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Cold Acclimatization of Tropical Men during Short- & Long-Term Sojourn to Polar Environment

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ABSTRACT

This study was undertaken to assess the status of cold acclimatization (CA) resulting from short- and long-term exposure of tropical men to severely cold environment of the Arctic and the Antarctic regions. Five Groups (seven each) of male subjects participated in this study. Cold-induced vasodilatation (CIVD) response was elicited during immersion of the right hand in cold water at 4 °C for 30 min at both the polar regions to evaluate peripheral CA. The 'standard cold test' at 10 °C for 2 hr was administered at the Arctic region on tropical and arctic residents and the data were compared with those for tropical men monitored at Delhi to ascertain the level of general CA. Group A (control) was studied at Delhi (29 °N, 77 °E), while Groups B and C were sailed to Antarctica (70 °S, 11.5 °E). Their CIVD responses were monitored during thirteenth month and seventh to eighth week of stay, respectively. There was no deliberate cold exposure, except during their 'occupation demand' outdoor duties. However, outdoor exposure for Group C was more. Group D was airlifted to the Arctic (70 °N, 38 °E) and studied during the seventh week of acclimatization. The subjects had regular deliberate cold exposure. For comparison, Group E of arctic residents was studied at the Arctic. Group B did not show any adaptive modification to cold even after an year of sojourn in antarctic environment compared to Group A; while Group C subjects, despite their short stay, showed better CIVD response. Group D subjects recorded significant improvement in the response of general cold exposure as well as peripheral vascular response to local cold stress; their responses were comparable to those of the arctic residents (Group E). It is evident that human CA is impossible just by living in the coldest region of the globe even for prolonged periods. Deliberate regular exposure to atmospheric cold is the mandatory factor in developing human CA, the degree of which is related to the intensity of cold exposure.

NOMENCLATURE

T_w	Temperature of the water bath
T_s	Skin temperature of the index finger
T_{or}	Oral (body) temperature
T_b	Average oral (body) temperature before and after immersion
$\overline{T}_{sk}$	Mean skin temperature
$\overline{T}_b$	Mean body temperature
Group A	Tropical Indian soldier (control)
Group B	Winter team member—long-term sojourn to Antarctica (civil and Services personnel)
Group C	Summer team member—short-term sojourn to Antarctica (IAF personnel)
Group D	Army volunteers—test subjects at Arctic
Group E	Arctic natives and migrants (temperate zone of Russia)
HR	Heart rate
BP	Blood pressure

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VE	Ventilation
VO_2	Oxygen consumption

1. INTRODUCTION

Transmigration of people to the region with entirely diverse climatic and meteorological conditions causes a strain on the physiological regulatory mechanisms. In India, a soldier born and brought up in the southern peninsula, may not have experienced a minimum temperature below +20 °C. He may have to guard the snowbound mountainous regions of northern frontiers, where, in winter, he has to face climatic vagaries like minimum ambient temperature dropping down to about - 40 °C with occasional high velocity snow blizzards. During Indo-China war, the casualties due to climatic vagaries prevailing at high altitude were more than those due to the war. Presently, a research station 'Maitri' in Antarctica is being maintained by India round the year by placing volunteers on rotation. Exposure to such stressful environment evokes a series of physiological responses in human regulatory system for acclimatization.

The question arose whether a tropical man hailing from a country like India can adapt to and live in the new stressful environment of the polar regions, combating severe cold stress, altered solar periodicity and high geomagnetic activity. Since human beings are provided with neither fur coat nor thick layers of subcutaneous fat for insulation, their cold tolerence capacity is limited. Thus, human adaptation to cold is still a debatable issue, with some scientists reporting its possibility and others believing that man prefers behavioural adaptation rather than physiological process of acclimatization[1-14]. But prolonged exposure to cold stress may also result in alteration in physiological responses[10].

