ORIGINAL RESEARCH

Autonomic Nervous System and Adrenal Response to Cold in Man at Antarctica

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Objective.—To evaluate the role of the autonomic nervous system and adrenal system in acclimatization to cold in tropical men during short or prolonged sojourns at Antarctica.

Methods.—The study was carried out on volunteers of the 18th winter over team (WOT) and 19th summer team (ST) of an Indian Antarctic Expedition. The ST members were evaluated at Delhi; during voyage; and on days 7, 30, and 60 of their stay at Antarctica. Identical studies were performed in WOT members who had stayed at Antarctica for 14 months. The parameters examined included heart rate, blood pressure, oral temperature, index finger skin temperature, heart rate variability, urinary epinephrine and norepinephrine, and salivary cortisol.

Results.—The resting heart rate and blood pressure in ST members significantly increased ($P < .05$) on days 7 and 30 of their stay at Antarctica and returned to baseline Delhi values by day 60. The index finger temperature declined ($P < .05$) on day 7 at Antarctica and remained at lower levels during the entire period of observations. Heart rate variability showed an imbalance of autonomic nervous system effects with predominance of low-frequency band on day 7 of stay and returned to Delhi values by day 60. The urinary excretion of epinephrine and norepinephrine and salivary cortisol were also increased on day 7 and declined to baseline Delhi values after 2 months of stay. Compared with the ST group, the WOT group showed a significantly higher ($P < .05$) resting heart rate, blood pressure, and low-frequency power and urinary excretion of norepinephrine.

Conclusions.—These observations suggest that Antarctic residency during austral summer results in gradual attenuation of sympathetic tone and a shift of autonomic balance toward the parasympathetic side. However, WOT members showed a predominance of sympathetic and adrenal activity compared with initial responses of ST members, suggesting deconditioning or possible resetting of the autonomic nervous system.

Key words: heart rate variability, Antarctica, epinephrine, norepinephrine, cortisol

Introduction

Activation of the sympathetic component of the autonomic nervous system (ANS) and the adrenomedullary and adrenocortical systems has been well established to play a key role in acclimatization to both physical and psychological stress.¹ An intact sympathetic and adrenomedullary system is an absolute requirement for defense against cold to maintain body temperature and homeostasis through cardiovascular and metabolic effects.²

Humans have an extraordinary ability to adjust to any stressful environment, including prolonged exposure to cold stress, resulting in altered responses that may be categorized as adaptation, acclimatization, conditioning, habituation, or tolerance.^{3,4} Studies conducted on native men who were habitually exposed to significant cold without adequate clothing have suggested the possibility of cold acclimatization in such a population.^{5,6} During cold exposure, cardiovascular changes mediated by the sympathetic nervous system contribute both to heat conservation and to the delivery of oxygen and substrates to meet enhanced metabolic needs of the body.

It is well known that cardiovascular variables such as heart rate (HR), arterial blood pressure (BP), and stroke

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volume all fluctuate on a beat-to-beat basis. Frequency spectral analysis of HR variability (HRV), beat-to-beat changes in HR, is now well recognized as a method for noninvasive assessment of ANS control over the cardiovascular system. The influence of the sympathetic and parasympathetic innervation on modulation of the HR can be quantified by the power of the HRV spectrum in specific frequency bands. The low-frequency (LF) components (0.05–0.15 Hz) are expressed by sympathetic efferent activity over the heart, and high-frequency (HF) components (0.15–0.50 Hz) are produced by vagal restrain. Therefore, the analysis of HRV has become the most reliable and reproducible method of assessing ANS control over the circulatory system, as it is able to differentiate between the sympathetic and the parasympathetic components.⁷

Investigations on native persons of temperate regions have suggested that repeated exposure to cold in a cold chamber or during residency in an Arctic or Antarctic environment causes gradual diminution of the sympathetic response and concomitant enhancement of the vagal activation when the hands and face are exposed to cold.^{8,9} In spite of rather voluminous literature on effects of cold exposure on ANS and hypothalamic pituitary adrenal responses, the role of sympathetic and parasympathetic components of the ANS in HR and BP regulatory mechanisms during the course of short- or long-term sojourns at Antarctica in persons from a tropical region remains to be investigated. Therefore, the present study was conducted to evaluate the role of sympathetic and parasympathetic components of the ANS, as well as the aderenomedullary and adrenocortical system, in response to severe cold in healthy tropical men who stayed at Antarctica during the austral summer and austral winter.

