Unit
1B

Chapter 9
Temperature control

Figure 9.1 In very cold conditions, behaviour needs to be modified, such as by wearing warm, protective clothes

Unit content

Body systems
Organs within systems are organised for efficient functioning and interaction.

Systems:
- principal organs within the main body systems
- structural layout of at least two systems related to efficient functioning
- structure and function at cellular level related to tissue and organ levels
- interaction between systems.

Cells, metabolism and regulation
The body detects and responds to changes in its internal environment that are outside its tolerance limits. Dysfunctions are caused when tolerance limits are exceeded.

Tolerance limits:
- conditions resulting from exceeding tolerance limits *e.g. hypothermia, hyperthermia*
- individual difference related to tolerance limits *e.g. temperature*.

Humans live almost everywhere on the surface of the earth. Modern technology has made it possible for people to live comfortably in the Antarctic but even in pre-historic times humans lived in places of extreme temperature conditions. The Inuit (Eskimos) lived in the severe cold of the Arctic tundra, Australian Aboriginal people lived in the baking heat of the outback and American Indians survived in the extreme humidity of the Amazon rain forest. Humans have been able to live in every corner of the globe because of their ability to maintain a constant body temperature by modifying their behaviour and their environment.

Human body temperature must be kept constant at about 37°C. Organisms that are able to keep their body temperature relatively constant regardless of the outside temperature are said to be **homoiothermic**.

It is important to keep body temperature relatively constant, because many chemical reactions in cells are very heat-sensitive. A temperature around 37°C is best for these reactions. Cells that stay at this temperature are able to function efficiently.

When the environmental temperature is lower than 37°C, the warmer body will tend to lose heat to the surroundings. If environmental temperature is higher than 37°C, the cooler body will tend to gain heat from the surroundings.

Under most conditions, the internal body temperature is higher than the surrounding environmental temperature. Heat produced from the activity of body cells helps maintain body temperature by replacing heat lost. However, during exercise and other strenuous activity, the body produces more heat than it needs. This extra heat needs to be removed or body temperature will rise.

In very cold conditions heat loss is so high that the body must generate more heat, or behaviour must be modified to reduce the heat loss. Increase or decrease in body temperature can cause the breakdown of body functions and may even result in death. It is therefore extremely important that internal body temperature is regulated.

Any loss of heat from the body must be balanced by the amount of heat produced by body activities. That is, to keep body temperature constant, heat loss must equal heat gain (see Fig. 9.2).

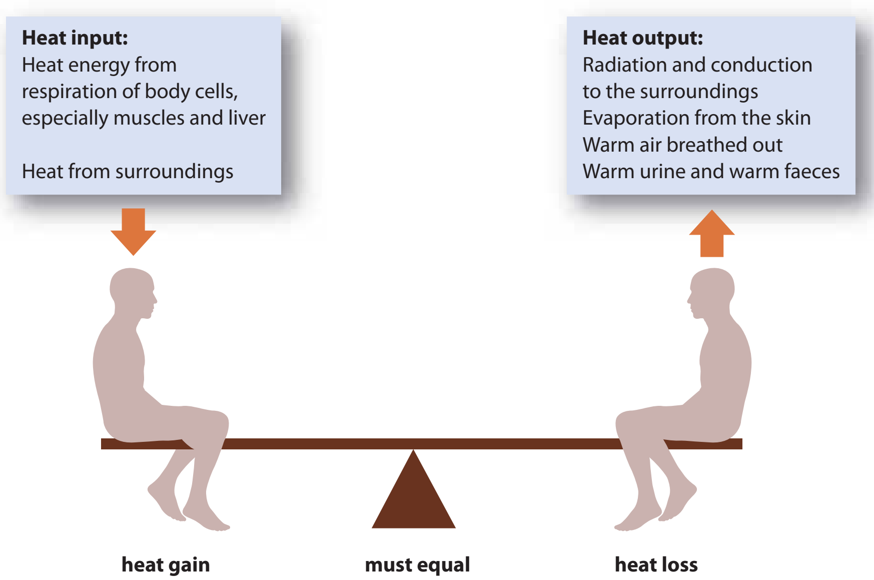


Figure 9.2 Maintaining body temperature is a balance between heat gain and heat loss

The transfer of heat

Heat transfer is when heat energy is moved from one place to another. Heat may be transferred by radiation, conduction, convection or evaporation.

