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Effects of alternating exposure to cold and heat for 14 days on cold tolerance in winter

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ABSTRACT

People are exposed to heat regularly due to their jobs or daily habits in cold winter, but few studies have reported whether parallel heat and cold exposure and diminish cold acclimation. This study was conducted to investigate the effects of alternating exposure to cold and heat on cold tolerance in eight young males. A daily acclimation program to cold and heat, which consisted of 2-h sitting at 10 °C air in the morning and 2-h running and rest at 30 °C air in the afternoon, was conducted for 14 consecutive days. Eight male subjects participated in a cold tolerance test (10 °C [± 0.3], 40%RH[± 3]) before (PRE) and after (POST) completing the alternating exposure program. During the cold tolerance test, subjects remained sitting upright on a chair for 60 min. Rectal temperature (T_{re}) was lower in POST than in PRE during the 60-min cold tolerance test ($P = 0.027$). During the cold tolerance test, systolic, diastolic, and mean arterial blood pressures in POST were lower than those in PRE ($P = 0.006$, $P = 0.005$, and $P = 0.004$). No significant differences in skin temperatures between PRE and POST were found for the cold tolerance test. There were no significant differences in energy expenditure during cold exposure between PRE and POST. Subjects felt less cold in POST than in PRE ($P = 0.013$) whereas there was no significant difference in overall thermal comfort between PRE and POST. These results suggest that cold adaptation can still occur in the presence of heat stress.

Introduction

People, who live in climatic zones with both hot summer and cold winter, are prone to cold and heat exposure over a short period of time: cold store workers during summer, meat processors in summer, greenhouse farmers in winter, or people who enjoy sauna or hot springs in winter. For such people, whether or not alternating exposure to cold and heat over a short period of time affects cold or heat tolerance is an important question. Some researchers have shown interests in acclimation from alternating exposure to cold and heat (Glaser, 1950; Glaser et al., 1959; Glaser and Shephard, 1963; Scott et al., 1940). However, previous studies focused on the local responses of body parts (*e.g.*, the hand) exposed to alternating temperatures, not the whole body. To the best of our knowledge, since the 1960s, very little research has been conducted on the effects of alternating exposure to cold and heat on the whole body. Also, Glaser and Shephard (1963) reported that living in climates with alternating temperature extremes induced acclimation to both cold and heat. This background has piqued our interest in determining more precisely the effects of alternating exposure to cold and heat on cold or heat tolerance.

The concept of parallel acclimation can be explained as simultaneous acclimation to two factors. There has been documentation of the positive effects of simultaneous acclimation to cold and heat on physiological and psychological thermal responses (Glaser and Shephard, 1963; Scott et al., 1940). More recently, alternating hot and cold water has been used as a treatment for acute sporting injuries and for rehabilitative purposes (Cochrane, 2004). Tipton et al. (2008) reported that the relationship between acclimation to cold and heat may be detrimental at the opposite end of the thermal spectrum. Their research was based on the morphological effects of heat and cold acclimation such as, reduced and improved insulation (Tipton et al., 2008). Acclimation with different approaches shows different acclimation patterns (Young, 1996).

On the other hand, there is considerable separate research on cold adaptation and on heat adaptation. Cold adaptation results primarily in greater homeostatic economy and a preservation of energy, often at the cost of a lower mean body temperature during cold stress. Repeated exposure to cold air may enhance metabolism. Some degree of

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insulative adaptation to cold occurs from repeated whole body cold exposure (Tipton et al., 2008). Eventually, the feeling of discomfort and pain subside both in whole body cold exposure and local cold exposure, leading to altered behaviour (Daanen and Van Marken Lichtenbelt, 2016). Heat adaptation, whether achieved by exposure to a hot environment or by endogenous heat produced during exercise, often brings about a lower mean body temperature during heat stress at the cost of greater body water loss (Saat et al., 2005; Tipton et al., 2008).

Humans have a remarkable ability to adapt to heat and a heat-acclimated person can tolerate extended exposure to virtually any naturally occurring hot-weather condition (Sawka et al., 1996; Tipton et al., 2008). Fox et al. (1967) showed that subjects experienced decreased heart rate, core and skin temperatures and increased sweating during the exercise-heat test after dry- and humid-heat acclimation for 12 days (2 hr·day^{-1}). The changes were significantly greater for the heat-acclimatized group than the control group. Sawka et al. (1983) examined the effect of hydration on physiological responses during exercise in hot-dry and hot-wet conditions, both before and after a 10-day heat acclimation program. They concluded that hydration level affected thermoregulatory heat acclimation. More scientific efforts have been focused on the time course and mechanisms for the acquisition of human heat acclimation than on its retention or decay (Pandolf, 1998; Tipton et al., 2008). Saat et al. (2005) reported that the decay of heat acclimation was significantly greater for those exercising in cold than those merely exposed to cold.

