Regulating Mechanisms

Human Internal Environment

A human's **internal environment** is the millions of body cells and the tissue fluid that bathes them.

For a healthy body, all body parts must work together keeping the internal environment within tolerable limits.

e.g. Human body must be maintained at 37°C to provide optimum conditions for enzyme controlled reactions

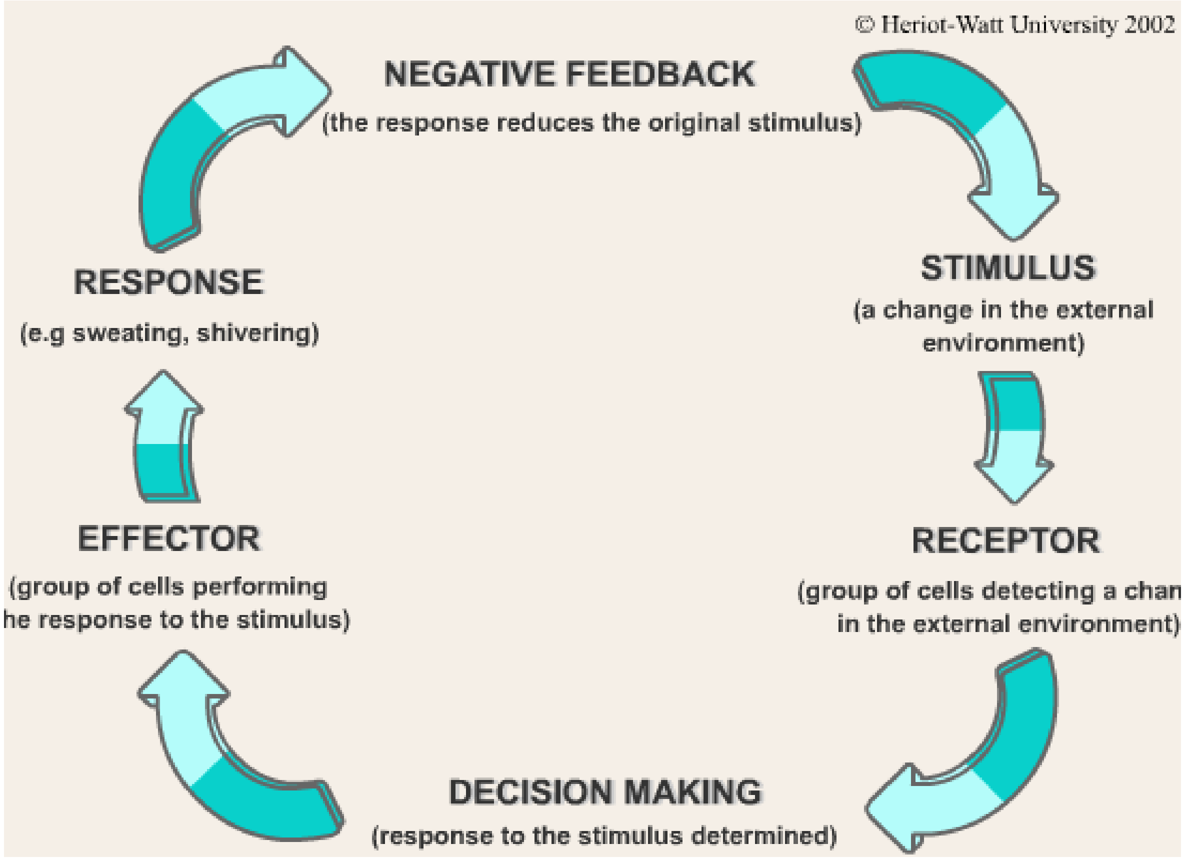
The features of the internal environment are controlled by homeostasis….

Homeostasis

HOMEOSTASIS is the maintenance of the body's internal environment within certain tolerable limits despite changes in the body's external environment (or changes in the body's rate of activity).

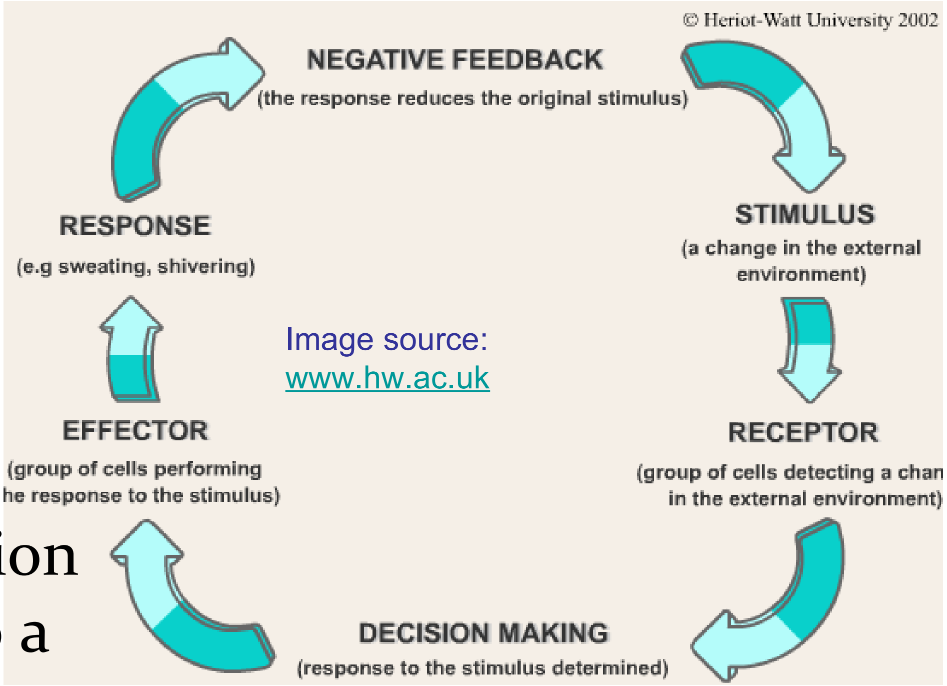
Negative Feedback Control

When a factor affecting the body's internal environment deviates from its norm (or set-point) the body responds to correct the change.



Negative Feedback Control
Receptors detect change and send messages to effectors.

- The change in the factor is detected by **receptors**.
- These send out nerve or hormonal messages which are received by **effectors**.
- The effectors then bring about certain responses which counteract the original deviation from the norm and return it to a set point.

