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From Pole to Pole –
A Thermal Challenge

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Summary

The issues of thermal physiology, protection, modeling, survival, and injury have been addressed in thousands of publications over the decades, and the topic of thermal protection and survival has been the subject of several NATO DRG and AGARD symposia. Therefore, rather than review the current state of the art of the field which is the subject of the many papers that will be presented at this Symposium, this paper re-examines some of the pioneer work in cold physiology that has laid the foundations of our current understanding as to how humans have adapted to severe cold climates, often without modern technology or clothing. Scholander, Hammel, Elsner, Andersen, and Hart are some of the scientific pioneers that have provided evidence from field trials that a variety of physiological adaptations can develop in the human species exposed to different climatic extremes ranging from one Pole to the other Pole. From these classical field studies, several different types of cold acclimatization of native races were identified. This paper reviews how some of these acclimatizations can be or have been applied to modern man. In conclusion, it appears that a rapid technique using intermittent exposure to severe cold for inducing cold adaptation or cold habituation does exist and does induce beneficial effects in soldiers required to subsequently perform and sleep under arctic conditions. It appears to be a hypothermic type of adaptation and eliminates the negative effects of cold diuresis. Furthermore, this technique appears to persist over a significant period of time even in a temperature environment making it even more of a desirable military technique. One sees a shift of the shivering threshold to a lower temperature, a shorter period of adaptation, and an increase in cold tolerance. It appears to be more akin to the type of adaptation demonstrated by the Australian aborigine and Kalahari bushman, that is, an Insulative Acclimatization.

Introduction

The issues of thermal physiology, protection, modeling, survival, and injury have been addressed in thousands of publications over the decades, and the topic of thermal protection and survival has been the subject of several NATO DRG and AGARD symposia (Table 1).

Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076.

TABLE 1. List of DRG and AGARD Reports and Symposia on Operations in Extreme Thermal Environments

Borg, A and Veghte JH	The physiology of cold weather survival	AGARD-R-620 1974
Lorentzen, FV	Cold: physiology, protection and survival	AGARD-AG-194, 1974
Boutelier, C	Survival and protection of aircrew in the event of accidental immersion in cold water	AGARD-AG-211, 1979
Brooks, CJ	The human factors relating to escape and survival from helicopters ditching in water	AGARD-AG-305(E) 1989
AGARD Conference, Victoria, Canada, 1993	The support of air operations under extreme hot and cold weather conditions	AGARD-CP-540, 1993
NATO RSG-20	Handbook on predicting responses to cold exposure	AC/243(Panel 8) TR/20, 1995

Therefore, rather than review the current state of the art of the field which is the subject of the many papers that will be presented at this Symposium, this paper will re-examine some of the pioneer work in cold physiology that laid the foundations of our current understanding as to how humans have adapted to severe cold climates, often without modern technology or clothing.

Adventure, economics, national security, athletics, and scientific curiosity have been major motivating forces behind man venturing into such inhospitable climates as the Arctic and the Antarctic, particularly since man has evolved as a tropical animal. But certain civilizations have existed in such environments for decades with no modern technology. Beginning with Darwin during the voyage of the Beagle in 1831 (Moorehead, 1969), and subsequent explorers, scientists have been driven to investigate how such populations adapted to their harsh environments and survived. The foundations of our knowledge as to how man can adapt physiologically to different thermal environments (Figure 1) were laid by the studies carried out on the:

- Australian Aborigines,
- Kalahari Bushmen,
- Alacaluf Indians of Tierra del Fuego,
- Arctic Indians and Eskimos, and
- nomadic Lapplanders.

Scholander, Hammel, Elsner, Andersen, and Hart were some of the scientific pioneers that provided evidence from field trials that a variety of physiological adaptations can develop in the human species exposed to different climatic extremes ranging from one Pole to the other Pole. From these classical field studies, several different types of cold acclimatization of native races were identified. This paper will review some of these earlier studies and how some of these acclimatizations can be or have been applied to modern man.

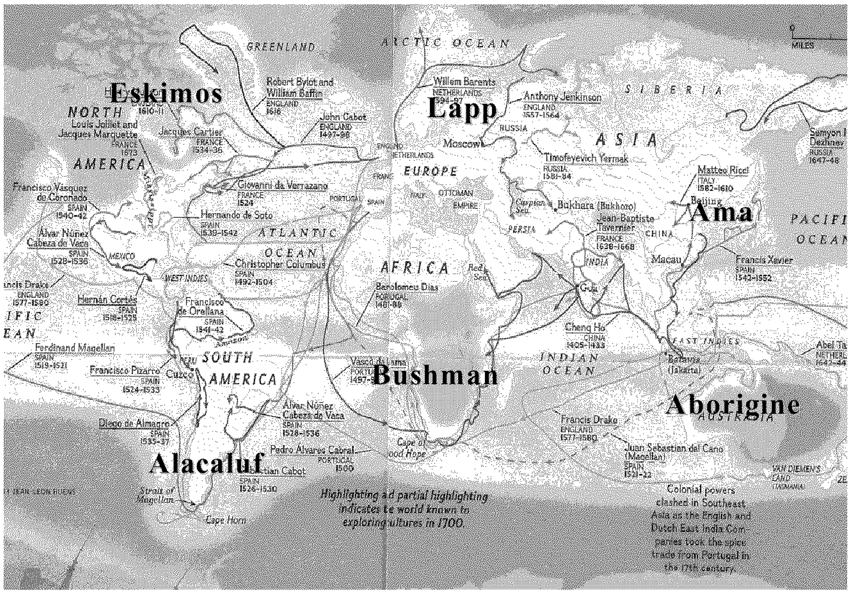


Figure 1. Native groups studied by early investigator

Australian Aborigine

One of the first native groups investigated were the aborigines of central Australia who have existed in a semi-desert environment with average nightly temperatures of 4°C with a high radiant heat loss (Scholander et al. 1958). Their sleeping habits consisted of lying naked between two small fires. This then was a group intermittently exposed to periodic cold. The aborigines were described by FitzRoy as "the lathy thinness of their persons, which seemed totally destitute of fat, and almost without flesh..." (Moorehead 1969). This, then, was a race devoid of any peripheral body fat to provide any insulation (Figure 2).

The standard techniques used by Scholander and his colleagues (1958) to perform field evaluations of the metabolic and thermal responses to cold of these and subsequent native groups consisted of measuring the thermal and metabolic responses of the natives sleeping in a tent for an 8-hour period on a cot lightly covered with a blanket at an air temperature of about 3°C. Oxygen consumptions, rectal and skin temperatures were monitored continuously and the data compared to the responses of a control group of white subjects, usually the investigators themselves.

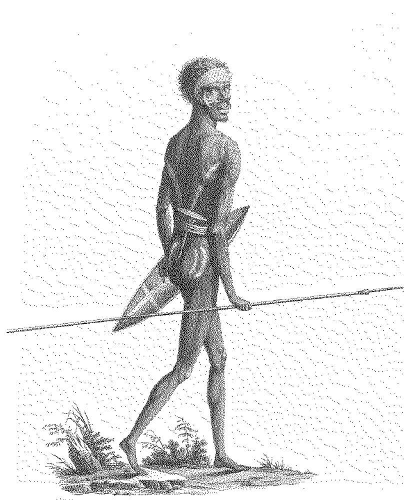


Figure 2. Australian aborigine.

