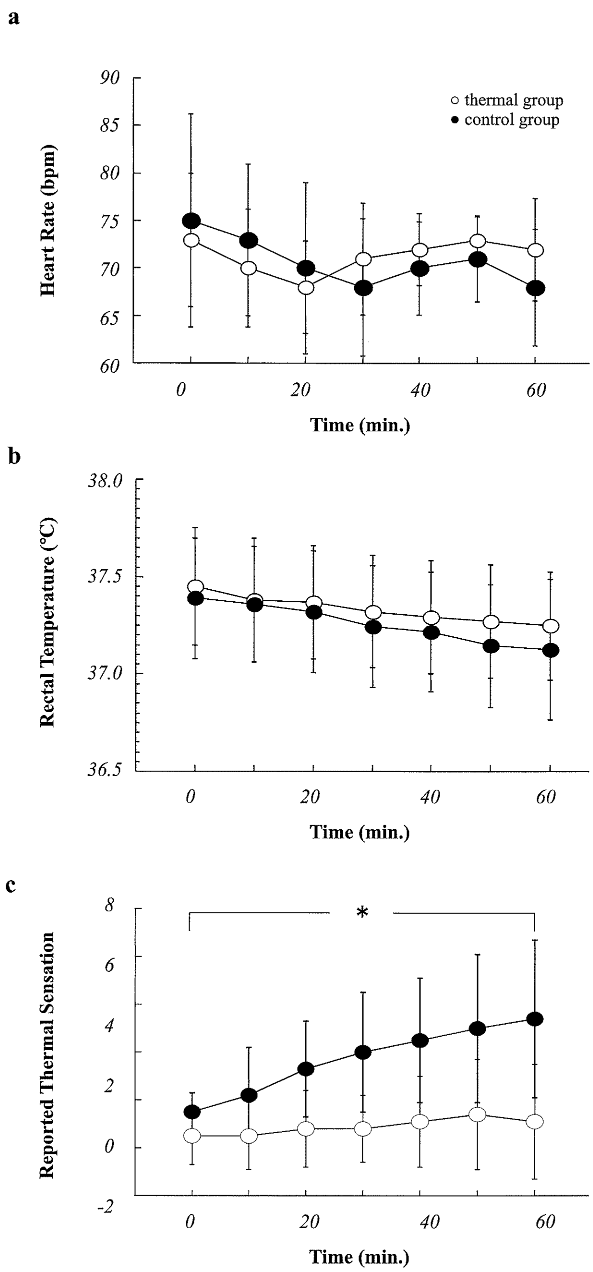

Fig. 5 Comparison of the heart rate, the rectal temperature and reported thermal sensation for thermal group and control group while living in a snow cave (Onodera et al.: *Jpn J Mountain Med* 28(1): 90-93, 2008). Values are mean (SD). Significant difference: *$p<0.05$. a, heart rate; b, rectal temperature; c, reported thermal sensation.

nervous system activity significantly decreased while living in a snow cave. These data suggest correlations between autonomic nervous system activities and thermal countermeasures (Fig. 6).

Furthermore, we hypothesized (study G) that decreases in body temperature are controlled by the use of a rescue sheet in addition to previous thermal countermeasures while living in a snow cave [15-17]. A rescue sheet was light and thin, and able to block the wind. A rescue sheet is also called a survival sheet. There was no statistically significant change in heart rate, SSTS, parasympathetic nervous system activity, or rectal temperature (ANOVA; $P < 0.05$). In addition, the use of a rescue sheet clearly maintained not only physiological but also subjective indices. These findings suggest that behavioral thermoregulation is