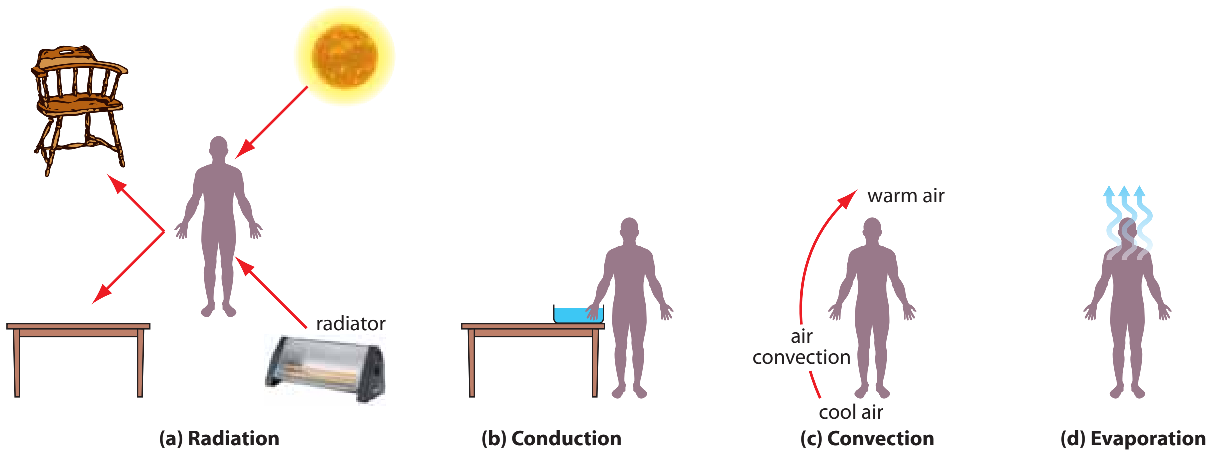


Figure 9.3 Mechanisms of heat transfer

Radiation

The surface of our bodies constantly gives off heat by a mechanism called **radiation**. Radiation is the transfer of heat from one object to another without the objects being in contact. Heat will radiate from your body to cooler objects, such as the ceiling, floor and walls of the room you are in. When sitting close to another person you can sometimes feel the heat radiating from the person's body.

If the objects around you are hotter than body temperature, you will absorb heat from them by the process of radiation. The hotter an object is, the more heat it will radiate to its surroundings.

On a cold day during winter you may feel quite warm if you are in the sunshine. This is because the radiant heat from the sun is enough to warm you, even though the air temperature is cool. On the other hand, in a cool room, our bodies radiate a lot of heat to the surroundings.

Conduction

When heat is transferred to another object through contact, it is called **conduction**. Conduction involves a transfer of heat from particle to particle within an object or from the particles of one object to the particles of another. The heat moves from the object at the higher temperature to the object at the lower temperature. A hot object *loses* heat to a colder one by conduction. On the other hand, a cold object in contact with a hotter one *gains* heat by conduction.

Convection

When cool air makes contact with your body, it becomes warmed and thus less dense. It is pushed away as denser air takes its place, which in turn becomes warmed and is pushed away. This flow of air is called a **convection** current. The faster the flow of air, the faster the rate of heat transfer. This is why fans and breezes aid convection, as they help to move away the warmed air. Convection also helps conduction, as it makes sure a cool air supply is in contact with the body. In fact, without convection, the transfer of heat by conduction between the body and air particles would be almost negligible.

Evaporation

Evaporation is the conversion of a liquid, such as water, to a vapour. A considerable amount of heat energy is required to change water from a liquid to a gas. This heat energy is absorbed from the surface from which evaporation is taking place. The surface is therefore cooled as water evaporates from it. This cooling effect of evaporation is used by the body in sweating.

Table 9.1 Methods of heat transfer

Method of heat transfer	The way it works
Radiation	Heat is transferred from one object to another without the objects being in contact
Conduction	Heat is transferred from one object to another by physical contact
Convection	Cool air, when in contact with the body, is warmed, then carried away by convection currents
Evaporation	Heat is removed from the body when liquid is converted to a vapour, such as occurs during sweating

Keeping cool

Respiration of nutrients takes place in all the cells of the body (see Chapter 7). The purpose of respiration is to release energy and some of that energy is in the form of heat. Some of the heat is necessary to maintain body temperature. However, a considerable amount of the heat produced is more than the body requires and needs to be removed. Body temperature will rise if this extra heat is not removed. The main organ from which heat is lost is the skin. Smaller amounts of heat are lost with gases breathed out from the lungs, and with the faeces and urine.

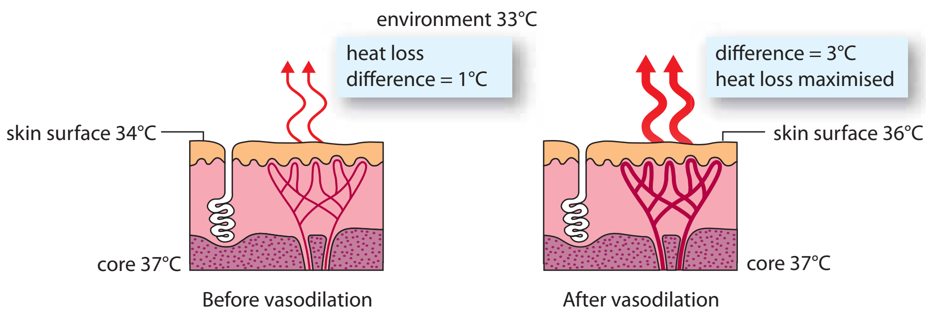
For heat to be lost from the skin, it must be transferred from the internal organs of the body to the surface of the skin. This transfer of heat depends on the flow of blood to the surface. The body can modify its functions to increase the loss of heat from the suface of the skin. This is referred to as a **physiological response** as it involves a change in the way the body works.

Increasing heat loss from the skin

Blood vessels carry heat from the core of the body to the skin where the heat can be lost to the environment. This is often the situation in warm climates where the body must lose heat to maintain a constant temperature. Blood vessels in the skin become larger in diameter. This is called **vasodilation**. It allows a larger amount of warm blood to flow from the core to the body surface. This increases the temperature of the body surface, so that heat loss can take place (see Fig. 9.4). This method of heat loss is most effective for environmental temperatures that range between 20°C and 28°C.

