Overview

The human body readily responds to changing environmental stresses in a variety of biological and cultural ways. We can acclimatize to a wide range of temperature and humidity. When traveling to high altitudes, our bodies adjust so that our cells still receive sufficient oxygen. We also are constantly responding in physiological ways to internal and external stresses such as bacterial and viral infections, smog, dietary imbalance, and overcrowding.

Inuit (Eskimo) living in a polar desert

This ability to rapidly adapt to varying environmental conditions has made it possible for us to survive in most regions of the world. We live successfully in humid tropical forests, harsh deserts, arctic wastelands, and even densely populated cities with heavy pollution. Most other animal and plant species are restricted to one or relatively few environments by their more limited adaptability.

Humans normally respond to environmental stresses in four ways:

biological responses (1–3)

1. genetic change
2. developmental adjustment
3. acclimatization
4. cultural practices and technology

responses without genetic change (2–4)

The first three are biological responses. The last three occur during our lifetime without further genetic change.

Genetic Change

When an environmental stress is constant and lasts for many generations, successful adaptation may develop through biological evolution. Those individuals who inherit a trait that offers an advantage in responding to particular stresses in the environment are more likely to survive longer and pass on more of their genes to the next generation. This is evolution through natural selection. For instance, people whose ancestors have lived in areas that have had endemic malaria for thousands of years often inherit some degree of immunity to this serious disease. The high incidence of sickle-cell trait among the people of Central Africa is largely the result of indirect selection for this trait by malaria. Heterozygous carriers of the sickling gene usually do not have sickle-cell anemia and are sufficiently resistant to the malarial microorganism that they are at a selective advantage. Another example of a genetic solution to an environmental stress is our ability to produce sweat as an aid in cooling our bodies in hot environments. It is not surprising that we have this capability since our prehuman ancestors were tropical animals.

Genetic change in response to environmental stresses usually takes many generations to become widespread in a population. Fortunately, we also have other ways of responding more quickly as individuals during our own lifetime. The word **adjustments** is used here to refer to these shorter term physiological changes that are not inheritable. The word **adaptations** is reserved for inheritable genetic changes developed in a population over a long period of time.

Developmental Adjustment

One of the more powerful types of adjustments to environmental stresses is a change in growth patterns and development. This occurs in childhood and typically results in anatomical and/or physiological changes that are mostly irreversible in adulthood. Such permanent changes are referred to as **developmental adjustment** or **developmental acclimatization**.

Among humans, developmental adjustments result from both natural environmental pressures and cultural practices. An example of the latter was the now illegal custom in China of tightly wrapping or binding the feet of young girls with cloth in order to hinder normal growth. While this caused permanent, crippling deformities of the foot bones, it also resulted in extremely tiny feet which were considered to be very attractive. Parents crippled their daughters with good intentions. Small feet would make them more attractive marriage partners for rich important men and save them from a life of drudgery.

X-ray of an early 20th century Chinese woman's bound foot

The growth was stunted and the bones were significantly deformed so that they could fit into a tiny pointed slipper.

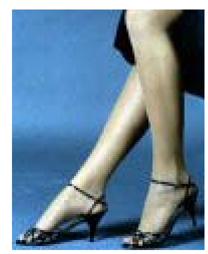
Late 19th century British actress (Lillie Langtry) who typified the ideal of beauty with her wasp-shaped waist achieved with a tight corset

It is easy to condemn the old Chinese custom of foot binding as being barbaric. However, it is worth considering that North Americans and Europeans have intentionally altered parts of the bodies of their children and themselves with unpleasant procedures as well. In the late 19th century, tight corsets worn by girls when their bodies were still growing had the effect of deforming lower rib bones dangerously in towards their lungs. Some rich women even had lower ribs surgically removed in order to achieve a stylish "wasp-shaped" waist. A 19 inch circumference was the ideal.

Intentional deformation of parts of the body is not something that only happened in the past. In China today, there is a growing concern among many upwardly mobile middle class men and women that they are too short. Thousands have sought a solution to this problem by having their legs lengthened. This is achieved by a long, painful process involving the surgical breaking of the two lower leg bones in both legs and then using adjustable metal braces that are anchored with steel pins implanted in the bone just below the knees and above the ankles to progressively extend the length by nearly 1/16 inch (about 1 mm.) a day as the bones heal. This widens the gap at the break areas, thereby stimulating new bone growth. As a result, the average patient permanently adds about 3 inches (7-8 cm.) to their height in half a year.

Intentional body deformation is a common practice in North America today as well. It is customary for middle and upper class parents to have the teeth of their children straightened with retainers and braces. This is a long, costly, and somewhat painful experience that alters the alignment of teeth. In part, it is done to preserve and improve their functioning. However, a strong motivation is to enhance appearance. Nose straightening and other forms of plastic surgery are often done for the same reason, despite the fact that they are painful. It is assumed by parents that these kinds of body alteration will increase the likelihood that their children will grow up to be more successful in life. This was also the motivation of rich Chinese parents in the past who bound the feet of their daughters and of contemporary Chinese who undergo leg lengthening.

Permanent changes to the shape of body parts may be unintended. For instance, wearing leather shoes that enclose the feet makes them narrower than they would be otherwise.   Similarly, the practice of women wearing shoes with pointed toes, high heels, and often too small of a size commonly result in a number of painful orthopedic deformities. Driving this outwardly illogical Western cultural practice is the belief that small feet are attractive for women. The American Academy of Orthopaedic Surgeons has reported that 9 out of 10 women in the United States wear shoes that are too small for their feet, and 7 out of ten subsequently have developed painful bunions, hammertoes, or other foot deformities.



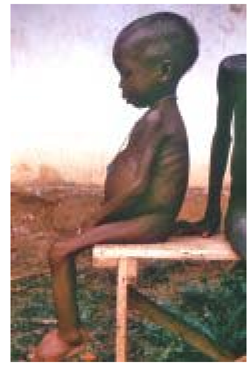
Fashionable high heeled shoes

What makes such developmental adjustments to parts of our bodies possible is the fact that humans have a high degree of **physiological plasticity**. That is to say, we can be physically molded by our environment during the growing process. Adults are the result of genetically inherited traits that were shaped to a certain degree in each of us by our environment as we grew up.

Marasmus

Extreme undernourishment or overnourishment in early childhood can result in devastating developmental adjustments. When there is a prolonged shortage of food, as is experienced in a famine situation, people can develop **marasmus**. Symptoms include extreme emaciation, diarrhea, anemia, and apathy. Women with marasmus usually stop ovulating and, subsequently, cannot become pregnant. The loss of insulating body fat makes people with marasmus highly vulnerable to death resulting from a drop in core body temperature when the air falls below 60-65° F. Young children who survive marasmus usually develop short adult stature and some degree of permanent brain damage.

