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Peripheral Vascular Response to Local Cold Stress of Tropical Men during Sojourn in the Arctic Cold Region

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Abstract Peripheral vascular response to local cold stress was studied on 4 groups of volunteers by eliciting cold-induced vasodilatation (CIVD) response during immersion of right hand in cold water (4°C) for 30 min, to examine whether tropical men can get acclimatized to local cold compared to temperate zone people, during Arctic cold exposure. Group A and B (10 each) were drawn from tropical region of India, while Group C and D (6 each) from temperate zone of Russia and natives of Arctic, respectively. Initial study was conducted on control Group A at Delhi. Group B was airlifted to the Arctic (70°N, 38°E), where measurements were done on them during the seventh week of acclimatization, then they were flown back to Delhi and retested. For comparison, study was done at the Arctic on six migrants (Group C) from temperate zone of Russia and 6 natives (Group D) of the Arctic. There was a significant improvement of CIVD response and peripheral blood flow of tropical men due to acclimatization to Arctic environment, which was similar to that of the migrants but lower than the natives. Thus local cold acclimatization is possible even in tropical men as in those of the temperate zone people.

Key words: cold-induced vasodilatation (CIVD), peripheral blood flow, local cold acclimatization, natives of Arctic, temperate zone people.

Prolonged exposure to cold can induce cold acclimatization (CA) in animals [1–3], though the occurrence of this phenomenon in man is controversial [4, 5]. The natives of cold regions and cold-acclimatized men maintain higher peripheral blood flow under local cold exposure and they are also less susceptible to cold injuries [6–11]. This might be due to their improved metabolic response to cold and higher status of peripheral blood flow under local cold stress. The cold-induced vasodilatation (CIVD) response or heat output is a good index for the latter [10, 12]. This parameter was correlated to the degree of cold injury in monkeys, and the animals with higher heat output and CIVD response were better protected against frostbite [13].

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Repeated exposure to moderately severe cold for a considerable length of time inside a cold chamber caused physiological habituation to cold and improvement in CIVD response of tropical men [14]. A significant reduction in the CIVD response of tropical lowlanders was observed during exposure to high altitude where cold co-exists with hypoxia [11, 15], but information is lacking about the responses of tropical men during sojourn in the severe cold environment of Arctic region where there is no hypoxia.

The present study was, therefore, undertaken to evaluate the CIVD response and peripheral blood flow under local cold stress, on exposure of tropical men to natural cold environment of Arctic after their sojourn there for a period of more than 6 weeks. The responses were compared with those of Arctic natives as well as temporary residents of that region, i.e. migrants from temperate zone of Russia. The changes in the proneness to cold injury acquired, if any, were also evaluated.

METHODS

Cold-induced vasodilatation (CIVD) was studied on 4 groups of young healthy male volunteers. Two groups (10 each) were drawn from tropical region (India) and other two groups (6 each) from temperate zone (Russia) and Arctic natives, respectively. Group A (control) consisted of ten Indian soldiers hailing from different regions of the country, who had never been to an extreme cold environment. They had a mean±SEM age of 32.5±1.01 years, body weight (BW) 65.4±1.17 kg, height (Ht) 170.7±0.79 cm, and body surface area (BSA) 1.76±0.02 m^2. Experiments were conducted on them at Delhi, where the range of environmental temperature during the study period was 21 to 33.5°C. They were made to rest in a temperature-controlled room (24–26°C) for 1 h and were not allowed to smoke or engage in any form of exercise during this period. Detailed experimental procedure was explained to each subject before the start of the experiment and their informed consent was also obtained. The oral temperature (T_b) was taken by a clinical thermometer, placed sublingually for 5 min. The subjects sat on a comfortable seat and the CIVD response was elicited by immersing the right hand, up to the level of styloid process, in a constantly stirred water bath of 25 *l* maintained at 4±0.2°C by addition of ice water [15]. The temperature of the water bath (T_w) as well as the skin temperature (T_s) of the immersed hand was measured at the beginning and thereafter every minute for 30 min from the index finger (ventral side, at a site 1 cm from the finger tip) and over a prominent wrist vein, about 10 cm proximal to styloid process. The contralateral hand index finger T_s was also monitored every minute simultaneously. All these measurements were made with YSI telethermometer (Model 46 TUC), keeping the probes on sites by double layers of adhesive tape. A thin layer of grease was also applied above the adhesive tape to ensure that no water entered through the tape. T_b was again recorded at the end of immersion period.