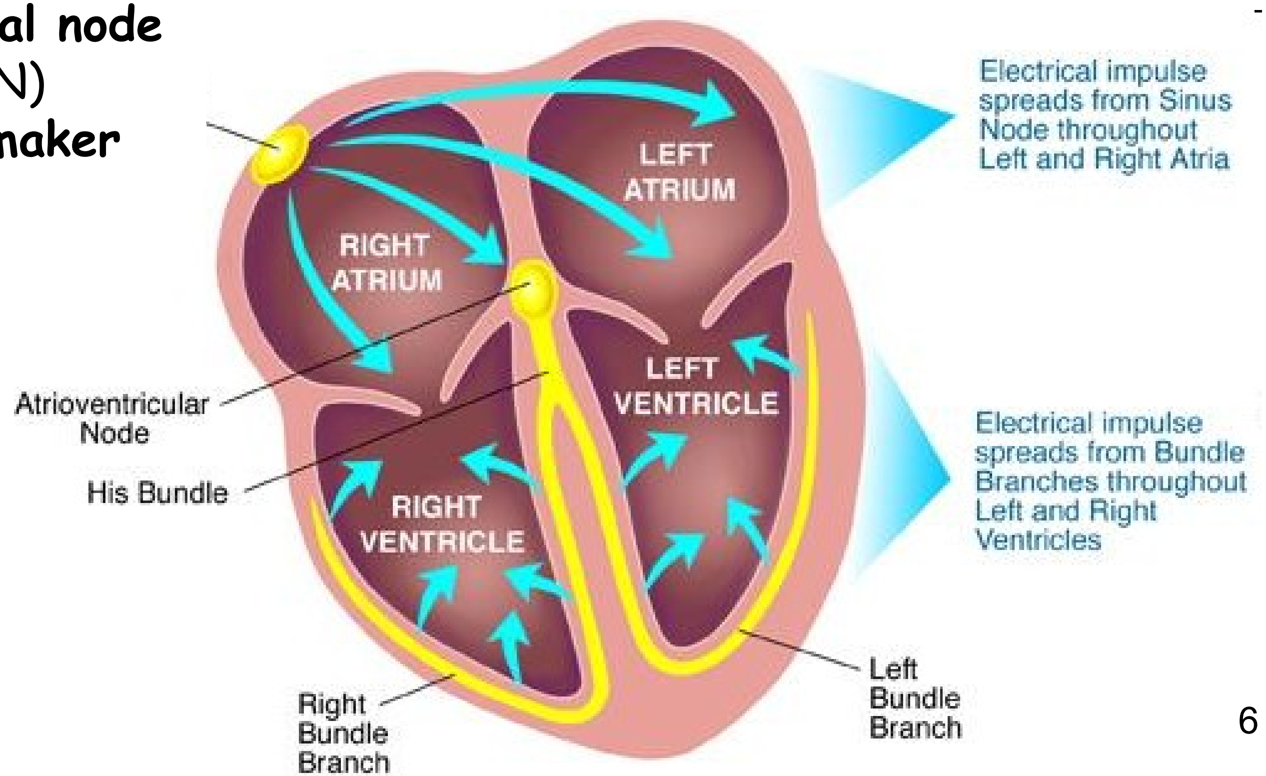


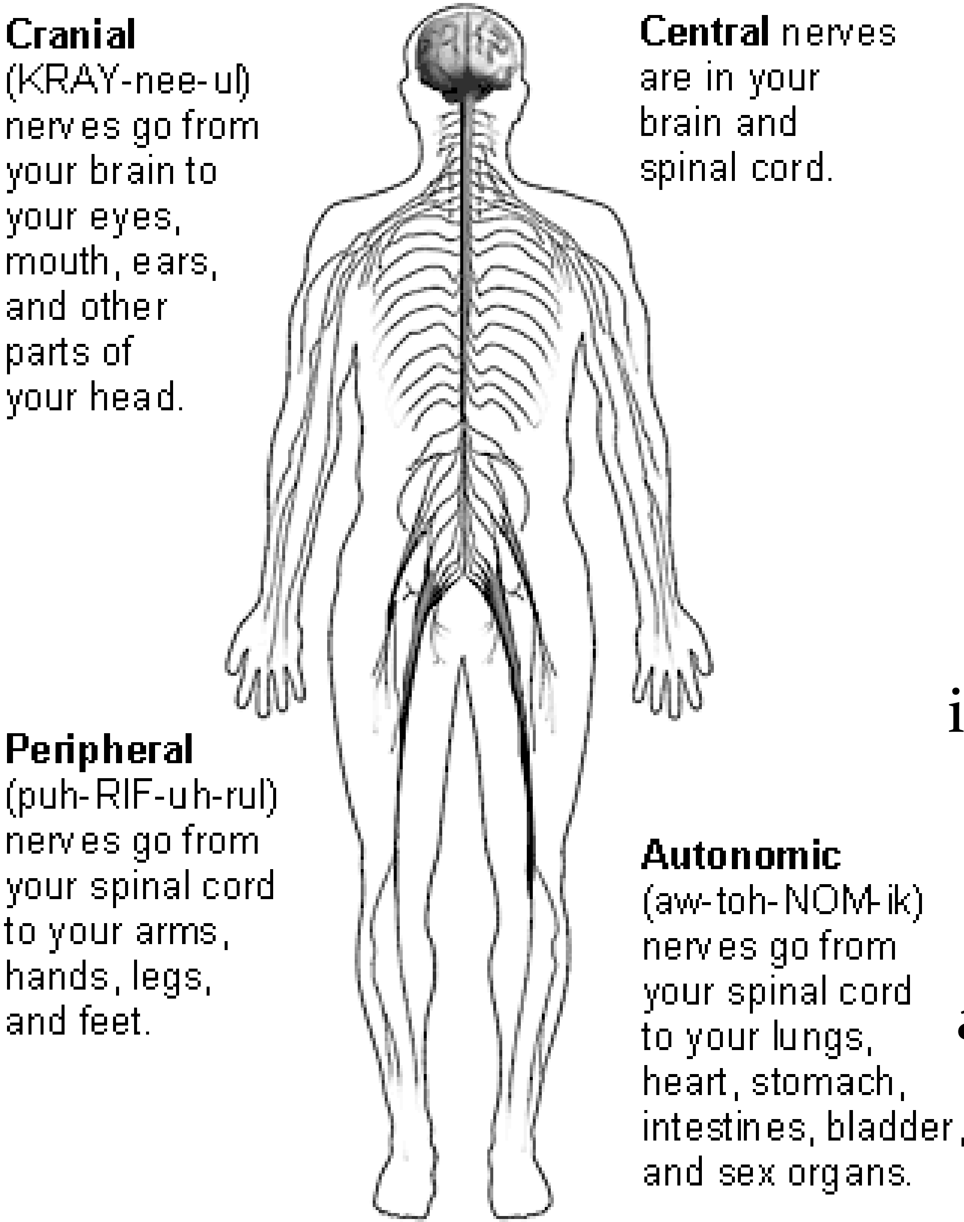
- This corrective homeostatic mechanism is called **NEGATIVE FEEDBACK CONTROL**.
- It provides the stable environmental conditions needed by the body's community of living cells to function efficiently and survive.

Control of Heart Rate: Pacemaker

Although the heartbeat is initiated by the **pacemaker** tissue also known as a **Sino-atrial node** (SAN). However, heart rate is not set at a fixed pace. Heart rate can be altered by **nervous** and **hormonal** activity both of which exert control over rate (though not initiation) of heartbeat.

Sino-atrial node (SAN) = Pacemaker





The Nervous System

The **nervous system** is a network of specialised cells that communicate information about an individual's surroundings and itself.

It processes this information and causes reactions in other parts of the body.

Control of Heart rate.
The Autonomic Nervous System

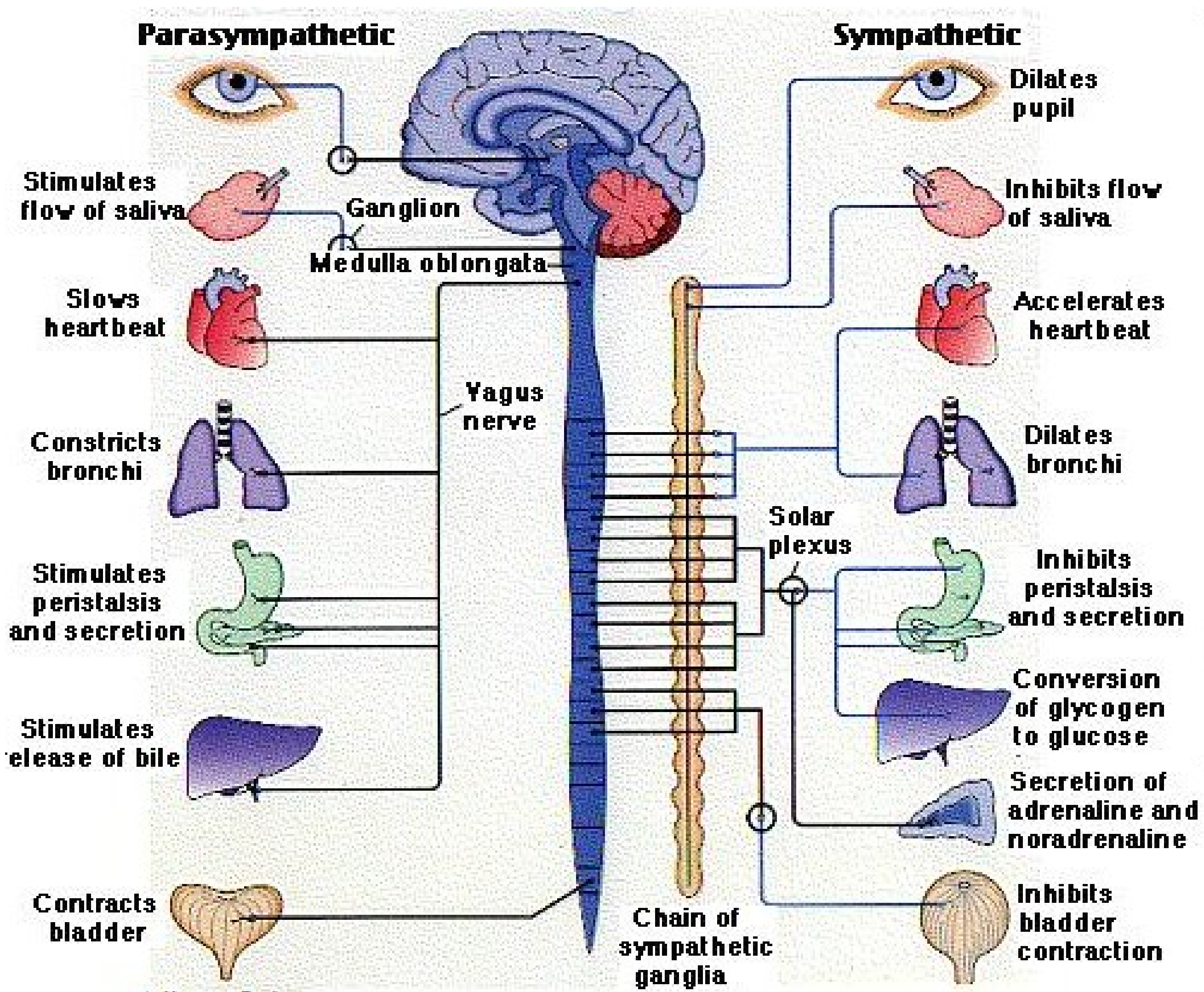
- The **autonomic nervous system** (ANS) controls involuntary responses to stimuli by the body.
- Autonomic nerves serve
  - heart muscle
  - smooth muscle
  - Glands
  - all internal organs.

- The ANS acts on these various effectors to maintain:
  - homeostasis within the body (parasympathetic branch)
  - response to stress – the "fight or flight" response (sympathetic branch)

Parasympathetic v Sympathetic

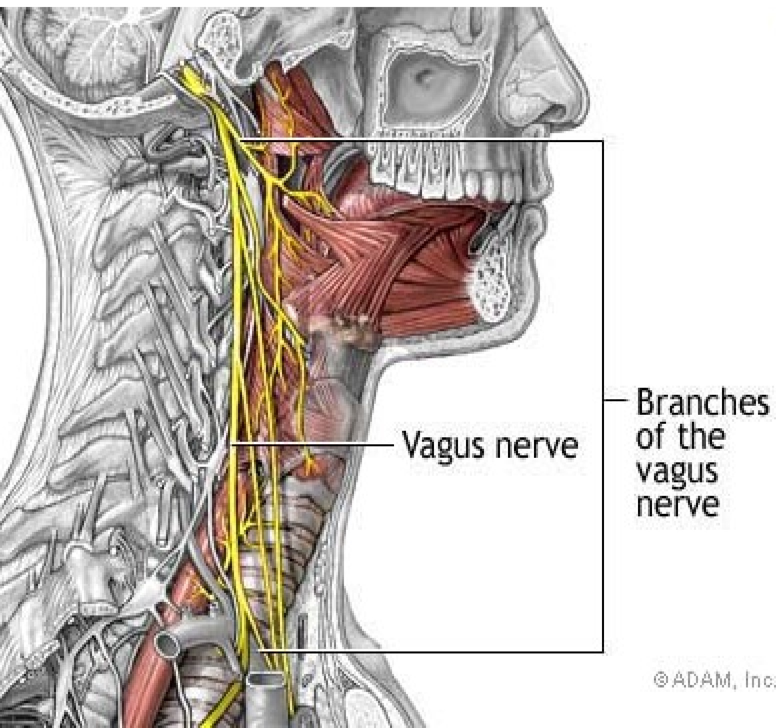
homeostasis

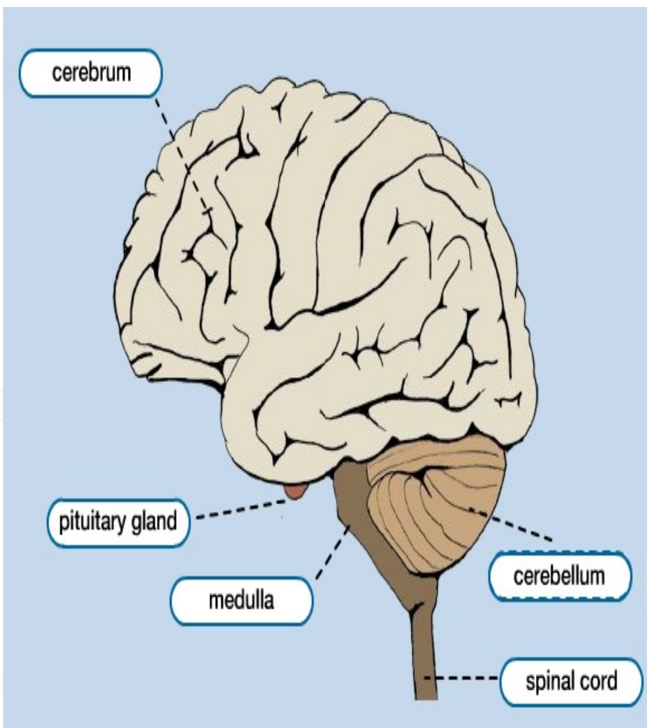
response to stress



The Autonomic Nervous System: The Vagus Nerve

The vagus nerve is the longest nerve in the body, and one of the most important. It sends commands to, and takes information from many important organs including the heart and lungs.