As we have already mentioned, most studies have focused on either cold or heat acclimation along with deacclimation. Research on alternative exposure to opposite thermal stimuli to investigate the effect of parallel exposure to cold and heat on cold or heat tolerance is very few. In this regard, the effects of alternating exposure to cold and heat on physiological responses and subjective perception need to be examined. Our first step was to investigate the effects of short-term parallel exposure to both cold and heat on physiological and psychological tolerance to cold. The effect of the identical cold and heat exposure program on heat tolerance will be reported through further studies. For the present study, we designed a 14-day cold and heat acclimation program and examined cold tolerance before and after the acclimation program. We hypothesized that 1) physiological cold tolerance traits would not weaken and 2) psychological cold tolerance traits would be enhanced through alternating exposure to cold and heat. A control group without the 14-day program was not included in the present study and the hypotheses were tested through pre- and post- trials of an identical experimental group.

Methods

Ethical approval

The procedures for this study were approved by the Institutional Review Board of Seoul National University (IRB No. 1603/001–023). Full explanation of procedures, discomforts, and risks were given to all participants prior to obtaining written informed consent.

Subjects

Eight male subjects participated in the present study (24.1 yr [± 3.8] in age, 1.74 m [± 0.05] in height, 72.6 kg [± 12.3] in body weight, and 1.9 m^2 [± 0.1] in body surface area). Seven were non-smokers and all of them exercised regularly. None of them had any diseases or took medicine regularly. All subjects took part in a medical check-up before their participation and visited the laboratory for 16 days: 14 consecutive days of parallel exposure to cold and heat and 2 days for cold tolerance testing (Pre-test [PRE] and Post-test [POST]). All experiments were conducted in February 2016 which had 0.2 °C mean air temperature (T_a), −10 °C average minimum T_a, 14.4 °C average maximum T_a, and 52%RH mean air humidity (KMA, 2016). Korean winters are generally considered to last from Dec to Feb. Regarding their pre-experimental acclimatization states, all subjects were to have obtained natural cold acclimatization because this study was conducted during the winter season. They were instructed to refrain from strenuous exercise, caffeine, and alcohol consumption for the day preceding testing, during the parallel exposure program, and the day of cold tolerance testing.

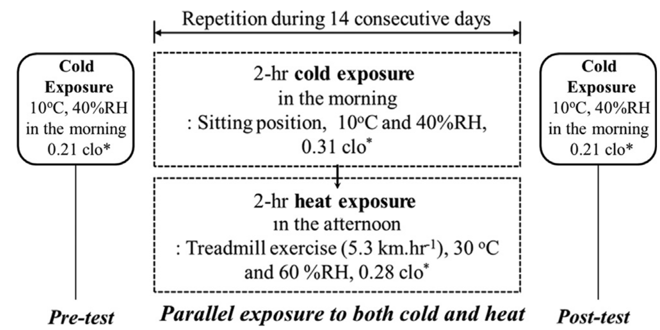

Fig. 1. Experimental protocol. Cold tolerance tests were conducted before and after the parallel exposure program of 14 consecutive days. The pre- and post-tests were conducted at the same time in the morning. *: Clo unit refers to the insulation of experimental clothing worn in each test.

Parallel exposure to cold and heat

All subjects experienced the parallel exposure program to both cold and heat on 14 consecutive days: two hours of cold exposure in the morning and two hours of heat exposure using exercise and passive heating in the afternoon (Fig. 1). For cold exposure in the morning, all subjects wore a short-sleeve T-shirt, half-length trousers, underpants (all 100% Cotton, all 0.31 clo estimated by ISO, 2007) and backless slippers. After wearing these items, subjects moved into a climate chamber (10 °C in T_a and 40%RH in air humidity) and remained sitting on a chair for two hours. After the 2-hr cold exposure, subjects had lunch and took a break for about two hours for recovery. Thereafter, they had exercise- and passive-heat acclimation training for two hours in the afternoon: two 45-min bouts of treadmill exercise (5.3 km·hr^{-1}) and 15-min rest in a hot environment (30 °C in T_a and 60%RH in air humidity). They all wore half-length trousers, underpants (all 100% Cotton), socks and running shoes (I_{cl} 0.28 clo estimated by ISO, 2007). During the parallel exposure program to cold and heat, heart rate (HR) was measured every 1 s using a HR monitor (RS400, Polar Electro, Finland) for the whole duration of each trial (120 min). Also, systolic (SBP) and diastolic (DBP) blood pressures were measured at 20 ~ 30 min intervals using an automatic sphygmomanometer (JPN1, Omron Healthcare Co., Ltd., Japan) and the cuff was wrapped around the right upper arm and remained in place throughout. Mean arterial pressure (MAP) was calculated as: MAP = (2 × DBP + SBP)/3.