From the T_s of the right hand index finger, the value of T_s before immersion, the minimum T_s during immersion, the time for first temperature rise after immersion, the T_s at the first rise after immersion, the highest T_s during immersion, the average T_s during immersion from 6 to 30 min, and the fall of wrist vein T_s during immersion as well as the fall of contralateral hand index finger T_s during immersion of the other hand were determined. Using the formula F (ml/cm^2 per min) $=14.6(T_s-T_w)/(T_b-T_s)$, the peripheral blood flow [16] was calculated, where T_s=skin temperature, T_w=water bath temperature, and T_b=oral temperature. For this, the average T_s of the index finger for the last 25 min of 30-min immersion (6–30 min) and average of T_b before and after immersion were used. CIVD index as proposed by Takano and Kotani [17] was also been evaluated.

Group B consisted of another 10 young healthy soldiers of Indian Army drawn from the different parts of India. Of these, one belonged to hilly area and one from hot humid region of South India, while all others belonged to north and central parts of the country where environmental condition is almost identical. Their mean ±SEM age, BW, Ht, and BSA were 26.0±1.07 years, 63.9±1.32 kg, 171.3±1.09 cm, and 1.75±0.02 m^2, respectively. They were airlifted to the Arctic region of Russia (70°N, 38°E) and were staying in the field camp (wooden huts), during Arctic winter, i.e. from December 1990 to February 1991. The climate of this region was characterized by low environmental temperature which ranged as follows: Max. −12 to −8.5°C (except one day, when Max. temperature reached to −2°C) and Min. −37 to −17.5°C during the study period with occasional high velocity winds. The temperature inside the living huts ranged between 7 to 20°C. There was 18 to 20 h darkness during the period of stay. They had to do all kinds of indoor and outdoor activities regularly including physical and Yogic exercises, clearing of snow from surrounding camp areas, fetching water from a frozen lake, playing football, skiing on snow, marching on snowy terrains, and thereby had the daily outdoor exposure for about 4 to 6 h. They wore hand-gloves while working under very severe cold situations, such as water fetching and snow clearance. During their stay at the Arctic all the subjects were maintained on a diet supplying about 4,200 kcal, with 14% proteins, 25% fats, and 61% carbohydrates. They stayed there for 8 weeks and the experiments were conducted on them in a similar manner in a temperature-controlled room (24–26°C) at the Arctic during the seventh week of their sojourn. Then they were flown back to Delhi and retested after 6 weeks of deacclimatization.

At the Arctic the study was conducted in the same way at the same temperature-controlled room on 6 migrants (Group C) and 6 natives (Group D). Six migrants were from temperate zone of Russia, who were temporary residents of the Arctic region for a period not less than 8–10 weeks. They had a mean±SEM age of 27.8±3.03 years, BW 79.5±7.02 kg, Ht 174.0±2.77 cm, and BSA 1.91±0.06 m^2. They lived in the same camp and dined in the same kitchen with the tropical (Indian) volunteers. Group D consisted of 6 natives who were born and brought up in the Arctic region and had never been outside the cold region of Russia. This group of volunteers were also in the same age range, except one who was 58 years old. This particular subject was not born in the Arctic but was staying in that area for the last 30–35 years. His main routine job was snow clearing and camp maintenance. The mean$\pm$SEM of age, BW, Ht, and BSA of this group were 34.8 $\pm$4.74 years, 78.7$\pm$7.34 kg, 177.3$\pm$2.62 cm and 1.95$\pm$0.08 m^2, respectively.

Statistical analysis was done by one-way classification of analysis of variance, using Newman-Keuls multiple range test for post hoc comparison of different groups. Unpaired *t*-test for comparing two different groups and paired *t*-test for comparing paired group were also used.