Significant differences in the metabolic and thermal responses were found between the aborigines and the white controls. The controls responded typically by elevating their metabolic rates above basal by about 28 %, accompanied by drops of about 0.8°C in rectal temperature (Tre), 1.5°C in mean body temperature (Tb), and 2.4°C in mean skin temperature (Tsk) over the 8-hr period with bursts of shivering and disturbed sleep throughout the night (Figure 3, Panel A).

The metabolic and thermal responses of the aborigines differed significantly from the white controls, as the aborigines did not increase their metabolic rate, but in fact, experienced a decrease of about 7-8 %. This was accompanied by a greater drop in rectal temperature, almost 2-fold greater than the control, along with significantly greater drops in mean body and mean skin temperature of (Figure 3, Panel B). The natives slept comfortably with little shivering.

These findings led the investigators to propose the existence of an ***Insulative Acclimatization*** in the aborigines although it could also be classified as a ***Hypothermic Insulative Acclimatization.*** Further experiments in different seasons on a group of tropical aborigines not exposed to cold during sleep demonstrated the persistence of such an acclimatization supporting the concept that this was a racial characteristic.

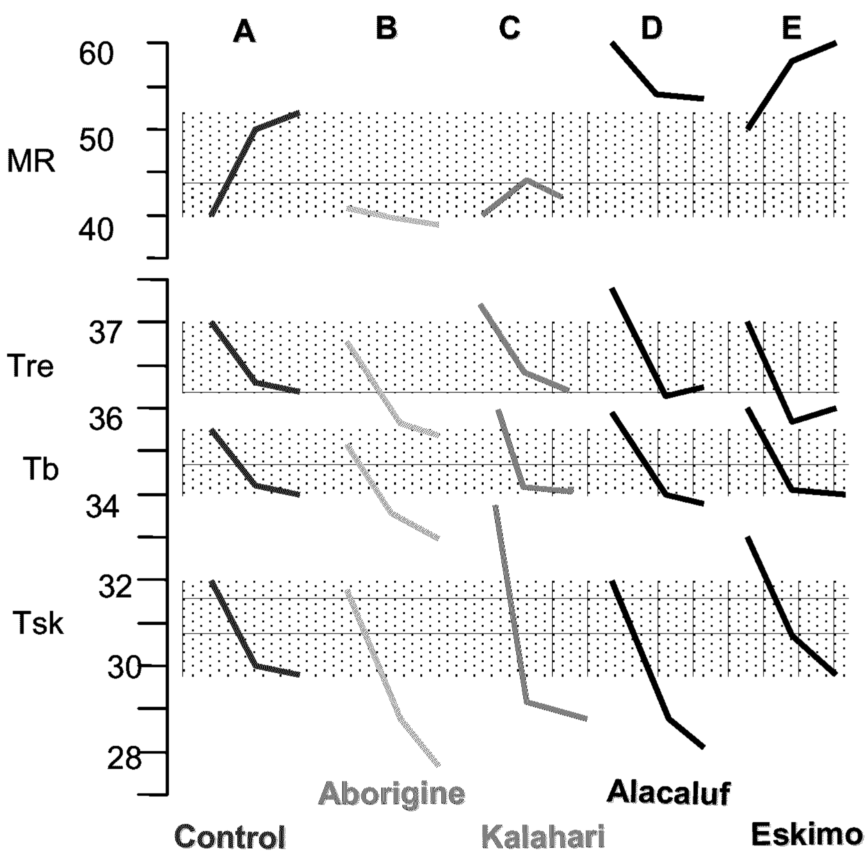


Figure 3. Comparative responses to a standard cold field test of different native populations.

Kalahari Bushmen

A Bushman's body is the product of a million years of hunting-gathering life in the Kalahari climate. As he moves across the Kalahari, his heart must increase flow rate 8-fold when he runs across the desert at top speed. His heart has evolved into a machine more efficient than any man has ever designed. Bushmen can carry loads equal to their own weight and travel over the desert for hours without visible fatigue.The Bushmen of the Kalahari Desert wear little or no clothing and are rather small and lean with a resultant larger surface area per unit weight (Figure 4). Although their body build reflects the demands of the hot desert to shed heat more efficiently during the day, they are exposed to overnight cold down to 0°C in July making their body build a disadvantage without other compensatory mechanisms. One Bushman camp was described thus: "They had burned all their firewood the night before, and now it was too cold to go for more, or even go for food - so they sat cold, hungry, thirsty, and even tired, since they had been too cold to sleep during the night.- waiting with infinite patience - for noonday when the sun would give a little warmth".

Figure 4. Kalahari Bushman

Wyndham and Morrison (1958) and Hamel and coworkers (1962) found that when exposed to cold overnight, the Bushman's responses were similar to those of the aborigines of Australia. They did not shiver, showed little increase in metabolic rate over 8 hours, with rapid drops in body temperature, but not as low as that of the aborigine (Figure 3, Panel C). They appeared to rely on ***Insulative Acclimatization*** to survive in the cold.

Alacaluf Indians

Darwin during the voyage of the Beagle was one of the first scientists to become fascinated with the Alacaluf Indians of Tierra del Fuego (Moorehead, 1969). He described the climate of Tierra del Fuego as an appalling climate, one of the worst in the world. The cold exposure of the Alacaluf differed from that of the Australian aborigines and the Kalahari Bushmen in that the Alacaluf were exposed to a cold climate throughout the 24-hour day, and not just at night when they slept. On catching sight of the natives, his first thought was how much closer they were to wild animals than to civilized humans. (Figure 5).

"They were huge creatures...the trunk of the body is large, in proportion to their cramped and rather crooked limbs" who went naked except for a guanaco skin over their shoulders. "It was marvelous the way they could stand the cold. One woman who was suckling a baby came out to the Beagle in a canoe, and she sat there calmly in the tossing waves while the sleet fell and thawed on her naked breast. On shore these people slept on the wet ground while the rain poured through the roofs of their crude skin huts". It was obvious that this tribe had adapted physiologically in some manner to the extreme climate with very little in the way of protective garments.

