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Paper No. : 06 Human Growth Development and Nutrition

Module : 8 Adaptation of growth rates to cold stress

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Subject Name	Anthropology
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Summary

Learning Objectives

1. Find out how human adult physiologically respond to both chronic and acute cold stress
2. Determine the physiological responses of newborn infants to cold stress.
3. Examine the adaptive responses of human growth rates to cold stress.
4. Find out how humans acclimatized to cold climates
5. List out the individual factors that determine tolerance to cold stress.
6. Understand how man adapt himself in cold water.

Introduction

Adaptation is the process of physiological, genetic and biochemical modification to a particular environment and/or stress in order to survive and reproduce. It involves five levels: Genetic adaptation (evolution of advantageous characteristics), developmental adaptation or plasticity (acquiring of appropriate responses in a particular environment during growth) and long term acclimatization (acquired over the years but reversible during change in environment), seasonal acclimatization (changes reversible annually) and short term acclimatization (daily or irregular responses to changes).

The rate of growth is affected both by intrinsic (genetic) and extrinsic (environmental) factors. By mid-twentieth century, slower maturation and reduced growth which were responses to physical environment were considered adaptive. Since the 1960s, the theory that growth is a way for humans to adapt to their immediate surrounding has been there. This theory is different from the view that slow growth is a direct effect of adverse conditions like socio-economic status or dietary patterns. Thus researchers used two contradictory interpretations of growth patterns influenced by environment. Cold climate is one of the physical environmental factors affecting growth rate which is interpreted in an adaptive framework.

In a man's life, he is particularly susceptible to cold stress during the few months after birth and old age. This chapter discusses the effect of cold stress on human growth rate, physiological responses with which man counteract such stress, the individual factors that modify and affect these responses and the process of acclimatization to cold stress.

1. Physiological responses to chronic cold stress: Adaptive changes

Physiological responses to cold are dependent upon the age and the physical fitness of the concerned individual, intensity and duration of exposure to cold temperature.

The amount of insulation determines the degree of cold stress. The moderate cold stress experienced for prolonged periods of time, either seasonally or throughout the year is referred to as chronic cold stress. During prolonged cold exposure, homeothermy can be maintained by two mechanisms:

(i) Enhancement of metabolic processes which increases heat production(metabolic adapatation)
(ii) Increased insulation or its correlates to decrease heat loss (Insulative adaptation)

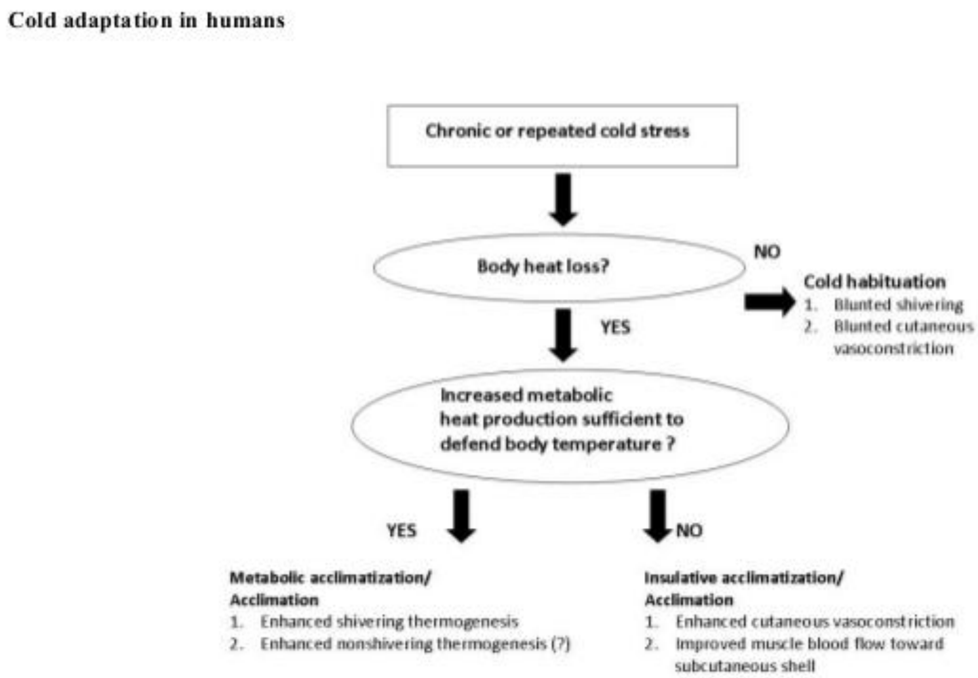

Fig 1: Cold adaptation in humans

(Source:http://loneswimmer.com/2011/04/17/extreme-cold-adaptation-in-humans-part-3/)