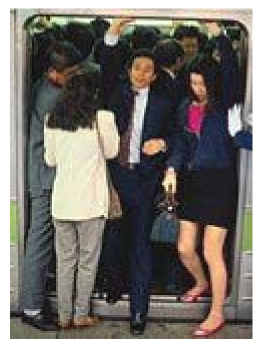
A lack of specific kinds of nutrients can result in other life threatening health problems. For instance, when babies and very young children have a diet that is extremely low in protein, they will likely develop **kwashiorkor**. Also contributing to this condition is an inadequate consumption of vitamins A and E as well as the minerals zinc and selenium. Typical symptoms of kwashiorkor include edema (or swelling) due to fluid retention (especially in the abdomen), stick-like legs and arms with little fat or muscle mass, apathy, and loss of hair and skin pigmentation in patches. As in the case of marasmus, children with kwashiorkor are likely to have their growth retarded.



Kwashiorkor

Even specific vitamin deficiencies alone can result in serious health problems for children despite otherwise adequate diets. For example, a lack of vitamin D can cause the bone disease known as rickets, while inadequate amounts of vitamin A can cause permanent blindness and impair the immune system. Nearly 100 million people in the world today have vitamin A shortages. Most live in Asia. In order to reduce this deficiency, a new strain of genetically modified rice ("golden rice") that has relatively high amounts of vitamin A is now grown extensively in Asia. However, a diet that has too much vitamin A is equally harmful. It can cause birth defects (especially cleft palate) and can interfere with the cells that produce new bone, resulting in a dramatic increase in the risk of fractures.

Developmental adjustment does not only result in defects and disorders. Dietary changes also can have a positive effect if nutrition is improved. This has been the case in Japan since the end of World War II. The Japanese Education Ministry reported that children have been significantly taller in each generation since then. In 1986, for instance, 14-15 year old Japanese boys averaged 7 inches taller than did comparable aged boys in 1959. A key changing factor in Japanese lifestyle has been diet. It is likely that this was mostly responsible for the increased body size. Between 1961 and 1971, Japanese consumption of animal protein rose 37% while plant food consumption dropped 3%. In the cities of Japan and other increasingly affluent areas of East Asia, food habits have changed dramatically over the last several decades. Hamburgers, pizza, and other high fat Western foods are very popular with the young and affluent. In Japan today about one fourth of the calories consumed are fat—this is 5 times higher than just after WWII. Lending support to the hypothesis that diet changes of this sort can result in significant developmental adjustments is a recent two year study of children in Kenya. It found that the inclusion of only 60 grams (about two spoonfuls) of meat a day to the diet of young children resulted in the development of 80% greater upper-arm muscle compared to children who were strict vegetarians. A diet that included a comparable amount of milk instead of meat resulted in an increase of 40%. Foods of animal origin are important in the diet of young children because they contain nutrients that are difficult to get from non-meat or non-dairy sources. However, too much animal protein and fat can result in obesity and other health risks.

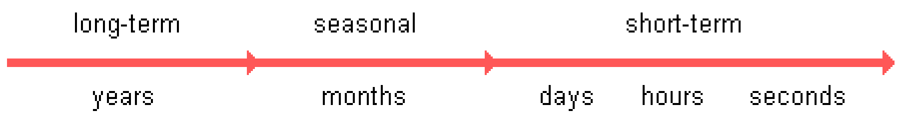


Contemporary tall Japanese

Acclimatization

All other forms of adjustment to environmental stresses are usually reversible whether they occur in childhood or adulthood. These reversible changes are referred to as **acclimatization** or **acclimatory adjustment**. It is useful to consider the different forms of acclimatization in terms of the length of time over which they can occur.

Forms of Acclimatization

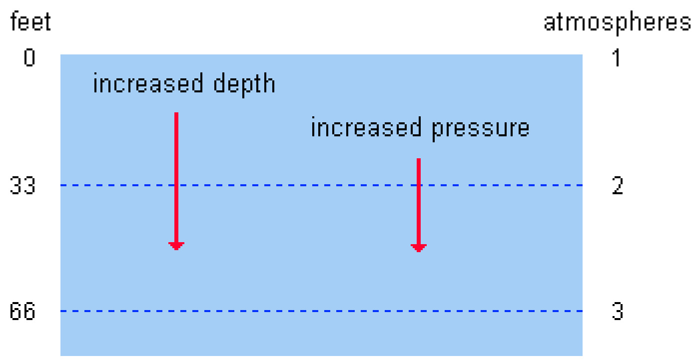


An example of a long-term acclimatization is people who lose excess body fat and are very slender as a result of mild, long-term undernourishment. If they later increase their diet to a consistent level of excessive calories, they will very likely retain more body fat and eventually become obese. They experience long-term acclimatization when they initially lose body fat and again later when they retain it. In both cases, they are acclimatizing to the available food supply.

Tanning as a seasonal acclimatization

Anatomical and/or physiological adjustments also may develop over even shorter time periods. For example, many people acquire dark skin tans during the summer months and lose them during the winter. This change in skin coloration is a seasonal acclimatization to the destructive effects of ultraviolet radiation from the sun.

When skin divers descend into the ocean, they experience rapidly increased water pressure. Within seconds, they can suffer from excruciating pain in their ears due to the unequal pressure inside and outside of their ear drums. They must equalize this pressure by blowing hard through their nose. By doing this, they are making a short-term acclimatization to the changed environment. When traveling to a high altitude, it is common to experience a progressive drop in the ability to hear due to a similar pressure inequality from one side of the ear drum to the other. This difference in pressure experienced in mountains can usually be cancelled out by yawning, swallowing, or chewing gum. However, if someone has a stuffy nose, it is often difficult to equalize the pressures. As a result, they are liable to have considerable pain in their ears.



Changing water pressure requires short-term acclimatization for skin divers

The difference between the kinds of acclimatization is not only in the amount of time it takes for the adjustment to initially occur. Usually, the shorter the time for acclimatization, the quicker it is also in reversing once the environmental stress is no longer present.

Combined Effects

Genetic adaptation and the three types of adjustments to environmental stresses are not always distinct phenomena. Acclimatization occurring in childhood may result in permanent anatomical changes, as is often the case with malnutrition. When an acclimatization is successful in providing good health and longevity, it can give individuals a selective advantage in passing on their genes to the next generation. This can have a strong determinant effect on the direction of evolution. In turn, genetic change can play a significant role in adjustment since the ability to acclimatize is ultimately dependent on genetic makeup.

Adaptability to specific environmental stresses varies from person to person and from population to population. We are not all biologically equal. For instance, some groups of people are more successful in adjusting to high altitudes. Others can better handle intense heat and high humidity. Adaptive responses tend to occur in spatial clusters around the world. Usually, the most efficient adaptations for specific environmental stresses are found in areas where those stresses are most common. This is evidence that natural selection has occurred in the successfully adapting population.