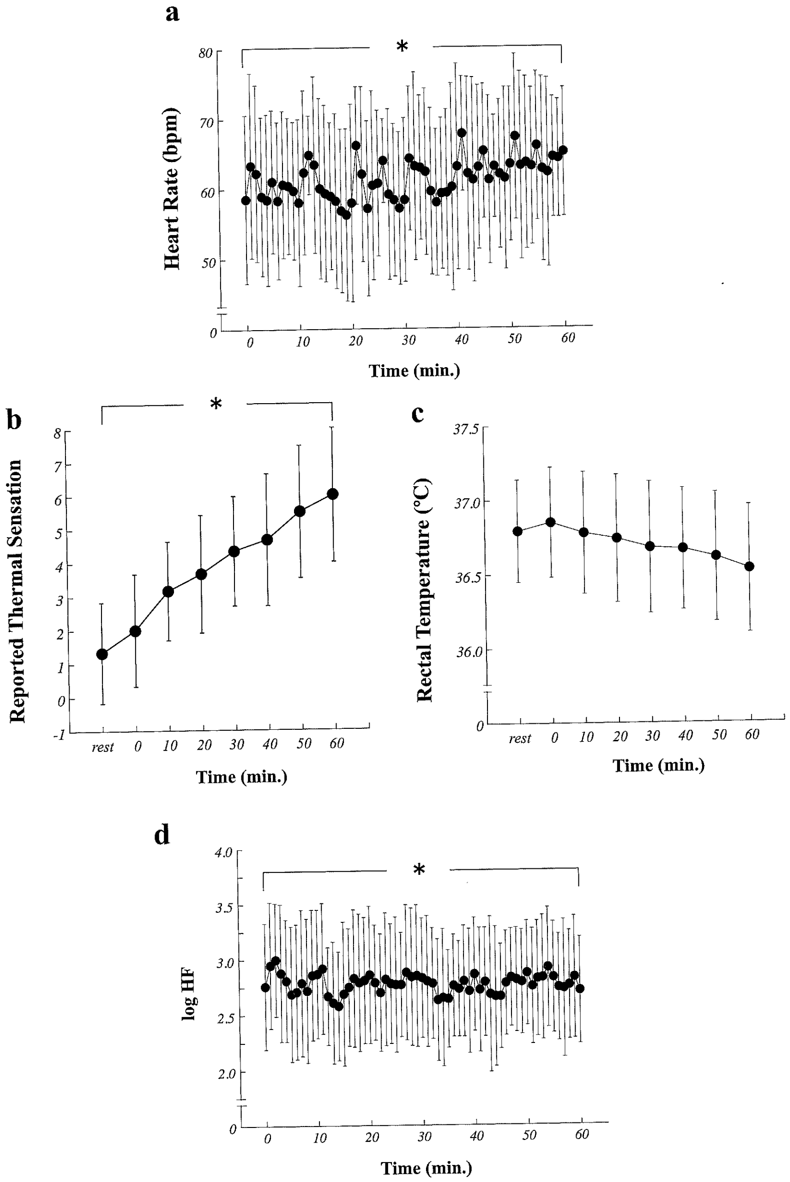

Fig. 6 Change in the heart rate, the rectal temperature, reported thermal sensation and logHF while living in a snow cave by the use of an insulating material, thermal underwear, thermal gloves, thermal socks and heat- and steam-generating sheets (Onodera et al.: *Jpn J Mountain Med* 29(1): 173-176, 2009). Values are mean (SD). Significant difference: *$p<0.05$. a, heart rate; b, rectal temperature; c, reported thermal sensation; d, logHF.

effective to counteract hypothermia.

Measures can be adopted to counteract adaptation of the autonomic nervous system in response to extreme cold; however, it is considered that hypothermia is inevitable while continuously living in a snow cave, regardless of adaptations of the autonomic nervous system. Notably, experimental conditions are unlikely to mimic the conditions encountered by a mountaineer while sheltered in a bivouac on a snow-covered mountain. The proposed rescue sheet, which weighs only 200g, is particularly effective to protect against the cold; therefore, mountaineers should consider carrying more than two pieces while mountain climbing in all seasons.

4. Lesson from the Mount Tomuraushi accident

The report on the Mount Tomuraushi accident (2141 m; the height above sea level) [1] was to speculate that the accident led to hypothermia causing a remarkable drop in air temperature in the summer of 2009. The margin of safety for body temperature is 28℃ . If the temperature decreases further than this, it poses an extremely high risk of serious injury. Reportedly, the core temperature of the mountaineers decreased to less than 9℃ over a span of 2 h and each individual suffered from cardiac arrest. The findings of this report contraindicate a decrease in core temperature and increase of symptoms and inhibiting the control of core temperature by shivering, changing to the disturbance of consciousness, and sleepiness in case of extreme cold.

5. Remarkable changes in the physiological index of the elderly

Thermally insulated underwear is extremely useful to maintain body temperature in the elderly while mountain climbing during the winter. Sweat is a known factor that leads to a drop in body temperature; therefore, changing to dry clothes will inhibit a decrease in body temperature. The following physiological signs of the elderly when exposed to extreme cold mimic those of younger individuals [2, 19]:

① Marked decreases in skin temperature of the trunk

② Heat radiation is not effective to ameliorate decreases in peripheral circulation

③ Increase in systolic blood pressure

④ Sensitivity to cold decreases over time

Thus, the physiological load for the elderly may be increased in response to a cold environment and thermoregulation may decrease sensitivity to cold temperatures.

6. Remarkable changes of physiological index in women

Women better adapt to cold environments by reductions in skin temperature compared with men because of thermoregulation benefits owed to an increased body fat ratio. No significant differences were observed in heart rate or rectal temperature as stress indices in response to living in a snow cave [18]. However, both systolic and diastolic blood pressures after living in a snow cave were higher than those recorded before exposure. In addition, the reported thermal sensation scores were significantly increased. It could be argued that increased peripheral artery resistance causes the phenomena in women (Fig. 7). Under the same conditions, these trends in blood pressure were not observed among men [10-17]. Therefore, these data suggest that the increase in reported thermal sensation and blood pressure are remarkable in woman while living in a snow cave.