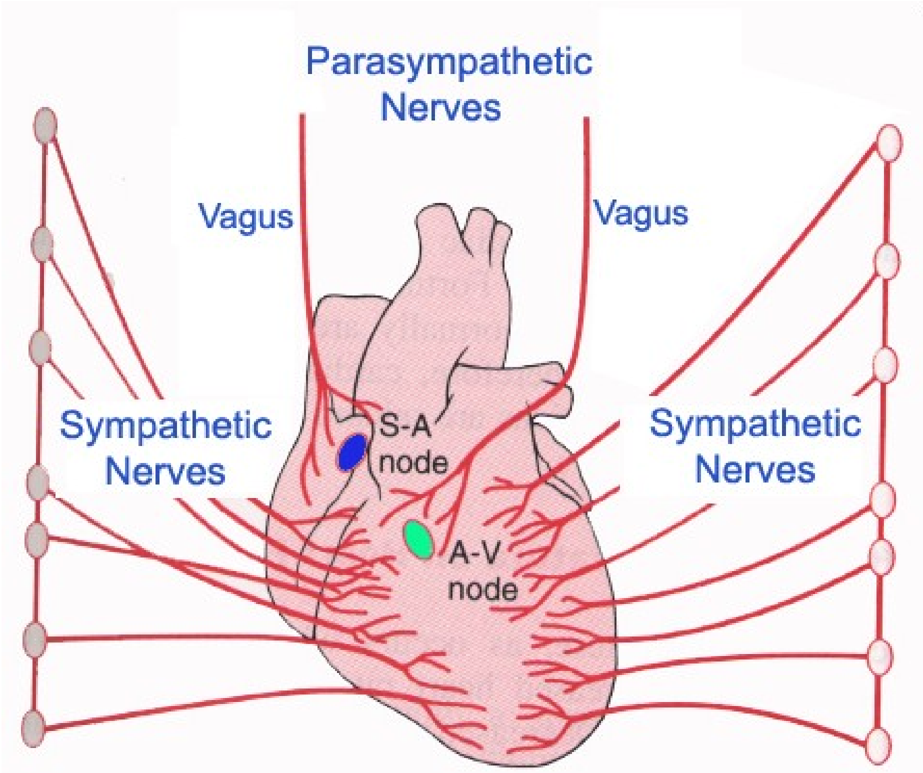




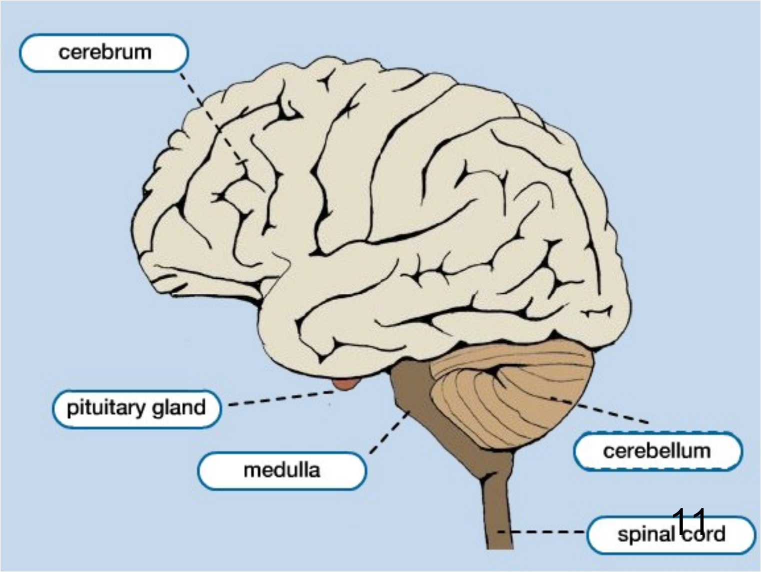
People have two vagus nerves, one for each side, running roughly parallel from the medulla in the brain to the bowels.

A. Control of Heart Rate: Autonomic nervous control

The heart is part of the **autonomic nervous system**. It has branches of 2 parts of the autonomic nervous system. These 2 pathways have opposite effects on heart rate (are antagonistic).



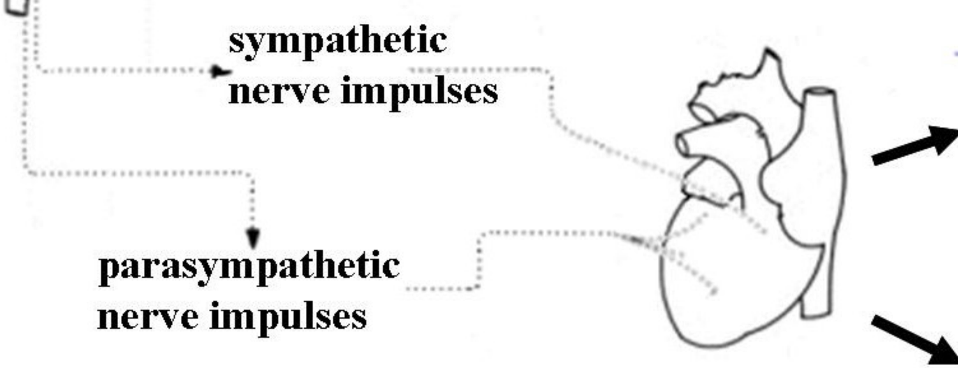
Heart rate is regulated by control centres within the medulla of the brain.

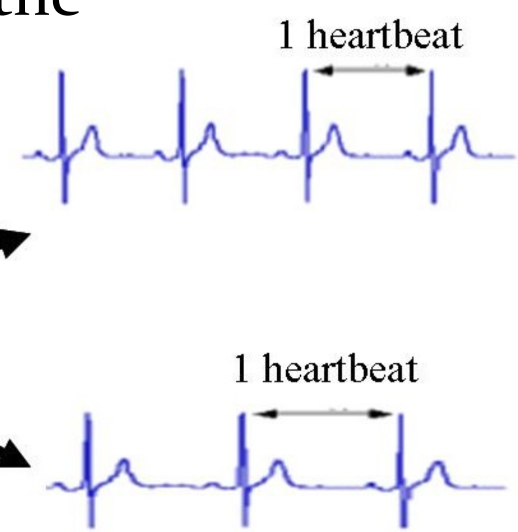


A. Control of Heart Rate: Autonomic nervous control

The **sympathetic cardiac nerves** carry nerve impulses from the **cardio-accelerator** centre of the brain to the heart.

Causes an **increase** in heart rate





The **cardio-inhibitor** centre sends nerve impulses via the **parasympathetic vagus nerve**.

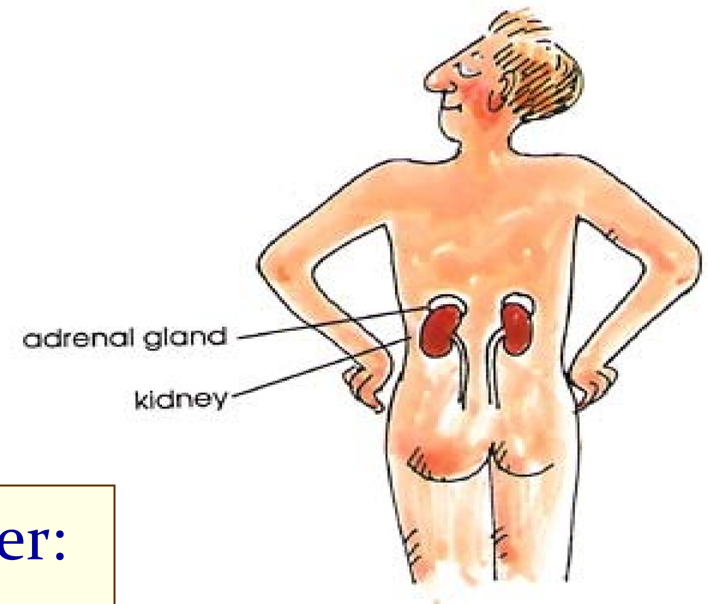
Causes a **decrease** in heart rate

Two antagonistic pathways

- The sympathetic and parasympathetic pathways are antagonistic to one another. i.e. They have an opposite effect on heart rate.
- An increase in the number of nerve impulses conducted to the to the pacemaker by the **sympathetic nerve** causes an **increase** in heart rate.
- An increase in the number of nerve impulses conducted to the to the pacemaker by the **parasympathetic nerve** causes a **decrease** in heart rate.

Control of Heart Rate: Hormonal Control

The adrenal glands produce the hormone adrenaline, which also affects heart rate.

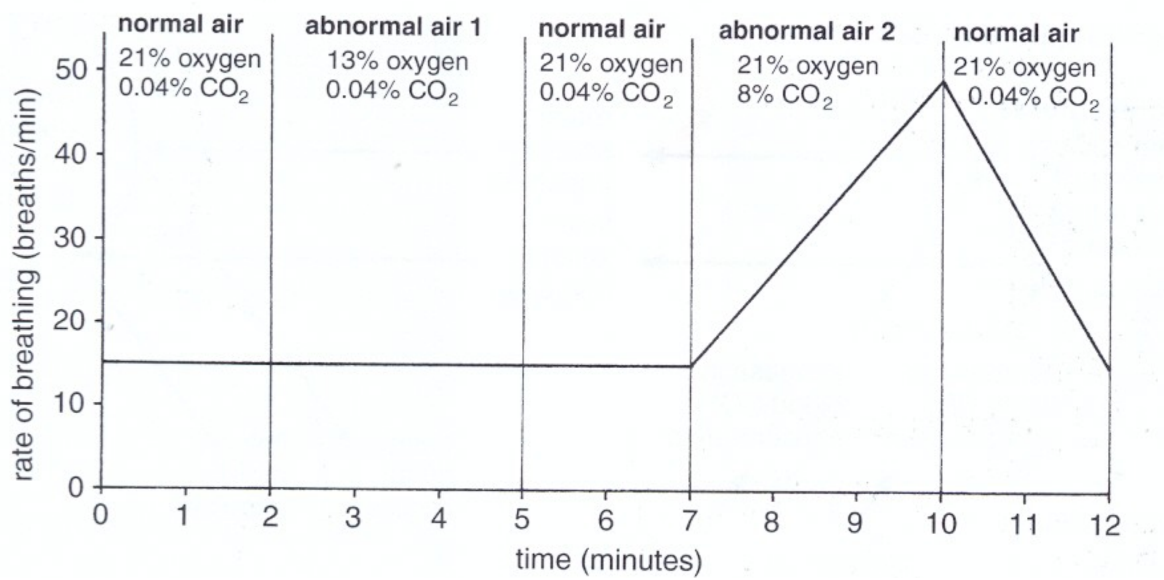


During exercise or stress….

Sympathetic nervous system causes the adrenal glands to release adrenaline → At pacemaker: adrenaline causes an increase in the rate of cardiac impulses → Increase in heart rate

Carbon dioxide as the stimulus

Experiments show (see Torrance p188) high levels of **CO_2** acts as the stimulus to trigger an increase in breathing rate. The graph below shows the results!