Pre-test and post-test cold tolerance

To evaluate the effect of parallel exposure to cold and heat on cold tolerance, a control group (one exposed to cold only) is required. However, the present study tested only one subject group without a control group and compared responses before (PRE) the 14-day parallel exposure program to those after (POST). Subjects took a cold tolerance test before and after the 14-day parallel exposure program. The PRE and POST tests were conducted at the same morning time (AM 09:30–11:30). They arrived at the laboratory and entered a preparation room at least 60 min before the start of the measurements to adapt to the controlled environment (27 °C). After all subjects were identically dressed in half-length trousers, underpants (both 100% Cotton, 0.21 clo estimated by ISO, 2007) and backless slippers, they were instrumented for physiological response measurements. Before moving into the cold chamber, baseline rectal temperature, skin temperatures, heart rate and blood pressure were collected for 10 min and this 10 min period was regarded as a rest period.

Subjects moved into the climate chamber (10 °C [± 0.3] and 40% relative humidity [± 3]) and remained sitting on a chair for the duration of the experiment. For the entire 60 min trial, skin temperatures were measured every 1 s on the following eleven body regions: the forehead, left chest, left abdomen, lower back neck (near the 7th cervical vertebra), left scapular, left forearm, left hand, left middle finger pads, left thigh, left calf, and left foot (LT-8A, Gram Ltd., Japan). Mean skin temperature (T_{sk}) was calculated using a modified Hardy and Dubois' equation (Hardy and DuBois, 1938): $T_{sk} = 0.07 \times T_{forehead} + \{0.35 \times (T_{chest} + T_{scapular} + T_{abdomen})/3\} + 0.14 \times T_{forearm} + 0.05 \times T_{hand} + 0.19 \times T_{thigh} + 0.13 \times T_{calf} + 0.07 \times T_{foot.}$ Rectal temperature (T_{re}) was measured every 1 s using a thermistor probe inserted 16 cm beyond the anal sphincter of the rectum. Mean body temperature (T_b) was calculated: $T_b = 0.65 \times T_{re} + 0.35 \times T_{sk}$. HR, SBP and DBP were measured using the same equipment as the parallel exposure program: every second interval in HR and 10 min intervals in blood pressure. Energy expenditure was measured during the initial (0–5 min) and last (55–60 min) 5-min periods using an automatic respirometer (Quark b^2, Cosmed Co., Italy). Prior to each measurement, the respirometer was calibrated with room air, a standard gas mixture (4% CO_2, 16% O_2, and balance nitrogen) and the volume was calibrated using a 3-litre syringe.

Psychological thermal sensation was measured on a 9-point scale (-4: very cold ~ 4: very hot) on the whole body and local body parts (the head/face, trunk, hands, and feet) and thermal comfort was measured on a 7-point scale (-3: very uncomfortable ~ 3: very comfortable) on the whole body every 20 min (ISO, 1995). Onset time (unit: second) and frequency of shivering were obtained from each subject's self-evaluations.

Data analysis

Data were expressed as means with standard deviation (SD). Physiological values for 10-min rest were averaged, and the values of the 60-min cold exposure were averaged. Among physiological measurements, only energy expenditures were averaged for the initial and last stages. Statistical analyses were conducted using IBM SPSS for Windows version 21 (IBM SPSS Statistics, USA). Normality was evaluated with the Shapiro-Wilk's test and all data normally distributed were analysed with a paired *t*-test between PRE and POST and between rest and cold exposure for each trial. Onset time of shivering was regarded as the maximum value (3600 s) when participants showed no shivering for 60 min and was converted into minutes in the results. For all statistical analyses, an alpha level of 0.05 was used.