Methods

SUBJECTS

The study was conducted on 30 male volunteers of the 18th winter over team (WOT) and the 19th summer team (ST) of an Indian Antarctic Expedition. The ST subjects were 15 fresh inductees who stayed at Antarctica for 2 months during the austral summer, whereas WOT subjects were 15 volunteers who had stayed at Antarctica during the previous austral summer and winter for 14 months and were available for investigation when the ST group reached Antarctica. Baseline values for WOT members could not be obtained because these subjects were available only after prolonged wintering at Antarctica. The subjects of both groups were homogenous in respect to their physical characteristics such as age,

Table 1. Physical characteristics of the Antarctic study groups*

	Members		P
	ST (n = 15)	WOT (n = 15)	(ST vs WOT)
Age (y)	33.7 ± 1.7	32.9 ± 1.9	>.05
Weight (kg)	66.7 ± 2.9	66.8 ± 2.8	>.05
Height (cm)	172.3 ± 2.2	171.6 ± 2.4	>.05
Body mass index	23.1 ± 0.7	22.7 ± 0.8	>.05

*Values are expressed as mean ± SEM. ST indicates summer team; WOT, winter over team.

weight, height, and body mass index (Table 1) and were free of any cardiorespiratory disorder symptoms.

The baseline measurements in ST members were done at Delhi (29°N, 77°E) in November when the maximum temperature was 22 ± 1.2°C and the minimum temperature was 15 ± 2.0°C. The measurements were repeated again during the first week of the ship voyage and on days 7, 30, and 60 of stay at Antarctica. The members were initially airlifted from Mumbai to Cape Town, South Africa (40°S, 12°E), during the first week of December. The voyage started from Cape Town on a German ice-class ship and reached India Bay (Antarctica) after 15 days. The members were then airlifted to the Indian Antarctic Station, Maitri, where they stayed for 2 months. The route map of the expedition from Mumbai to Maitri is shown in Figure 1. Maitri is located at Schirmacher Oasis (70°S, 12°E) on moraine soil and is about 1800 km from the South Pole. Here, the sun is continuously seen above the horizon from November to February, or austral summer, and remains below the horizon from May to August, or austral winter. The ST members were accommodated in unheated summer huts in which the temperature ranged between 5 and 15°C. The mean ambient temperature and wind velocity were -0.94 ± 0.28°C and 14.7 ± 0.95 knots. While performing outdoor duties, the members used special polar clothing provided by the Indian Department of Ocean Development to protect them against extreme cold. In carrying out routine duties such as taking scientific observations and collecting samples, their hands and face were frequently exposed to the external environment. Daily cold exposure ranged between 4 and 6 hours.

The WOT members stayed at Antarctica in a centrally heated main station where the temperature was maintained between 20 and 22°C irrespective of outside temperature. They were provided with a regular supply of warm running water and other amenities. The highest maximum ambient temperature of 6°C was recorded in January, and the lowest minimum temperature of -43°C

Figure 1. Schematic diagram showing the route map of the Indian Antarctic Expedition.

was recorded in August. The members spent most of their time engaged in specialized jobs inside the laboratory. During outdoor work, they were protected with proper polar clothing and footwear. They remained in their dwelling units when environmental conditions became extreme (eg, severe temperature drops, high winds, blizzards). The duration of their day-to-day outdoor exposure was approximately 1 hour per day.

RECORDINGS

Basal parameters

A calibrated anthropometric scale was used to measure height, and a human-weighing balance with a resolution of 0.5 kg was used to measure body weight with the subjects clad in a pair of shorts. All parameters were recorded over a 10-minute period between 0600 and 0700 hours in fasting subjects relaxed for 30 minutes in a supine position in a thermally comfortable room. During the experiment and the preceding day, the subjects did not take any medication, coffee, alcohol, or tobacco, which are known to alter cardiovascular status. The electrocardiogram (ECG), HR, BP, oral temperature (T_{oral}), and index finger skin temperature (T_{finger}) were measured. All measurements were made in triplicate, and concordant values were taken as basal readings. The ECG and HR were recorded with a computerized polygraphic recording system (MP100, BIOPAC Systems Inc, Santa Barbara, Calif), the BP was measured with a digital BP monitor (HEM-722C1, Omron Corp, Tokyo, Japan), the T_{oral} was recorded with a digital clinical thermometer (MC 101F, Omron Corp), and the T_{finger} was recorded from the index finger of the right hand with a thermister probe connected to the computerized polygraphic recording system.