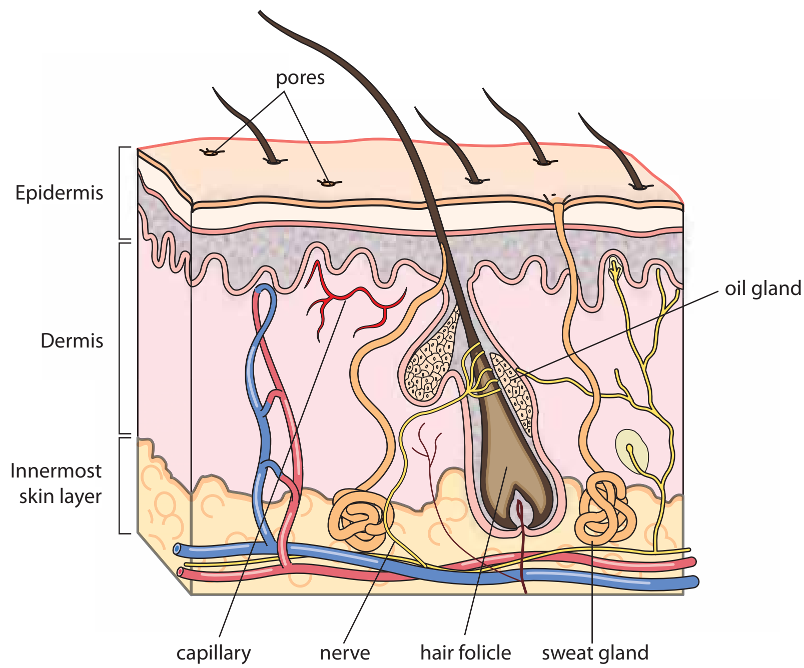
At temperatures above 28°C (a frequent occurrence in many parts of Australia) additional mechanisms, such as sweating, are needed to increase heat loss from the body.

Figure 9.4 The effect of vasodilation



Sweating is the release of fluid from the **sweat glands**. Humans have millions of tiny sweat glands all over the body. These glands are a simple coiled tube with a duct that opens at the surface of the skin in a tiny depression called a **pore** (see Fig. 9.5). As cells surrounding the gland contract, sweat is pumped to the skin surface.

Figure 9.5 Section of skin showing a hair and pores of sweat glands



Sweat is water containing dissolved substances, mainly salt, along with small amounts of urea, lactic acid and potassium. Evaporation of the water cools the skin and the blood flowing through capillaries in the skin.

The cooling effect of sweating is only effective when the environment is fairly dry. If a lot of moisture is contained within the air, then sweat cannot evaporate. When humidity (the water vapour concentration of the air) and temperature are both high, individuals often suffer considerable discomfort as the sweat remains on the skin or simply drips off. Therefore, it is only when humidity is low that sweating is a really effective means of preventing body temperature from rising (see Fig. 9.6).

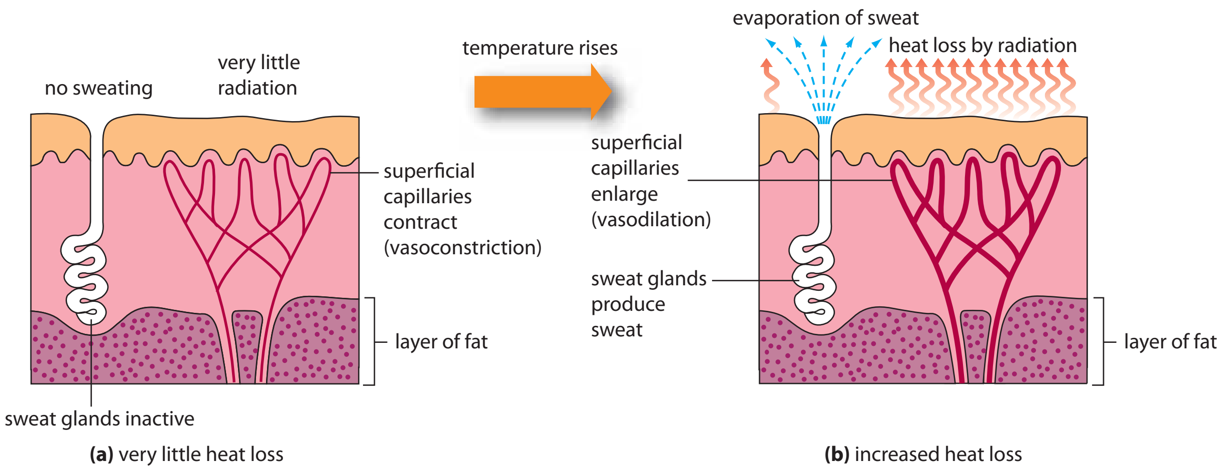


Figure 9.6 Heat loss from the skin: the evaporation of sweat cools the body and vasodilation allows heat to be lost by radiation

As environmental temperature rises, heat loss by sweating becomes more important. When the outside temperature is greater than that of the body, sweating is the only way heat can be lost.