Results

Heart rate and blood pressure

At rest (T_a 27 °C), there were no significant differences in HR, SBP, DBP and MAP between PRE and POST (all $P > 0.05$). During cold exposure, HR was lower in POST than in PRE ($P = 0.054$, Fig. 2A), while SBP, DBP, and MAP in POST were higher than those in PRE ($P = 0.006$, $P = 0.005$ and $P = 0.004$, respectively; Fig. 2B, C, and D). There was no significant difference between the 10-min rest period and the 60-min cold exposure in HR for PRE ($P = 0.184$). HR during cold exposure tended to be lower than that at rest in POST ($P = 0.059$; Fig. 2A). There were no significant differences in HR between the rest and cold exposure ($P = 0.591$; Table 1). All blood pressures were greater during cold exposure than at rest (all $P < 0.05$; Fig. 2B, C, and D, Table 1). Increases in SBP, DBP, and MAP were greater in PRE than those in POST (Table 1). During the parallel exposure program, HR showed a significant reduction than the HR of the first day. During heat exposure there were no significant differences in MAP and during cold exposure, there were no significant differences in HR and MAP except for on two days: HR on the 4th day and MAP on the 11th day were lower than their respective values on the first day (Fig. 3).

Rectal and skin temperatures

T_{re} was lower in POST than in PRE during the cold tolerance test ($P = 0.027$) whereas there was no significant difference at rest at 27 °C between PRE and POST ($P = 0.197$; Fig. 4A). Also, T_{re} showed a tendency to increase in PRE ($P = 0.094$) but showed no tendency to change in POST ($P = 0.324$) during the cold tolerance test (Fig. 4A). T_{sk} was lower both in PRE ($P < 0.001$) and in POST ($P < 0.001$) during cold exposure than at rest (Fig. 4B). T_b at rest at 27 °C and during cold exposure were 35.56 °C (± 0.24) and 33.74 °C (± 0.33) in PRE ($P < 0.001$) and 35.34 °C (± 0.33) and 33.62 °C (± 0.20) in POST ($P < 0.001$). Finger temperatures at rest at 27 °C and during cold exposure were 34.40 °C (± 1.07) and 18.41 °C (± 2.64) in PRE ($P < 0.001$) and 32.61 °C (± 3.41) and 17.49 °C (± 1.91) in POST ($P < 0.001$). No significant differences between PRE and POST were found in any local skin temperatures at rest at 27 °C and during cold exposure (all $P > 0.05$). There were no significant differences in changes of rectal, mean skin, and mean body temperatures between PRE and POST (all $P > 0.05$, Table 1).

Energy expenditure

Energy expenditures during cold exposure were 1.91 $kcal \cdot min^{-1}$ (± 0.31) and 1.87 $kcal \cdot min^{-1}$ (± 0.20) in the initial and last stages, respectively in PRE, while 1.97 $kcal \cdot min^{-1}$ (± 0.51) and 1.87 $kcal \cdot min^{-1}$ (± 0.44) in the initial and last stages, respectively, in POST. There were no significant differences for both stages between PRE and POST (both $P > 0.05$) and also no significant differences between the initial and last stages during cold exposure (both $P > 0.05$).

Subjective perceptions and shivering onset time

For overall thermal sensation, subjects felt significantly less cold in POST than in PRE ($P = 0.013$; Fig. 5A) while there was no significant difference in whole body thermal comfort ($P = 0.188$; Fig. 5B). As for local body parts, subjects tended to be less cold on the head/face in POST than in PRE ($P = 0.085$). They felt less cold on the trunk and hands in POST than in PRE ($P = 0.007$ and $P = 0.019$, respectively; Fig. 5C and D). There were no significant differences with the feet between PRE and POST ($P = 0.232$). No significant difference in onset time of shivering was shown ($P = 0.572$): 23.9 min (± 27.7) and 33.7 min (± 24.4) in PRE and POST, respectively. Also, there was no significant difference in shivering frequency between PRE and POST ($P = 0.166$): 9.5 times (± 11.9) and 2.8 times (± 3.6), respectively.