HRV recording

The HRV recording was performed between 0700 and 0800 hours after the subjects relaxed for 30 minutes in a supine position. They were instructed to breathe normally at a rate of 15 breaths per minute paced by a digital metronome to control the influence of respiration over the HRV spectrum. The standard bipolar limb lead II ECG was recorded continuously on the computerized polygraphic recording system for 10 minutes with the subjects in a supine position. Then the subjects were told to stand, and the ECG recording was repeated for 10 minutes to examine the ANS response to postural change.¹⁰

Data acquisition

The ECG was recorded with an alternating-current amplifier with 1.5-Hz high-pass filter and 35-Hz low-pass filter setting. The ECG recordings were digitized with a 32-bit analog-to-digital converter at a sampling rate of 500 Hz and stored on a laptop personal computer by using Acqknowledge 3.7.1. software (BIOPAC Systems Inc). The recorded ECG was visually inspected off-line, and only noise-free data were included for analysis. The R waves were detected to obtain point event series of successive R-R intervals, from which the beat-to-beat HR series were computed by using the menu option's simple formula of $\text{IHR} = 1/\text{RR}_i$, where IHR is Instantaneous Heart Rate and RR_i is successive RR intervals. The derived IHR from the processed ECG data was re-sampled, displayed, and stored as a separate channel in the same file. The time domain parameters such as mean and SEM were calculated from the IHR data file.

The beat-to-beat HRV was included after removing the mean and trend from the HR series for further analysis. The data ends were padded with zeros until the number of samples became a power of 2. A hamming window was applied on the data to avoid spectral leakage.¹¹ The HRV power spectrum was obtained by fast Fourier transform analysis. The energy in HRV series of the following specific frequency bands were studied: 0.04 to 0.15 Hz for the LF component, 0.15 to 0.50 Hz for the HF component, and the LF:HF ratio (Figure 2). The LF and HF values were expressed as normalized (also called relative or fractional) units (ν), that is, power centered at the frequency of interest (LF or HF) divided by total power.¹² The LF and HF normalized unit values were calculated by the formulae $\text{LF power } (\nu) = \text{LF}/(\text{LF} + \text{HF}) \times 100$ and $\text{HF power } (\nu) = \text{HF}/(\text{LF} + \text{HF}) \times 100$.

HORMONAL PARAMETERS

Urinary catecholamines

Urine was collected over the course of 24 hours for estimation of urinary epinephrine and norepinephrine, and an aliquot was stored at -20°C for analysis at a later date. Urinary catecholamines were measured by high-performance liquid chromatography with a Bond-Elut strong cation exchange and an affinity phenylboronic acid extraction column in series. The elute obtained from the phenylboronic acid column was then chromatographed on a reverse-phase C_{18} column with mobile phase containing pentane and heptanesulfonate as ion pair reagents. The detection was achieved with an amperometric (electrochemical) detector set at an oxidation

Figure 2. Schematic representation of heart rate variability analysis of a single subject recording.

potential of +0.55 V. The sensitivity of the assay for detection of the catecholamines was $<2 \mu\text{g/L}$ urine.¹³

Salivary cortisol

The morning (0800 hours) and evening (1600 hours) saliva were collected with a synthetic polystyrene cotton plug placed sublingually for 5 minutes. The cotton plugs soaked with saliva were then placed inside a saliva-collection device (Salivette, Sarsfedt, Nümbrecht, Germany) and centrifuged at 3000g for 10 minutes. The saliva

was aspirated and stored at -20°C for cortisol assay. The salivary cortisol was estimated by using commercially available radioimmunoassay kits obtained from M/S Immunotech (Marseille Cedex, France) in 40 μL of saliva. The antisera used in this kit showed 6% cross-reactivity with prednisolone. The sensitivity of the assay for detection of cortisol in the sample was $<10 \text{ nM}$ with 95% probability. The saliva samples, reconstituted standards, and controls were incubated with anticortisol antibody and ^{125}I -cortisol. After 1 hour of incubation at room temperature, solid-phase second antibody was added to