1.1Metabolic Adaptation to cold

Nonshivering cold-thermogenesis localized mainly in brown adipose tissue is developed and less economical shivering thermogenesis is gradually replaced for increased tolerance to severe cold. Changes in secretion, release and physiological effects of catecholamines with nonadrenaline causes greater heat production .

1.2 Insulative adaptation to cold

Cold acclimatization in man is done by an increase in the thickness of the subcutaneous fat which acts as an insulating agent.

1.3 Hypothermic cold adaptation

Hypothermic cold adaptation involves the development of hypothermia i.e., reduced thermogenic response to cold, due to the shift of the threshold for cold defense reactions to the lower levels of skin and the cervical spinal cord temperatures. This may be caused when an individual is attributed to repeated cold stimuli. This result in a decrease in core body temperature(temperature of brain,thoracic and abdominal viscera) and reduce shivering. Reduced shivering is more economical and it increases cold-tolerance. This kind of cold adaptation can be found among the Amas (Korean women pearl divers) and Australian aborigines.

2. Physiological effects of acute cold stress

When an individual is subjected to severe cold stress for short periods of time, then such kind of cold stress is referred to as ‘acute’.

2.1 Changes in body heat loss

Core temperature is maintained at a higher level than the surrounding environment but since heat is lost from the surface of the body, the skin is cooler than the core of the body. This gradient of temperature between the core of the body and the skin can be modified by altering insulation of the skin and the tissues in order to regulate heat loss by convection and conduction. Insulation of the tissue is determined by the thickness of the skin and the subcutaneous fat and the rate of blood flow in the tissues.

2.1.1Vasoconstriction

When an individual is subjected to a temperature of 0ºC or even 15ºC, subcutaneous blood vessels are constricted to reduce the cutaneous blood flow. Vasoconstriction directs the flow of venous blood through the veins that are close to the arteries .As such, arterial blood entering the limb at a high temperature comes in contact with cooled venous blood. A countercurrent heat exchange establishes across the walls from the arteries to the veins. This mechanism helps in decreasing the skin temperature and conserves the metabolic heat of and the body core thereby less heat is lost.

People suffering from Raynaud’s disease or anoxeria nervosa have a local defect in their blood vessels and hence they exhibit an increased vasoreactivity to cold environment.

Vasoconstriction is produced by the efferent sympathetic nerves and this sympathetic stimulation can be reinforced by cooling of the skin.

2.1.2 Vasodilation

When skin temperature falls below 10ºC, blood vessels in the hands and feet dilate frequently which is referred to as vasodilation. This occurs when the body core is warm and the extremities are exposed to cold. The cyclic phenomenon of the body wherein the body alternates back and forth between vasoconstriction and vasodilation to compensate for the risks created by both the mechanisms was first described by Lewis in 1930 and is known as ‘Lewis hunting phenomenon’(Fig). The intensity of the “hunting rhythm” varies in healthy individuals .

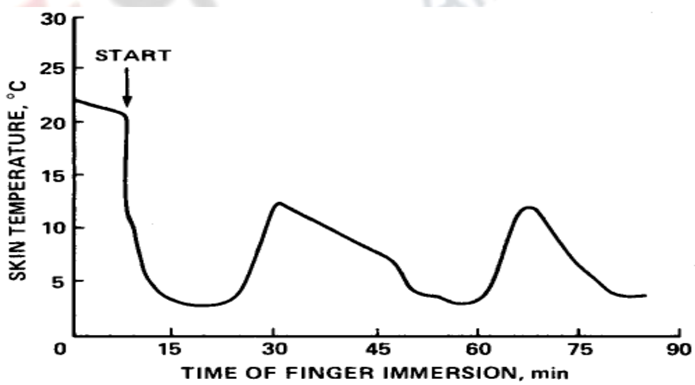

Fig:2 Lewis hunting phenomenon : Immersion of a finger in ice water (from Lewis 1930)

2.1.3 Loss of heat from the head and trunk

At 4ºC, heat loss from the head accounts for one half of the total resting heat production. The facial skin due to its close proximity to the thermal core areas, stabilizes well above freezing even under severe cold conditions although facial circulation doesn't undergo vasoconstriction.