Most of the earlier studies on human cold acclimatization have been conducted on the volunteers of temperate zone. The present study was, therefore, undertaken on subjects of tropical origin to re-investigate the controversial question regarding the possibility of human CA. The study assesses the status of cold acclimatization resulting from short- and long-term sojourns with varying degrees of exposure to the natural cold environment of Arctic and Antarctic regions. The status of peripheral cold acclimatization of tropical men has been evaluated by examining the cold-induced vasodilatation (CIVD) response during a local cold challenge test at both the polar regions and comparing them with the responses of tropical controls monitored at Delhi. The responses of tropical subjects during a standard cold-test at Delhi and at the Arctic region were compared with the responses of Arctic residents recorded at the Arctic region to ascertain the level of general acclimatization achieved.

2. MATERIALS & METHODS

2.1 Subjects

Five Groups (seven each) of male volunteers (20-38 years) participated in this study. They were homogeneous in respect of physical characteristics like age, height and body weight. Group A (control) consisting of tropical Indian soldiers was studied at Delhi (29 °N, 77 °E), where the ambient temperature ranges from 20.5 to 33.5 °C. The subjects of Groups B and C were members of the Indian Scientific Expedition who sailed to Antarctica (70 °S , 11.5 °E).

Group B (winter team member—long-term sojourns) consisted of both civilian scientists and the Services personnel who stayed at Indian Antarctic station *Maitri* for fourteen months. They were provided with regular supply of warm running water and other amenities. The temperature inside *Maitri* was maintained between 22 and 28 °C, even though the outside ambient temperature dropped down to -38.5 °C during winter. They experienced both polar days and nights. The scientist volunteers were primarily engaged in their specialised jobs mostly inside the laboratory, while the others were responsible for operation and maintenance of wireless system as well as the kitchen and the store. During outdoor work too, they were protected with proper insulative clothing and footgear. Further, during peak winter, when the environmental conditions would become bad with minimum temperature reaching -38.5 °C along with frequent high velocity snow blizzard and occasional packed weather conditions for days together, they mostly remained confined inside the station. Thus, their exposure to severe cold was limited and insufficient. Moreover, the observers had no control over the duration and frequency of their day-to-day outdoor exposure, which is a genuine difficulty with the Expedition members. Even though the members of the Expedition volunteered as subjects willingly, they were mainly responsible for their own assigned expedition tasks.

The subjects of Group C were represented by the Indian Air Force personnel (summer team members—short-term sojourns), who stayed onboard the Expedition ship, which was air-conditioned (23-27 °C). The ambient temperature during Antarctic summer ranges from 0 to -10.5 °C, with occasional high velocity wind and snow blizzard. There was almost 24 hr daylight. In Antarctica, they were engaged in repair, maintenance and operational duties of four helicopters, including loading, unloading and transporting of men and materials between the ship and the station. They had to perform a lot of outdoor activities, sometimes even during snowfall and blizzard conditions. Thus, they were invariably and quite frequently exposed to outdoor cold environment for about 3 hr daily, even though the observers had no control over their exposure schedule. They were sailed back to India after three months.

The subjects of Group D comprised Army volunteers, primarily engaged as 'test subjects' only. They were flown to the Arctic region of Russia (70 °N, 38 °E) and put in the field camp (wooden huts) with inside temperature ranging from 7 to 20 °C during Arctic winter (December to February—short-term sojourns), when the outside ambient temperature ranged from -8.5 to -37 °C. There was 18- 20 hr darkness with occasional wind and frequent snowfall. They had to perform all types of outdoor and indoor activities regularly, including physical and yogic exercises, marching and skiing on snowy terrains, clearing snow from the surrounding camp areas and fetching water from the frozen lake. It was ensured that these men had quite frequent and sufficient outdoor cold exposure for 4-6 hr daily. After eight weeks, they were flown back to Delhi.

For comparison, the subjects of Group E were studied at the Arctic region. This Group was represented by both Arctic natives and migrants from the temperate zone of Russia. They also stayed in the field camp and dined in the same kitchen during the study period. Comparison of the responses of subjects of Group D to those of subjects of Group E was made with the assumption that they (Group E) being natives of the cold region, were already adapted to cold. This assumption seemed to be reasonable.