Table 2. Resting heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), oral temperature (T_{oral}), and index finger skin temperature (T_{finger}) on different days of stay at Antarctica in summer team (ST) members and winter over team (WOT) members†

	Days of stay of ST					WOT
	Delhi	Ship	Day 7	Day 30	Day 60	
HR (beats/min)	56.1 $\pm$ 3.0	56.6 $\pm$ 2.8	69.7 $\pm$ 3.2‡*	64.8 $\pm$ 2.2‡*	60.2 $\pm$ 3.3	63.5 $\pm$ 3.2‡d*
SBP (mm Hg)	106.7 $\pm$ 3.3	110.2 $\pm$ 1.8	120.6 $\pm$ 2.9‡*	113.6 $\pm$ 2.5‡*	106.7 $\pm$ 2.6	120.2 $\pm$ 2.6‡§*
DBP (mm Hg)	76.3 $\pm$ 3.2	81.8 $\pm$ 3.1	86.4 $\pm$ 2.1‡*	82.2 $\pm$ 1.9‡*	80.4 $\pm$ 3.1	85.4 $\pm$ 1.9‡§*
T_{oral} ($^{\circ}\text{C}$)	36.6 $\pm$ 0.1	36.7 $\pm$ 0.3	36.6 $\pm$ 0.2	36.6 $\pm$ 0.2	36.6 $\pm$ 0.2	36.8 $\pm$ 0.3
T_{finger} ($^{\circ}\text{C}$)	35.7 $\pm$ 0.3	36.6 $\pm$ 0.2	34.7 $\pm$ 0.2‡*	31.0 $\pm$ 0.2‡*	32.2 $\pm$ 0.2‡*	31.5 $\pm$ 0.2‡*

†Values are expressed as mean $\pm$ SEM.

‡ Significance vs Delhi.

§ Significance vs day 60.

* $P < .05$.

the mixture to precipitate the antibody-bound hormone. The supernatant was aspirated and the antibody-bound ^{125}I -cortisol was counted in an autogamma counter. Cortisol levels of individual samples were calculated from the standard curve. The inter- and intra-assay variability at 3 different points was $<10\%$. All samples of the same batch were processed in 2 consecutive assays with the same batch of reagents to avoid larger interassay variations.

STATISTICAL ANALYSIS

Statistical analysis was carried out by 2-way classification of analysis of variance by using Newman-Keuls multiple-range test with Bonferroni home correction for comparison of data of the ST group. Independent Student's t test was used for comparing 2 different sets of data (between ST and WOT values). Data are reported as mean $\pm$ SEM. A value of $P < .05$ was considered statistically significant.

Results

HR AND BP

The resting mean HR in the ST group did not show any significant change in the first week of voyage on the ship but showed a significant increase ($P < .05$) on days 7 and 30 at Antarctica and returned to baseline Delhi values by day 60 of stay. However, the HR in the WOT members was significantly higher ($P < .05$) compared with Delhi values in the ST group (Table 2). The resting mean systolic BP (SBP) and diastolic BP (DBP) in the ST group did not change significantly during the voyage and showed a marked rise ($P < .05$) on day 7 at Antarctica and started declining thereafter. The SBP as well

as DBP remained significantly high on day 30 and returned to Delhi values only by day 60 of stay at Antarctica. The SBP and DBP in WOT members were significantly higher compared with Delhi or day 60 values of the ST group (Table 2).

T_{ORAL} AND T_{FINGER}

In the ST group, the T_{oral} did not show any significant change during the voyage or on different days of stay at Antarctica compared with Delhi values. Similarly, the T_{oral} of the WOT group was also not significantly different from the ST values. The T_{finger} in the ST group did not show any significant change during the voyage but showed a consistent decline ($P < .05$) on days 7, 30, and 60 of stay at Antarctica. The T_{finger} in WOT members was significantly lower ($P < .05$) than the ST Delhi values (Table 2).