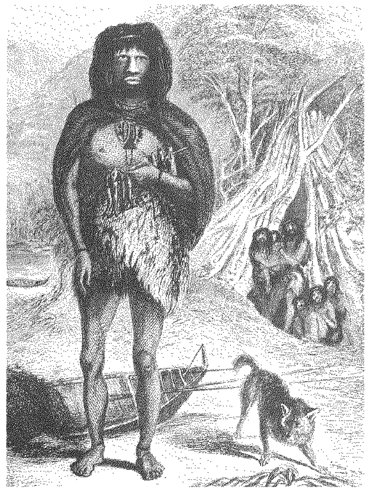


Figure 5. Alacaluf Indian (from Moorehead, 1969)

A team of scientists led by Hammel (1960) studied the metabolic and thermal responses of the Alacaluf during a night of cold exposure sleeping on a canvas cot in an unheated tent for 8 hours. They found that the Alacaluf had a resting metabolic rate about 160% higher than the white controls, which remained higher than the final elevated rate in the white controls. No other significant differences were evident between the two groups in rectal, body and skin temperature except for warmer toes in the Alacaluf, which were 2°C to 3°C higher than the controls (Figure 3, Panel D). They also had an undisturbed sleep in such a climate whereas the control subjects experienced difficulty sleeping due to the cold. As noted by Darwin, "at night they sat tgether round the campfires, the sailors shivering in the bitter cold, the Fuegians sweating in the heat of the fire". This pattern of thermal responses was called ***Metabolic Acclimatization***.

Arctic Indians and Eskimos

Figure 6. Eskimos with bare extremities, but with excellent whole body insulation.

The Arctic Indians of the Yukon and the Arctic Eskimos were studied by Irving (1960), Elsner (1960) and by Hart (1962). (Figure 6). The normal pattern of cold exposure of the Eskimo and the Arctic Indians consisted of exposure to intermittent exposures to severe cold while traveling, hunting and trapping and sleeping in cool environments on the trail. Otheerwise, they were very well protected having developed an ideal Arctic clothing. Normally, during the day, the extremities were only exposed to the cold (Figure 6) and this is where the Eskimo stands out in terms of physiological adaptation. This native population showed responses similar to that of the Alacaluf, but with initial resting metabolic rates lower than the Alacaluf but significantly higher than the controls. However, whereas the initial metabolic rate decreased slightly during the cold test in the Alacaluf, it increased in the Eskimo to levels comparable to the Alacaluf (Figure 3, Panel E). The pattern of acclimatization exhibited by the Eskimo appeared to be more of a ***Metabolic Acclimatization*** although they demonstrated superior acclimatization of their exposed extremities.

Surprisingly, another Arctic population, the nomadic Lapps, with a life style similar to the Arctic Eskimo demonstrated a response that was more comparable to the Australian aborigine than other Arctic natives, that is, no increase in metabolic rate and a large drop in rectal temperature, reflective of a **Hypothermic Insulative Acclimatization** (Andersen et al. 1960).

Summary of Findings on Native Populations

These different modes of acclimatization to the climate become more distinct from a plot of the metabolic responses of each of the above groups as a function of their mean body temperature (Figure 7). By comparing the average metabolic response of each of the groups above as a function of their mean body temperature, two distinct patterns of cold acclimatization were evident, Metabolic Adaptation, and Hypothermic Insulative Adaptation. The typical unacclimatized North American or European demonstrated a low basal metabolic rate which increased markedly as body temperature decreased. Characteristic of a Hypothermic Insulative Adaptation, the Australian aborigine and the Kalahari Bushman had an initial metabolic rate similar to the white control, but one which decreased or did not change as body temperature decreased. A Metabolic Adaptation was evident in the Alacaluf Indian who began with a high resting metabolic rate which declined slightly with a falling body temperature; and the Arctic Indian and Eskimo with a metabolic rate intermediate between the Alacaluf and the control which increased as body temperature decreased.

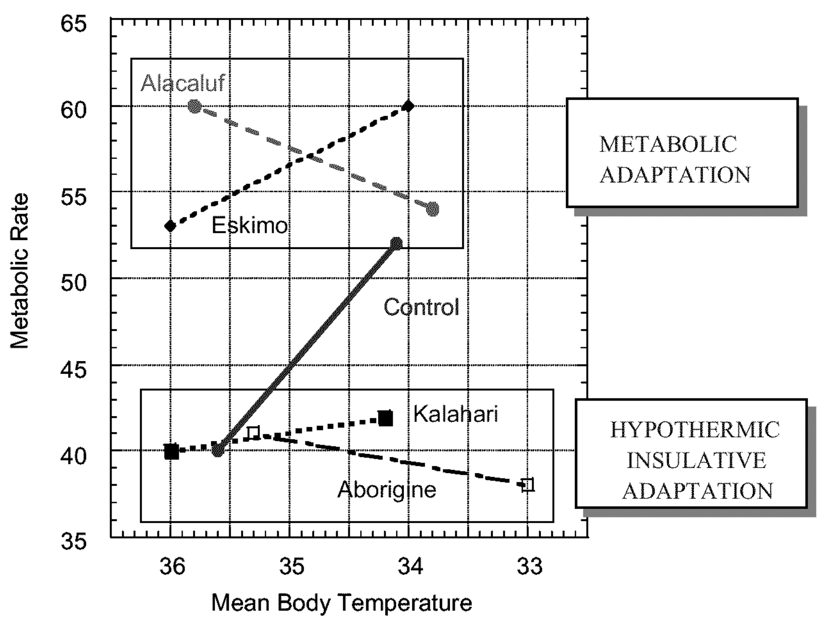


Figure 7. Heat production as a function of mean body temperature before (left points) and after the standard 8 hour cold exposure test..

LABORATORY/CHAMBER STUDIES ON ANIMALS AND HUMANS

The question subsequently pursued by investigators, partially driven by military requirements, was whether acclimatization to cold could be induced in a normal north american/european population, what type of acclimatization, and how quickly in order to have any practical military value. Therefore, it was necessary to try to relate these field studies of native populations to studies on both laboratory animals and humans in climatic chambers where the various variables could be controlled, including diet.

Approaches to Cold Adaptation

The experiments of LeBlanc's and Carlson's groups on animals exposed to cold were key to our understanding of the mechanisms of cold adaptation and the role of the autonomic nervous system in our responses to cold temperatures. From their work, two types of adaptation to cold were demonstrated in rats (Figure 8):

a) Metabolic Adaptation resulting from continuous exposure for weeks to moderate cold (6°C), and

b) Hypothermic Insulative Adaptation resulting from a series of intermittent exposures to severe cold (-20°C).

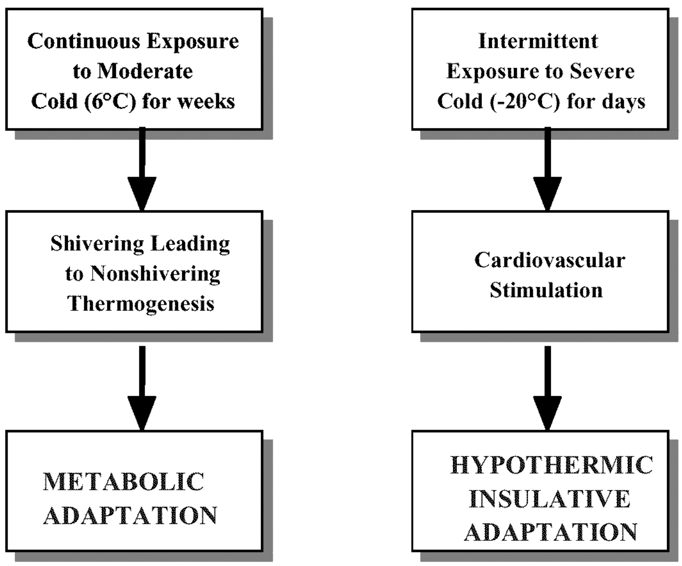


Figure 8. Types of adaptations induced in animals.