3. TEST PROCEDURE

3.1 CIVD Response

After relaxing for 1 hr in a thermoneutral room (26-28 °C), the subjects were made to sit on a comfortable seat and their CIVD response, which is an index of peripheral cold acclimatization, was elicited by asking them to immerse their right hands in a constantly stirred water bath maintained at 4 ± 0.2 °C, by addition of ice water[13]. The T_w as well as the T_s of the right hand were measured with YSI telethermometer (Model 46TUC) at the beginning and thereafter every minute during 30 min immersion. From the above recordings, the initial steady value of T_s before immersion, the average T_s during last 25 min of immersion and the highest T_s reached during immersion were determined. The T_{or} was recorded before and after immersion. The CIVD index, as proposed by Takano and Kotani[15], was computed.

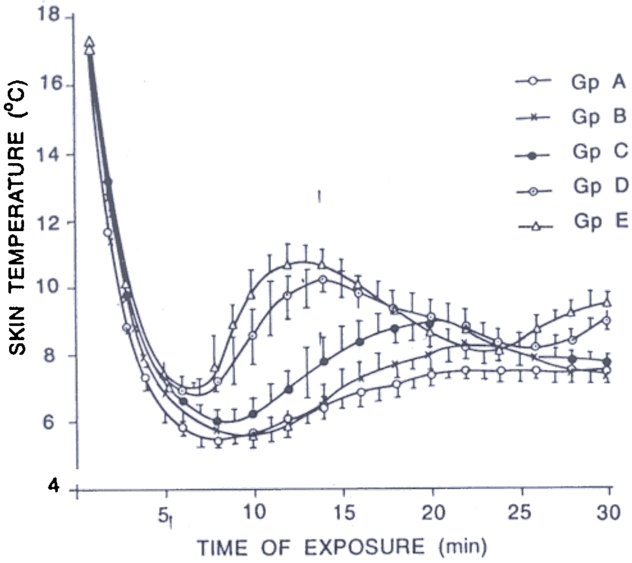

Figure 1. Patterns of mean (± SEM) CIVD responses of all the five Groups of subjects at different locations: Group A (control subjects at Delhi), Group B (winter team members at Antarctica), Group C (summer team members at Antarctica), Group D (tropical subjects at Arctic), and Group E (Arctic residents at Arctic). Initial index finger temperature (°C) before immersion of Group A=33.2, Group B=33.3, Group C=33.4, Group D=33.4, Group E=33.5.

Using the formula of Hsieh, *et al*[16]. the peripheral blood flow,

F (ml.dm^{-2}.min^{-1}) = 14.6 $(T_s - T_w)/(T_b - T_s)$

was calculated (average T_s of last 25 min).

The CIVD response was recorded initially on Group A subjects at Delhi. The responses of Groups B and C were monitored in the thirteenth month and seventh to eighth week of their stay at the Antarctica, respectively. At the Arctic region, the CIVD responses were measured on Groups D and E simultaneously during the seventh week of acclimatization of Group D in the same way and in a similar temperature controlled room (26-28 °C). One of the observers was common to both the polar regions.

3.2 Standard Cold Test

The standard cold test was administered on the subjects of Groups D and E at the Arctic region in a cold room maintained at 10 °C, wearing only shorts for 2 hr, to evaluate and compare the status of central adaptation of the two Groups to cold. The *HR, BP,* $\dot{V}E$, $\dot{V}O_2$, T_{or} and skin temperatures of chest, upper arm, thigh and lower leg as well as the index finger and great toe were recorded initially, after they relaxed in an adjacent thermoneutral room (26-28 °C) for 1hr and thereafter every 30 min during cold exposure. The T_{sk} and T_b were calculated[17]. Visible shivering activity was observed carefully and graded in arbitrary units by one of the observers every 30 min during cold exposure[14]. Standard cold test was administered at Delhi for Group D subjects only.

Statistical analysis for multiple comparison of various physiological responses within the Group under different conditions has been done by the method of two-way classification of ANOVA using the criterion of least significant difference. Unpaired '*t*-test' for comparison between two different Groups and paired '*t*-test' for comparing paired Group were also used.

4. THE RESULTS

The patterns of mean (± SEM) CIVD response of various Groups recorded at different locations are depicted in Fig. 1. The values of T_s before immersion, the responses induced by cold water immersion, the peripheral blood flow under local cold stress and the CIVD index of all the five Groups are given in Table 1.