Cultural Practices and Technology

It is important to remember that humans do not only interact with their environments biologically. We use culture as well. Over the last half million years at least, we invented technological aids that allowed us to occupy new environments without having to first evolve biological adaptations to them. Houses, clothing, and fire permitted us to live in temperate and ultimately arctic regions despite the fact we still essentially have the bodies of tropical animals.

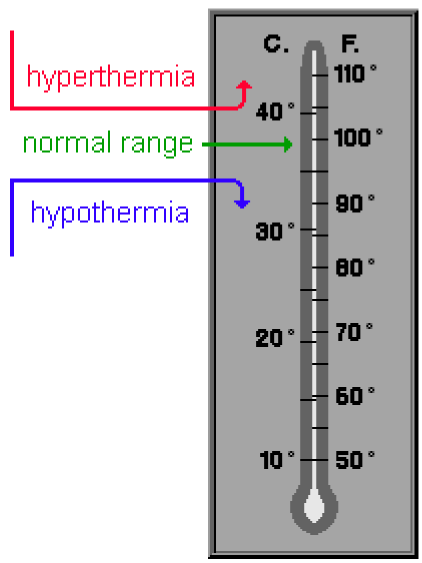
FA-18 fighter pilot using cultural
technology to adapt to high altitude

This does not mean, however, that human-made technology eliminates the biological adaptive advantages of particular individuals or groups. People who have thicker layers of fat insulation under their skin still usually survive better in cold climates, while people who are slender do better in hot ones.

In the next four sections of the tutorial you will learn how our bodies respond to several common kinds of environmental stresses.

Adapting to Climate Extremes

Humans and many other mammals have unusually efficient internal temperature regulating systems that automatically maintain stable core body temperatures in cold winters and warm summers. In addition, people have developed cultural patterns and technologies that help them adjust to extremes of temperature and humidity.



In very cold climates, there is a constant danger of developing **hypothermia**, which is a life threatening drop in core body temperature to subnormal levels. The normal temperature for humans is about 98.6 ° F. (37.0 ° C.). Hypothermia begins to occur when the core body temperature drops to 94° F. (34.4° C.). Below 85° F. (29.4°C.), the body cools more rapidly because its natural temperature regulating system (in the hypothalamus) usually fails. The now rapid decline in core body temperature is likely to result in death. However, there have been rare cases in which people have been revived after their temperatures had dropped to 57-60° F. (13.9-15.6° C.) and they had stopped breathing.

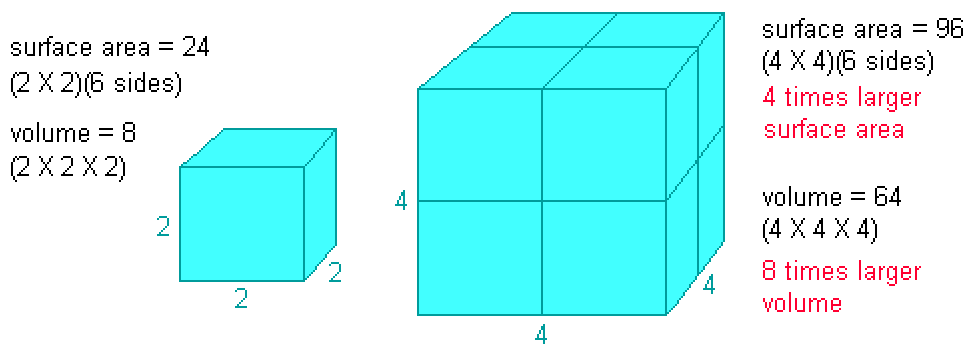
In extremely hot climates or as a result of uncontrollable infections, core body temperatures can rise to equally fatal levels. This is **hyperthermia**. Life threatening hyperthermia typically starts in humans when their temperatures rise to 105-107° F. (40.6-41.7° C.). Only a few days at this extraordinarily high temperature level is likely to result in the deterioration of internal organs and death.

Body size and shape are significant factors in how efficiently an individual responds physiologically to cold and hot climates. Two 19th century naturalists, Carl Bergmann and Joel Allen, formulated rules concerning these factors.

Bergmann's Rule

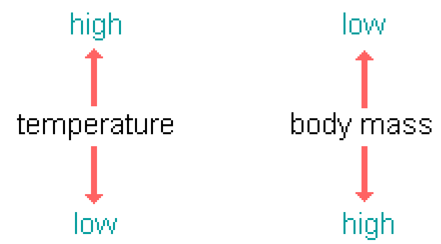
In 1847, the German biologist **Carl Bergmann** observed that within the same species of warm-blooded animals, populations having less massive individuals are more often found in warm climates near the equator, while those with greater bulk, or mass, are found further from the equator in colder regions. This is due to the fact that big animals generally have larger body masses which result in more heat being produced. The greater amount of heat results from there being more cells. A normal byproduct of metabolism in cells is heat production. Subsequently, the more cells an animal has, the more internal heat it will produce.

In addition, larger animals usually have a smaller surface area relative to their body mass and, therefore, are comparatively inefficient at radiating their body heat off into the surrounding environment. The relationship between surface area and volume of objects was described in the 1630's by Galileo. It can be demonstrated with the cube shaped boxes shown below. Note that the volume increases twice as fast as the surface area. This is the reason that relatively less surface area results in relatively less heat being lost from animals.



Comparison of cube surface areas and volumes illustrating Bergmann's rule

Polar bears are a good example of this phenomenon. They have large, compact bodies with relatively small surface areas from which they can lose their internally produced heat. This is an important asset in cold climates. In addition, they have heavy fur and fat insulation that help retain body heat.

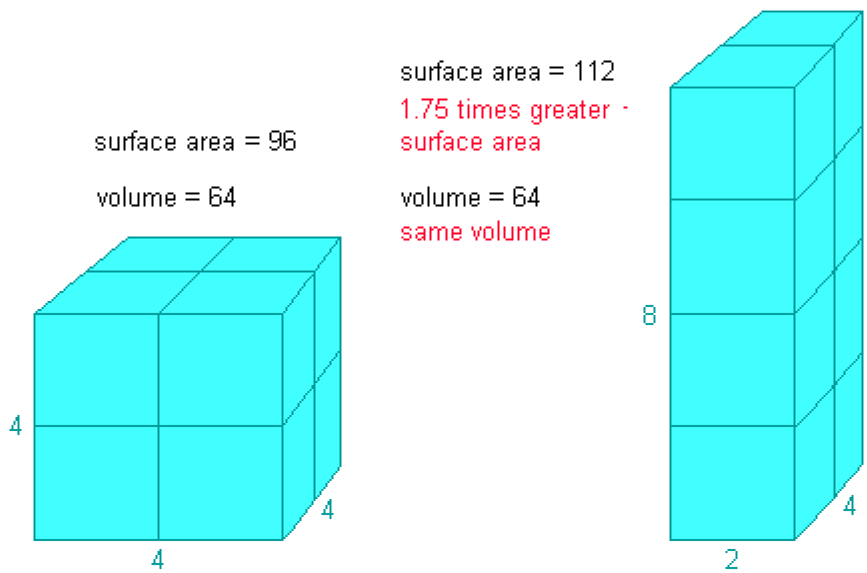


Negative correlation between environmental temperature and body mass in warm blooded animals

Massive polar bear bodies are predicted by Bergmann's rule

Bergmann's rule generally holds for people as well. A study of 100 human populations showed a strong negative correlation between body mass and mean annual temperature of the region. In other words, when the air temperature is consistently high, people usually have low body mass. Similarly, when the temperature is low, they have high mass. However, there are exceptions.