ORTHOSTATIC RESPONSE

The change in posture from a supine to standing position significantly increased HR and DBP in the ST group on days 7 and 30 at Antarctica and returned to Delhi values by day 60 of stay. The ΔHR and ΔDBP in the WOT group members was significantly higher ($P < .05$) compared with ST Delhi values (Table 3). The SBP did not show any significant change in any of these groups with change in posture.

HRV RESPONSE

LF Activity

The LF activity in the ST group when recorded in a supine position showed a significant increase ($P < .05$)

Table 3. Heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) response (Δ) to orthostasis at Delhi and on different days of stay in Antarctica in summer team (ST) members and winter over team (WOT) members†

	Days of stay of ST				WOT
	Delhi	Day 7	Day 30	Day 60	
HR (Δ)‡	9.6 $\pm$ 0.2	14.6 $\pm$ 0.5§*	13.5 $\pm$ 0.5*	11.1 $\pm$ 1.0	13.4 $\pm$ 0.6§ *
SBP (Δ)‡	2.2 $\pm$ 2.0	3.0 $\pm$ 2.0	1.8 $\pm$ 2.4	2.1 $\pm$ 2.0	2.1 $\pm$ 2.2
DBP (Δ)‡	4.2 $\pm$ 1.3	8.8 $\pm$ 1.6§*	7.3 $\pm$ 1.6*	4.8 $\pm$ 1.3	6.8 $\pm$ 1.2§ *

†Values are expressed as mean $\pm$ SEM.

‡ indicates rise over the supine values.

§ Significance vs Delhi.

|| Significance vs day 60.

* $P < .05$ vs Delhi.

on day 7 at Antarctica. The LF power values on days 30 and 60 at Antarctica were not significantly different than the Delhi values. However, the LF power of the WOT group in a supine position was significantly higher ($P < .05$) when compared with ST Delhi or day 60 values (Figure 3).

LF Response

The change in posture from a supine to standing position caused increased LF activity ($P < .05$) in the ST and WOT groups at Delhi and on all days of stay at Antarctica. The standing LF power in the ST group showed a significant rise on day 7 at Antarctica, declined on day 30, and returned to Delhi values by day 60 of stay. However, the WOT group LF power was significantly higher ($P < .05$) in the standing position compared with either day 60 or Delhi values of the ST group (Figure 3).

HF Activity

Figure 4 shows HF power values recorded at Delhi and during residency at Antarctica. The supine HF power showed a significant decline on days 7 and 30 at Antarctica and returned to Delhi values on day 60. The supine HF activity in the WOT group was also significantly lower compared with Delhi values of the ST group.

HF Response

The HF power response to standing in the ST group showed a significant decline at Delhi but did not show any further reduction during stay at Antarctica. Similarly, in the WOT group the HF response to standing was not significantly different from the ST Delhi values (Figure 4).

Figure 3. Low-frequency response to orthostasis at Delhi and on different days of stay at Antarctica in summer team members (ST) and winter over team members (WOT). Note: Values are expressed as mean $\pm$ SEM. Difference from Delhi * $P < .05$; difference from supine ^a $P < .05$.

Figure 4. High-frequency response to orthostasis at Delhi and on different days of stay at Antarctica in summer team members (ST) and winter over team members (WOT). Note: Values are expressed as mean $\pm$ SEM. Difference from Delhi * $P < .05$; difference from supine ^a $P < .05$.

LF:HF Ratio

The supine LF:HF ratio in the ST group showed a significant increase ($P < .05$) on days 7 and 30 at Antarctica and returned to Delhi values by day 60 of stay. The supine LF:HF ratio in the WOT group was also significantly higher than the Delhi ST values (Figure 5).

The change of posture from a supine to a standing position in the ST and WOT groups caused a significant increase in LF:HF ratio at Delhi and on days 7, 30, and 60 at Antarctica. The standing LF:HF response in the ST group on day 7 of arrival at Antarctica was higher than the Delhi response. The standing LF:HF ratio in the WOT group was not significantly different from the Delhi or day 60 ST values (Figure 5).