It was astonishing but true that Group B subjects, who stayed continuously for more than a year in the severely cold region of Antarctica, did not show any adaptive modification in their CIVD response compared to Group A subjects. Group B subjects had neither 'occupational demand' nor 'deliberate' regular exposure to outside ambient cold. On the other hand, Group C subjects, despite their short stay in the comparatively mild cold weather at the Antarctica, showed significant ($p < 0.05$) improvement in their peripheral vascular response when the measurement was made during seventh to eighth week of their sojourn, compared to Group A subjects monitored at Delhi.

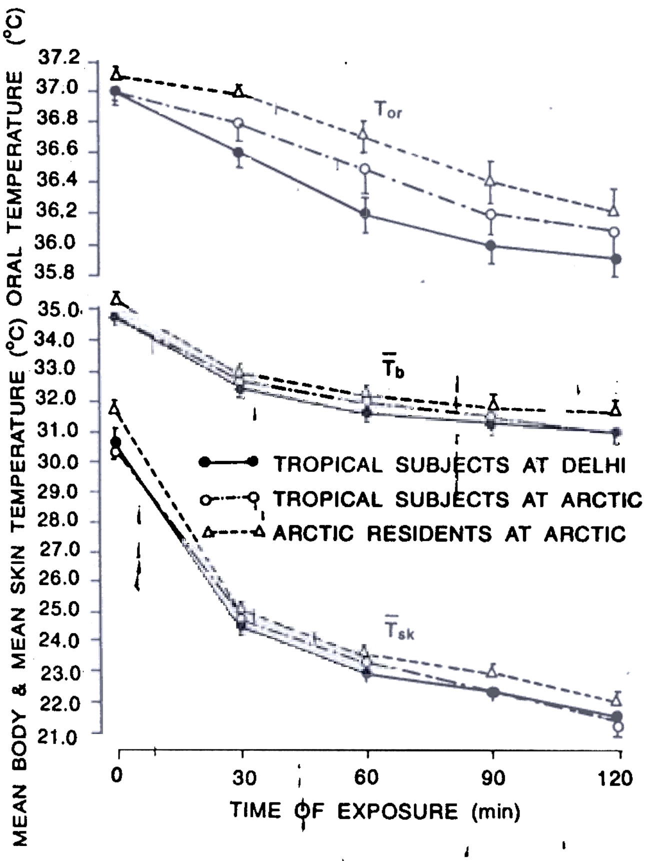

Figure 2. Responses of oral (T_{or}), mean body ($\overline{T}_b$) and mean skin ($\overline{T}_{sk}$) temperatures of Arctic residents (Group E) and tropical subjects (Group D) during standard cold test at Arctic and Delhi.

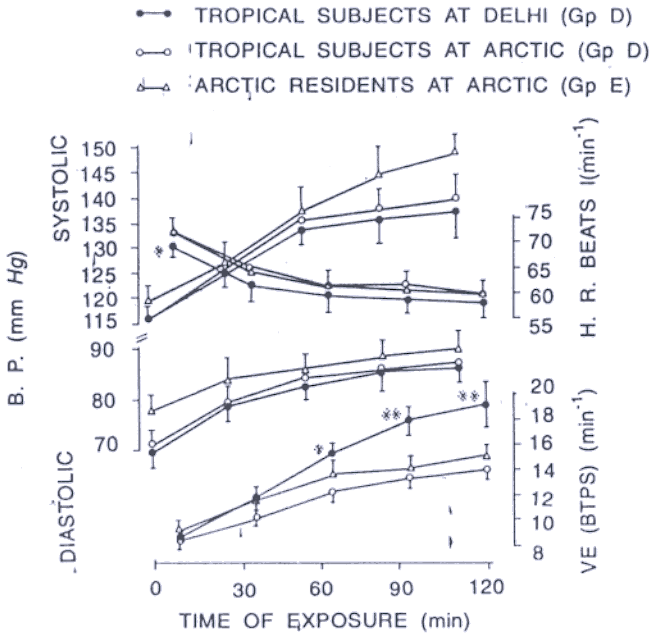

Figure 3. Responses of heart rate (*HR*), blood pressure (*BP*) and ventilation ($\dot{V}E$) of Arctic residents (Group E) and tropical subjects (Group D) during standard cold test at Arctic and Delhi.
*** $p < 0.05$;**
**** $p < 0.01$; Comparison between the values ine Arctic and Delhi.**

The former group (Group C) had frequent and sufficient exposure to cold because of their assigned expedition tasks during this short stay period.