A corollary of Bergmann's rule stated that a linear shaped mammal will lose heat to the environment faster than a more compact one of similar size. The boxes below illustrate this fact. Note that the long, narrow box has the same volume but greater surface area. It is comparable to a tall, slender animal.

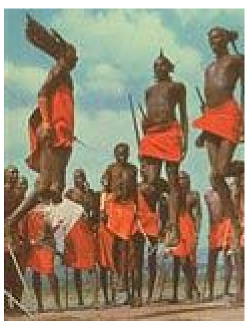


Comparison of different shaped box surface areas and volumes illustrating a corollary of Bergmann's rule relating to body shape

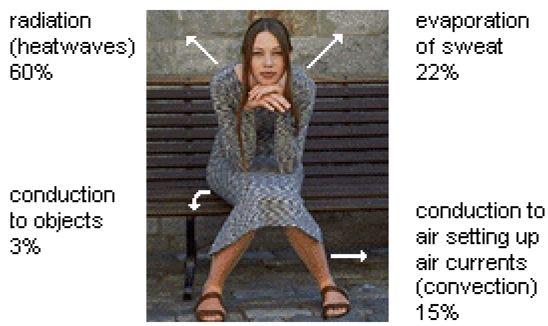
Allen's Rule

In 1877, the American biologist **Joel Allen** went further than Bergmann in observing that the length of arms, legs, and other appendages also has an effect on the amount of heat lost to the surrounding environment. He noted that among warm-blooded animals, individuals in populations of the same species living in warm climates near the equator tend to have longer limbs than do populations living further away from the equator in colder environments. This is due to the fact that a body with relatively long appendages is less compact and subsequently has more surface area. The greater the surface area, the faster body heat will be lost to the environment.

This same phenomenon can be observed among humans. Members of the Masai tribe of East Africa are normally tall and have slender bodies with long limbs that assist in the loss of body heat. This is an optimal body shape in the hot tropical parts of the world but would be at a disadvantage in subarctic regions. In such extremely cold environments, a stocky body with short appendages would be more efficient at maintaining body heat because it would have relatively less surface area compared to body mass.



Slender East Africans with long arms and legs predicted by Allen's rule



Normal processes of body heat loss in a moderate climate

We lose heat to the surrounding environment in several ways, as shown in the illustration above on the right. However, simple **radiation** is the process that is responsible for most of the loss, except in hot dry climates where **evaporative cooling**, or sweating, can be more significant.

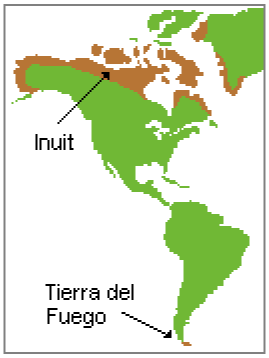
Cold Climate Responses

Many people living in freezing climates drink alcohol to warm themselves. This increases blood flow to the body extremities, thereby providing a feeling of warmth. However, it results only in a temporary warming and can speed up the loss of heat from the vital internal organs, resulting in more rapid death from hypothermia. A much more effective cultural response to extremely cold temperatures is the use of insulating clothing, houses, and fires. People all over the world also adapt by limiting outdoor activities to warmer times of the day. In some societies, sleeping in family groups with bodies pushed up against each other is also done in order to minimize heat loss during the cold months of the year.

When the environment is very cold, life can depend on the ability of our bodies to reduce heat loss and to increase internal heat production. As Bergmann and Allen observed, the human physiological response to cold commonly includes the evolution of more massive, compact bodies with relatively less surface area. Shivering can also cause a short-term warming effect. The increased muscle activity in shivering results in some heat production. There are three additional important types of biological responses to cold conditions found among humans around the world:

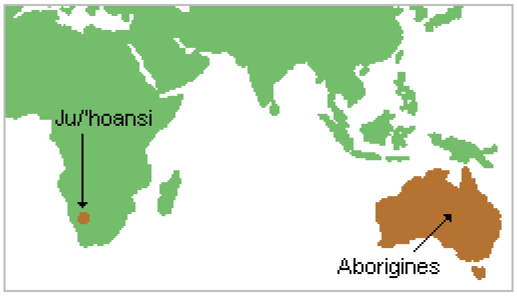
1. increased basal metabolic rate
2. fat insulation of vital organs
3. change in blood flow patterns

Different populations usually develop at least one of these important adaptive responses to consistently cold conditions. People living in harsh subarctic regions, such as the Inuit (Eskimo) of the far northern regions of the western hemisphere and the Indians of Tierra del Fuego at the southern end, traditionally consumed large quantities of high calorie fatty foods. This significantly increases the basal metabolic rate, which, in turn, results in the production of extra body heat. These peoples also wore heavy clothing, often slept in a huddle with their bodies next to each other, and remained active when outdoors.



Inuit man

The Ju/'hoansi of Southwestern Africa and the Aborigines of Australia usually respond physiologically to the cold in a different way. Thick fat insulation develops around the vital organs of the chest and abdomen. In addition, their skin cools due to vasoconstriction at night. As a result, heat loss is reduced and the core body temperature remains at normal levels. However, the skin feels very cold.



This response would not be adaptive if the Kung and the Aborigines lived in consistently freezing environments because the concentration of body heat in their torsos would allow the loss of fingers, toes, and other appendages from frostbite. Their physiological adaptation is to environments that rarely stay below freezing long and that do not have abundant high calorie fatty foods.

Hot Climate Responses

Adapting to hot environments is as complex as adapting to cold ones. However, cold adaptation is usually more difficult physiologically for humans since we are not subarctic animals by nature. We do not grow dense fur coats nor do we usually have thick layers of fat insulation like polar bears.

The effect of heat on our bodies varies with the relative humidity of the air. High temperatures with high humidity makes it harder to lose excess body heat. This is due to the fact that when the moisture content of air goes up, it becomes increasingly more difficult for sweat to evaporate. The sweat stays on our skin and we feel clammy. As a result, we do not get the cooling effect of rapid evaporation.