Only the 'abnormal' air type 2 is found to cause breathing rate to increase sharply. It is concluded that it is the high level of CO_2 in the 'abnormal air that acts as a stimulus triggering increased rate of breathing.

Carbon dioxide as the stimulus, Con’t

- Further experiments show
  - Depth of breathing also increases in response to inhalation of air rich in $CO_{2.}$,
  - In a person under going strenuous exercise it is the increased level of CO_2 in the bloodstream that acts as the main stimulus for bringing about an increase in rate and depth of breathing.

Oxygen as a stimulus

- It is worth noting that experiments also show that severe lack of oxygen will eventually also cause an increased rate and depth of breathing.

The effect of Exercise on the Respiratory System: Homeostatic control: Part 1

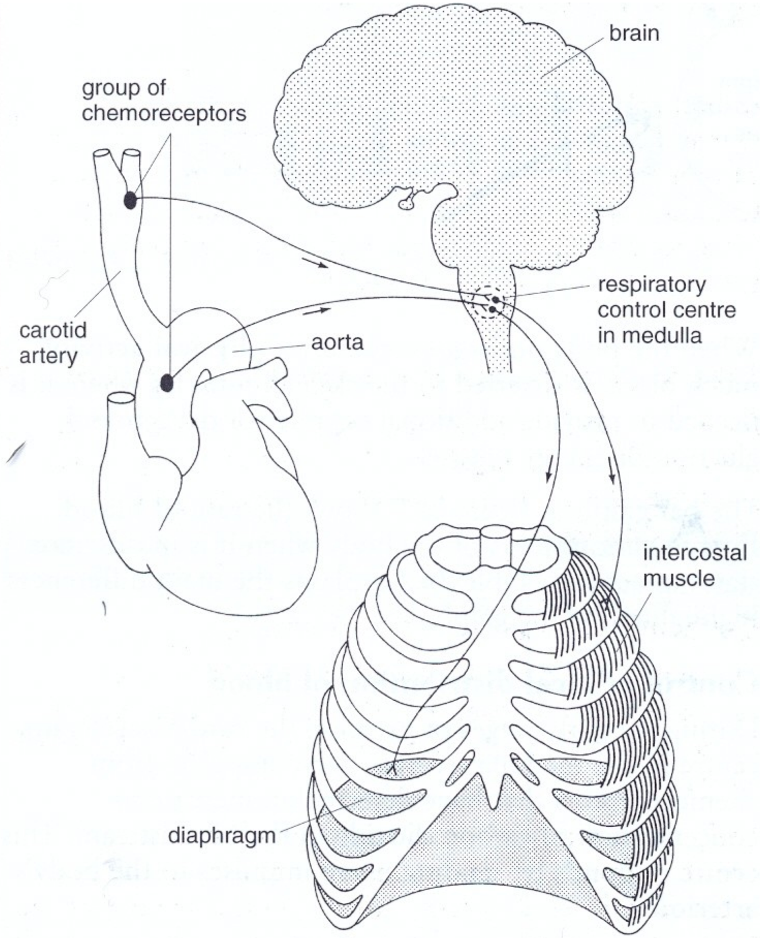


Figure 24.5 Nerve pathway triggered by chemoreceptors

- **Chemoreceptor's** in the carotid arteries and aorta are sensitive to the concentrations of CO_2 in the bloodstream. A rise in CO_2 levels during vigorous exercise causes these sensory cells to send an increased number of nerve impulses to the **respiratory control centre** in the **medulla**.

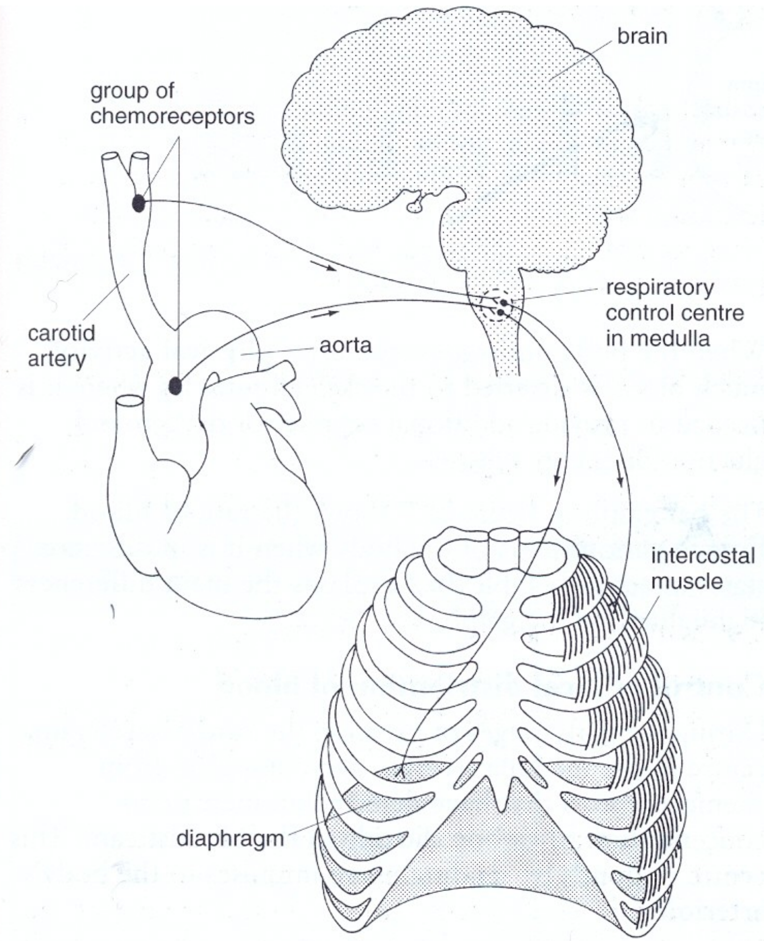


Figure 24.5 Nerve pathway triggered by chemoreceptors

- This region of the brain responds by sending a greater number of nerve impulses to the **intercostal muscles** and diaphragm. The subsequent increased activity of these structures brings about an increase in rate and depth of breathing.
- Excess CO_2 is removed and the internal environment is kept within tolerable limits.

SUMMARY: The effect of Exercise on the Respiratory System: Homeostatic control

High CO_2 concentration

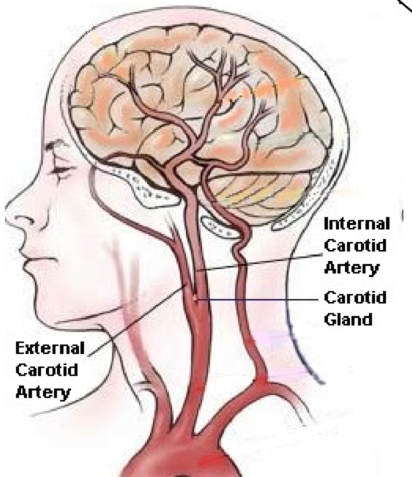
More nerve impulses sent to respiratory control centre in medulla

More nerve impulses sent to intercostal muscles and diaphragm

Breathing rate & depth increases causing a return to normal CO_2 concentration

Chemoreceptors in cartoid arteries & aorta detect CO_2 concentration

An example of **negative feedback control**



Control of local distribution of blood

- All parts of the body require an adequate supply of blood to function efficiently. But the demands by each part are not constant.
- At rest the '***vegetative functions***' (digestion, urine production etc.) are promoted.
- When the body undergoes '***strenuous activity***' much blood is diverted to the skeletal muscles (for extra O_2 and glucose).

Control of local distribution of blood

During exercise…

Chemoreceptors detect **CO_2** concentration

→ Increase in **CO_2** concentration →

Nerve impulses sent to cardio-accelerator centre in medulla

An example of **negative feedback control**

Nerve impulses sent to arterioles in **working muscles** causing arteriole wall to relax to **increase blood flow**

Nerve impulses sent to arterioles in **abdominal organs** cause muscles in arteriole wall to contract to **restrict blood flow**

Distribution of blood to tissues during exercise

During exercise blood flow to various parts of the body changes.

Tissue	Change due to exercise	Reason
Heart	Increase	to meet its demand for more glucose and oxygen
Brain	None	Basic energy demands of cells not affected
Kidneys	Decrease	kidney processes can be postponed until the exercise is finished
Skin	Increase	allow the heat produced in muscles to be radiated from the surface of the skin
Intestines & liver	Decrease	processes of digestion and absorption can be postponed until the exercise is finished
Skeletal muscles	Increase	to meet their demands for more glucose and oxygen

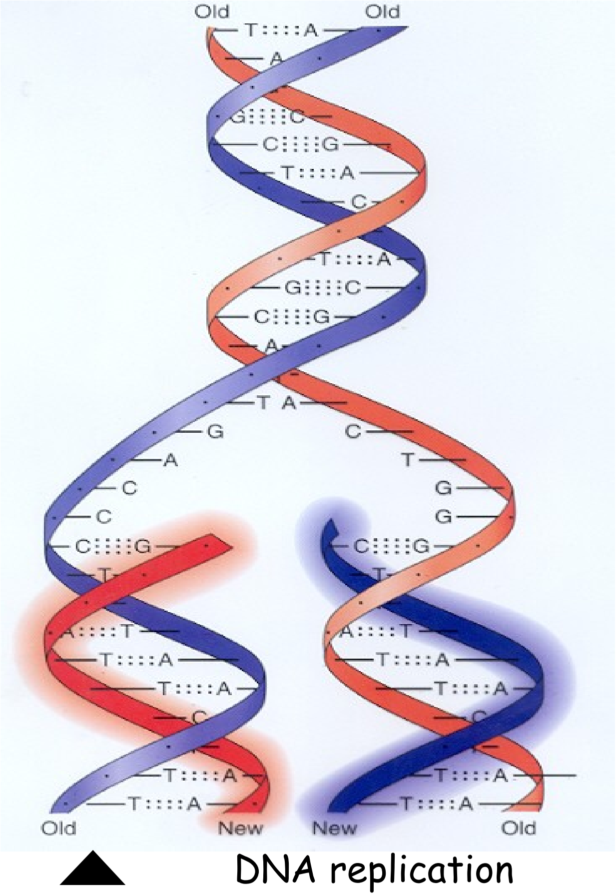
Regulation of Blood Glucose Concentration

Blood sugar level must be kept within a certain range to provide the energy needed by cells for:

- Synthesis of DNA, proteins and other complex molecules.
- Active uptake of ions.
- Muscle contraction.

Cells are therefore constantly using up the blood sugar.