By physical conductance, heat is transferred from the deep tissues and organs to the body surface. Therefore, a person immersed in cold water loses little heat from the extremities and more heat from the trunk due to high tissue conductance to this area.

2.1.4 A protective layer-subcutaneous fat

Subcutaneous fat reduces heat loss from the body and cools the body core and extends the thermal metabolic responses to cold. The minimum core temperature of the body when exposed to 10ºC or 15º C has been found to be positively associated to body fat percentage which is indicative of less cooling ability in obese individuals than lean ones. An inverse correlation was seen between the skin temperature and body fat percentage. Body fat plays an active role in the metabolic reaction to cold as it is observed that the lowering of the respiratory quotient with duration of cold exposure is more in obese than lean individuals.

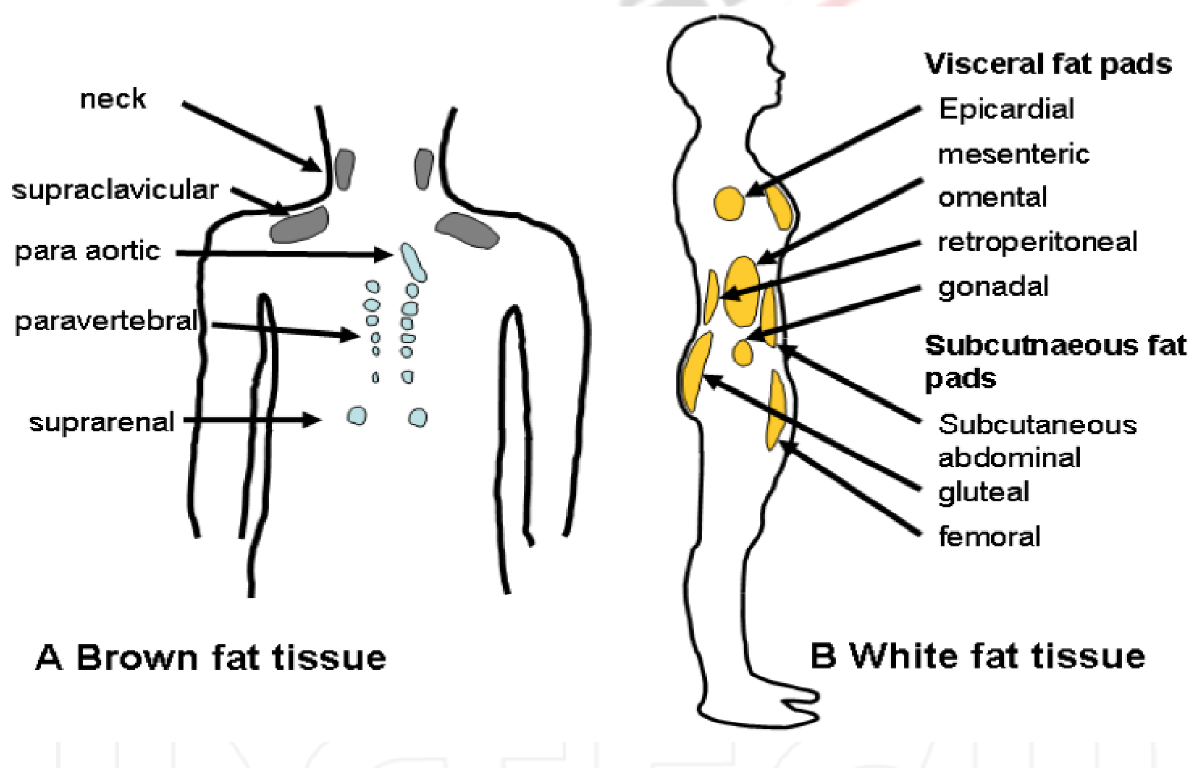

Fig 3: Distribution of Brown Adipose and White Adipose tissue in adult

(Source: https://www.quora.com/How-does-weather-affect-energy-utilization-in-the-human-body)