RESULTS

Classification of CIVD response was done on the basis of the duration of initial vasoconstriction (time for first rise after immersion) and magnitude of rise in T_s while the hand was immersed in cold water. Four types of responses, viz. typical hunting phenomenon, proportional control form of CIVD, slow, steady, and continuous type of rewarming, and NO CIVD were observed in this study according to the changes in T_s during local cold exposure (Fig. 1). These responses were in accordance with the earlier observations in men and animals [13, 15, 18]. All the subjects experienced similar pain during the initial stage of immersion and this continued throughout the exposure in those who had either very poor or NO CIVD response. The pain sensation was, in general, in step with the fall of skin temperature and presumably reflected the changes in finger blood flow. At the Arctic perception of pain was comparatively less for all the subjects including the tropical people, while during retest at Delhi the same subjects complained of higher intensity of pain and their CIVD responses became also poor.

One of the tropical subjects of group B, who hailed from South India, experienced a frank vasovagal attack at the Arctic which occurred within 5 min of cold immersion, and the experiment was discontinued. The attack was characterized by yawning, profound sweating, extreme distress, slurring of speech, and near fainting. After 5 d the same subject again volunteered for the test, when he could complete the 30 min cold exposure, though with great distress but without any sweating or yawning. This response was included in the results, even though he exhibited very poor CIVD response. This subject hails from the hot humid region of the southern part of India where he does not experience cold climate throughout the year. Contrary to the attenuated responses of all others he showed an improved response during retest.

The pattern of CIVD, i.e. the responses of the changes in the finger and wrist vein temperatures induced by cold immersion, as well as the peripheral blood flow and CIVD index of all the groups of subjects are depicted in Table 1. The initial CIVD responses of the tropical (control) subjects of Group A and those of Group B during retest on deacclimatization after 6 weeks of their return from the Arctic were almost similar.

Changes in the pattern and the magnitude of CIVD response were seen at the

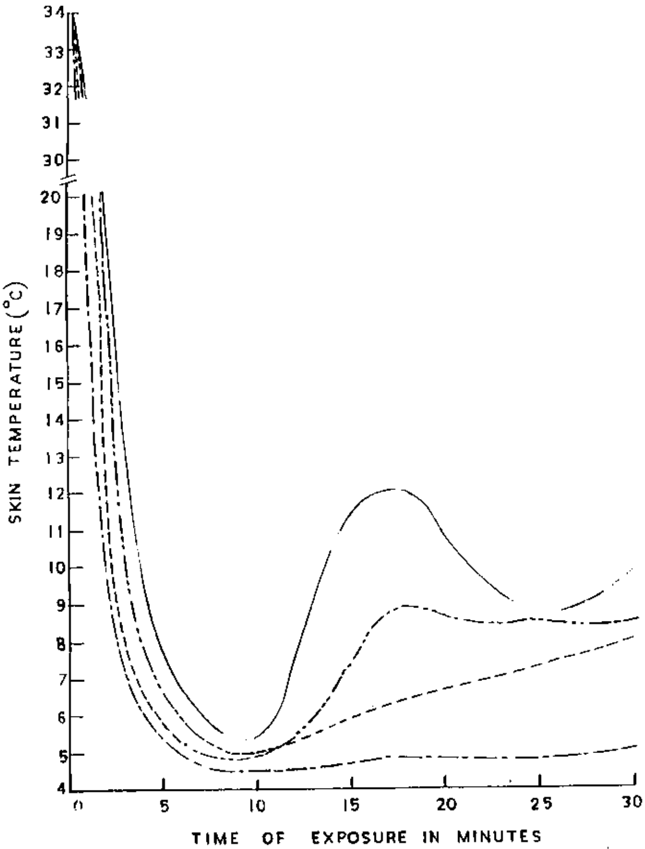

Fig. 1. Various types of cold-induced vasodilatation (CIVD) response from the tip of the index finger. ——, typical hunting phenomenon; -··-, proportional control form; ----, slow, steady, and continuous rewarming; -·-·, no CIVD response.

Arctic in the tropical subjects of Group B after they had more than 6 weeks of acclimatization in that region. There was significant improvement in the values of mean T_s ($p<0.05$), the highest T_s ($p<0.01$), finger blood flow, and CIVD index ($p<0.05$) when Arctic values of the tropical subjects (Group B) were compared with those of the initial responses of tropical control subjects of Group A, monitored at Delhi. The values of the responses of tropical subjects (Group B) and migrants (Group C) recorded at the Arctic were almost identical. The response of the native (Group D) was the highest. On comparison with the Arctic responses of either the tropical men (Group B) or migrants (Group C), the natives (Group D) had apparently the superior responses (Figs. 2 and 3) even though the values were not statistically different (Table 1). This might be due to a small sample size and

Table 1. The responses of the changes in finger and wrist vein temperatures induced by cold immersion as well as the peripheral blood flow and CIVD index of different groups of subjects.