Discussion

This study is original in terms of exploring the influences of alternating exposure to cold and heat for short periods of time on cold tolerance. To the best of our knowledge, few studies have shown whether or not cold adaptive traits are improved after parallel exposure to cold and heat. The principal finding of the present study was that thermoregulatory and cardiovascular responses during the cold tolerance test improved (in terms of more stable rectal temperature and smaller increased blood pressure) after the parallel exposure program to cold and heat. Also, subjects felt less cold during the cold tolerance test after the 14-day parallel exposure to cold and heat. These results supported the hypothesis that alternating exposure to cold and heat would reduce thermal, cardiovascular and subjective strain under cold stress, which indicates that cold adaptation can still occur in the presence of heat

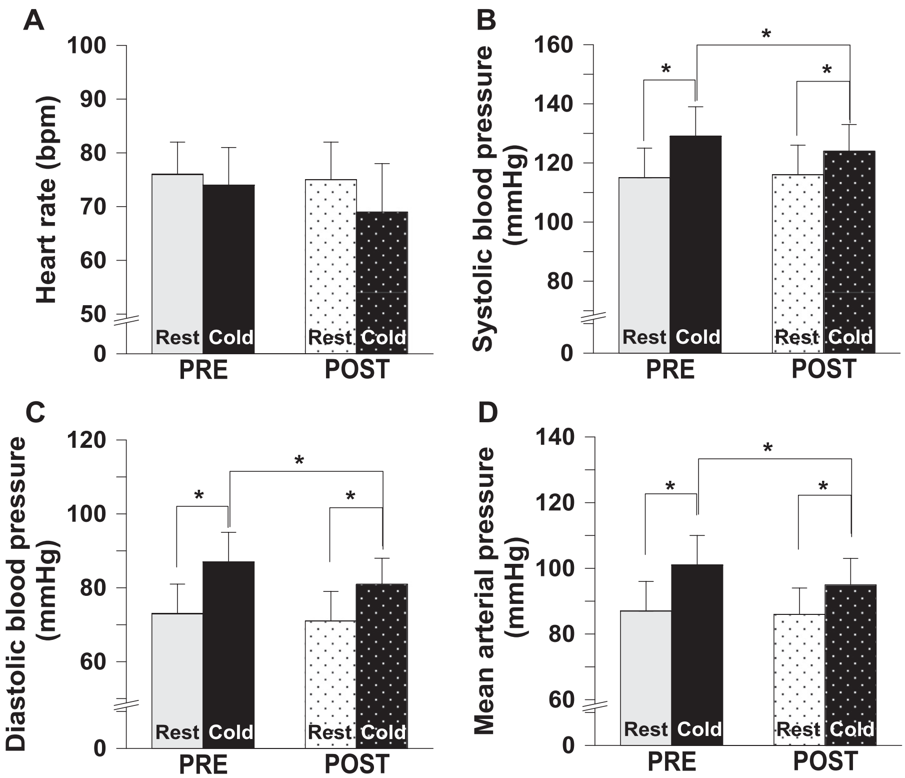

Fig. 2. Heart rate and blood pressures at rest (27 °C) and during cold exposure (10 °C): A. Heart rate, B. Systolic blood pressure, C. Diastolic blood pressure, D. Mean arterial pressure (*: $P < 0.05$). PRE and POST represent before and after stages of a 14-day parallel exposure protocol to cold and heat. Parallel exposure program consisted of 2-hr cold exposure (10 °C, 40% RH) and exercise- and passive-heat exposure training for two hours (30 °C, 60%RH, two 50-min treadmill walks, separated by 10 min rests) per day. PRE and POST tests were conducted at an air temperature of 10 °C and air humidity of 40%RH for 60-min. All data were averaged over the whole duration of the test (Mean ± SD).

Table 1
Changes in physiological responses during cold tolerance tests.

	Changes between rest and cold exposure		P values between PRE and POST
	PRE	POST	
ΔHR (bpm)	−3 ± 7	−5 ± 12	0.591
ΔSBP (mmHg)	14 ± 4*	8 ± 8*	0.026
ΔDBP (mmHg)	14 ± 4*	10 ± 4*	0.056
ΔMAP (mmHg)	14 ± 3*	9 ± 5*	0.007
ΔT_{re} (°C)	0.09 ± 0.13	0.05 ± 0.14	0.532
ΔMean T_{sk} (°C)	−5.37 ± 0.45*	−5.00 ± 0.94*	0.393
ΔMean T_b (°C)	−1.81 ± 0.20*	−1.72 ± 0.30*	0.520
ΔT_{finger} (°C)	−16.0 ± 2.3*	−15.1 ± 3.2*	0.612

HR (heart rate), SBP (Systolic blood pressure), DBP (Diastolic blood pressure), MAP (mean arterial pressure), T_{re} (rectal temperature), T_{sk} (skin temperature), and T_b (body temperature); PRE and POST represent before and after stages of a 14-day parallel exposure protocol to cold and heat. A cold tolerance test was conducted at an air temperature of 10 °C and air humidity of 40%RH. *: The asterisk means a significant difference between rest and cold exposure in each variable ($P < 0.05$).

stress.