2.2.1 Shivering thermogenesis

The body tries to adapt to cold stress by increasing the rate of heat production through shivering when the vasoregulatory mechanisms are not sufficient to counteract the heat loss. Shivering refers to the involuntary contractions of the skeletal muscles throughout the body for regulating heat production when exposed to cold surrounding for a long period. The primary muscle response to cold exposure is termed as “preshivering” or “thermal” muscle tone. Both preshivering and shivering contractions appear first in the extensor muscles of the upper limbs and the trunk followed by the extremities.

2.2.2 Magnitude of shivering

While shivering, the average increase in metabolism is 4 to 5.5 times the level of basal metabolic rate (BMR). Physical fitness, body size, insulation, etc., are the factors responsible for the onset and intensity of shivering. It is suppressed by physical exercise i.e., voluntary muscle contractions although this does not occur when body temperature is reduced.

2.2.3 Control of shivering

Neurons activated by the stimulation of cold receptors controls shivering. The primary center involved in controlling shivering is located in the dorsomedial posterior hypothalamus. Secondary centers are in the ventro-lateral posterior hypothalamus,ventro-medial forebrain septum,ventro-medial preoptic region of anterior hypothalamus and some points of the cerebral cortex. Cooling and warming of the spinal cord evokes shivering and reduces shivering respectively.

3. Physiological responses to cold in infants

An infant is exposed to severe cold stress at the moment of birth as he is delivered naked to the extra uterine environment from the warm maternal environment. A newborn respond to the cold temperature by vasoconstriction and then by nonshivering heat production .Thin skin, high body surface to mass index, scanty subcutaneous fat, inability to shiver and very poor motor development account for thermal instability of the newborn babies.

3.1 *Metabolic changes after birth*

An increase in the weight of the metabolically active tissues in relation to weight of the body with reduction in the extracellular body fluid volume may be a factor for rapid increase in metabolism within the first few days of life after birth. An infant produces heat by metabolizing his carbohydrate and fat stores (mainly brown adipose tissue). The infant’s liver glycogen is completely exhausted within few hours following birth and blood glucose concentration falls very low.

3.2 Metabolic responses in Newborn babies

During the first 12 hour after birth, the metabolic response to cold is very light as compared to infants more than 4 days old. All babies become very active at very low temperature but their rectal temperatures fall at a rate of 1ºC/hr. This indicates that a baby left unclothed at a room temperature may become hypothermic. Even clothed babies may increase heat production to compensate the cooling of uncovered faces or for cool air that is breathed in.

3.3 Mechanisms of thermogenesis of brown adipose tissue

Uncoupling of oxidation with ATP synthesis in the brown adipose tissue generates heat. It is controlled by the central nervous system. Heat production in the tissue is enhanced by the interaction of the noradrenaline and beta-adrenergic receptors of the brown adipose membrane.

3.4 Factors affecting the amount of brown adipose tissue in newborns

Thermogenic capacity of brown adipose tissue in newborns is enhanced by short periods of starvation towards the end of gestation period or feeding with a diet containing linoleic acid. Tolerance of cold in newborns is decreased when brown adipose tissue is reduced due to prolonged maternal undernutrition.

4. Adaptive responses of human growth rates to cold stress

Cold climate effects growth and development, body size and proportions. This can be expected as we can see the differences in the physique of man. Body size and proportions of warm-blooded polytypic animals are related to temperature according to Allen's and Bergmann's rules. Allen's rule states that longer extremities relative to body size are found in warmer climates and vice versa in colder climates. While, Bergmann's rule states that a larger body size is expected in colder than warmer temperatures. A delay in skeletal age .i.e., a difference about a year in adolescence is seen among the people living in hot regions due to their linear build. People in colder climates are found to be heavier with larger trunks and shorter legs .Rates of weight gain is fastest in winter. Greatest increase in weight often is in September through November. This seasonal rhythm is not established on children until they are 2 years old. However this seasonal trend doesn't conform to the individual growth patterns due to differences in endocrine reactivity. But climate seems to have a minor effect on overall human growth rate. Few studies have examined the relationship of growth patterns to temperature. Each major race of mankind differs in stature according to the climatic condition they are subjected to live. Growth variation during different seasons have been observed .A longitudinal study suggested that 30% of the children have increase and decrease growth velocity cycles dependent on season while the remaining children showed growth accelerations and decelerations which could not be associated with seasons.