In dry hot weather, humidity is low and sweat evaporates readily. As a result, we usually feel reasonably comfortable in deserts at temperatures that are unbearable in tropical rain forests. The higher the desert temperatures, the more significant of a cooling effect we get from evaporation. This relationship between relative humidity and air temperature is quantified below. When the apparent temperature is in the light yellow range, heat exhaustion and cramps are likely for humans. In the bright yellow range, life threatening heat stroke is likely.

	air temperature (F°)									
	70°	75°	80°	85°	90°	95°	100°	105°	110°	115°
relative humidity	apparent temperature									
10%	65°	70°	75°	80°	85°	90°	95°	100°	105°	111°
20%	66°	72°	77°	82°	87°	93°	99°	105°	112°	120°
30%	67°	73°	78°	84°	90°	96°	104°	113°	123°	135°
40%	68°	74°	79°	86°	93°	101°	110°	123°	137°	
50%	69°	75°	81°	88°	96°	107°	120°	135°	150°	
60%	70°	76°	82°	90°	100°	114°	132°	149°		
70%	70°	77°	85°	93°	106°	124°	144°			
80%	71°	78°	86°	97°	113°	136°	157°			
90%	71°	79°	88°	102°	122°	150°	170°			
100%	72°	80°	91°	108°	133°	166°				

(Source: *U.C. Berkeley Wellness Letter,* Aug.1996)

While evaporative cooling is very effective in dry climates, there is a major drawback. That is the rapid loss of water and salts from the body through sweat. This can be fatal in less than a day if they are not replaced. It is common to lose a quart or more of water through sweating each hour in harsh summer desert conditions. Commercial "sport drinks" are designed to help people in these situations rehydrate and replenish lost mineral salts. It is easy and inexpensive to create your own equivalent drink without the unnecessary food coloring and sugar that the commercial drinks often include to make them more appealing to customers.

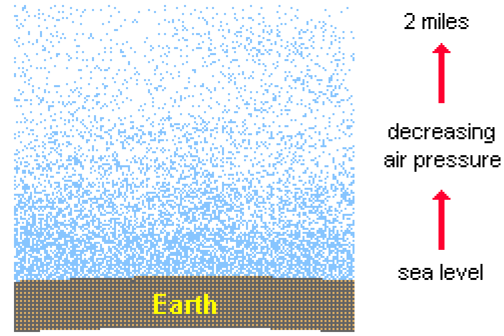
Most people have the ability to physiologically acclimatize to hot conditions over a period of days to weeks. The salt concentration of sweat progressively decreases while the volume of sweat increases. Urine volume also reduces. In addition, vasodilation of peripheral blood vessels results in increased heat loss through radiation. Vasodilation also causes flushing, or reddening, of the skin since more blood is close to the surface.

NOTE: Sweating is not only a mechanism for getting rid of excess body heat. Our sweat contains a number of different substances, including pheromones that can have powerful effects on the hormone systems of others who are physically close to us. Researchers at the Monell Chemical Senses Center in Philadelphia have shown that pheromones in the sweat of men can cause an increase in the amount of luteinizing hormones released from a woman's pituitary gland at the base of her brain. This in turn can shorten the time until the next ovulation. Subsequently, human male pheromones are now being considered as potential future fertility drugs for women. Pheromones released by sisters and other women living together can cause a synchronization of their menstrual cycles. It is likely that human males also respond subconsciously to female pheromones in a way that affects their reproductive systems.

Adapting to High Altitude

There are two major kinds of environmental stresses at high altitude for humans. First, there are the alternating daily extremes of climate that often range from hot, sunburning days to freezing nights. In addition, winds are often strong and humidity low, resulting in rapid dehydration. Second, the air pressure is lower. This is usually the most significant limiting factor in high mountain regions.

The percentage of oxygen in the air at two miles (3.2 km.) is the same as at sea level (21%). However, the air pressure is 30% lower at the higher altitude due to the fact that the atmosphere is less dense--that is, the air molecules are farther apart.

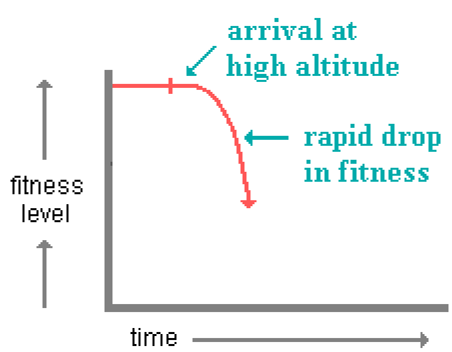


Air pressure decreases as altitude increases

Click here for more information about the earth's atmosphere

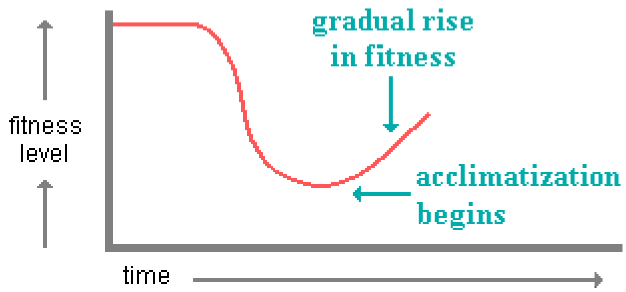
When we breathe in air at sea level, the atmospheric pressure of about 14.7 pounds per square inch (1.04 kg. per $cm.^2$) causes oxygen to easily pass through selectively permeable lung membranes into the blood. At high altitudes, the lower air pressure makes it more difficult for oxygen to enter our vascular systems. The result is **hypoxia** , or oxygen deprivation. Hypoxia usually begins with the inability to do normal physical activities, such as climbing a short flight of stairs without fatigue. Other early symptoms of "high altitude sickness" include a lack of appetite, distorted vision, and difficulty with memorizing and thinking clearly. In serious cases, pneumonia-like symptoms (pulmonary edema) and an abnormal accumulation of fluid around the brain (cerebral edema) develop, leading to death within a few days if there is not a return to normal air pressure levels. There is also an increased risk of heart failure due to the added stress placed on the lungs, heart, and arteries at high altitudes.

When we travel to high altitudes, our bodies initially develop inefficient physiological responses. There is an increase in breathing and heart rate to as much as double even while resting. Pulse rate and blood pressure go up sharply as our hearts pump harder to get more oxygen to the cells. These are stressful changes, especially for people with weak hearts.



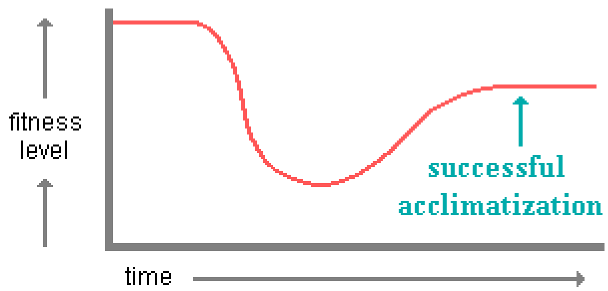
Initial inefficient response to low oxygen pressure

Later, a more efficient response normally develops as acclimatization takes place. More red blood cells and capillaries are produced to carry more oxygen. The lungs increase in size to facilitate the osmosis of oxygen and carbon dioxide. There is also an increase in the vascular network of muscles which enhances the transfer of gases.