Thermal and cardiovascular responses

It is typical for core body temperature to increase in severe cold. For the present study, rectal temperature increased by 0.09 °C during the cold tolerance tests before starting the 14-day parallel exposure program, whereas rectal temperature increased by 0.05 °C during the identical cold tolerance test after the parallel exposure program (Fig. 4A). Heat exposure may have reduced the rise in core temperature that is typically found following cold acclimation (Fox et al., 1967; Glaser, 1950; Sawka et al., 1996; Tipton et al., 2008). When considering adaptation memory as related to the exposure time (Glaser and Shephard, 1963; Horowitz, 2014), cold tolerance tests were completed at the same time of day as the cold acclimation, not the heat acclimation. Thus, it seems that the effects of cold acclimation on cold tolerance could be dominant in the present study because subjects conducted both 14-day cold exposure and cold tolerance tests in the morning.

At the same time, there was no difference in energy expenditure between PRE and POST. Hammel (1964) and Tipton et al. (2008) suggested that humans could adapt to cold in three ways: hypothermic adaptation (lowered body temperature), insulative adaptation (increased insulation) or metabolic adaptation (elevated metabolic rate). It seems that parallel exposure to cold and heat for 14-days resulted in hypothermic acclimation.

Cardiovascular responses such as SBP, DBP, and MAP were lower in POST than in PRE (Fig. 2, Fig. 3, Table 1), which implies that cardiovascular burdens due to cold were also smaller in POST. An important factor in arterial stiffness is blood pressure and a commonly-used technique called pulse-wave velocity is best represented by MAP (Quinn et al., 2012). Smaller increments in blood pressures might due to decreased arterial stiffness. Given our positive thermal and cardiovascular responses under cold stress, it needs to further discuss whether or not the degree of heat and cold exposure over a short period of time was the same amount of thermal stress. In this way, however, our results could support of the claim that heat exposure training during cold winter has little negative effect on cold tolerance. In this present study, shivering tended to be more delayed and weaker in POST than in PRE, but this difference was not statistically significant and was consistent with energy expenditure. On the other hand, several studies on cold-air stress showed shivering habituation (Armstrong and Thomas, 1991; Hessemer et al., 1986; Mathew et al., 1981; Silami-Garcia and Haymes, 1989) despite differences in air temperature, exposure duration, acclimation period, and sex. Silami-Garcia and Haymes (1989) found shivering habituation in females after 10-days of cold acclimation (10 °C, 1 hr·day^{-1}). The thermoregulatory and cardiovascular results of the present study suggest that our subjects underwent hypothermic acclimation rather than metabolic acclimation.