The mechanisms by which these two types of adaptation occur differed. Metabolic adaptation required a continuous prolonged exposure to moderate cold (ca. 6°C) over weeks and was characterized by an increased urinary excretion of noradrenaline (Fig 9A) and an increased noradrenaline sensitivity (Fig 9B; adapted from Leduc 1961, and Hsieh and Carlson 1957). These findings by Leduc and Hsieh and Carlson were key to our understanding of the mechanisms of cold adaptation and of the role of the autonomic nervous system in the responses of animals to cold. Also, during these changes, shivering was gradually replaced by a non-shivering mechanism of heat production.

However, as pointed out by Leblanc (1975), however, it is rare that modern man is exposed to continuous cold, and that intermittent repeated exposures are more the norm. A simple method of developing cold adaptation in a short period of time would have greater military value. LeBlanc, in fact, carried out a series of studies to examine the effects of short-term repeated periods of exposure to more severe cold (IS) to assess whether an increased tolerance and adaptation to cold could be induced in a much shorter time, hours and days instead of weeks (1967).

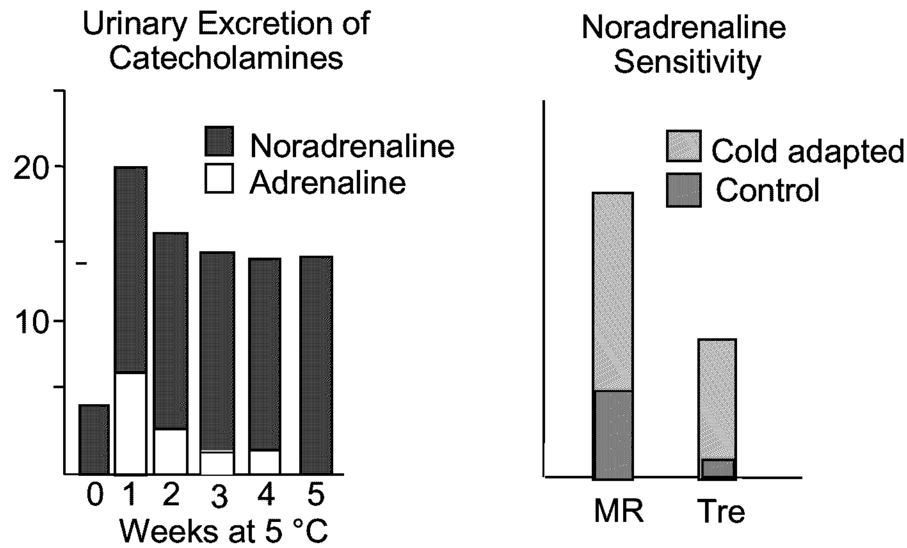


Figure 9 . Left panel shows the pattern of urinary excretion of noradrenaline and adrenaline during adaptation to moderate cold for 5 weeks, and the right panel the response of oxygen consumption (MR) and rectal temperature (Tre) in control and cold-adapted animals to noradrenaline infusion. Adapted from adapted from Leduc 1961, and Hsieh and Carlson 1957).

From his experiments on mice, he showed that although there was some increase in noradrenaline and adrenaline excretion during three days of repeated exposures to severe cold, the sensitivity to noradrenaline infusion on oxygen consumption was significantly different (LeBlanc et al. 1967). The normal increase in oxygen consumption observed in chronically adapted rats during noradrenaline infusion was not evident in the IS adapted rats (Figure 10). Thus, whereas the rats chronically exposed to moderate cold (CM) demonstrated characteristics of metabolic adaptation, the IS rats did not exhibit any increase in oxygen consumption, similar to the Kalahari bushmen and the Australian aborigine. Furthermore, he showed that the colder the temperature that the mice were adapted to by the IS technique, the better their survival times at different temperatures.

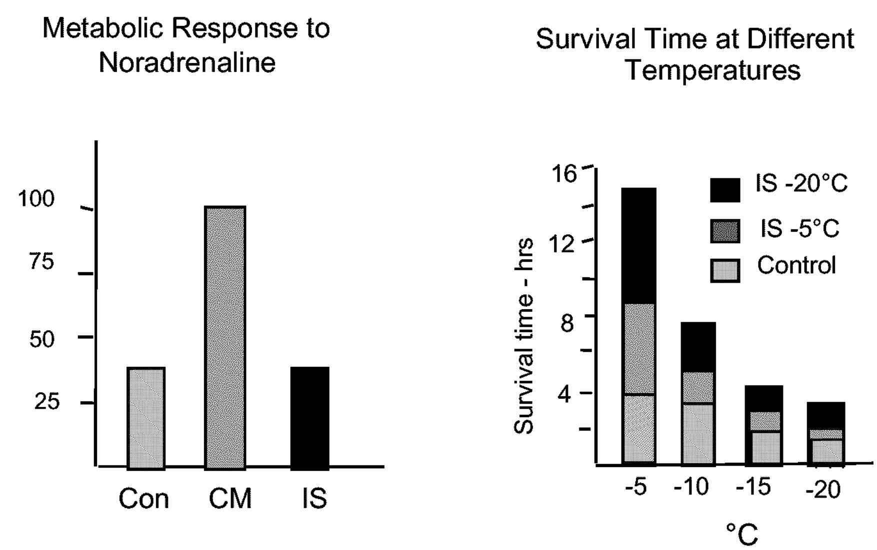


Figure 10. Response in oxygen consumption to noradrenaline infusion in control rats (Con), in rats chronically exposed at 10 °C for 6 weeks (CM), and in rats adapted to intermittent stress (IS) (9 exposures per day for 10 min each at –10 °C for 3 days). Survival times at different temperatures of rats adapted to cold by intermittent exposures to –20°C and –5°C are shown in the right panel.

Field and Laboratory Studies on Humans

A variety of approaches have been investigated to improve human cold tolerance and acclimatization. A partial summary of the three major approaches investigated in earlier studies are shown in Table 2. These have involved natural exposure to external climates, exposure to cold air in climatic chambers, and repeated immersions in cold water or cold air.This review will next examine two of the natural acclimatization studies in more detail and the application of the Boutelier technique for adaptation by exposure to intermittent severe cold in more detail.