Parameters	Mean±SEM					Significance									
	Gp A	Gp B_D	Gp B_A	Gp C	Gp D	Gp A vs Gp B_D	Gp A vs Gp B_A	Gp A vs Gp C	Gp A vs Gp D	Gp B_D vs Gp B_A	Gp B_D vs Gp C	Gp B_D vs Gp D	Gp B_A vs Gp C	Gp B_A vs Gp D	Gp C vs Gp D
1. Initial T_s before immersion (°C)	33.21 ±0.16	32.76 ±0.40	33.27 ±0.41	33.50 ±0.43	33.57 ±0.47	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2. Minimum T_s during immersion (°C)	5.49 ±0.24	5.00 ±0.14	6.00 ±0.33	6.57 ±0.60	7.28 ±0.68	NS	NS	NS	**	**	**	***	NS	NS	NS
3. Time for first temp. rise after immersion (min)	11.1 ±1.2	10.2 ±1.2	9.0 ±0.9	10.5 ±2.2	8.2 ±0.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4. T_s at the first rise after immersion (°C)	5.62 ±0.25	5.18 ±0.17	6.47 ±0.39	6.88 ±0.64	8.02 ±0.98	NS	NS	*	*	**	**	**	NS	NS	NS
5. Highest T_s during immersion (°C)	7.42 ±0.32	7.75 ±0.37	10.35 ±0.80	10.80 ±1.21	13.05 ±1.14	NS	**	**	***	*	*	***	NS	NS	NS
6. Average T_s during immersion (°C)	6.63 ±0.29	6.41 ±0.29	8.41 ±0.63	8.55 ±0.90	10.27 ±0.76	NS	*	*	***	*	*	***	NS	NS	NS
7. Fall of wrist vein T_s during immersion (°C)	6.98 ±0.38	6.21 ±0.51	8.03 ±0.62	9.27 ±0.82	10.28 ±1.53	NS	NS	*	*	***	**	**	NS	NS	NS
8. Fall of contralateral hand T_s during immersion of other hand (°C)	4.42 ±0.49	5.04 ±0.54	4.28 ±0.55	3.58 ±0.83	3.13 ±0.73	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9. Blood flow (ml/cm^2 per min)	1.277 ±0.155	1.162 ±0.151	2.335 ±0.399	2.398 ±0.520	4.021 ±0.707	NS	*	*	***	*	*	***	NS	NS	NS
10. CIVD index	31.5 ±3.5	29.0 ±3.7	51.5 ±7.8	53.7 ±11.1	77.8 ±10.4	NS	*	*	***	*	*	***	NS	NS	NS

Gp B_D indicates values of Gp B at Delhi. Gp B_A indicates values of Gp B at Arctic. Mean±SE. $*p<0.05$; $**p<0.01$; $***p<0.001$.