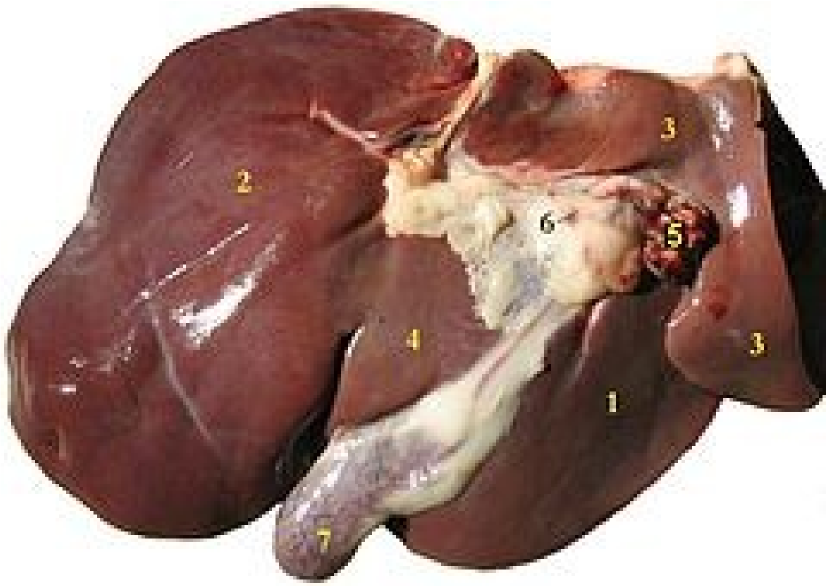
To ensure a regular supply regardless of food consumed the body uses homeostasis!



DNA replication

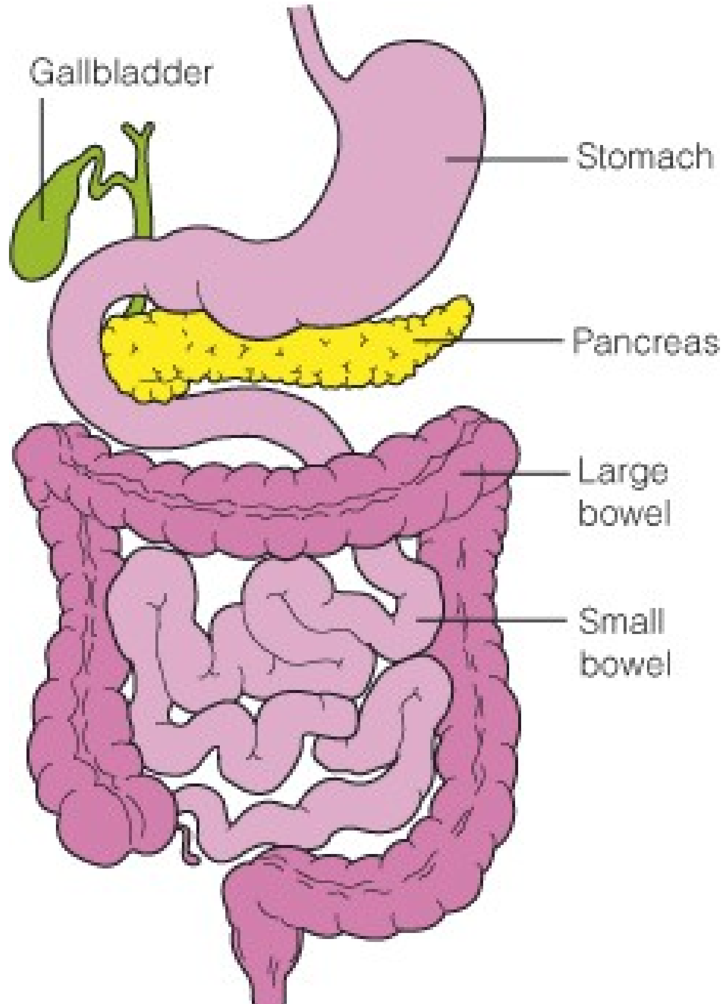
Liver as a storehouse

- About 100g of glucose is stored as GLYCOGEN in the liver. Glucose can be added or removed from this reservoir if stored carbohydrate depending on supply and demand.



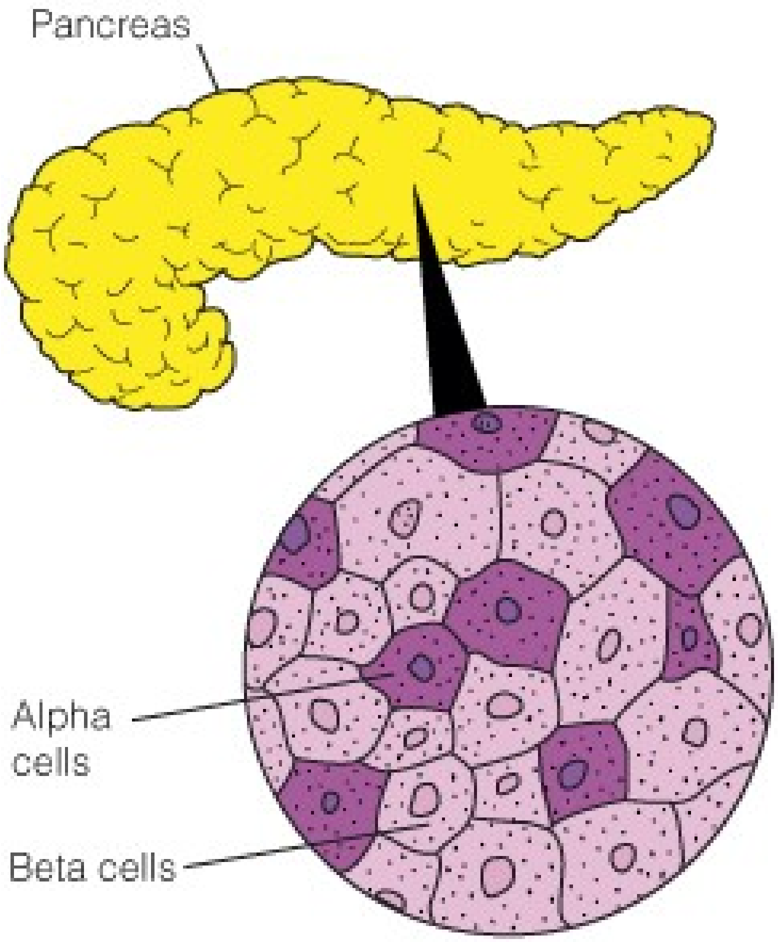
Control of blood sugar: Insulin and glucagon

- **Insulin** and **glucagon** are two hormones that control how much glucose (sugar) is in the blood
- These hormones are made in the **pancreas.**
- Your pancreas contains small groups of cells called the ***islets (or islands) of Langerhans.***



Pancreas

- When you eat a meal, the amount of **sugar** in your blood **rises**. The cells in your pancreas react by making **more insulin**.
- When your blood sugar levels are low, the cells in your pancreas react by making **more glucagon**.



What does insulin do?

- After digestion, glucose enters your bloodstream.
- The Islets of Langerhans in the pancreas detects an increase in blood sugar level.
- These cells produce the hormone insulin, which is then transported to the liver in the bloodstream.
- Insulin activates an enzyme to catalyse the reaction

$$\text{glucose} \longrightarrow \text{glycogen}$$

- This decreases the blood sugar level.
- Glycogen, a long chain carbohydrate, is stored in the liver until it is needed e.g. when you are sleeping

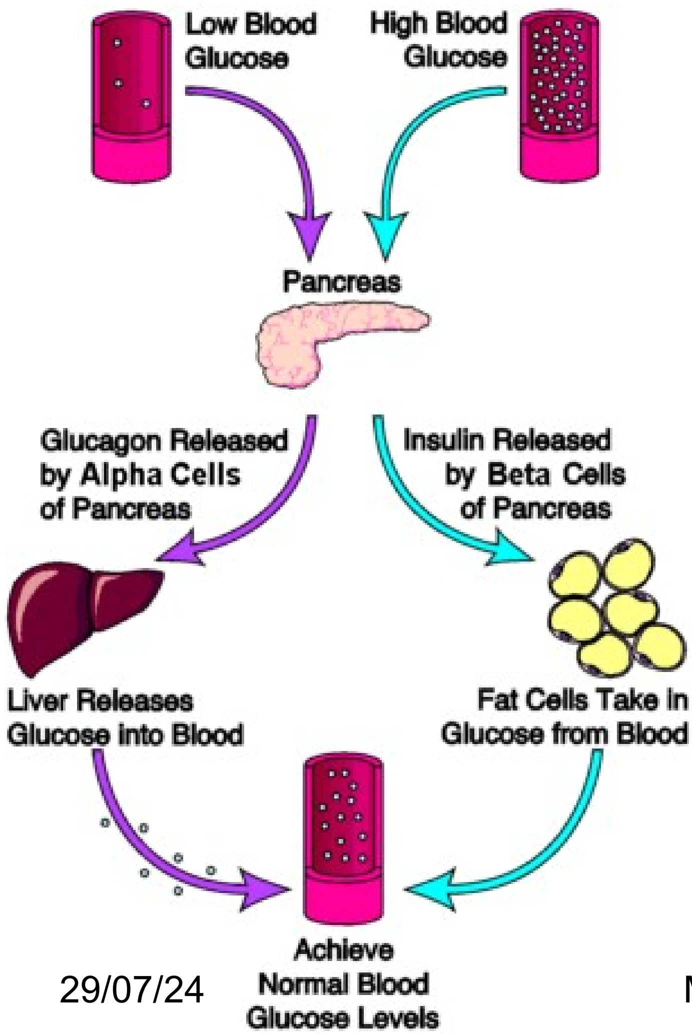
What does glucagon do?