Body's thermoregulatory process can be used to explain the relationship between body proportion and the temperature of the environment. In cold environments, heat retention is vital to avoid hypothermia, hence less body surface area is more essential. Crognier studied the relationship between anthropometric measurements and climate in East African, Middle Eastern and European populations and found out that low temperature was correlated with cranial measurements. He said that it could be due to the capability of the brachycephalic head shape to retain more heat in colder climates but this argument could not be accounted for the correlation as cultural practices to protect the head such as hat were present. Boas also found out that the shape of the skull is plastic and can be changed only in a single generation. At the end of the 19th century, children of immigrants to the US were found to have a different head shape than their parents. Malina and Bouchard suggested that growth in cold climate is shortened due to the relationship between a sturdy body type and early maturation. Bogin studied growth patterns in height of children in Gautemala and found out that preadolescent boys and girls and post-adolescent boys showed a seasonal pattern while adolescent children do not. Some studies had suggested that the seasonal rhythm of weight gain exists in children. Lower incidences of menarche were observed in Finland and South Africa during the winter months. A study on children and adolescents in response to exercise in the cold was conducted among club swimmers in a pool at 20.3ºC and it was observed that the rate of cooling decreased with age in both the gender. Children with less subcutaneous insulation and with large surface to body weight ratio had the fastest rate of cooling.

(A) An Inuit family

(B) Eskimos of Alaska

Fig 4: Artificial adaptation to cold stress among the inhabitants of cold regions.

4.1 The Mongoloid face

Coon, Garn and Birdshell have hypothesized that the Mongoloid face is adaptive of life in colder climates. People living in colder regions such as the Arctic and northern Asia have broad, flat faces which helps them in reducing the effects of frostbite. Brow-ridges, frontal sinuses and nasal prominence are reduced, orbital and malar regions are more flattened and widened to retain more layers of fat for additional warmth.

4.2 Eyes

The epicanthic fold common among Northern and Eastern Asian populations is a protective feature of the eye from the hard driving snow typical in these regions.

4.3 Skin colour

Lighter skin is prevalent among the people living in colder regions as this allows the penetration of the sun's ultraviolet rays which helps the body in synthesizing vitamin D.

4.4 Nose-shape

Smaller, longer and narrower noses are generally found among the people in colder regions. This adaptive feature of the nose moistens and warms the incoming air because the vapour pressure helps in the exchange of moisture between the respiratory surface and the air. The activity of the cilia of the nose is reduced more by drying than by heating or cooling. Under normal conditions, soot and bacteria are cleared in the respiratory tract through mucus secretion. The rate of mucus secretion is positively correlated with humidity of the inspired air. This sensitivity of the drying of the respiratory epithelium could be the cause for high incidence of sinus and respiratory infections among the Eskimos.

4 .5 Hair

Straight hair is mostly found in people living in colder climates as it keeps the neck and head warm and also allows cold moisture to run off the scalp more easily.

5. **Acclimatization to cold**

5.1 Metabolic adaptation in man

Acclimatization means increased tolerance to cold. It develops gradually. Newcomers to Arctic regions wear all their clothing in the beginning but as winter approaches and temperature falls, they no longer sought any extra protection. Men who go for expeditions during winters wear less at work than at the beginning. The members of such expedition who spent more time indoors were found to have suffered frostbite at low temperatures within 1½ minutes while those who spent more time outdoors resisted frostbite for nearly 10 minutes. Well adapted individuals are keener in appreciating their lower limb and take necessary precautions to prevent frostbite.