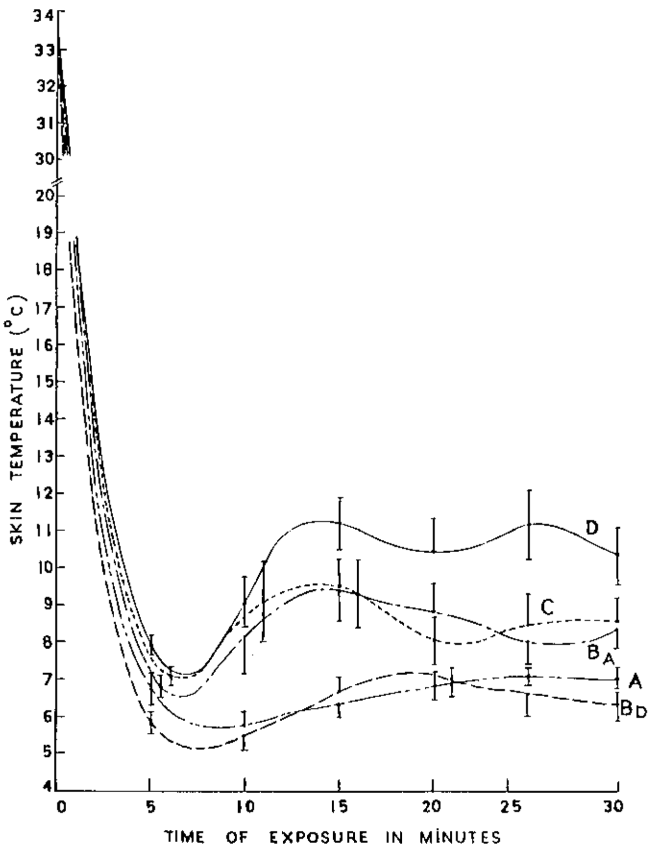

Fig. 2. Pattern of mean CIVD response of various groups (mean±SEM). ----, Group A (tropical control subjects, initial at Delhi); ----, Group B_D (tropical subjects, during retest at Delhi); – –, Group B_A (tropical subjects, at Arctic); ·······, Group C (migrants from Central Russia, at Arctic); ——, Group D (native subjects, at Arctic).

the wide individual variations. The calculated blood flow also showed a similar pattern. This was due to the fact that peripheral blood flow was calculated from T_s, T_w, and T_b, of which T_s was the main variable, while the other two showed negligible changes. Hence the peripheral blood flow during immersion was proportional to the changes in the magnitude of CIVD response. This was also the case for CIVD index.

The initial wrist vein T_s of various groups was identical (range: 32–33°C). Marked fall in wrist vein T_s was noticed during immersion of the hand in cold water. This fall was generally greater for those who showed very good CIVD response. The initial index finger T_s of contralateral hand of various groups (range:

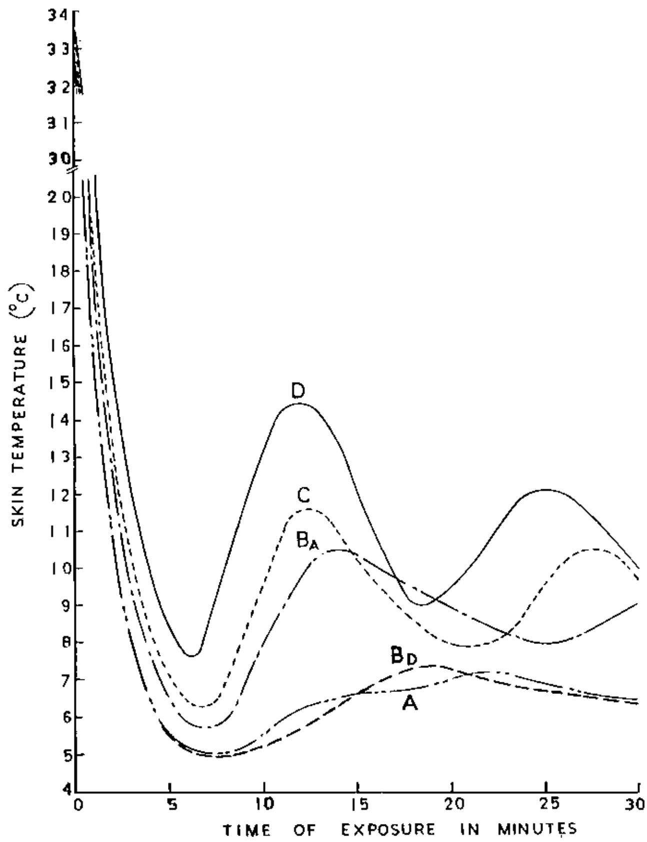

Fig. 3. Typical cases of the pattern of CIVD response of an individual from each group, at Delhi and at the Arctic. Group A: S.J., 34 years old; Group B_D and B_A: A.K., 22 years old; Group C: A.S., 38 years old; Group D: P.K., 32 years old. ---, Group A (tropical control subject, initial at Delhi); ----, Group B_D (tropical subject, during retest at Delhi); --, Group B_A (tropical subject, at Arctic); ......, Group C (migrant from Central Russia, at Arctic); ——, Group D (native subject, at Arctic).

32.8–33.7°C) was more or less similar to those of the initial T_s of the immersed hand. There was an ultimate fall of T_s of contralateral (left) hand in all the subjects (except one of Group B at the Arctic), which showed intermittent rise and fall (data not shown) during immersion of the right hand. This phenomenon seems to be a sensitive index of the time of onset of vasodilatation, since it usually occurred before the immersed hand T_s began to rise. This cooling of the contralateral T_s was generally less for those who showed better CIVD response. Oral temperature monitored before and after the local cold exposure usually showed a slight fall or rise for very good or very poor CIVD response eliciters, respectively. However, no definite relation of the CIVD response with this parameter was observed. Some subjects showed no change in T_b during hand immersion in cold water for 30 min.