The subjects of Group D, who were deliberately and regularly exposed to the Arctic cold environment, recorded a modified change in the pattern and magnitude of the CIVD response and showed highly significant ($p < 0.01$) improvement in their peripheral vascular phenomenon due to seven weeks of acclimatization (Fig. 1). Responses of this Group of tropical subjects (Group D) were almost similar to those of the Arctic residents (Group E) and there existed no statistically significant difference between them. The perception of pain during local cold stress at the Arctic region was also less compared to other Groups of tropical people.

The values of T_{or}, $\overline{T}_{sk}$ and $\overline{T}_b$ of Groups D and E showed a gradual and significant ($p < 0.001$) fall during standard cold test at the Arctic region (Fig. 2). The fall in T_{or} was slightly less in Arctic residents (Group E) compared to Group D, but this was not statistically significant. Similarly there was no marked difference in *HR*, *BP* and $\dot{V}E$ or $\dot{V}O_2$ changes between Groups D and E during cold exposure in the Arctic region, but the values were entirely different for Group D, when the same tests were conducted at Delhi (Fig. 3).

The initial $\dot{V}O_2$ measured in the Arctic region was similar in both the Groups (D and E), which recorded a gradual and significant ($p < 0.001$) rise during standard cold exposure, but this difference in rise was not statistically significant . The resting $\dot{V}O_2$ of Group D subjects measured at Delhi was