- **Glucagon stops your blood glucose level from dropping too low.**
- When you exercise, your body uses the glucose in your blood to power your muscles. Your pancreas senses that you're using up your glucose supply.
- As your blood glucose level drops, your pancreas stops making insulin and your pancreas makes glucagon
- Glucagon activates an enzyme in your liver which catalyses the following reaction

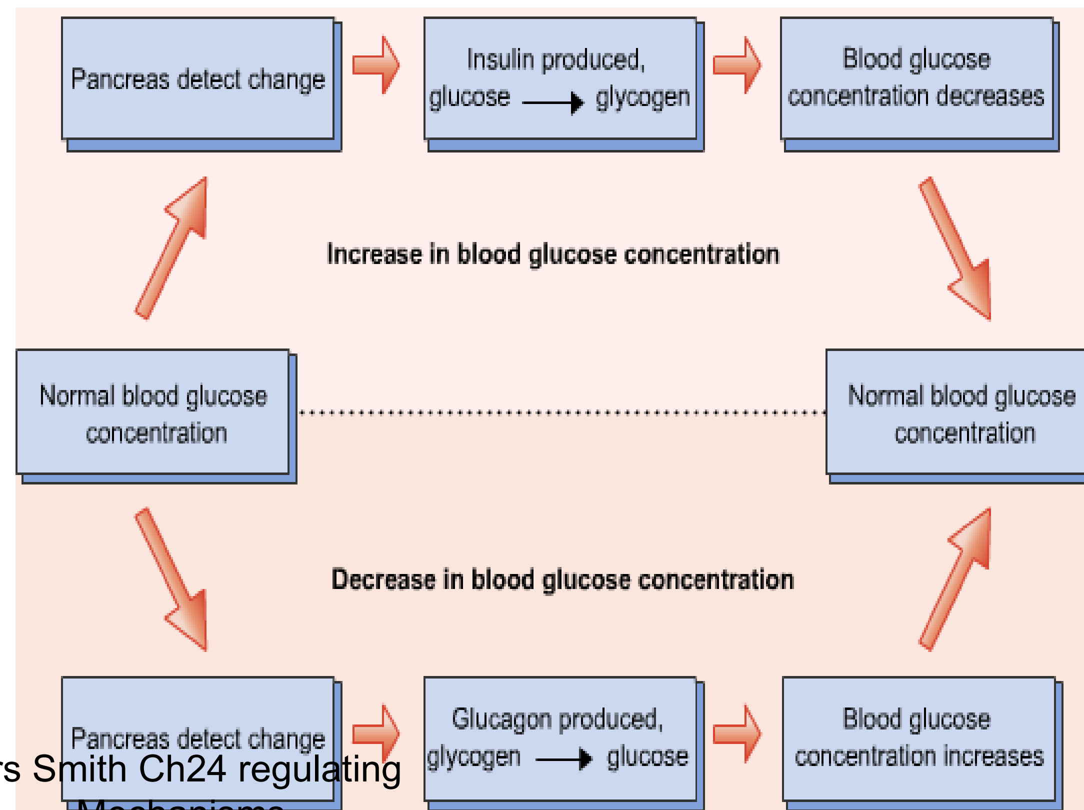
$$\text{Glycogen} \longrightarrow \text{Glucose}$$

- These activities push up the amount of glucose in your blood.

Control of blood sugar



$$\text{Glucose} \underset{\text{Glucagon}}{\overset{\text{Insulin}}{\rightleftharpoons}} \text{Glycogen}$$

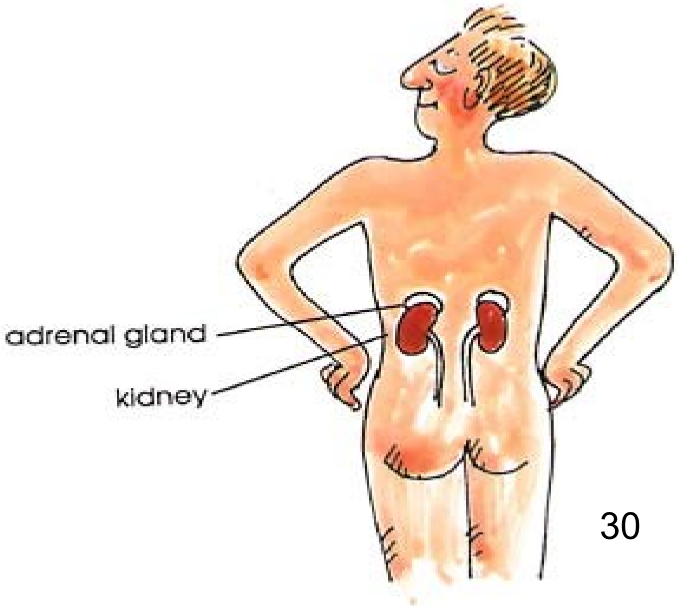


Adrenaline – Stress Response

The adrenal glands produce the hormone adrenaline in an emergency when the body needs a *quick supply of glucose (for 'fight or flight')*

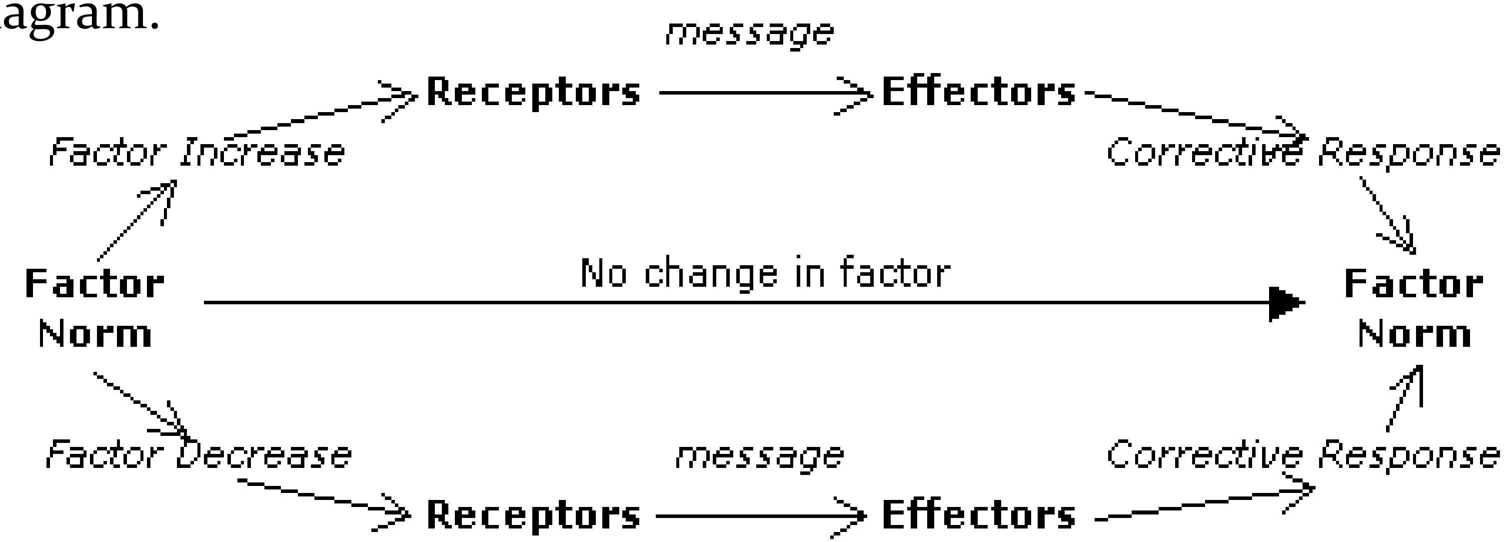
Adrenaline is secreted by the adrenal gland and inhibits the secretion of insulin and promotes the breakdown of glycogen to glucose, overriding the normal homeostatic control.

When the crisis is over the normal homeostatic control then returns the blood sugar level to its norm.



Alternative Homeostasis

All factors controlled by homeostasis can be represented by a standard diagram.

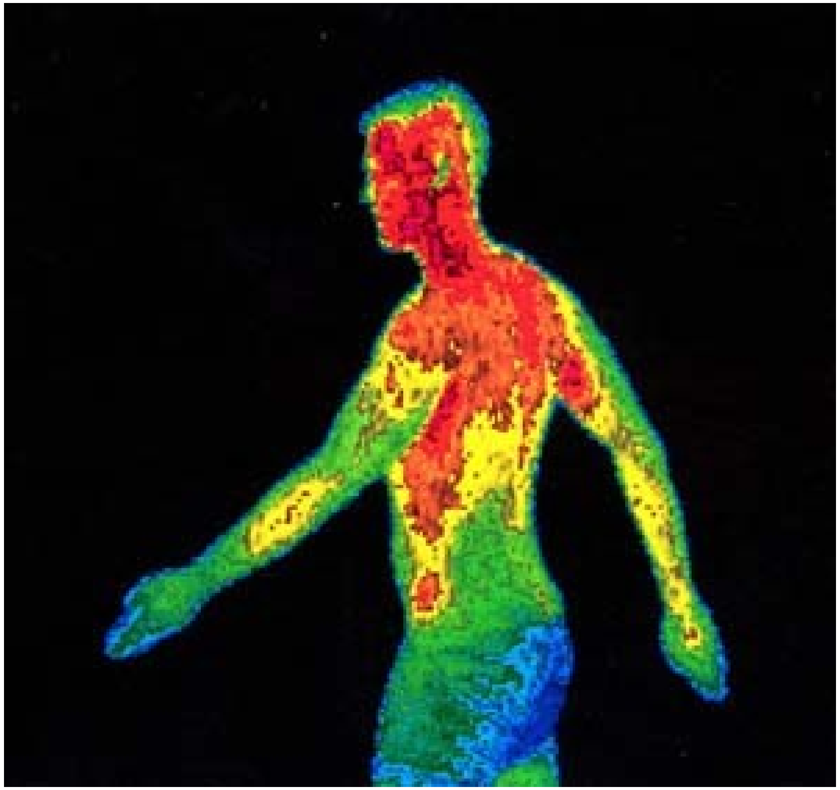


When a factor deviates from the norm and is returned to normal it often overshoots the mark, which triggers the reverse set of corrective mechanisms.

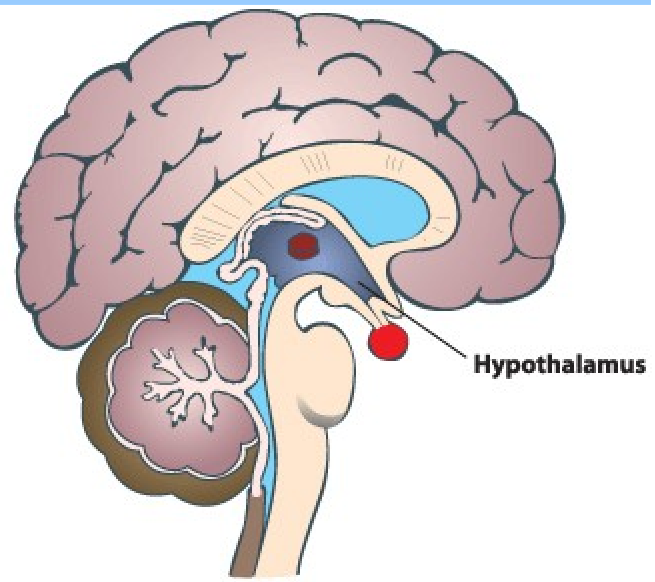
So factors in a state of **dynamic equilibrium** are **constantly wavering on either side of the norm**. This is usually represented by 2 linked circuits.

Control of Body Temperature

- Core body temperature must remain at 37^{o}C
- Careful control of the blood supply to the skin can do this by reducing blood flow to the colder extremities in cool conditions.



Regulation of Body Temperature



- Another example of homeostasis is the body's regulation of body temperature.
- The hypothalamus (the body's temp-monitoring centre)monitors body temperature in two ways:
  1. It contains central thermoreceptors which are sensitive to temperature changes in the blood, allowing detection of the body's core temperature.
  2. It acts as a thermostat by detecting nerve impulses from thermoreceptors in the skin (this conveys info about the surface temp of the body).