Changes in blood vessel diameter and increase in sweating are reflex responses. They occur automatically without any thought on our part. There are also conscious actions that we can take to keep cool.

Voluntary responses

Most people will reduce the amount of activity they are doing when they start to feel body temperature rising. By reducing activity, they reduce the amount of energy that needs to be released by the muscles. This reduces the amount of heat energy produced so that the person does not feel as hot.

As body temperature begins to rise, a person may also look for somewhere cooler. If outside in the sun they may move under the shade of a tree, or go indoors. Reducing activity, or moving to cooler surroundings, is a **behavioural response**, because the person has acted in a conscious way to keep cool.

Another behavioural response is to use a fan to improve the effectiveness of sweating. A fan moves moist air away from the surface of the skin, so that more sweat can evaporate. Electric fans in buildings keep the air moving. People feel more comfortable because sweat evaporates quickly, removing more heat from the skin.

Technology has enabled the internal temperature of buildings and our modes of transport to be cooled by air conditioning. In such situations the air temperature surrounding the body is cooler than it would have been without the air conditioning. Our bodies do not have to lose as much heat in such circumstances allowing us to remain far more comfortable.

Keeping warm

If the environmental temperature falls, or if a person goes from a warm room into a cold environment outside, loss of body heat will increase. There will then be a tendency for body temperature to fall. Reflex and voluntary responses will maintain constant body temperature.

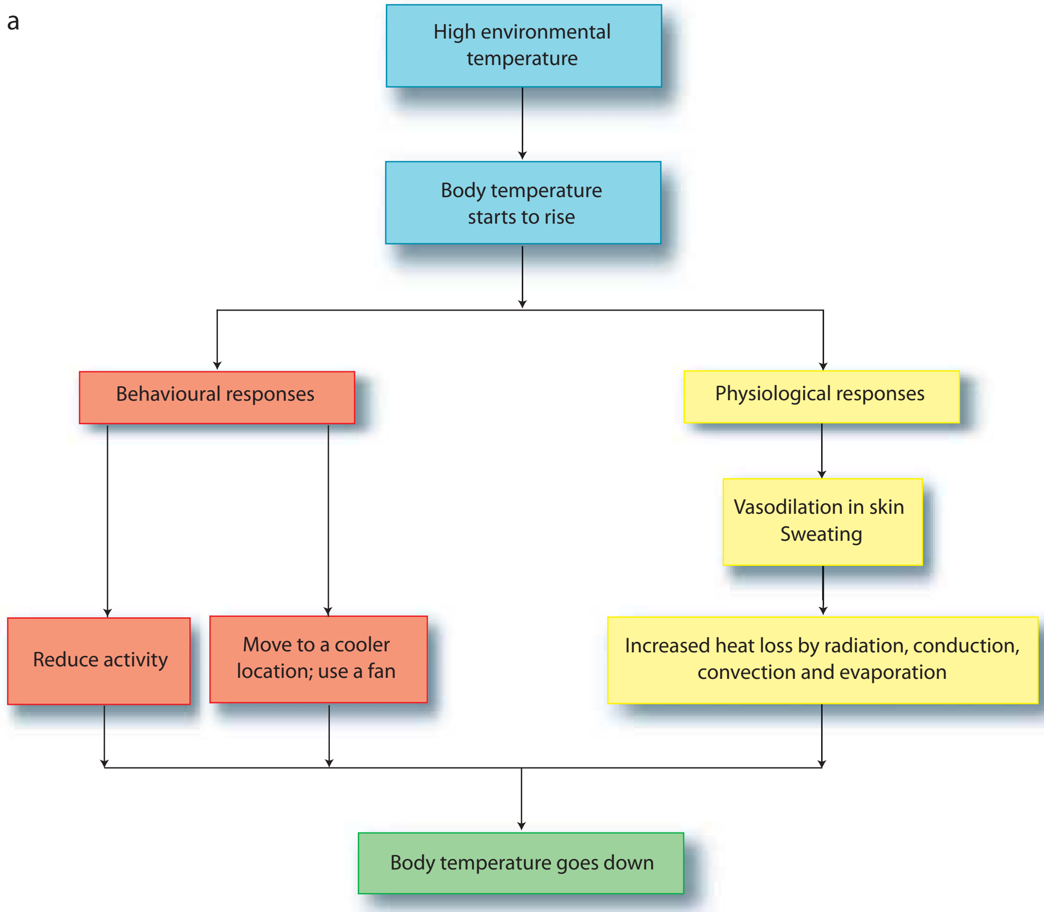


Figure 9.7 Responses to a rise in body temperature

Reducing heat loss

One response to falling temperature is **vasoconstriction** of skin blood vessels. This narrowing of the skin blood vessels decreases the flow of warm blood from the internal organs to the skin. Therefore less heat is transferred from the internal body organs to the skin (see Fig. 9.8). If there is less heat in the skin because there is less warm blood flowing through it, there will be less heat lost from the body surface. In this way, skin vasoconstriction helps to maintain body temperature in cold conditions.