Table 2. Methods of Acclimatization

Method	Conditions	Investigators
Natural exposure to external climate	Clothed men in the Arctic engaged in outdoor activities for up to 12 hr/day for 6 weeks	LeBlanc 1956
	Camping for 6 weeks in mountains at 3 to 5 °C	Scholander 1958
	Seasonal changes from Oct to Feb, 1 hr/day/month exposure in nude to 14 °C.	Davis and Johnston 1961
	Troops working and sleeping in unheated tents in Arctic for 16 days at –30 to –20 °C	Radomski et al. 1982
Artificial acclimatization to cold air	1 week at –29 °C in climatic chamber	Horvath et al. 1947
	Subjects wearing shorts during day and sleeping under woolen blanket for 2 weeks at 15.5 °C	Iampietro et al. 1957
	Exposure of subjects wearing shorts for 8 hr/day over 31 days at 11.8 °C	Davis 1961
	Subjects spending 7.5 hr/day for 19 days at 6 °C	Keatinge 1961
	Clothed subjects for 8 hr/day for 5 weeks at 5 °C	Joy 1963
	Subjects in shorts at 5 °C for 4 hr/day, 5 times per week for 6 weeks	Newman 1968
Artificial acclimatization in cold water	1 hr/day immersion for 8 weeks at 32 to 21 °C	Lapp and Gee 1967
	Diving 1hr every day for 1 month in water at 0 to 3 °C wearing neoprene suit	Skreslett et al. 1968
	Daily immersion for 20-50 min 5 days/week for 2 weeks at 15 °C (French Baths)	Boutelier et al. 1974

Natural Acclimatization

Two groups of scientists examined seasonal changes in two different groups of subjects in two different climates (Leblanc, 1956; Davis & Johnston, 1961) to assess whether chronic exposure of humans to cold for months will induce the type of cold acclimatization observed in the chronically adapted rats and in native populations. LeBlanc followed a group of soldiers posted from Winnipeg to Fort Churchill at the end of October where they lived outdoors for approximately 12 hr/day, 6 days a week, from the end of November until April. Their activity consisted of daily walks of 10 miles and standing motionless on guard duty for 2-3 hr at night. Their metabolic and thermal responses were measured at the end of November, December, and February.

In the Davis and Johnston study, subjects were examined once monthly from October to February. These were laboratory personnel who normally worked 40 hr/week in air-conditioned facilities and in heated quarters in the winter. Their combined data are re-plotted in Figure 11.Although the studies of Davis and Johnston and Leblanc described above did involve individuals exposed to intermittent cold, such individuals were well protected by clothing and their type of exposure would not be typical of one of intermittent repeated exposures to extreme cold. It is evident from these two different experiments in two different climates with different daily periods of exposure to cold that cold-induced heat production decreased significantly from Oct to Mar, and that the % shivering decreased to low levels by Feb. Body temperature data did not show any significant trends.

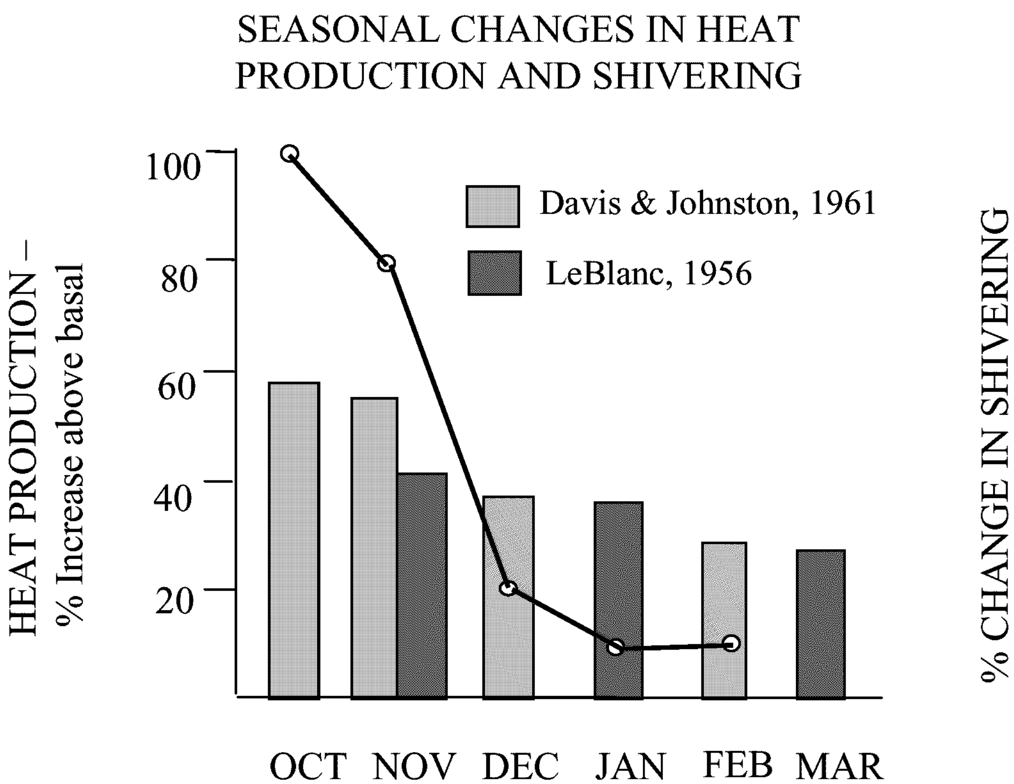


Figure 11. Seasonal changes in heat production in two groups of subjects from October to March. The Davis group was located in Kentucky and mean monthly temperatures varied from 13 to –4 °C from Oct to Feb. The Leblanc group were located in Fort Churchill in the Canadian sub-arctic with seasonal temperatures varying from –11 to –30 °C. The solid bars represent heat production as a % change from basal levels and the solid line represents the % shivering in the Davis group.

Davis and Johnston (1961) pointed out that the decrease in heat production was much less than the decrease in shivering and suggested that this might be due to a compensatory increase in non-shivering thermogenisis to replace shivering heat production. On the other hand, this data could also be interpreted as the development of Insulative Acclimatization, rather than an increase in non-shivering thermogenesis. However, such a process of acclimatization has little military value because of the long period of time required to induce some form of acclimatization.

Artificial Acclimatization

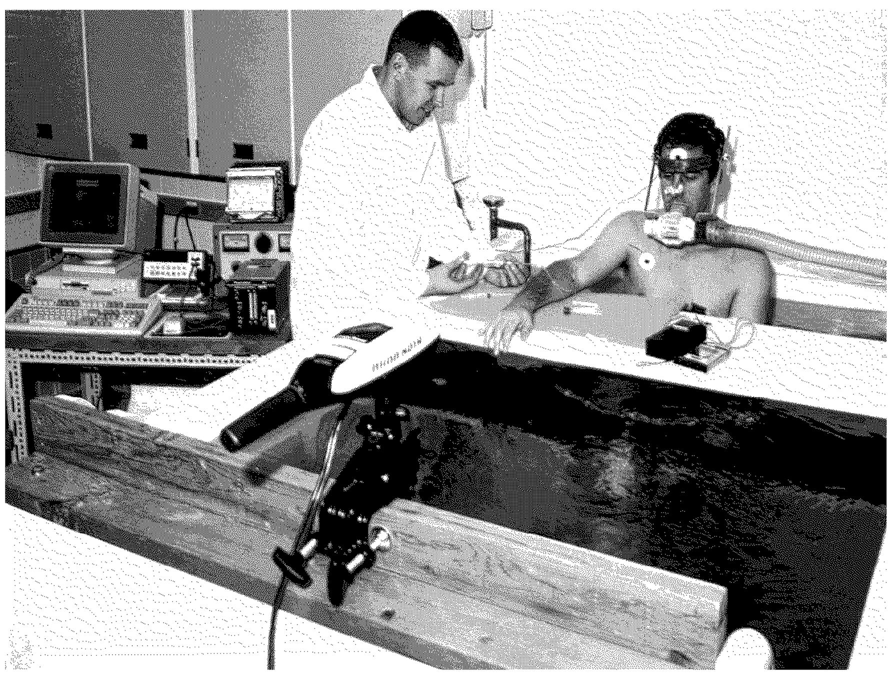
Humans are generally much more exposed to intermittent severe cold (IS) than to continuous cold (CM) and various groups have shown the development of a type of IS adaptation in humans. There are two basic techniques for rapidly inducing whole body IS-adaptation in humans:

- : short daily immersions of nude humans in cold water *(french baths)* ((Boutelier et al. 1974); and
- repeated nude exposures to cold air (Bruck et al. 1976).