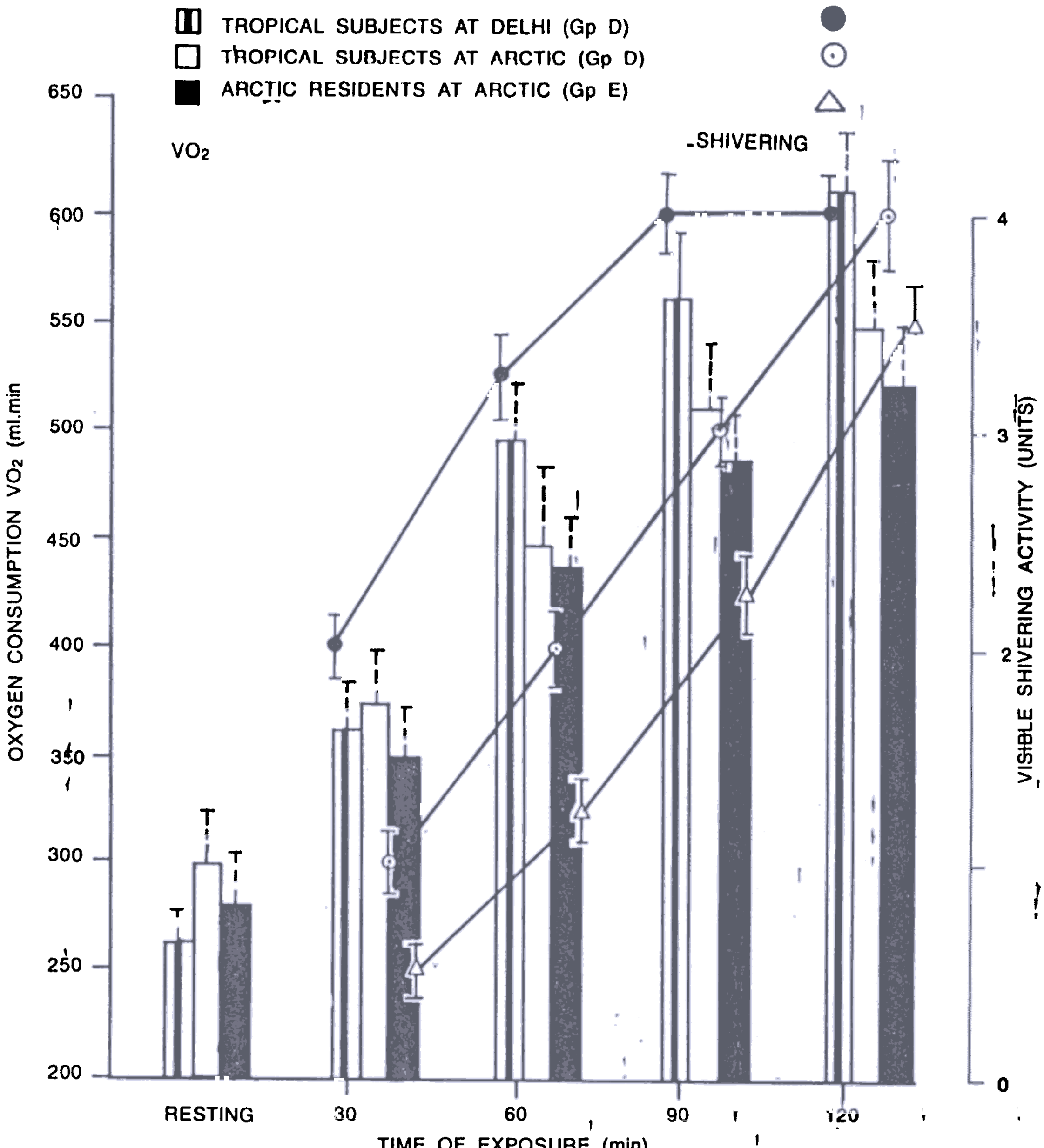

Figure 4. Visible shivering activity (units) and oxygen consumption (ml.min^{-1}) of Arctic residents (Group E) and tropical subjects (Group D) during standard cold test. Visible shivering recorded at intervals in arbitrary units (0 = no shivering; 1 = mild shivering with burst; 2 = moderate shivering with burst; 3 = marked generalised discontinuous shivering; 4 = very marked and continuous shivering). Vertical line-bars indicate mean $\pm$ SEM of shivering and vertical dot-bars indicate mean $\pm$ SEM of $\dot{V}O_2$.

significantly ($p < 0.05$) less compared to the values for Groups D and E recorded in the Arctic region. When standard cold test was administered on Group D at Delhi, $\dot{V}O_2$ showed a steeper rise, despite a lower resting value. They (Group D) also shivered maximally during cold exposure at Delhi.

The tropical men (Group D) after seven weeks of acclimatization in the Arctic environment showed less increase in the responses of VO_2 and shivering as compared to their own responses monitored at Delhi (Fig. 4). The responses of tropical volunteers (Group D) were comparable to those of the Arctic residents (Group E), apparently due to deliberate exposure and outdoor activities of these men to the Arctic cold environment, at least 4 hr daily.

5. DISCUSSION

The aim of the study conducted in the natural cold environment of polar region was to re-investigate the controversial question whether man can get acclimatized to cold. If yes, whether human CA is possible just by living in severely cold weather environment or it is a 'must' that the subjects in truth should allow their bodies to get exposed to ambient cold.

An interesting finding is: "The cold acclimatization of man is not possible just by living in the coldest region of the globe even for prolonged period." This has been demonstrated in the winter team members of Group B, which is primarily due to insufficient frequency and severity of cold exposure. This corroborates the observation of Bridgeman[18]. These subjects preferred behavioural adaptation with all the comforts and amenities available at the station, which is in accordance with an earlier finding[5]. It was thought earlier that the Eskimos who live in the extreme cold region of the Arctic region are cold acclimatized[19,20]. This has also turned out to be wrong, since they too keep their houses warm and wear good insulative clothing.

On the contrary, experiments on the members of Group C revealed adaptive modification to cold tolerance, despite their short stay under less cold conditions. This is mainly due to their assigned 'occupational duties' by which they were required to undergo general exposure to atmospheric cold quite frequently and regularly. This observation suggests that 'even comparatively mild cold extended over some weeks can be effective in triggering changes in physiological responses to cold tolerance'.