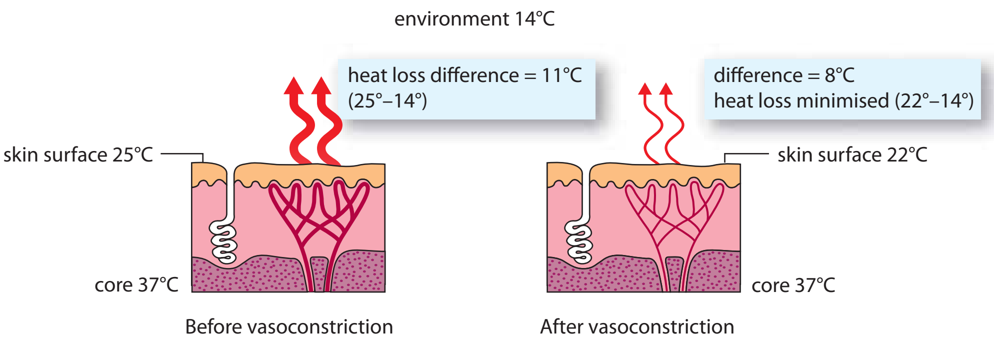


Figure 9.8 The effect of vasoconstriction

In cold climates, skin vasoconstriction is extremely important in reducing heat loss, because the reduced blood flow to the skin reduces surface body temperature. A lower surface temperature means that less heat is lost by radiation and there is no need to sweat (see Fig. 9.9). Skin vasoconstriction can be so efficient that up to 99% of the blood flow to the skin of the fingers may be reduced during exposure to cold.

Heat is lost from the surface of the body. Therefore reducing surface area can reduce heat loss. You may have noticed how, if you get cold in bed, you automatically curl into a ball. This reduces your surface area and reduces heat loss.

Increasing heat gain

Reducing blood flow to the surface of the body is an effective means of controlling heat loss within the fairly moderate temperature range of 20°C to 28°C. At temperatures lower than 20°C, large heat losses may occur and increased heat production, often by shivering, is necessary.

When there is a fall in body temperature, the brain will send messages to the skeletal muscles to begin to contract. These contractions are known as **shivering**. Contracting muscles require more energy, some of which is converted into heat. Shivering can therefore increase body heat.

For animations showing temperature control mechanisms visit http://www3.fhs.usyd.edu.au/bio/homeostasis/Human_BodyTC_Pg01.htm

Voluntary responses

Body heat can also be produced by voluntary activity such as foot stomping, hand clapping and running. All of these activities require muscle contraction and therefore release heat. If such conscious activity is carried out, you no longer have the urge to shiver.

We are also able to use other conscious behaviour to help us gain heat. When we become aware of cold conditions we can move to a warmer place, such as standing in the sun or moving indoors. We may also light a fire or turn on a heater. To reduce heat loss we can put on more clothing.

Figure 9.9 summarises the responses to conditions in which body temperature may fall.

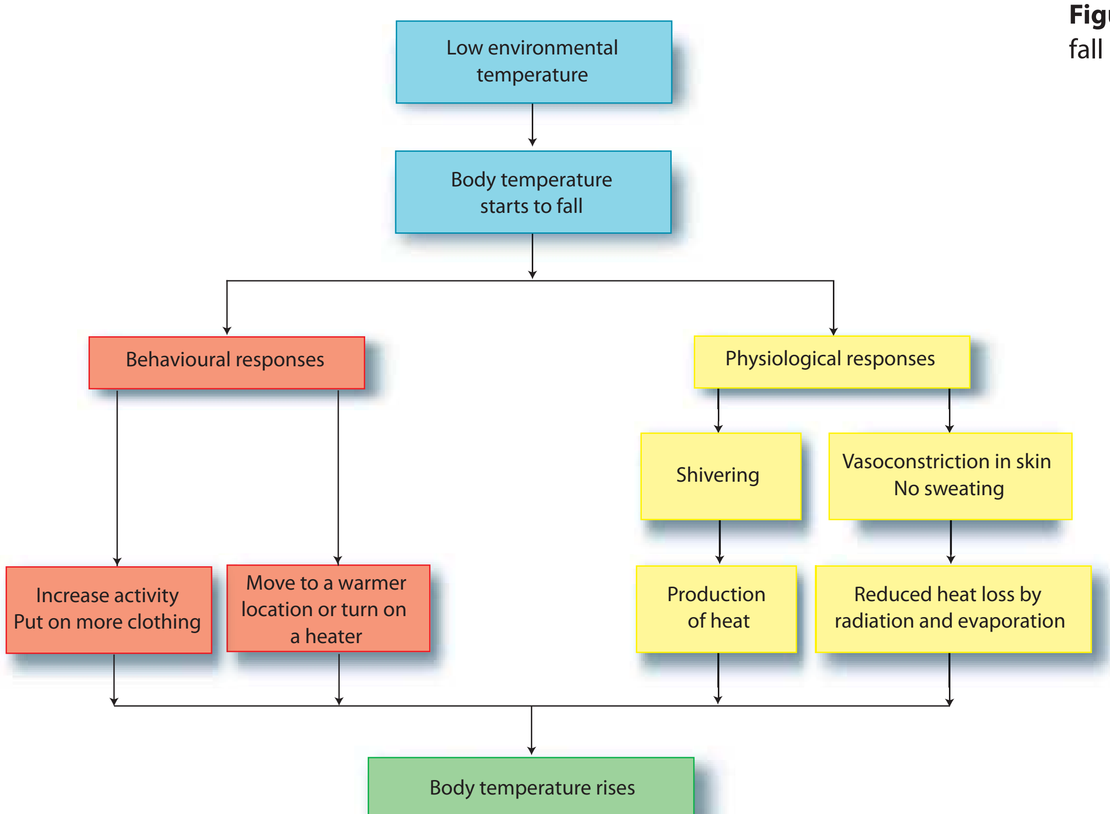


Figure 9.9 Responses to a fall in body temperature

Controlling body temperature

Body temperature is regulated by a small group of nerve cells called the **hypothalamus**. It is located in the brain and is almost completely surrounded by the cerebrum (see Fig. 8.5 on page 92). The hypothalamus contains a number of temperature receptors, or **thermoreceptors**, which detect the temperature of the blood. Thermoreceptors are also located in the skin.