However, the practical value of such techniques to military personnel subsequently going into the Arctic for a period of time had not been assessed.

Operation Kool Stool

In order to address this deficiency, Operation Kool Stool, a joint military experimental trial between our centre in Toronto, DCIEM, and the French air force and army medical laboratories, LAMASS and CRSSA, was carried out to assess the feasibility, practicality, and value of applying the "*french bath*" technique to rapid pre-adaptation of troops being airlifted into an Arctic environment. This was a joint military group composed of Canadian army subjects with no prior preadaptation to the cold (NPA) and a group of French soldiers who were preadapted to cold-water immersion (PA). Prior to embarking for Toronto, the French troops were subjected to the Boutelier IS technique of a total of nine daily immersions in water at 15°C for 25 to 40 minutes until their rectal temperature had reached an end-point of 35 °C (Figure 12). Immersion times gradually increased from 25 minutes to 40 minutes by the end of the last immersion indicating an increasing tolerance to cold with each repeated immersion.



F*igure 12. French bath immersion technique in cold water This consisted of 9 immersions in water at 15°C for 25-40 minutes.*

The French troops arrived in Toronto 15 days after the last immersion and along with Canadian troops who had not undergone IS adaptation, were subjected to a standard nude cold tolerance test (NEC1) which consisted of lying semi-nude on a cot at 10°C for 60 minutes. Five days later, the troops were flown to Fort Churchill where they spent 16 days and nights performing 6 hr of light outdoor activity daily and sleeping in standard Canadian Forces sleeping bags in unheated tents. Over the period of the trial, the mean nightly temperatures varied between –25°C and –30°C, with one warm night of –10°C half way through the trial.

While in the Arctic, sleep polysomnography, diuresis, catecholamine and 17-OHCS excretion, and thermal and psychosociological responses were continuously monitored. Subjects experienced the greatest cold discomfort and its effects on diuresis and sleep while in their sleeping bags during the night. At the end of the 16-day trial, the troops were flown back to Toronto and subjected to a second nude cold tolerance test (NEC2). Some of the changes observed in the parameters are shown in subsequent figures. The complete study has been published in a Franco-Canadian Accord Volume (Radomski et al.. 1982) and certain chapters in the open literature.

Figure 13 shows the metabolic responses of the non-preadapted (NPA) and the preadapted (PA) groups to the nude cold tolerance tests before (NEC1) departing for the Arctic, and after 16 days in the Arctic (NEC2). A significant difference between the two groups prior to departure for the Arctic (NEC 1) was seen. Whereas the NPA group exhibited the normal increase in metabolism upon exposure to cold, the PA group did not increase their metabolic rate until after 50 min. After 16 days in the Arctic, the NPA group showed a similar response to the PA group to a NEC 2, in that no significant increase in metabolism occurred over the 60 min of cold.

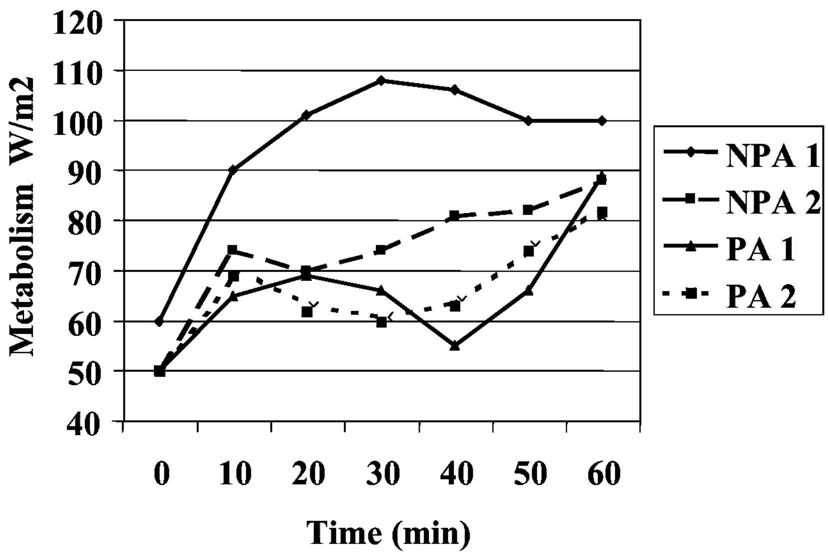


Figure 13. Metabolic responses of the non-preadapted (NPA) and the preadapted (PA) groups to the nude cold exposure tolerance test before and after 16 days in the Arctic.

Comparing the MR to the mean body temperature (Figure 14) revealed a similar metabolic response in the NPA group as observed by Hammel in his early experiments with control subjects (Figure 3) whereas the response of the PA group was more reflective of the Kalahari Bushman in that metabolism showed little increase (an insulative adaptation!). After 16 days in the Arctic, no differences in the MR vs Tb relationship were seen in the PA group, but it appeared that the NPA group had altered its response with a smaller increase in MR with a drop in Tb suggesting that the NPA group was developing more of an insulative adaptation rather than a metabolic adaptation. Prior to departing for the Arctic, there were no differences in the response of the extremities to cold-water immersion (cold-induced vasodilatation response – CIVD) whereas after 16 days in the Arctic, a significantly improved adaptation of the extremities had developed in all of the subjects resulting in warmer extremities (Figure 15).