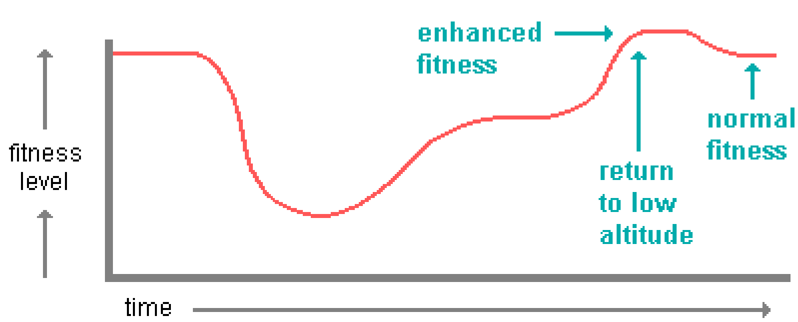
Beginning of successful acclimatization to low oxygen pressure

However, successful acclimatization rarely results in the same level of physical and mental fitness that was typical of altitudes close to sea level. Strenuous exercise and memorization tasks still remain more difficult. In addition, the rate of miscarriages is usually higher at altitudes above two miles.



Increased fitness level after successful acclimatization to low oxygen pressure

On returning to sea level after successful acclimatization to high altitude, the body usually has more red blood cells and greater lung expansion capability than needed. Since this provides athletes in endurance sports with a competitive advantage, the U.S. maintains an Olympic training center in the mountains of Colorado. Several other nations also train their athletes at high altitude for this reason. However, the physiological changes that result in increased fitness are short term at low altitude. In a matter of weeks, the body returns to a normal fitness level.



Enhanced fitness level for a short period of time after returning to low altitude

Who Is Most Likely to Have High Altitude Sickness?

Most lowland people begin to develop hypoxia symptoms at 1-2 miles altitude. However, there are some permanent settlements in the Andes Mountains in South America and the Himalaya Mountains in Asia that are at altitudes of 3 miles. Mountain climbers have reached peaks that are over 5 miles high, but only by using tanks of oxygen to assist in breathing. The highest peaks are too high for any human to acclimatize naturally.

Climbers at the top of Mt. Logan, Yukon Territory, Canada (19,850 feet altitude)

There is considerable variability between individuals and between populations in their ability to adjust to the environmental stresses of high mountain regions. Usually, the populations that are most successful are those whose ancestors have lived at high altitudes for thousands of years. This is the case with some of the indigenous peoples living in the Andes Mountains of Peru and Bolivia as well as the Tibetans and Nepalese in the Himalaya Mountains. The ancestors of many people in each of these populations have lived above 13,000 feet (ca. 4000 meters) for 5,000-10,000 years.

Peruvian Indian woman and Tibetan man

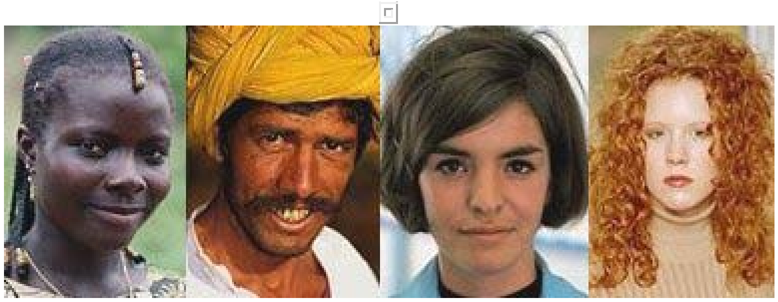
(Her cheeks are red primarily due to increased blood flow near the skin surface. More red blood cells help her get oxygen to the tissues of her body.)

The implication is that natural selection over thousands of years results in some populations being genetically more suited to the stresses at high altitude. However, different populations respond physiologically to low oxygen pressure in somewhat different ways. The primary solution of Indians from the high mountain valleys in Peru and Bolivia has been to produce more hemoglobin in their blood and to increase their lung expansion capability. Both result in an increase of oxygen carried by the blood. In contrast, the common solution of Tibetans and Nepalese who live at high attitudes generally has been to breathe faster in order to take in more oxygen and to have broader arteries and capillaries, thereby allowing much higher rates of blood flow and subsequently greater amounts of oxygen delivered to their muscles.

Whether you personally will experience high altitude sickness in the future may be at least partly a consequence of your genetic inheritance. Those individuals who have low expression levels of the *PDP2* gene generally have more severe symptoms. This gene codes for a protein that assists in the conversion of food into fuel for our bodies. In some way, it apparently also helps in acclimatization to low oxygen pressure.

Skin Color Adaptation

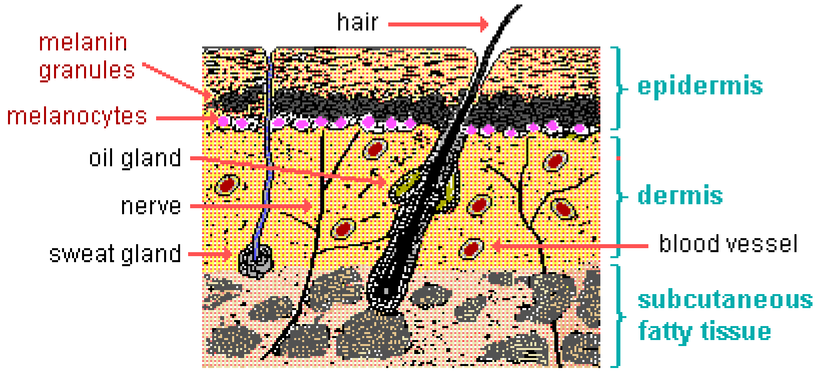
Human skin color is quite variable around the world. It ranges from a very dark brown among some Africans, Australians, and Melanesians to a near yellowish pink among some Northern Europeans. There are no people who actually have true black, white, red, or yellow skin. These are commonly used color terms that do not reflect biological reality.



Some of the variation in human skin coloration
(Sub-Saharan African, Indian, Southern European, and Northern European)

Skin color is due primarily to the presence of a pigment called **melanin**. Both light and dark complexioned people have this pigment. However, two forms are produced--pheomelanin, which is red to yellow in color, and eumelanin , which is dark brown to black. People with light complexioned skin mostly produce pheomelanin, while those with dark colored skin mostly produce eumelanin. In addition, individuals differ in the number and size of melanin particles. The latter two variables are more important in determining skin color than the percentages of the different kinds of melanin. In lighter skin, color is also affected by red cells in blood flowing close to the skin. To a lesser extent, the color is affected by the presence of fat under the skin and carotene, a reddish-orange pigment in the skin.