These skin thermoreceptors provide the hypothalamus with information about the external environment. Thus the hypothalamus receives information about the temperature of the environment and the temperature of the blood. It can then automatically trigger responses that maintain a constant body temperature.

The hypothalamus is the body's main temperature-regulating centre. Nerve impulses sent out by the hypothalamus control activities that help to either increase or decrease body temperature. For example, it is messages from the hypothalamus that stimulate nerves to cause blood vessels to constrict or to dilate. Shivering is also controlled by the hypothalamus. It is able to send messages to the parts of the brain that control skeletal muscle activity (see Fig. 9.10).

Figure 9.10 The role of the hypothalamus in maintaining a constant body temperature

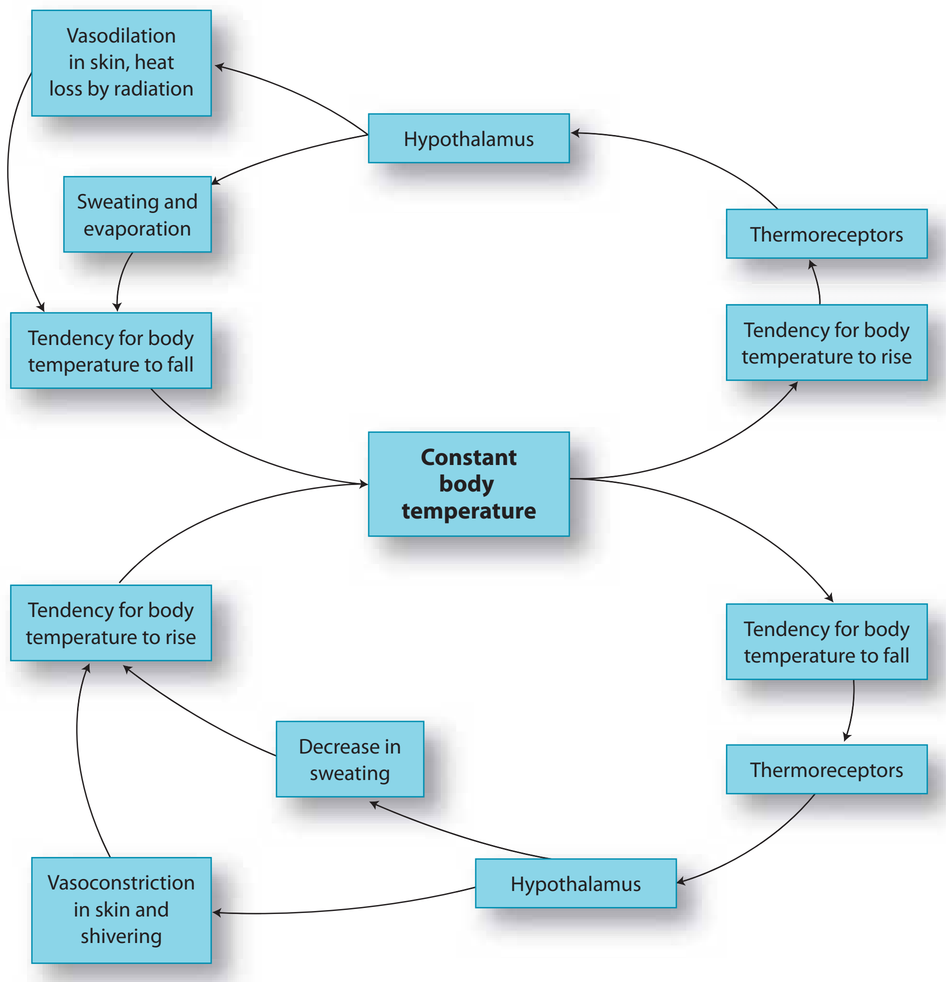


Table 9.2 Ways to regulate body temperature

Stimulated by cold conditions		Stimulated by hot conditions	
Decreasing heat loss	**Increasing heat production**	**Increasing heat loss**	**Decreasing heat production**
Constriction of blood vessels in the skin	Shivering	Dilation of blood vessels in the skin	Relaxing skeletal muscles
Reducing surface area, for example, by curling into a 'ball'	Increased voluntary activity	Sweating	Decreased voluntary activity
Conscious behaviour, for example, by putting on extra clothes, sheltering from the wind	Increased cellular activity	Conscious behaviour, for example, removing clothing, turning on a fan	Decreased cellular activity
Reduction in sweating			

Individual differences

People differ in their ability to tolerate extremes of temperature. Body build is very important in temperature tolerance because a person's build determines their surface area in relation to body volume. Because heat is gained and lost through the surface of the body, surface area is vital, particularly with regard to heat loss.