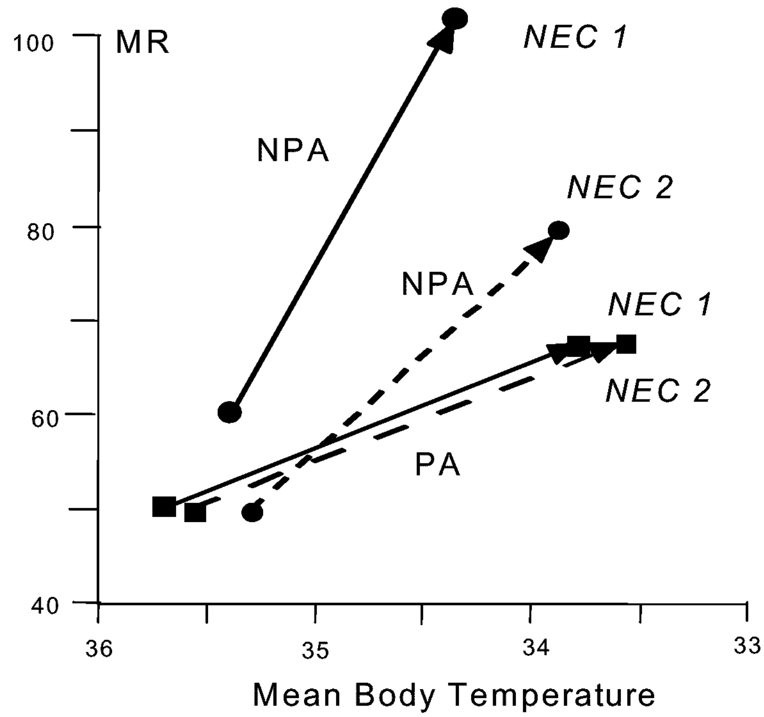


Figure 14. Change in the metabolic rate (MR) as a function of mean body temperature. A significant difference existed between the NPA and PA groups prior to the Arctic sojourn (NEC 1) and after 16 days in the Arctic (NEC 2).

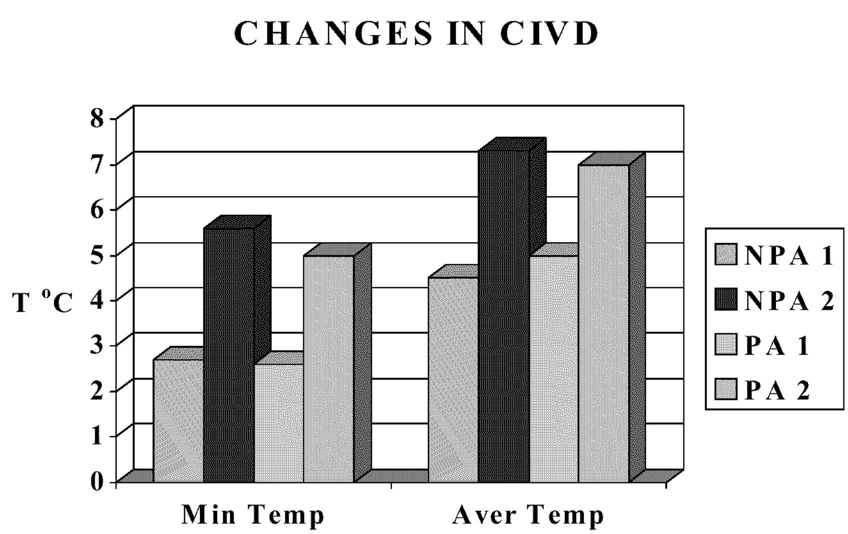


Figure 15. Changes in the Cold Induced Vasodilation response before and after 16 days in the Arctic. Min Temp is the lowest temperature to which the fingers dropped, and Aver Temp is the average temperature over the period of immersion of the finger in ice water.

Cold diuresis is a well-known condition in humans exposed to cold and this was evident in our NPA group during the night with significantly increased urine output (Figure 16). Cold diuresis also interferes with sleep as subjects find themselves getting out of their sleeping bags to urinate, thus increasing their cold exposure during the night. However, we were surprised to find that the PA subjects showed no cold-induced diuresis during their sojourn in the Arctic suggesting that the normal decrease in ADH found in the cold was prevented by prior cold adaptation. The 17-OHCS response was similar to the diuresis response, with the NPA group showing increased excretion of 17-OHCS during the night, reflective of a stress response, whereas the PA group showed no such stress response.

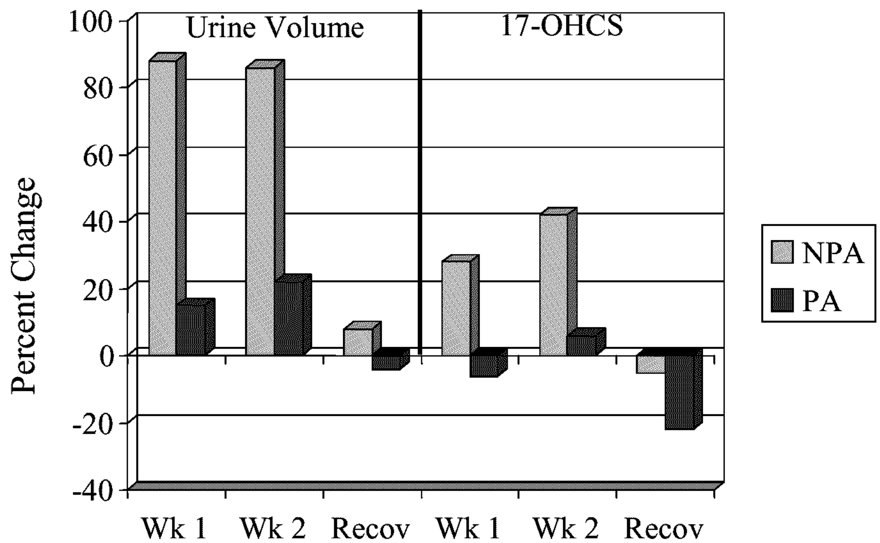


Figure 16. Cold-induced diuresis and 17-OHCS excretion in NPA and PA subjects in the Arctic. The values are expressed as percent change from normal.

We also found significant differences in hormonal responses between the two groups in the Arctic (Figures 17). Although the NPA group showed the expected increase in noradrenaline as has been observed by others, no such increases occurred in the PA-group, a characteristic of IS-adapted animals. It is known that IS adaptation of animals results in no changes in noradrenaline excretion or sensitivity to noradrenaline. This is in keeping with a hypothermic insulative type of adaptation.

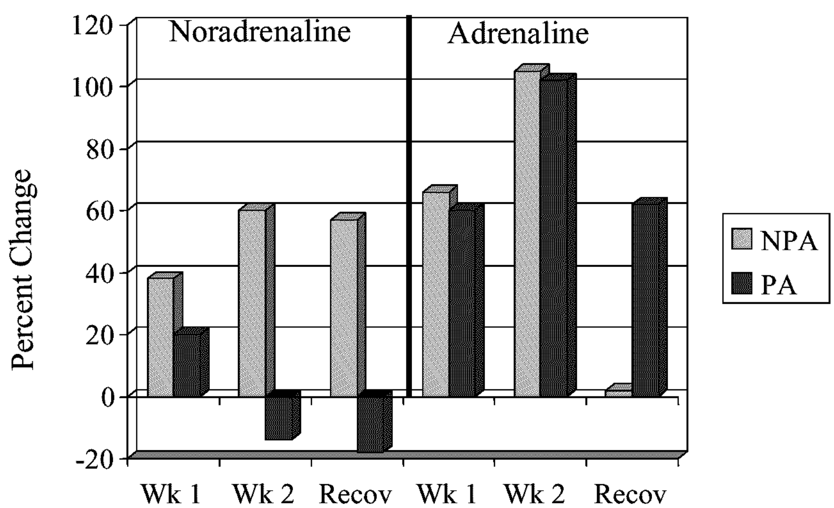


Figure 17 .Percent change in norepinephrine and epinephrine excretion in the NPA and PA groups in weeks 1 and 2 in the Arctic and during recovery in a temperate environment.