Melanin is normally located in the epidermis, or outer skin layer. It is produced at the base of the epidermis by specialized cells called **melanocytes**.



Cross section of human skin
(colors are not true to life in this illustration)

Nature has selected for people with darker skin in tropical latitudes, especially in nonforested regions, where **ultraviolet radiation** from the sun is usually the most intense. Melanin acts as a protective biological shield against ultraviolet radiation. By doing this, it helps to prevent sunburn damage that could result in DNA changes and, subsequently, **melanoma** --a cancer of the skin. Melanoma is a serious threat to life. In the United States, approximately 54,000 people get this aggressive type of cancer every year and nearly 8,000 of them die from it. Those at highest risk are European Americans. They have a 10 times higher risk than African Americans.

Ultraviolet radiation reaching the earth usually increases in summer and decreases in winter. The skin's ability to tan in summertime is an acclimatization to this seasonal change. Tanning is primarily an increase in the number and size of melanin granules due to the stimulation of ultraviolet radiation.

While skin tanning is often most noticeable on light complexioned people, even those with very dark brown skin can tan as a result of prolonged exposure to the sun. Some Northwest Europeans have substantially lost the ability to tan as a result of relaxed natural selection. Their skin burns and peels rather than tans. This is due to the fact that they produce a defective form of a skin protein (melanocortin-1 receptor or Mc1r) which is necessary for the production of melanin. They are at a distinct disadvantage in tropical and subtropical environments. Not only do they suffer the discomfort of readily burning, but they are at a much higher risk for skin cancer. The same is true of albinos.

Irish boy who is essentially unable to tan

It would be harmful if melanin acted as a complete shield. A certain amount of shortwave ultraviolet radiation (UVB) must penetrate the outer skin layer in order for the body to produce **vitamin D**. Approximately 90% of this vitamin in people normally is synthesized in their skin and the kidneys from a cholesterol-like precursor chemical with the help of ultraviolet radiation. The remaining 10% comes from foods such as fatty fish and egg yolks. Simple vitamin D is converted by our bodies into two sequential forms. The last form, commonly referred to as vitamin D_3, is needed for the intestines to absorb calcium and phosphorus from food for bone growth and repair. Calcium is also necessary in adults to maintain normal heart action, blood clotting, and a stable nervous system. Vitamin D plays an additional important role in promoting the production of cathelicidin, which apparently is an effective defender against fungal, bacterial, and viral infections, including the common flu.

Too much ultraviolet radiation penetrating the skin may cause the break down of folic acid (or folate--one of the B vitamins) in the body, which can cause anemia. Pregnant women who are deficient in folic acid are at a higher risk of having miscarriages and babies with neural tube defects. Because folic acid is needed for DNA replication in dividing cells, its absence can have an effect on many body processes, including the production of sperm cells. It may be that the ability to produce melanin was selected for in our early human ancestors because it helped preserve the body's folic acid supply in addition to reducing the chances of developing skin cancer.

People who live in far northern latitudes, where solar radiation is relatively weak most of the year, have an advantage if their skin has little shielding pigmentation. Nature selects for less melanin when ultraviolet radiation is weak. In such an environment, very dark skin is a disadvantage because it can prevent people from producing enough vitamin D, potentially resulting in rickets disease in children and osteoporosis in adults. Contributing to the development of osteoporosis in older people is the fact that their skin generally loses some of its ability to produce vitamin D. Women who had prolonged vitamin D deficiencies as girls have a higher incidence of pelvic deformities that prevent normal delivery of babies.

The Inuit people of the American Subarctic are an exception. They have moderately heavy skin pigmentation despite the far northern latitude at which they live. While this is a disadvantage for vitamin D production, they apparently made up for it by eating fish and sea mammal blubber that are high in D. In addition, the Inuit have been in the far north for only about 5,000 years. This may not have been enough time for significantly lower melanin production to have been selected for by nature.

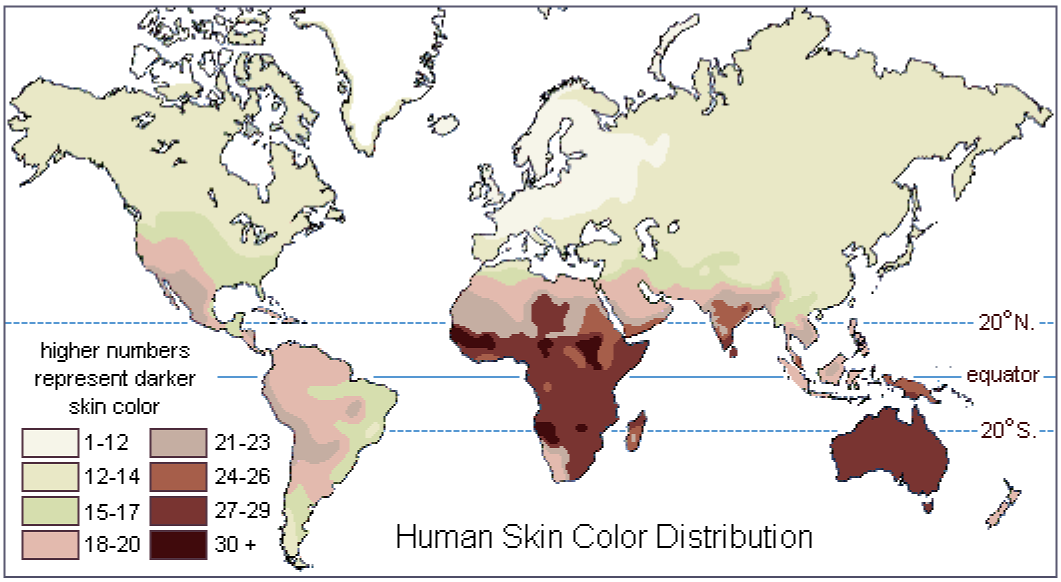
In the United States and other developed nations, milk is now usually fortified with vitamins D and A in order to prevent developmental problems such as those described above. However, the popularity of soft drinks and other alternatives to milk along with a decrease in the amount of time spent outdoors has led to a considerable rise in the rate of rickets disease. Not surprisingly, vitamin D deficiency is most acute in the winter in temperate and colder zones.

There is also a strong correlation between the amount of sunlight that children are exposed to and whether or not they will develop multiple sclerosis as adults. Most cases of this degenerative neural disorder are in the temperate regions of the world where the sunlight is rarely intense. Children growing up in tropical and subtropical regions rarely develop MS regardless of where their ancestors came from. This protection apparently continues for those who move to far northern or far southern regions after 16 years of age. What processes are responsible for this protection from MS and its possible relationship to skin color are unknown.