People who are short and heavily built have a much smaller surface area in relation to their volume than people who are tall and thin. The short, stout person will lose less heat and will be better able to survive in cold conditions. A tall, slim person, with larger surface to volume ratio, will lose heat more rapidly and will be better suited to survival in very hot conditions.

These differences in body build can be seen in ethnic groups who live in extreme temperature conditions. For example, the Inuit, who live near the Arctic Circle, have a short, rounded body shape. They are well adapted for life in cold conditions. On the other hand, Australian Aboriginal people, who live in the very hot conditions of central Australia, are very tall and thin. They are adapted to survive in extreme heat.

Exceeding temperature tolerance limits

Individuals vary in tolerance of high and low temperatures. This variation may be due to their particular genetic make-up, like the Inuit and the Australian Aboriginal people, or it may be due to the environment in which they usually live. However, if temperatures get too high or too low the body cannot function normally and the person may die if exposure to extreme temperatures is prolonged.

When a person is exposed to high temperatures, **hyperthermia** may occur. This is when the core body temperature becomes very high. For most people this would be at a temperature around 43°C. Heat stroke and fever are two ways core body temperature can become excessively high.

Learn more about hyperthermia at http://www.medicinenet.com/hyperthermia/article.htm

When the outside temperature and relative humidity are high, it is difficult for the body to lose heat by radiation or evaporation. In this situation, the body's temperature control system breaks down and body temperature rises even higher. This condition is called **heat stroke** and can be very serious if brain cells are affected. Treatment consists of cooling the body as quickly as possible by immersing the patient in cool water.

During the course of an infection, such as the common cold or influenza, there is often a rise in body temperature, called a **fever**. This change in body temperature is not due to a breakdown of the temperature-regulating mechanisms. Instead the temperature control centres in the hypothalamus reset the body temperature to a higher level. For example, instead of being set at the usual 37°C it may be reset to 39°C. Thus, a person with fever regulates body temperature in response to heat or cold, but always at this new, higher level.

Up to a point, fever is beneficial. High body temperatures are believed to inhibit the growth of some bacteria and viruses. In addition, heat speeds the rate of chemical reactions that may, in turn, help the body cells repair themselves more quickly during a disease. However, fever can be harmful if the temperature is too high. Generally speaking, death will result if body temperature rises to between 44°C and 45°C.

Find out more about hypothermia at http://www.betterhealth.vic.gov.au/bhcv2/bhcarticles.nsf/pages/Hypothermia

On the other hand, an individual exposed to very low temperatures may suffer from **hypothermia**. This is when the core body temperature becomes very low. For most people this would be at a body temperature around 33°C. Such a low temperature may result from exposure to very cold weather or from immersion in icy water. In these situations, cellular activity slows and not enough heat is produced to replace that being lost from the body. Core body temperature continues to fall, and death may occur.

Wet or damp clothing, an uncovered head and inadequate clothing during cold, winter weather can increase chances of hypothermia. Some people have survived hypothermia with body temperatures as low as 29°C. The low temperatures slow the chemical reactions in cells so much that, although breathing and heartbeat have ceased, the cells do not die.

Working scientifically

Activity 9.1 Convection currents

This activity is a simple demonstration to show the movement of water by a convection current as it is warmed. The same sort of movement occurs when air is warmed.

You will need

1000 mL beaker; water; food colouring; an eye-dropper or pipette; Bunsen burner; tripod stand

What to do

1. Add about 800 mL of cold water to the beaker.
2. Use an eye-dropper or pipette to carefully add a drop of food colouring to the bottom edge of the beaker of water. Do not let it spread through the water.

3. Gently heat the beaker at the point just below the dye.
4. Record your observations.

Studying your observations

1. Draw a diagram of the beaker and indicate the pattern of movement of the dye.
2. On your diagram use arrows to show the path of the food dye as the water became heated.
3. Describe what happened as the water became heated. What term is used to describe this movement?

Activity 9.2 The loss of heat

This activity will demonstrate that the hotter an object is, the faster it will lose heat.

You will need

Two 1000 mL beakers, boiling water; two thermometers; timer; graph paper; pencils of two different colours

What to do

1. Prepare a table to record your results with a column for time, a column for the temperature of beaker one and a column for the temperature of beaker two.
2. Add boiling water to one beaker and a mix of boiling water and cold water to the other so it is at a temperature between 60°C and 70°C.
3. Begin recording the temperature of both beakers every minute for ten minutes.
4. Record your results in the table.
5. Once all the data has been recorded, draw a graph of the temperature for the two beakers. Use one pencil colour for the first beaker and the other pencil colour for the second beaker of water.

Studying your observations

1. Which beaker of water lost heat the fastest at the start of the activity?
2. What temperature was recorded for the boiling water at the start of your recordings? Explain why this was not 100°C.
3. Did both beakers reach the same temperature by the end of the experiment? If so, how long did it take for this to occur?
4. Using the results of this activity what can you conclude about heat loss from a person at different environmental temperatures?

Activity 9.3 Insulation

This activity demonstrates the effect of insulation on heat loss.