The rate of heat production is decreased in winter as can be seen among the Norwegian, British and Swedish men. On the contrary, an increase in heat production in winter was observed among the Japanese and the lack of this response in western people temporarily living in Japan was attributable to differences in diet, physical activity and body surface area. Eskimos also showed larger increase in BMR than Europeans living in the same cool environment. An increase in BMR in winter also occurs among the Korean Amas who dive throughout the year wearing bathing suits. BMR as a defense mechanism against body cooling in water seems to be less important. It remains uncertain that metabolic alterations depends on direct cold exposure or endocrine function or on peculiarities of diet but may depend on the stimulation of sympathetic activity.

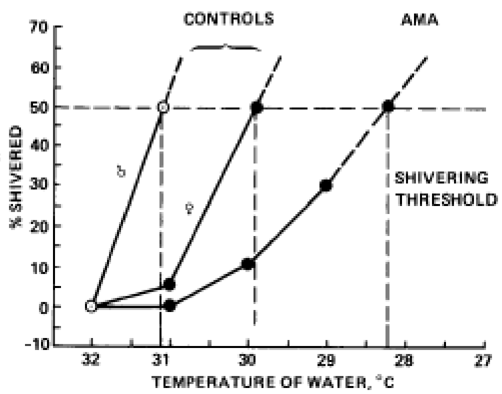

Fig 5: Comparison of shivering thresholds in control Korean women and men with Korean amas(from Hong,1973)

Fat is perhaps more important than protein in exerting an adaptive response to cold. This kind of insulative adaptation can be directly related to the channel swimmers. Inhabitants living in the Arctic region consume large quantity of fat in order to keep their bodies warm. In conditions of severe exposure, increase in the production of heat reduces the fall of the rectal temperature. This allows the skin temperature to rise thereby, bringing in comfort to the individual under cold stress.

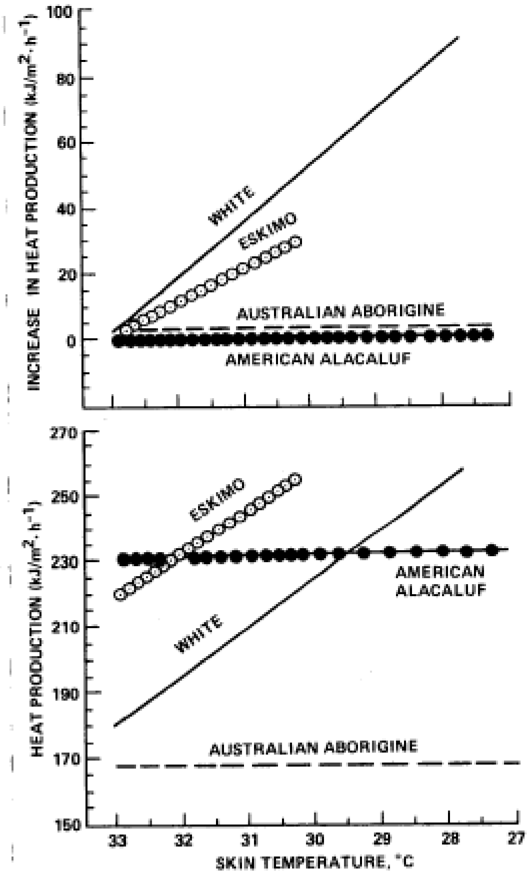

Fig 6: Thermal responses to skin cooling in representatives of various ethnic groups (from LeBlanc, 1975)

5.2 Local cold exposure

Local acclimatization is prevalent among the Eskimos, Arctic Indians,fisherman, lumbermen,etc. Men living or working in cold climate expose their hands and face more than the parts of the clothed body. It has been found that people who habitually expose their hands to cold respond to local cooling of their hands by less vasoconstriction and rapid vasodilation than unacclimatized individuals. Cooling of the hands reduces numbness and preserves the dexterity of the hand .It also causes elevation in blood pressure and increase in heart rate. Local face cooling also occurs wherein there is decrease in heart rate and elevation of blood pressure leading to a condition known as 'bradycardia'. However such a response could impose an extra load on the heart producing ischemia. A group of participants were kept in a cold room for 2 hours a day, 5 days a week for 5 weeks at -15ºC with heavy clothing but no hand gloves. They showed reduced tactile discrimination but the outdoor group scored higher on tactile discrimination than the indoor group. This point to a greater resting finger and blood flow in the hand of the habituated group. Hence cold acclimatization can be acquired. The central Australian aborigines sleep naked at about 0ºC and -45ºC. Under the same conditions, the field investigators were unable to sleep due to shivering and low skin temperatures. Similarly, the Bushmen of the Kalahari sleep under the same extreme cold environment with a single covering and a small fire. Europeans can also attain a high degree of cold tolerance. Norwegian students who stayed in the open for 6 weeks could not sleep with minimal exterior insulation but were able to sleep later .Eskimos have a greater tolerance to cold in the hands than the Europeans. Eskimo, Indian, Negro and European participants were immersed in water near freezing point. Negroes revealed a greater propensity to frostbite which was attributed to their experience in the Korean war. The ability of acclimatized man to use their hands efficiently is related to increased flow of blood.