Thermal sensation and thermal comfort

According to the present results, subjects felt less cold at the same

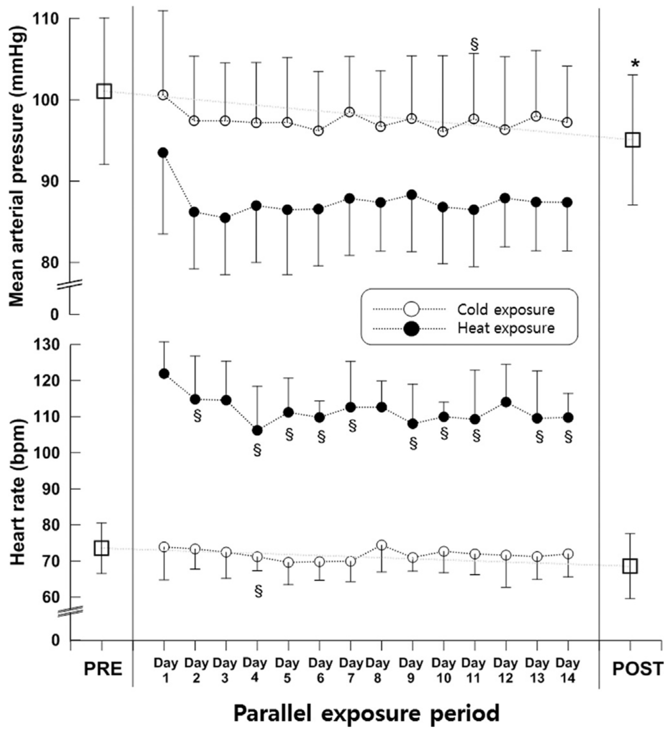

Fig. 3. Heart rate and mean arterial pressure before, during, and after a 14-day parallel exposure program to cold and heat. The parallel exposure program consisted of 2-hr cold exposure (10 °C, 40%RH) with 0.31 clo in clothing insulation and exercise- and passive-heat acclimation training for two hours (30 °C, 60%RH, two 50-min treadmill walks, separated by 10 min rests) per day. PRE and POST tests were conducted at an air temperature of 10 °C and air humidity of 40%RH wearing experimental clothing with 0.21 clo for 60-min. All data were averaged over the whole duration of the test: 60-min during cold exposure in PRE and POST, and 120-min during each cold and heat acclimation, respectively (Mean ± SD). *: Asterisk means a significant difference between PRE and POST ($P < 0.05$). §: The section signs mean significant differences between each day and the first day ($P < 0.05$).

intensity of cold after the parallel exposure to cold and heat while no significant difference was found in thermal comfort between PRE and POST (Fig. 5). It is interesting that psychological acclimation, such as thermal sensory acclimation was acquired through the 14-day cold and heat acclimation program. Secondly, unlike thermal sensation, the cold and heat acclimation program did not induce any improvement of thermal comfort. Thermal perception and preferences cannot be fully explained in terms of the energy balance of the human body (Nikolopoulou and Steemers, 2003). Thermal sensation is perceptual whereas thermal comfort is evaluative (ISO, 1995). The present results indicate that perception was acclimated but evaluation was not. As evaluation consists of more dimensions than perception, thermal comfort may involve all the following factors: naturalness, expectations, experience, time of exposure, perceived control, and environmental stimulation (Nikolopoulou and Steemers, 2003).

Limitations

First, as briefly mentioned in the introduction and method sections, having no control group who is exposed to cold only could be a limitation of the present study. And one may raise the question of whether the present experimental design was the proper way to test our hypotheses. To mitigate the effects of this limitation we conducted another analogous study using mice with control and experimental groups (Lee et al., 2017) and the study supports those of the present study. The 28-day experimental mice group of Lee et al. (2107) showed cold adaptive traits, while the control mice group did not. Also, one should bear in mind that previous parallel exposure studies with more than two experimental groups showed that alternate exposure to cold and heat augments resistance to climatic extremes (Glaser, 1950; Scott et al., 1940). Further studies with separated groups should be conducted to compare a control group to exposures to cold only and to heat only. Despite these limitations, there is a high possibility that parallel exposure to cold and heat positively affect cold tolerance when all results were synthetically considered.

Second, it remains unclear whether or not the cause of improved thermal and cardiovascular responses during the cold tolerance test were the effects of alternating thermal stimulation or the effects of regular exercise for the 14 consecutive days. A previous study reported that aerobically fit persons seem to develop heat acclimation more rapidly than less fit persons (Gardner et al., 1996).

Third, we could not determine that the level of cold stimulation was identical to the level of heat stimulation for the 14 days. The heat exposure which was composed by 2-hr exercise with short breaks at 30 °C air for consecutive 14 days was perhaps of insufficient heat load to modify cold adaptation. However, the 30 °C air is commonly experienced maximal air temperature in summer, Korea. From the practical viewpoint, the 2-hr exercise at the air temperature of 30 °C could be accepted for heat exposure training.

Finally, we conducted the cold tolerance tests at an identical morning time (AM 0930-1130) for 14 days (AM 1000–1200). Because of this schedule, heat exposure tests were conducted on the afternoons of these14 days. Horowitz (2014) found the effects of repeated heat exposure primarily during the same time of day that the exposure occurred. On the present cold and heat cross exposure schedule, the effects of heat exposure on cold acclimation might be diminished since the heat exposure was not performed at the same time as cold tolerance tests.