You will need

Two conical flasks, 100 mL; two thermometers; cotton wool; graph paper

What to do

1. Prepare a table to record your results with a column for time, a column for the temperature of flask one and a column for the temperature of flask two.

2. Wrap cotton wool around one of the flasks and leave the other uncovered.
3. Pour equal volumes of very hot water into each of the conical flasks.
4. Place a thermometer into each flask and record the temperature of the water each minute for ten minutes.
5. Plot your results on a graph.

Studying your observations

1. Which of the two flasks lost heat more quickly?
2. Why was it necessary to have the same volume of water in each flask?
3. Why was it necessary to start with water of the same temperature in each flask?
4. Use the result of this activity to explain why putting on a jumper helps you to keep warm on a cool day.

Activity 9.4 Fever

Table 9.3 shows the temperature recorded for a person who suffered from a viral infection and recovered after about ten days.

Table 9.3 Temperature recorded for a patient during a viral infection

Day	Time	Body temperature (°C)	Day	Time	Body temperature (°C)
1	8 am	37.1	7	8 am	39.1
	8 pm	37.4		8 pm	38.7
2	8 am	37.2	8	8 am	38.3
	8 pm	38.1		8 pm	38.1
3	8 am	38.6	9	8 am	37.7
	8 pm	39.2		8 pm	37.4
4	8 am	39.1	10	8 am	37.2
	8 pm	38.9		8 pm	36.9
5	8 am	39.2	11	8 am	37.1
	8 pm	39.3		8 pm	37.2
6	8 am	38.8			
	8 pm	39.0			

What to do

1. Plot these data on a graph. Make sure your graph conforms to all the conventions for drawing scientific graphs (see Chapter 1, page 8–9).
2. Describe in words what happened to the patient's temperature over the eleven-day period covered by the data.
3. Calculate the patient's average temperature from 8 am on day three to 8 pm on day eight.
4. During a fever the body's normal set temperature level is reset to a higher level. Explain how your graph indicates this characteristic of a fever.

Activity 9.5 Travelling to Antarctica

Antarctica is becoming a favoured destination for many Australian tourists. However, the extreme cold of the environment requires tour companies to ensure that their clients do not suffer from extreme heat loss. Consider what might be the consequences if a passenger on a ship cruising to Antarctica fell overboard. The icy water would mean the passenger would be in danger of dying from hypothermia.

This activity gives you an opportunity to research the treatment that is given to a person suffering from hypothermia.

1. Search for details on the treatment of hypothermia. This website may be a good starting point: http://hypothermia.org
2. List the steps that the medical team on board the vessel would need to take to ensure that the person recovered from being in the icy water.
3. To simulate the effect of cold icy water and wind on the surface of your skin, place your hand and arm into cold water for two minutes. Remove the hand and fan it with a piece of cardboard.
   (a) Does your skin feel colder with the effect of the fanning?
   (b) What method of heat transfer occurred when you fanned the surface of your skin?

REVIEW QUESTIONS

1. Birds and mammals are homoiothermic. What does this mean?
2. Explain why it is important for body temperature to be regulated.
3. Distinguish between radiation, conduction and convection.
4. **(a)** What is vasodilation?
   (b) How does vasodilation in the skin assist heat loss?
5. How does the evaporation of sweat from the surface of the skin result in a cooling effect?
6. Explain how humidity affects cooling by sweating.
7. What is the difference between core and surface temperature?
8. **(a)** What is vasoconstriction?
   (b) Explain how vasoconstriction in the skin contributes to heat regulation.
9. Describe how shivering helps in maintaining body temperature.
10. Describe the locations of the body's temperature receptors.
11. **(a)** What is hyperthermia?
    (b) Name two situations that may lead to a person suffering from hyperthermia.
12. In what situations may a person suffer from hypothermia?

APPLY YOUR KNOWLEDGE

1. To maintain a constant body temperature, the body needs to balance heat gain with heat loss. Discuss the ways by which the body gains and loses heat, and how a balance is maintained.
2. During strenuous exercise the body could become overheated. Explain where the extra body heat comes from and how the body responds to keep temperature constant.

3. Why does the body have thermoreceptors in the skin and in the hypothalamus? Could the body function with just one or the other? Explain.
4. Blood vessels in the skin can either constrict or dilate. Under what circumstances would **(a)** vasoconstriction and **(b)** vasodilation occur in the skin?
5. In very hot climates the body may receive more heat from radiation than it loses. Describe how the body can cool itself in these conditions.
6. In very cold weather it is our fingers and toes that feel coldest.
   (a) Why are fingers and toes affected by cold more than other parts of the body?
   (b) When very cold, people sometimes appear to be 'blue with cold'. What makes the skin appear blue?
7. After vigorous exercise the skin often appears red and flushed. Suggest a reason for this appearance.
8. In cold conditions wet clothing and windy conditions increase the chance of a person suffering from hypothermia. Explain why **(a)** wet clothing and **(b)** windy conditions would increase the chance of hypothermia.
9. An air conditioner can regulate the temperature in a room. It has a sensor that detects room temperature, a heater that warms the air if the room is too cold and a cooler that cools the air if the room is too hot. Temperature regulation in the human body works in a similar way. Explain what, in the human body, is:
   (a) the sensor
   (b) the heater
   (c) the cooler.