DISCUSSION

In the present study an attempt has been made to assess the local CA response of tropical men during prolonged exposure to the natural cold environment of the Arctic and to compare their responses with those of the migrants and natives of the Arctic. The important observations of the study are: the tropical men have shown significant improvement in CIVD response and peripheral blood flow during their stay at the Arctic, which reached almost the same level as that of the migrants from temperate zone. The tropical subjects felt less pain and comparatively less discomfort during local cold stress at the Arctic and it was of least intensity in natives. The values of the blood flow under all conditions were shown to support the changes in CIVD responses. Hsieh *et al.* [16] have shown a high correlation ($r=0.95$–0.99) between blood flow and skin temperature. Hence this method of calculating blood flow seems to be suitable for the present study. On exposure to the Arctic environment the responses of CIVD showed the maximum improvement, which on return to Delhi recorded a marked decline and became identical to that of Group A.

The improvement in the CIVD response observed during the sojourn at the Arctic may be contributed by increased blood supply to the extremities due to diminished sympathetic vascular tone. This adaptive modification might be brought about mainly by local as well as to some extent by general acclimatization to cold. This phenomenon is not restricted to the exposed extremity, but can be seen in the contralateral extremity as well.

Hammel [5] has shown the possibility of local CA in man even though arguments still exist about the general CA. Bridgeman [19] could not demonstrate peripheral CA in Antarctic scuba divers and one of the explanations given for this was the insufficient frequency or severity of cold exposure. Since the tropical men of the present study were living in the Arctic camp and engaging in outdoor activities, their hands and feet were likely to be quite frequently and sufficiently exposed to cold during the period of sojourn. Comparatively low T_s, especially those of the extremities in tropical men, measured under the clothing when exposed to the natural cold environment of the Arctic to evaluate Indian snow clothing (unpublished observations), indicated that they were indeed exposed to considerable cold stress even with clothing in their routine outdoor activity. This might be the primary factor which caused the improved physiological responses to cold. Hence they must have achieved a high degree of local CA along with general acclimatization, which is almost similar to that of the migrants from temperate zone, but lower than those of the natives. The superimposition of an additional stress like hypoxia over the cold stress as at high altitude, was reported to have resulted in suppressed physiological responses to cold [20–22], thereby accentuating the susceptibility to cold injuries [15]. This deterioration may be due to the hypoxic influence on the thermoregulatory mechanism [21] as well as to the enhanced sympathetic activity [23], resulting in the curtailment of a favorable vascular response to local cold stress [15].

In the present experiment it has been clearly shown that the prolonged exposure to the natural cold environment of the Arctic, where there is no hypoxia, improved the CIVD response and maintained a higher rate of extremity blood flow, causing a decreased susceptibility to cold injuries [3]. It appears that the human subjects during the initial 2 weeks of exposure to the Arctic environment remain more prone to cold injuries [24]. But, the subjects of the present study after 6 weeks of exposure to the Arctic environment have achieved local CA and less proneness to cold injuries as did the migrants from temperate zone, but not to the same extent as the natives. This finding is in accordance with the observations of Rivolier *et al.* [25] that the 2 months spent in Antarctica did improve the peripheral responses to cold. Thus, it can be concluded that the local CA is possible even in the tropical men as in the people of temperate zone and the process could be hastened by deliberate exposure of the extremities to local cold along with general cold exposure.