6. Tolerance to cold: Individual factors

Heat transfer follows Fourier's Law which states that the heat loss per minute is directly proportional to the surface of the body, the difference between the temperature of the body and the environment.

6.1 Surface area

The heat required to maintain homeostasis will be greater in a small than a large individual because the surface area is greater per unit of body weight when the total body is smaller. This same principle applies to children as well. A significant negative correlation between rectal temperatures and the measurements of hand and foot size of the highland Peruvian Quenchua Indians were observed when hands and feet were exposed for 2 hours at 10ºC.

6.2 Insulation of fat

The most important factor for heat loss is the degree of natural or artificial insulation. The thermal conductivity of subcutaneous fat is less than the muscle since it is not well vascularized. Due to this reason, the gradient between the body's surface temperature and the environment is smaller when the fat layer is greater. Thin individuals have increased heat production when immersed in cold water because of less fat insulation. Survival in cold water depends on the amount of the subcutaneous fat and the artificial insulation, eg., clothing. The effectiveness of subcutaneous fat depends on physical activity. Individuals having the same fat thickness who were swimming experienced a greater fall in rectal temperature than those who were at rest. This heat loss from activity could be detrimental for individuals with a high fat layer for human survival in cold water.

6.3 Gender

One would expect that under cold stress, women's internal body temperature would be more stable than men as they tend to be fatter than man. But since women usually have lower body weight and high ratio of surface area to weight than men, they have more areas for heat loss and less heat-producing capability.

6.4 Exercise

At a given water temperature during exercise, both men and women maintain same thermoregulatory responses and these benefits were due to the added heat production from physical activity.

6.5 Physical fitness

Seventeen healthy male volunteers were exposed to cold stress at 1º, 5º and 10º C and it was observed that the production of heat was directly correlated with maximal oxygen uptake. Maximal oxygen uptake is the peak value of oxygen consumption by an exerciser at the point of exhaustion or fatigue. This implies that fit individuals have more efficient thermoregulatory mechanisms against cold stress than unfit individuals.

6.6 Age

All the thermoregulatory responses can be triggered instantly after birth, even in premature babies. Without shivering, their heat production can be increased 100-200% above the resting metabolic rate. But due to larger surface area to volume ratio of newborns than adults, vasoconstriction is not as effective in adults for reducing heat loss. Thus if thermal balance has to be maintained at low metabolic rate in the newborn then the temperature must be 32-34ºC than the adults. Thermoregulatory responses are better in young adulthood than in old age as measured by responses of the fingers of the hand. Cold-induced vasodilation of the fingers and the hunting waves were more rapid in the no adult individuals than the older adult individuals. Recently, men from 20-73 years were exposed to 10º, 15º, 20º and 28ºC temperatures. It was observed that the older men have increased metabolic rate than the younger adults indicating that older people are more susceptible to cold stress than young individuals.

7. **Man in cold water**

Man can stay in a very narrow temperature range in water as compared to air without experiencing excessive cooling because the thermal conductivity and specific heat of water is 25 times and 4000 times greater than the values of air respectively. Hence a nude man will have difficulty in reducing heat loss in water even at a moderate temperature (20ºC-25ºC).The cold stress produced by the aquatic environment may become so severe and become life threatening too. The most vital factor determining the variability in cooling rate in water is the thickness of the subcutaneous fat. An obese person cools at a slower rate than a lean person and it can be a matter of life and death when immersed in water. Thermal balance in water is maintained by an increase in heat production by shivering. Heat conductance to the skin is increased due to the increased in blood flow during shivering or voluntary muscular contraction. This elevates the heat loss which is proportional to the difference between the temperature of the body core and the water. Heat loss by convection also doubles due to increased water turbulence created by the movements of the body during swimming. Individuals who worked at moderate intensity in cold water have an increased body temperature than when they worked as hard as possible. But maximum work can be performed only for a short period of time. The lean child cools very rapidly in water at 20ºC due to the large surface area of the skin per mass of the body facilitates heat loss from the body. In many regions of the world, swimming is common in 20ºC, however this may pose a risk for small, lean young swimmers who have not developed cold defense.