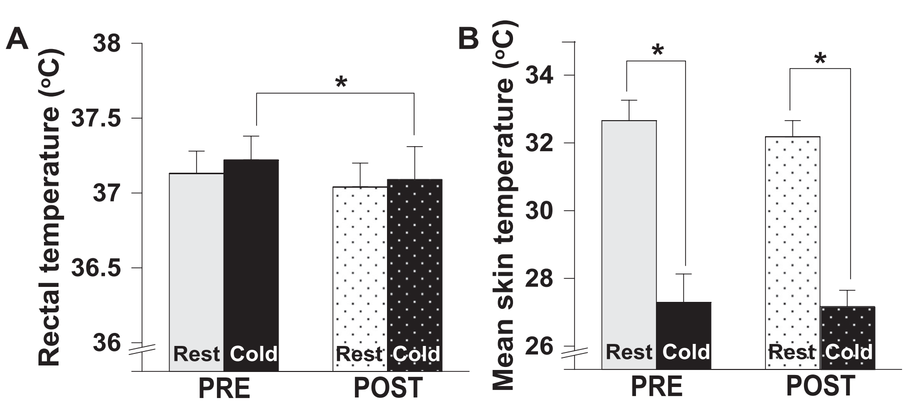

Fig. 4. Rectal and skin temperatures at rest (27 °C) and during cold exposure (10 °C): A. Rectal temperature, B. Mean skin temperature (*: $P < 0.05$). PRE and POST represent before and after stages of a 14-day parallel exposure program to cold and heat. The parallel exposure program consisted of 2-hr cold exposure (10 °C, 40%RH) and exercise- and passive-heat exposure training for two hours (30 °C, 60%RH, two 50-min treadmill walks, separated by 10 min rests) per day. PRE and POST tests were conducted at an air temperature of 10 °C and air humidity of 40%RH for 60-min. All data were averaged over the whole duration of the test (Mean ± SD).

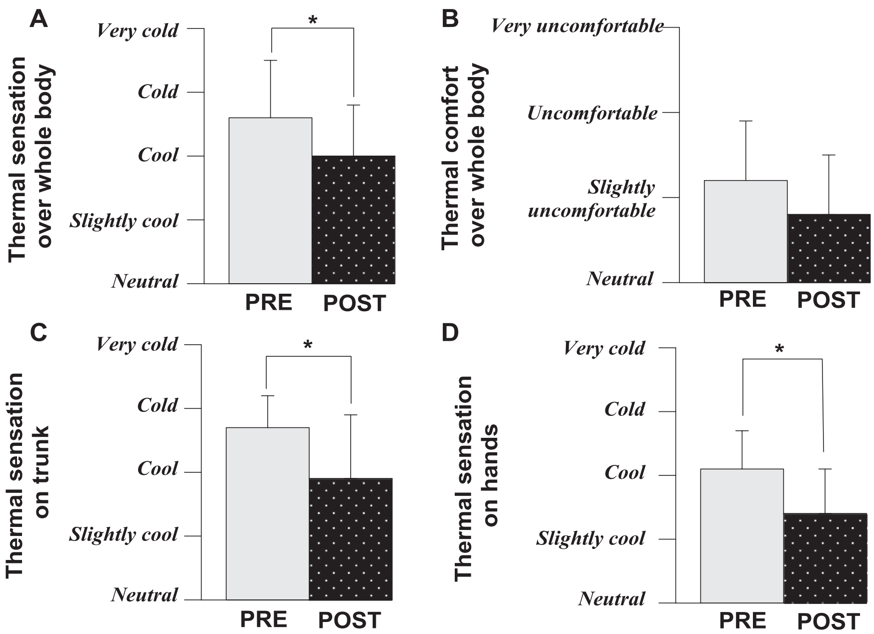

Fig. 5. Thermal sensations and comfort during cold-air exposure: A. Thermal sensation over whole body, B. Thermal comfort over whole body, C. Thermal sensation on trunk, D. Thermal sensation on hands (*: $P < 0.05$). PRE and POST represent before and after stages of a 14-day parallel exposure protocol to cold and heat. The parallel exposure program consisted of 2-hr cold exposure (10 °C, 40%RH) and exercise- and passive-heat acclimation training for two hours (30 °C, 60%RH, two 50-min treadmill walks, separated by 10 min rests) per day. PRE and POST tests were conducted in an environment of 10 °C and 40%RH for 60-min. All data were averaged over the whole duration of the test (Mean ± SD).

Conclusions

We proved the two hypotheses that the physiological traits of cold tolerance were not weakened and the psychological traits of cold tolerance were enhanced through parallel exposure to cold and heat for 14 days in winter. The cold adaptive traits were revealed through more stable core body temperature, cardiovascular responses and thermal perception during a cold tolerance test. We conclude that alternative heat exposure during the short-term cold acclimation program could diminish cold acclimation to some extent, but did not eliminate the cold adaptive traits and hypothermic cold adaptation can still occur in the presence of heat stress. These findings can be applied to a parallel exposure program to cold and heat for workers who are exposed to both cold and heat while at work as well as people who enjoy saunas or hot springs in winter.

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Conflicts of interest

There are no conflicts of interest.

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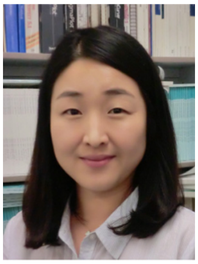

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