Regulation of Body Temperature

The hypothalamus sends nerve impulses to the effectors allowing the body to correct overcooling or overheating by:

1. Production of sweat.
2. Control of body hairs.
3. Vasodilation or Vasoconstriction of blood flow in the skin

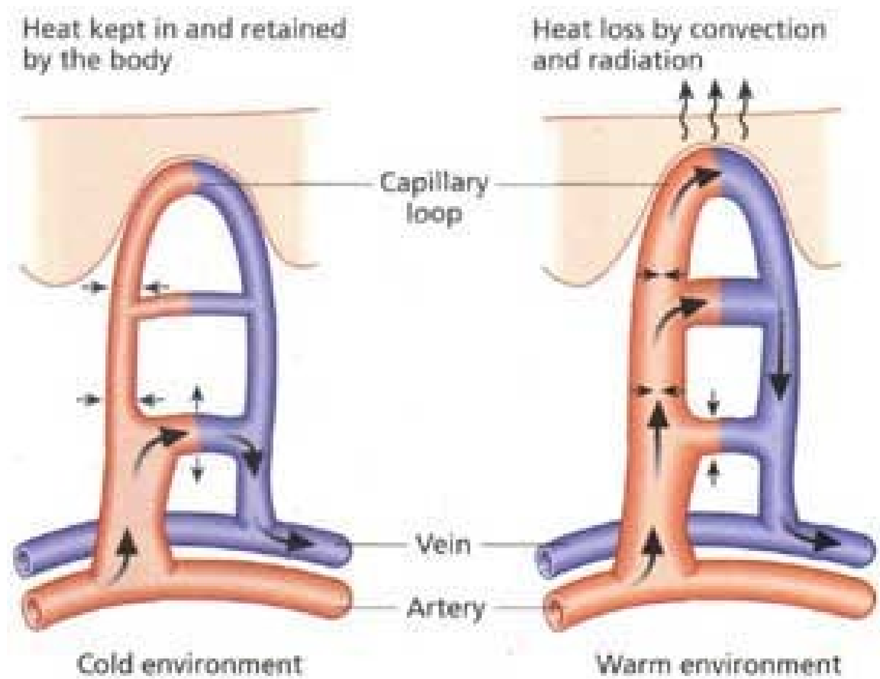
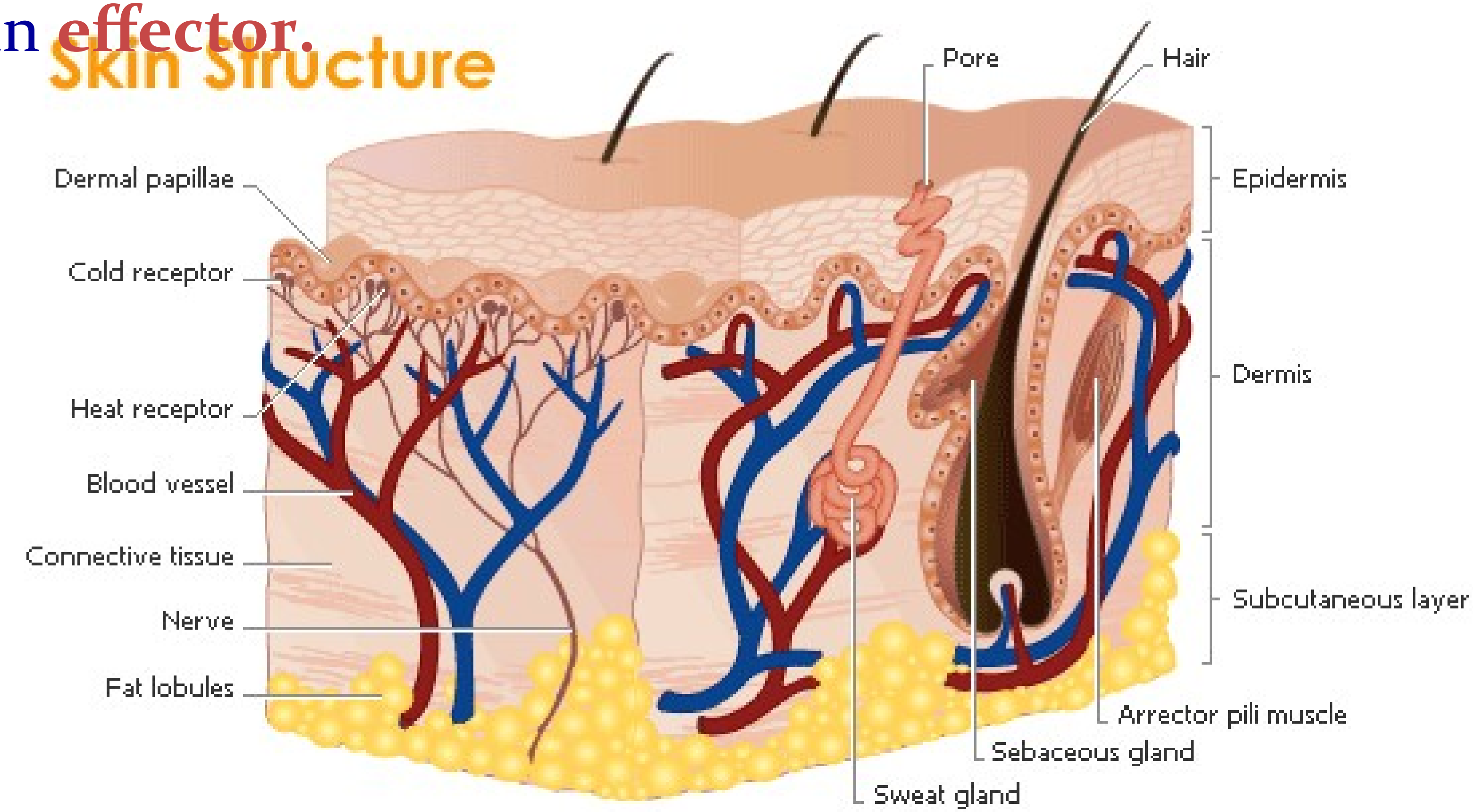


Image source: www.pg.com

Role of the Skin

The skin plays a leading role in temperature regulation. In response to nerve impulses from the hypothalamus the skin can act as both a **receptor** and an **effector.**



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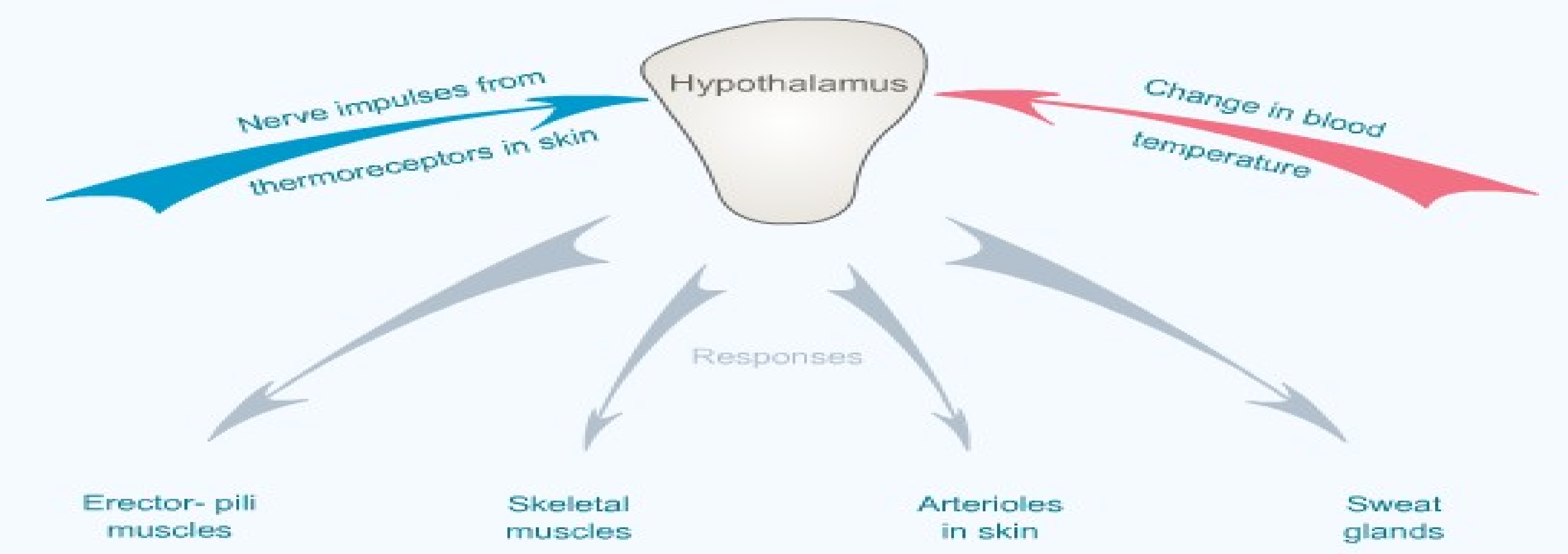
Role of the Skin



The skin helps to correct overheating of the body by

1.Increasing the rate of sweating.

2.Vasodilation

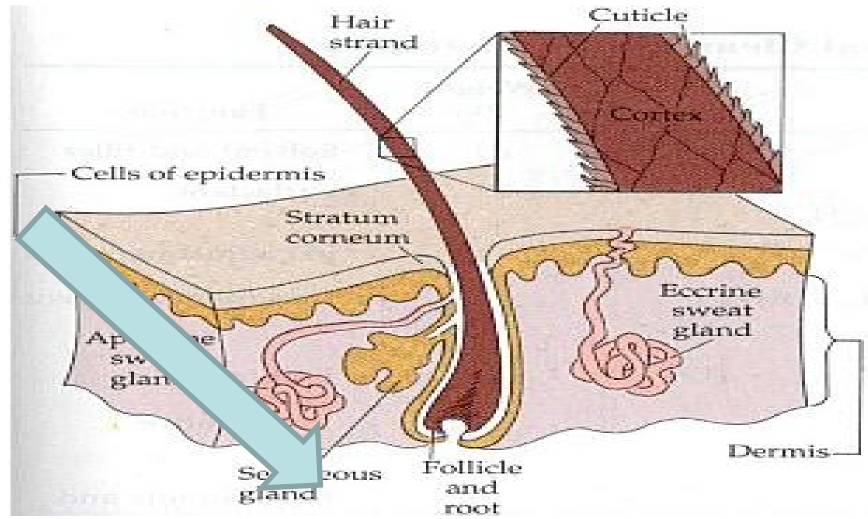
The skin help to correct overcooling of the body by

3.Decreasing the sweat of sweating.