The Arctic phase of the study on Group D indicates 'the possibility of cold habituation, if not acclimatization, even in tropical men due to regular and deliberate exposure to atmospheric cold'. This finding tallies with our earlier observations on similar subjects[13,14]. Their responses on cold exposure are indeed similar to those of the arctic residents tested in the Arctic region. The significant observations of this phase include (i) elevated resting metabolism of the tropical subjects (Group D) in the Arctic region with simultaneous reduction in cold-induced increase in $\dot{V}O_2$, (ii) a tendency for maintenance of higher oral temperature and comparatively less shivering on acute cold exposure, and (iii) a significantly improved CIVD response and peripheral blood flow during severe local cold stress similar to the level seen in arctic residents (Group E). It is evident from the observations that during seven weeks of deliberate regular exposure to an Arctic environment, the tropical men (Group D) had achieved a better tolerance to combat the stress of both local and standard cold exposures. They must have become conditioned or habituated to the stressful cold which did not evoke a response similar to that evoked by an identical exposure monitored at Delhi. The subjective experience of adaptation towards the end of sojourn at the Arctic region was their ability to perform many of the outdoor works with bare hands without much discomfort for quite some time. Attenuated sympathetic tone may lead to a gradual shift in the autonomic balance towards parasympathetic dominance which is likely to be responsible for increased cold tolerance[21,22]. This finding corroborates the observation of Rivolier, *et al*[23]. Almost similar findings were reported from the studies conducted in the Arctic region and the Antarctica following different CA patterns[9,12,24,25]. Till very recently, physiologists were of the opinion that 'man is a tropical animal and he can get acclimatized to heat only, but not to cold'. A remarkable reversal of this popular belief has come as a result of this study conducted in the extreme cold regions of the Arctic and Antarctica that 'cold acclimatization is possible even in tropical men, provided they allow their bodies to get exposed to ambient cold periodically, rather than just having lived in a severely cold

Table 1. Values of initial index finger (T_f), the responses induced by cold water immersion, the peripheral blood flow and CIVD Index of all the 5 Groups of subjects along with statistical comparisons

Parameter	Gp A	Gp B	Gp C	Gp D	Gp E	Statistical significance						
						A *vs* C	A *vs* D	A *vs* E	B *vs* D	B *vs* E	C *vs* D	C *vs* E
Initial Index Finger T_f before immersion (°C)	33.2 ±0.20	33.3 ±0.20	33.4 ±0.20	33.4 ±0.20	33.5 ±0.40	NS	NS	NS	NS	NS	NS	N
Min. T_f during immersion (°C)	5.3 ±0.12	5.2 ±0.19	5.6 ±0.36	6.1 ±0.29	6.5 ±0.50	NS	*	*	*	*	NS	N
Highest T_f during immersion (°C)	7.6 ±0.30	8.3 ±0.41	9.6 ±0.27	10.9 ±0.35	11.1 ±0.63	**	**	**	**	**	*	*
Average T_f during last 25 min.of immersion(°C)	6.7 ±0.22	7.0 ±0.31	7.7 ±0.29	8.7 ±0.21	8.9 ±0.45	*	**	**	**	**	*	*
Blood flow during immersion($ml.cm^{-2}.min^{-1}$)	1.32 ±0.12	1.49 ±0.17	1.84 ±0.16	2.42 ±0.13	2.50 ±0.28	*	**	**	**	**	*	*
CIVD Index	33.3	36.4 ±3.7	44.0 ±3.3	56.3 ±2.5	58.7 ±4.2	NS	**	**	**	**	*	

Values are mean ± SEM. NS = Not significant ; * = $p < 0.05$; ** $p < 0.01$
Statistical comparisons of A *vs* B, B *vs* C, and D *vs* E are all NS.

environment for prolonged period'. Thus, regular exposure to ambient cold is a mandatory factor in developing human CA, which necessitates recording of the nature, duration and severity of cold stress to which the subjects are exposed. Cold acclimatization provides adequate protection to cold injuries.

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