Summary

Adaptation is the process of physiological, genetic and biochemical modification to a particular environment and/or stress in order to survive and reproduce. It involves five levels: Genetic adaptation, developmental adaptation or plasticity, long term acclimatization, seasonal acclimatization and short term acclimatization. Cold climate is one of the physical environmental factors affecting growth rate which is interpreted in an adaptive framework.

The moderate cold stress experienced for prolonged periods of time, either seasonally or throughout the year is referred to as chronic cold stress. During prolonged cold exposure, homeothermy can be maintained by two mechanisms: Enhancement of metabolic processes which increases heat production(metabolic adaptation) and increased insulation or its correlates to decrease heat loss (Insulative adaptation).When an individual is subjected to severe cold stress for short periods of time, then such kind of cold stress is referred to as 'acute'. Under acute cold stress, subcutaneous blood vessels are constricted to reduce the cutaneous blood flow and direct the flow of venous blood through the veins that are close to the arteries (vasoconstriction).When skin temperature falls below 10ºC, blood vessels in the hands and feet dilate frequently which is referred to as vasodilation. The cyclic phenomenon of the body wherein the body alternates back and forth between vasoconstriction and vasodilation to compensate for the risks created by both the mechanisms was first described by Lewis in 1930 and is known as 'Lewis hunting phenomenon'. Subcutaneous fat reduces heat loss from the body and cools the body core and extends the thermal metabolic responses to cold. Heat production in response to cold is done by a process called

shivering when the vasoregulatory mechanisms are not sufficient to counteract the heat loss. A newborn respond to the cold temperature by vasoconstriction and then by nonshivering heat production

Growth can be considered as a monitor of the quality of the children's environment. Allen's rule states that longer extremities relative to body size are found in warmer climates and vice versa in colder climates. While, Bergmann's rule states that a larger body size is expected in colder than warmer temperatures. People in colder climates are found to be heavier with larger trunks and shorter legs. Malina and Bouchard suggested that growth in cold climate is shortened due to the relationship between a sturdy body type and early maturation. Bogin studied growth patterns in height of children in Gautemala and found out that preadolescent boys and girls and post-adolescent boys showed a seasonal pattern while adolescent children do not. Lower incidences of menarche were observed in Finland and South Africa during the winter months. A study on children and adolescents in response to exercise in the cold was conducted among club swimmers in a pool at 20.3ºC and it was observed that the rate of cooling decreased with age in both the gender. People living in cold climates have broad, flat faces which helps them in reducing the effects of frostbite. The epicanthic fold common among Northern and Eastern Asian populations is a protective feature of the eye from the hard driving snow typical in these regions. Lighter skin allows the penetration of the sun's ultraviolet rays which helps the body in synthesizing vitamin D. Smaller, longer and narrower nose moistens and warms the incoming air .Straight hair keeps the neck and head warm and also allows cold moisture to run off the scalp more easily.

Acclimatization means increased tolerance to cold and it develops gradually. Newcomers to Arctic regions wear all their clothing in the beginning but as winter approaches and temperature falls, they no longer sought any extra protection. It has been found that people who habitually expose their hands to cold respond to local cooling of their hands by less vasoconstriction and rapid vasodilation than unacclimatized individuals. Local face cooling also occurs wherein there is decrease in heart rate and elevation of blood pressure leading to a condition known as 'bradycardia'. Man can stay in a very narrow temperature range in water as compared to air without experiencing excessive cooling because the thermal conductivity and specific heat of water is 25 times and 4000 times greater than the values of air respectively. Individual factors responsible for tolerance to cold are body surface area, insulation of thickness of fat, gender, exercise, physical fitness and age.