New research by Nina Jablonski and George Chaplin has led to the discovery that women generally produce 3-4% less melanin in their skin than do men in all populations of the world. They suggest that this is probably due to the fact that women have far higher calcium requirements during their reproductive years. Mate selection preference and other cultural practices may also be partly responsible for this gender difference in skin coloration.

Skin Color Distribution Around the World

Before the mass global migrations of people during the last 500 years, dark skin color was mostly concentrated in the southern hemisphere near the equator and light color progressively increased further away, as illustrated in the map below. In fact, the majority of dark pigmented people lived within 20° of the equator. Most of the lighter pigmented people lived in the northern hemisphere north of 20° latitude.



(Data for native populations collected by R. Biasutti prior to 1940.)

Such a non-random distribution pattern of human skin color was predicted by **Constantin Wilhelm Lambert Gloger**, a 19th century German zoologist. In 1833, he observed that heavily pigmented animals are to be found mostly in hot climates where there is intense sunshine. Conversely, those in cold climates closer to the poles commonly have light pigmentation. The relative intensity of solar radiation is largely responsible for this distribution pattern.

There are exceptions to **Gloger's rule** in the animal kingdom. In some cases, these are due to the fact that the survival value of having a camouflaged body can be more important than the selective pressures of ultraviolet radiation. Among humans, mate selection preferences may counter some of the evolutionary trend in skin color predicted by Gloger. The Inuit case described earlier suggests that diet may also be a significant factor in some societies. In the United States today, milk is regularly fortified with vitamin D to reduce the likelihood of children having calcium deficiencies. Despite this effort, some segments of the population still have high rates of calcium deficiency--especially African Americans and the elderly.

NEWS: In the April 2001 issue of the journal Pediatrics, there is a report concerning malnutrition among children in the U.S. state of Georgia that indicates there is a high frequency of rickets *disease, especially among African Americans. This previously rare condition, which is caused by vitamin D deficiency, is making a comeback. There are now about 200,000 cases of it in Georgia. The study suggests that the dramatic increase in frequency is mainly due to three things: drinking milk substitutes that do not contain vitamin D, the failure to supplement breast milk, and insufficient exposure to sunlight. The popularity of carbonated soft drinks may also contribute to the problem because they usually contain phosphoric acid which can hinder bone growth.*

NEWS: In the February 2007 issue of the Journal of Nutrition, a research team led by Lisa Bodnar of the University of Pittsburgh School of Public Health reported that among 400 first-time pregnant women from that city who participated in their study, only 16.1% of African Americans and 52.9% of European Americans had sufficient amounts of vitamin D in their blood to be considered healthy at the end of their pregnancies. This was despite the fact that more than 90% of them had regularly taken standard doses of prenatal vitamin supplements. Tests of umbilical cord blood indicated that only 7.6% of the African American infants and 33.9% of the European American ones had adequate amounts of vitamin D at birth. The authors concluded that prenatal vitamins should include higher doses of vitamin D, especially in the northern regions of the U.S.

Nutritional Adaptation

We have seen that not all people can survive well at high altitude or under intense ultraviolet radiation. Similarly, there are major differences around the world in how effectively our bodies process particular foods. In addition, some people live well on daily diets that would be at a starvation level for others. Different human populations not only eat different foods, but their digestive systems often use them in somewhat different ways. For instance, the Inuit of Alaska, Northern Canada, and Greenland traditionally ate far more fat than most other populations and their gastrointestinal systems apparently are more capable of breaking fats down for use by their bodies. This is an indication that adapting to local nutritional opportunities has led to the evolution of related genetic differences among the populations of the world.

Many Indians in the Southwestern United States have what have been described as "thrifty genes". Their bodies are unusually efficient at utilizing the calories in their food and, subsequently, need to consume less than other people of their size in order to maintain a stable weight. The Tohono O'Odham Indians of Southern Arizona are an example. Until well into the 20th century, these traditional subsistence farmers had diets that mostly consisted of beans, squash, and corn with little animal protein and fat. Late 19th century photographs usually showed them to have slender to medium body builds. That is no longer true. Now, obesity and associated type 2 diabetes are very common problems for most of them. A dramatic change in diet was responsible for this deterioration in health. Most of them abandoned their traditional diet in favor of the fat and protein rich foods of their Mexican and European American neighbors. Their bodies are responding to what for them is an excessive amount of calories by storing much of it as body fat. This fat is storage for a famine that never comes.

Lactose Intolerance

The best documented differences in nutritional adaptation relates to milk sugar, or **lactose**, which is commonly found in uncooked dairy products. Most human adults have moderate to severe difficulty in digesting lactose. They experience bloating, stomach cramps, belching, flatulence, and even diarrhea when they drink milk. Not surprisingly, this commonly results in the exclusion of dairy products from their diet. This problem is most often due to an inability to produce sufficient amounts of the enzyme **lactase**, which breaks down lactose in the small intestine to aid its absorption into the blood stream. Those who have this problem are said to be **lactose intolerant** due to their lactase deficiency.

The ability to produce lactase is genetically controlled. The gene that codes for it is on chromosome 2. The vast majority of babies throughout the world can digest their mother's milk. However, there is a decline in lactase production as people grow older. This decline usually begins by two years of age, which is shortly after the time when babies are weaned in most societies. For some people, the reduction in lactase production does not start to occur until they are around twenty. More rarely, lactase continues to be produced at sufficient levels to consume milk throughout life.

Lactose intolerance is at its highest frequency in some parts of Africa, East Asia, and among Native Americans (as shown in the table below). Northern Europeans generally have the lowest frequency of this dietary problem.

POPULATION	LACTOSE INTOLERANT ADULTS
U.S.	
European Americans	2-19 %
Latinos (Hispanic Americans)	52 %
African Americans	70-77 %
Native Americans →	95 %
Asian Americans →	95-100 %
Mexico	83 %
Europe	
Sweden →	4 %
Switzerland	12 %
Spain	15 %
Finland	18 %
Estonia	28 %
England	32 %
Hungary	37 %
Greece	88 %
Jordan	79 %
Africa	
Southern Sudan (cattle herders)	17 %
Ibo and Yoruba (Nigeria) →	99 %

Asia	
Japan ⟶	90 %
Thailand ⟶	99 %
Australia (Aborigines)	85 %

Source: Robert D. McCracken, "Lactase Deficiency: An Example of Dietary Evolution," *Current Anthropology* 12 (Oct.-Dec. 1971, pp. 479-517) and Norman Kretchner, "Lactose and Lactase," *Scientific American* 277 (Oct. 1972, pp. 71-78)

Given this distribution pattern of lactose intolerance, it is not surprising that dairy products are popular among most Europeans but are rarely found in Asian, Native American, and most African cuisines (except among cattle herders in East Africa). In the majority of non-European populations, fresh milk is considered an unpleasant substance to be consumed only as a last resort. It is now clear that lactose tolerant Europeans are atypical for humanity and for the entire animal kingdom.