Menstruation is peculiar to women and has been associated with decreased body temperature during ovulation. Thus, female hormones could affect the control of core temperature. Most women tend to feel cold sooner when in the luteal phase [19]. The threshold of core temperature in a trained individual woman could lead to a smaller decrease, causing inhibition of female hormones in the luteal phase [19]. The change in thermal sensation reported by women was not small in the cold environment as well as in the summer [20].

7. Working out countermeasures for the cold environment

As countermeasures to hypothermia, the following should be considered [2, 3, 19]:

① To change into dry clothes

② To incubate the entire body

③ To gradually warm the neck, axillary, and inguinal regions by the use of hot water (approximately 36℃) in a plastic bottle applied to these regions. It is necessary to induce gradual warming to prevent shock induced by sudden warming of the fingers.

④ Water supply

: Do not offer hot drinks to anyone who is unconscious and do not consume alcohol.

⑤ Energy supply to raise body temperature

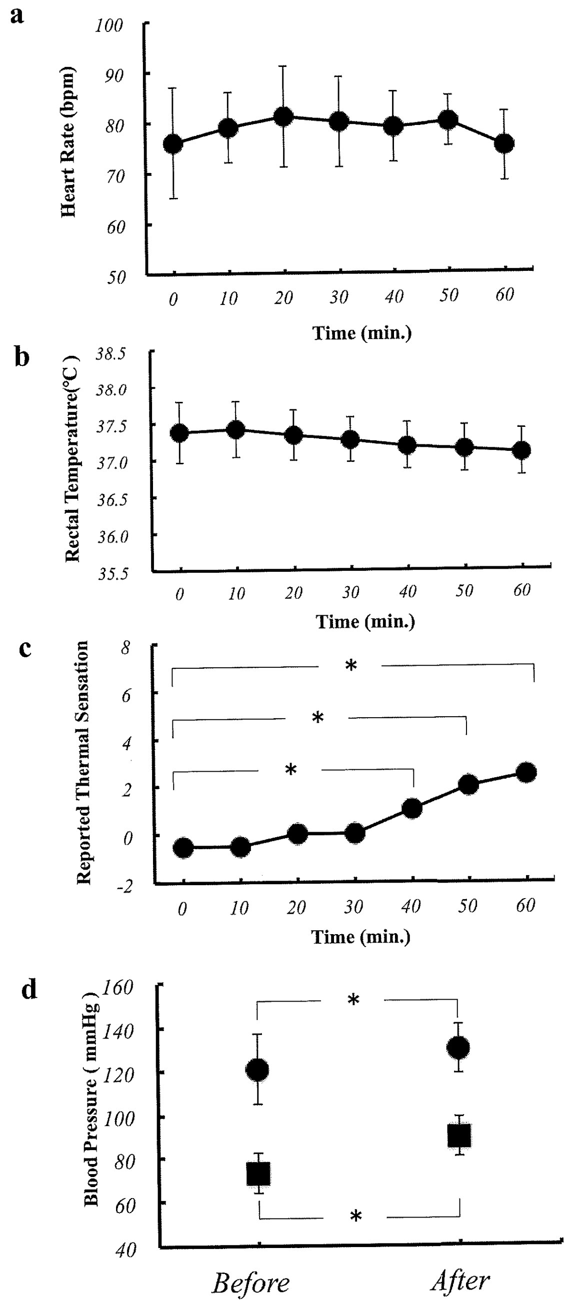

Fig. 7 Changes in the heart rate, the rectal temperature, reported thermal sensation and blood pressure while living in a snow cave in women by the use of an insulating material, thermal underwear, thermal gloves, thermal socks, heat-and steam-generating sheets and a rescue sheet. The heart rate, the rectal temperature and blood pressure are shown as the mean (SD), and reported thermal sensation is shown as the median (Onodera et al.: *Jpn J Mountain Med* 33(1): 71-76, 2013). Significant difference: $^{*}p<0.05$. a, heart rate; b, rectal temperature; c, reported thermal sensation; d, blood pressure.

: Mountaineers should carry preserved foods that are high in calories and protein for long-term field activity and consume it before the onset of hunger.

⑥ Consider preventive measures regarding the elderly, infants, and compromised patients, such as those with diabetes.

⑦ Have sufficient protection against the cold, such as knitted hats and scarves, to prevent heat loss from the face, neck, and head.

8. Conclusion

Apparel that protects against extreme cold should be worn for the entire winter season during mountain climbing. However, reports on the Mt. Tomuraushi tragedy confirm that sudden changes in weather pose a significant risk of hypothermia even during the summer. Therefore, precautions should be taken when confronted with cold environments. Shivering enables the production of body heat using energy, which is important for recovery after the disappearance of shivering. The findings of this study illustrate the importance of feed-forward adaptation for mountain climbers to survive unseen events, such as the onset of extreme cold.

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