CATECHOLAMINE EXCRETION

The urinary excretion of epinephrine and norepinephrine on days 7 and 30 at Antarctica was significantly higher ($P < .05$) than the Delhi values and returned to Delhi values by day 60 of stay. In the WOT group the urinary excretion of epinephrine and norepinephrine was significantly higher than the ST values on day 60 or Delhi values (Table 4).

SALIVARY CORTISOL

The morning (0800 hours) and evening (1600 hours) cortisol levels on days 7 and 30 were higher ($P < .05$) than the Delhi values but were not different on day 60

Figure 5. Low-frequency:high-frequency ratio response to orthostasis at Delhi and on different days of stay at Antarctica in summer team members (ST) and winter over team members (WOT). Note: Values are expressed as mean $\pm$ SEM. Difference from Delhi * $P < .05$; difference from supine ^a $P < .05$.

Table 4. Urinary epinephrine and norepinephrine excretion and salivary cortisol at Delhi and on different days of stay at Antarctica in summer team (ST) members and winter over team (WOT) members†

	Days of stay of ST				
	Delhi	Day 7	Day 30	Day 60	WOT
Catecholamines					
Epinephrine $\mu\text{g}\cdot\text{d}^{-1}$	4.5 $\pm$ 1.9	16.8 $\pm$ 2.9 ‡*	10.3 $\pm$ 1.3 ‡*	5.5 $\pm$ 2.3	10.5 $\pm$ 2.0 $^{\ddagger\$*}$
Norepinephrine $\mu\cdot\text{d}^{-1}$	44.1 $\pm$ 5.7	205.3 $\pm$ 15.5 ‡*	202.9 $\pm$ 18.5 *	60.5 $\pm$ 8.7	124.8 $\pm$ 8.7 $^{\ddagger\$*}$
Cortisol (nmL ⁻¹)					
Morning	22.0 $\pm$ 1.0	66.0 $\pm$ 2.4 ‡*	35.0 $\pm$ 2.2 ‡*	21.5 $\pm$ 1.0	20.9 $\pm$ 1.0
Evening	10.0 $\pm$ 1.1	30.0 $\pm$ 2.6 ‡*	16.0 $\pm$ 2.0 ‡*	10.3 $\pm$ 1.1	10.2 $\pm$ 1.1

†Values are expressed as mean $\pm$ SEM.

‡Significance vs Delhi.

§ Significance vs day 60.

* $P < 0.5$ vs Delhi.

of stay at Antarctica. The salivary cortisol levels in the WOT group were not significantly different compared with ST Delhi values (Table 4).

Discussion

The results of the present study suggest that the resting HR and BP in the ST group increased during the initial period of arrival and returned to Delhi values after 2 months of residency at Antarctica. The maximum rise in HR, SBP, and DBP was observed on day 7 of arrival and started declining thereafter. The T_{finger} showed a decline on day 7 of arrival and remained at lower levels during the entire period of observation. Compared with T_{finger} , the T_{oral} did not show any appreciable change. The sympathetic component of HRV (LF power) also increased on day 7 of stay at Antarctica and returned to Delhi values by day 60 of stay. The parasympathetic component of HRV (HF power) declined on day 7 of arrival and returned to Delhi levels after 2 months of residency at Antarctica. The sympathovagal balance (LF: HF ratio) showed a shift of autonomic balance toward sympathetic predominance initially but returned to Delhi values by day 60 of stay. The urinary excretion of epinephrine and norepinephrine as well as salivary cortisol was also increased on arrival at Antarctica. The increase in HR and BP, increased LF power, and marked reduction in HF power during the initial period of stay at Antarctica might be attributed to decreased vagal tone and reciprocal excitation of the sympathetic nervous system during the initial period of stay. The rise in DBP and decline in T_{finger} in the ST group on arrival at Antarctica suggests initial cutaneous peripheral vasoconstriction in these subjects.