Two typical cases of this study confirmed our earlier observation that the North Indians and Gurkhas were less prone to cold injuries, while the South Indians were more susceptible to the occurrence of frostbite [11]. One case was the tropical subject of Group B who was born and brought up in the southern part of India where there is no winter season and the general climate is only hot throughout the year. In day-to-day life, people of that region experience neither general cold stress nor localised cold exposure of extremities. This subject (J.R.) on exposure to Arctic cold condition showed very poor CIVD response (Fig. 4) and suffered from severe pain throughout cold immersion and, contrary to all other subjects, recorded a rise in contralateral index finger T_s. The same subject had the vasovagal attack during his first attempt of cold immersion at the Arctic. But, on return to Delhi, unlike the decline in responses of all other tropical subjects, he exhibited an improved CIVD response during retest. It is likely that in this subject, during the stay at the Arctic for 8 weeks there has been a certain degree of local CA, but it was masked by the influence of intense general cold response, viz. sympathetic vasoconstriction. On return to warm Delhi the local cold stimulus might have evoked an improved response due to some residual effect of local CA. The other case was the subject of Group B who was born and brought up in the hilly region of North India (Gurkha), where there is no summer season, and in everyday life his extremities are regularly exposed to very cold water and often to snowfall during winter months. His (P.P.) CIVD response at the Arctic was comparable to that of one of the best responses of the Arctic native (Fig. 4). When the test was done at Delhi 6 weeks after return from the Arctic, he showed relatively weaker CIVD response. These observations clearly indicate that CIVD response is influenced by climatic condi-

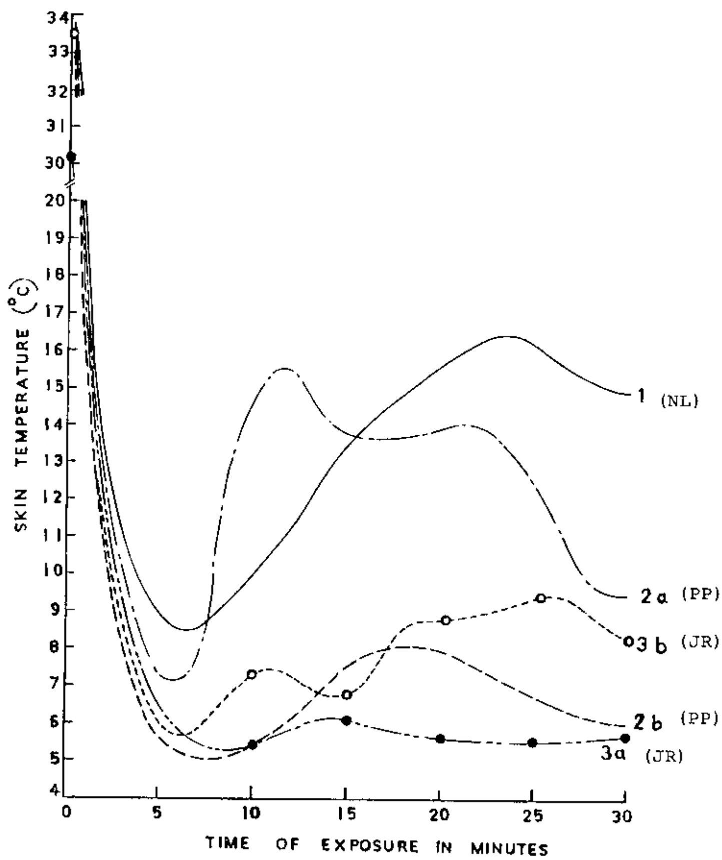

Fig. 4. CIVD response of specific individual cases. 1. Particular native (58 years old) at Arctic showing best CIVD response (——); 2. Particular tropical subject (24 years old) of North Indian hilly area: (a) very good CIVD response at Arctic (similar to native) (‒ ‒ ‒), (b) comparatively poor CIVD response at Delhi (during retest) (‐‐‐‐); 3. Particular tropical subject (27 years old) of South Indian hot humid region: (a) very poor CIVD response at Arctic (●‐‐‐‐●), (b) comparatively good CIVD response at Delhi (during retest) (○‐‐‐‐○).

tions of one's place of birth and domicile, which is in accordance with the observation by Itoh *et al.* [26].

In this study one particular native subject (N.L.) of Group D, whose main occupational duty was the clearing of snow around the camp, showed the highest peripheral blood flow and CIVD response (Fig. 4), even though he was the oldest volunteer (58 years old). He experienced neither any pain nor discomfort during cold immersion. He was well used to his job and often performed his duties with bare hands for hours, whereas the particular South Indian subject of Group B (discussed above), whose professional job was wireless operation, was unable to perform his daily physical training schedule without wearing hand-gloves. This supports a proposal by Yoshimura and Iida [27] that CIVD could be one of the cold tolerance indices and is greatly influenced by hand usage in occupational duties in a cold environment.

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