We were only able to do polysomnography on the NPA subjects. However, insomnia did occur as a result of the cold stress at night, mainly in the second half of the night (Figure 18). This was accompanied by intense shivering and awakenings.

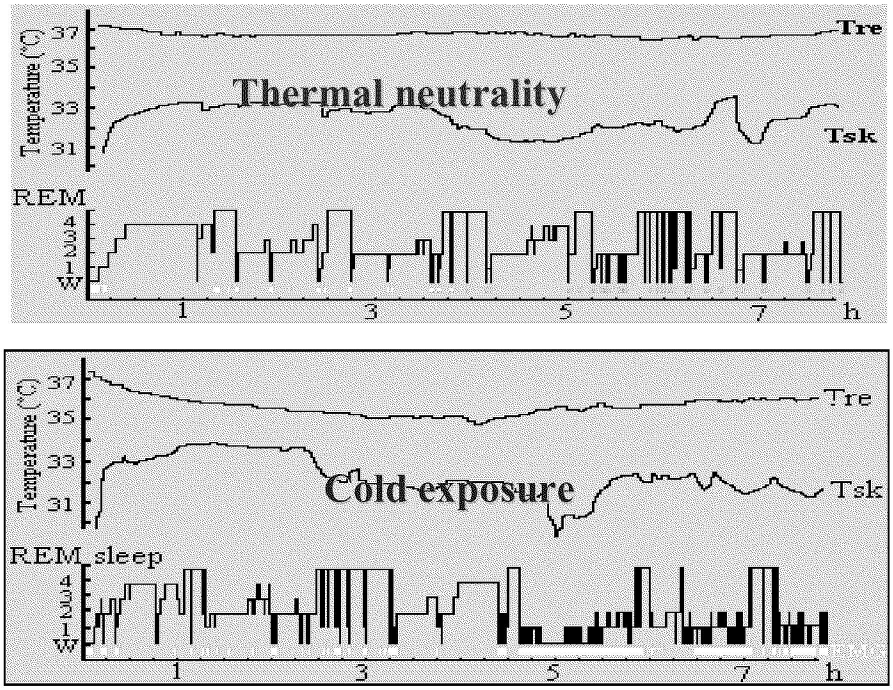


Figure 18. Rectal temperatures and hypnograms during sleep under thermal neutral conditions and during sleep in the tent in the Arctic.

The major sleep change was a chronic depression in paradoxical sleep, which appeared to be inversely correlated with 17-OHCS excretion and environmental temperature (Figure 19). As the excretion of 17-OHCS increased with a decreasing environmental temperature, the amount of PS deprivation increased. Other stresses have been found to produce similar effects.

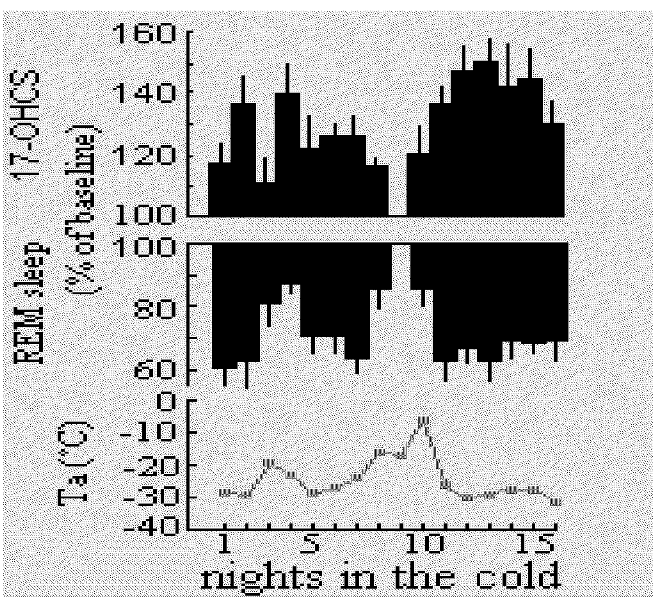


Figure 19. Variation in paradoxical sleep, environmental temperature, and 17-OHCS excretion.

Kool Stool Conclusions

In conclusion, it appears that IS technique using cold water immersions is (Figure 20):

- a rapid technique for inducing cold adaptation
- eliminates cold diuresis and therefore allows undisturbed sleep,
- persists over a significant period of time of the order of a month,
- results in a shift of the shivering threshold to a lower body temperature,
- requires a shorter period of time to induce and is a simple technique,
- similar to the hypothermic insulative responses shown by the Aborigines and the Bushmen.

In terms of military practical value, the IS technique would appear to be the method of choice for rapidly increasing cold tolerance in troops, such as special forces that might be airlifted at short notice into extreme thermal climates.

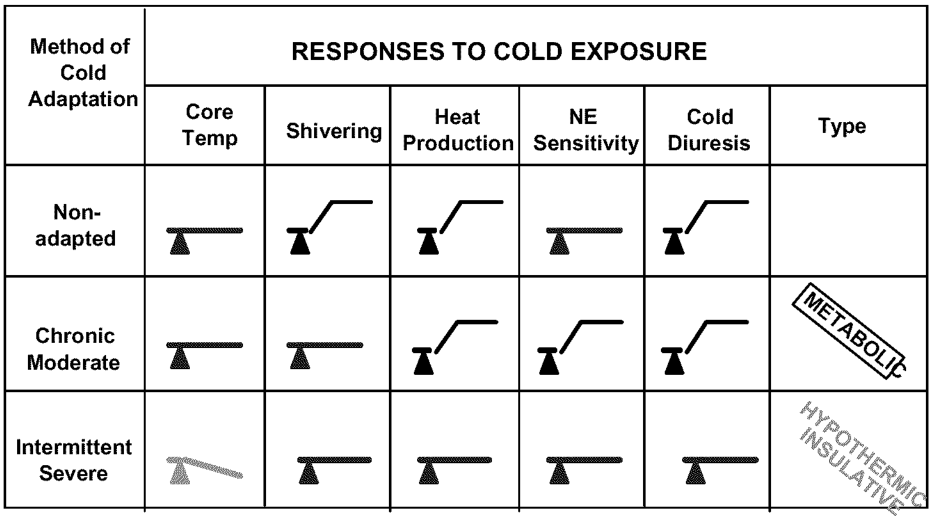


Figure 20. Summary of responses of non-adapted and cold-adapted humans and laboratory animals on subsequent exposure to cold (adapted from LeBlanc 1978).

This paper has attempted to review some of the classical studies of how different human populations have adapted to the cold with a minimum of resources and how one could induce an adaptation similar to these groups in a relatively short period of time. The rest of this Symposium will address the current advances in protecting man from cold and hot environments through technology, but technology does break down, and perhaps a combined approach of protection and rapid adaptation will prove more beneficial rather than solely relying upon technology

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