Acute exposure to cold is associated with reduction in

peripheral blood flow and increased metabolic heat production as a defense to maintain body temperature.¹⁴ The vasomotor response mediated by the sympathetic nervous system elicits peripheral vasoconstriction, resulting in reduction in peripheral blood flow and thereby increasing insulation of the body to loss of heat to the environment. The sympathetic stimulation during cold exposure is mainly induced by temperature receptors in the skin and temperature-sensitive neurons in the hypothalamus, lower brain stem, and spinal column.¹⁵ Integration of afferent neural input from these areas in the hypothalamus stimulates sympathetic outflow.¹⁵ Heat conservation is the main consequence of sympathetic activation, resulting in diminished subcutaneous blood flow and piloerection, both of which increase the insulation provided by integuments of the body.¹⁶ However, sympathetic activation increases susceptibility to cold-induced injuries such as frostbite in unacclimatized individuals when they are suddenly exposed to significant cold without proper protection. In addition to the mechanism that limits heat loss from the body during cold exposure, metabolic heat production is also simultaneously increased, which is facilitated by the sympathetic nervous system.¹⁷ Besides significant cold, other physical factors such as low humidity, high wind velocity, increased solar and ultraviolet radiation, geomagnetism, polar days and nights, and psychological stress at Antarctica would have also influenced the responses of the ANS to the Antarctic stress.

The neuroendocrine system, particularly the hypothalamic-pituitary-adrenal system, is put to maximal test in combating the stressful environment. Cold stress activates both adrenomedullary and adrenocortical systems. In our study, the ST group showed higher urinary epinephrine, norepinephrine, and salivary cortisol during

the first week of arrival at Antarctica, which remained high even after 1 month of stay and declined to baseline values on day 60 of residency. Previous studies have also shown a prompt increase in norepinephrine excretion, plasma norepinephrine, norepinephrine turnover,^{18,19} and cortisol secretion^{20,21} in subjects exposed to cold. Increased secretion of catecholamines not only stimulates the cardiovascular system but also enhances substrate availability through its metabolic effects. Norepinephrine and cortisol are known to increase blood glucose by stimulating glycogenolysis in the liver and mobilization of fatty acids from adipose tissue, thereby providing fuel for heat production to metabolically active tissues to compensate for excess loss of body heat.

These observations suggest that 8 weeks of regular exposure to an Antarctic environment can trigger changes in physiological responses to cold in summer period toward acclimatization. This was mainly because of the subjects' assigned occupational duties, which required them to undergo general exposure to atmospheric cold quite frequently and regularly during this period. This also suggests that even comparatively mild cold exposure extended over several weeks can be effective in triggering changes in physiological responses to cold. Attenuated sympathetic tone may lead to a gradual shift in autonomic balance toward the parasympathetic side, which is likely to be responsible for increased cold tolerance.^{22,23} These findings are consistent with the observation of Farrace et al.²⁴ Similar findings have been reported from studies conducted in the Arctic as well as Antarctic regions that follow different cold acclimatization patterns.^{25–27}

Compared with subjects who stayed at Antarctica for 2 months, the subjects who stayed at Antarctica for 14 months showed high resting HR, SBP, DBP, LF power, and norepinephrine excretion, indicating the maintenance of higher sympathetic activity even after their prolonged residency. This might be primarily because of deconditioning or possible resetting of the ANS in these subjects as a result of reduction in physical activity and insufficient frequency and severity of cold exposure during the austral winter. Frequent high wind velocity, blizzards, and occasional packed weather conditions for days together forced these subjects to remain confined inside the station without significant exposure to the outside environment. These findings suggest that winter subjects were able to minimize their cold strain during winter by short outdoor exposures and efficient indoor heating, thus limiting the development of the acclimatization response. This further suggests that the cold acclimatization of men is not possible just by living in the coldest region of the globe even for prolonged periods without periodically exposing themselves to ambient

cold. Therefore, these subjects preferred behavioral adaptation with all the comforts and amenities available at the station, which is in accordance with earlier findings.²⁵

Conclusion

These observations suggest that regular cold exposure at Antarctica (at least for 8 weeks) during austral summer results in attenuated sympathetic tone and gradual shift in the autonomic balance toward the parasympathetic side by the eighth week of stay, which may be helpful for increased cold tolerance and prevention of cold injuries. However, WOT members showed a predominance of sympathetic and adrenal activity though to a relatively lesser magnitude compared with initial responses of ST members at Antarctica. This might be attributed to deconditioning or possible resetting of the ANS after extended residency at Antarctica.

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