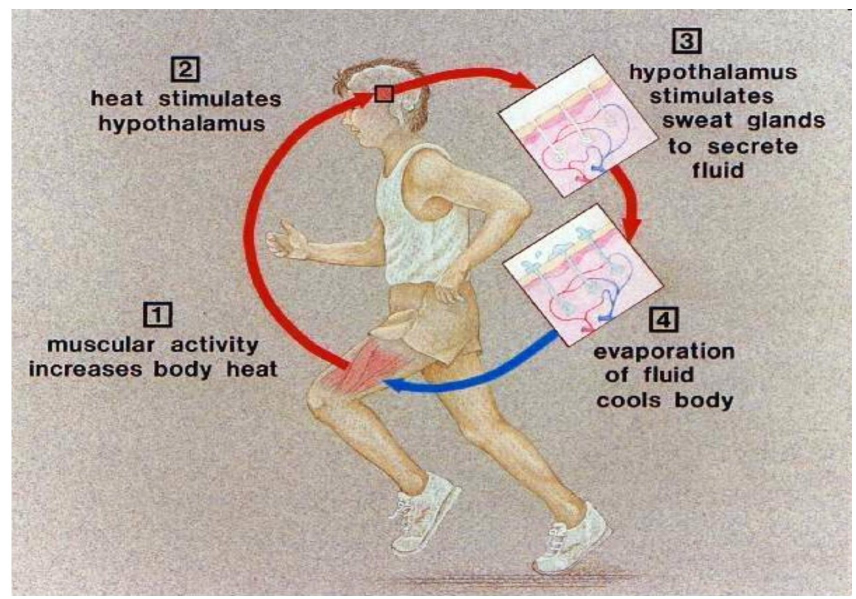
4.Vasoconstriction

5.Contraction of erector muscles

Sweat glands dampen the skin. This loses heat by causing evaporation of the sweat



. When we sweat, heat energy from the body causes water from sweat to evaporate which cools the body.

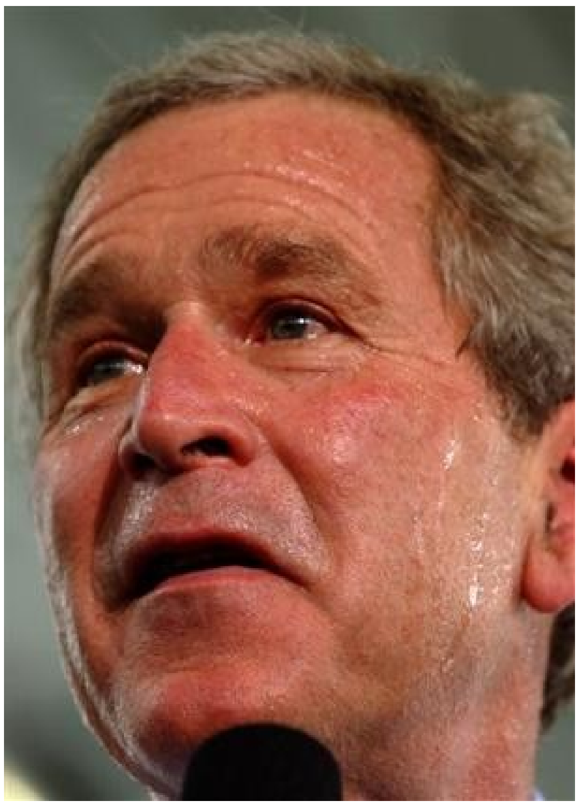


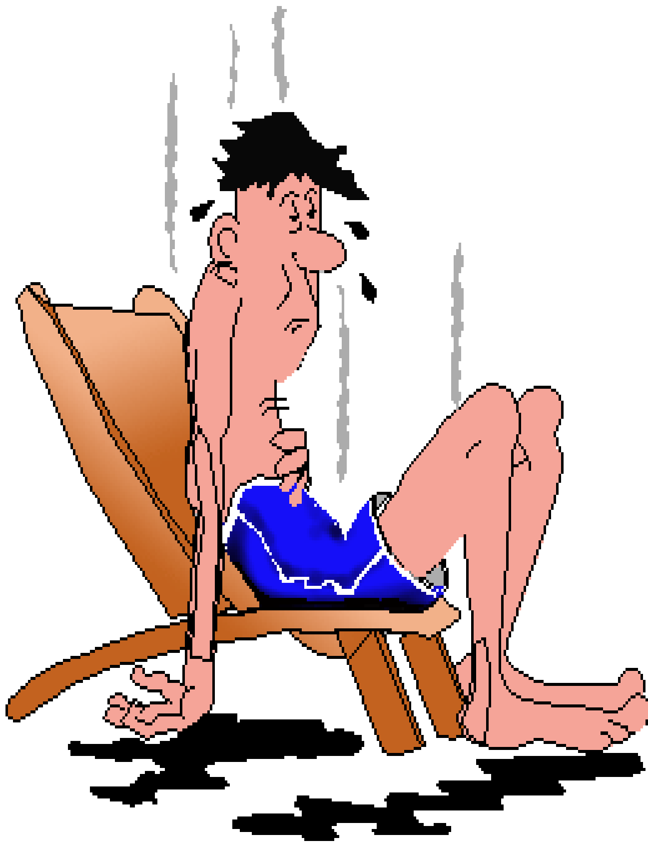
. when we are cold sweating in inhibited to conserve heat.

Sweating under pressure!

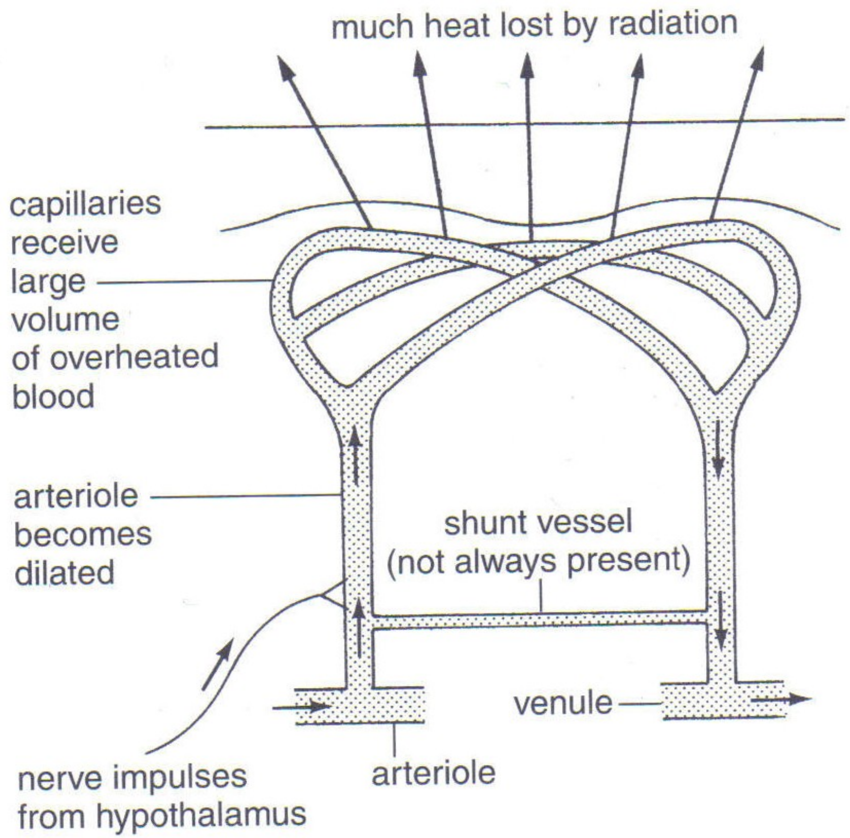
Sweating caused by heat

Sweating caused by muscular contraction





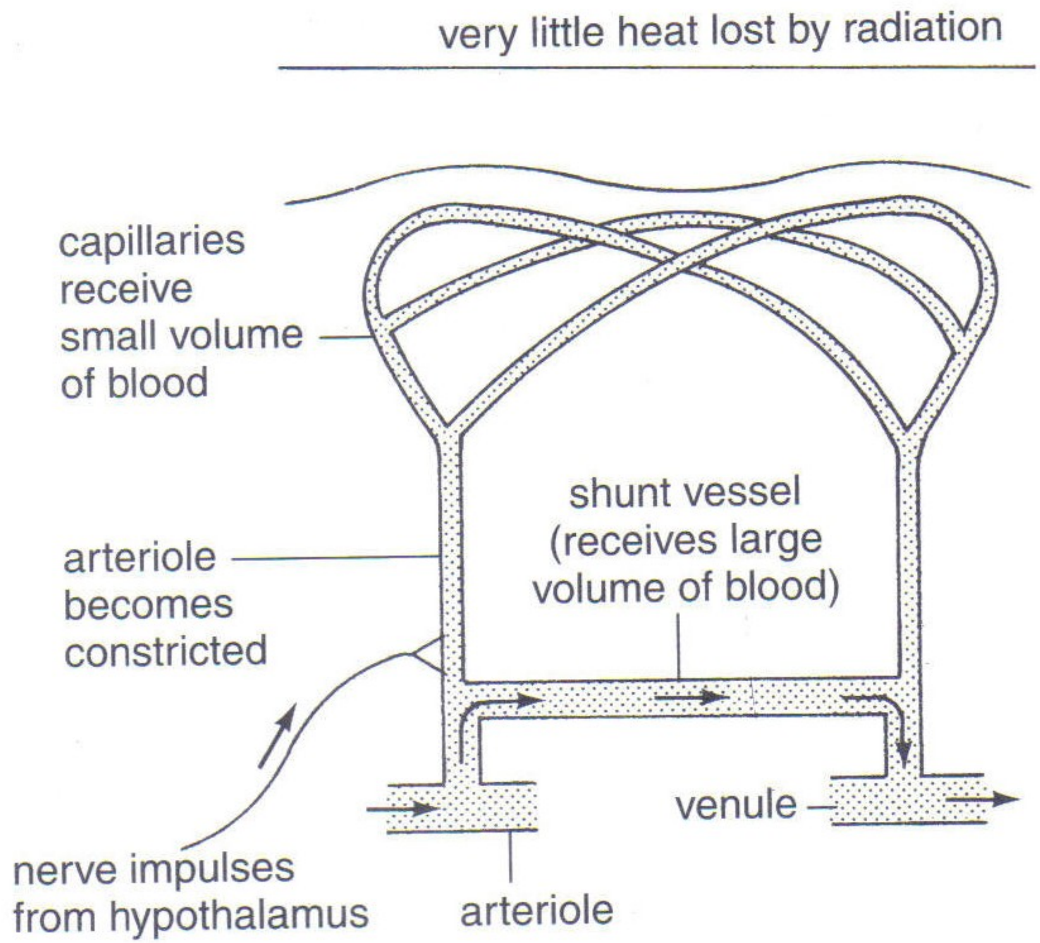
Correct overheating: Vasodilatation



When we get **too hot** arterioles leading to the skin become **dilated**, which allows lots of blood to flow near the skins surface and a loss of heat from the blood by radiation.

Correct overcooling: Vasoconstriction

When we are **cold** arterioles leading to the skin become **constricted**, which reduces the flow of blood to the skins surface so only a little heat is lost from the blood by radiation.

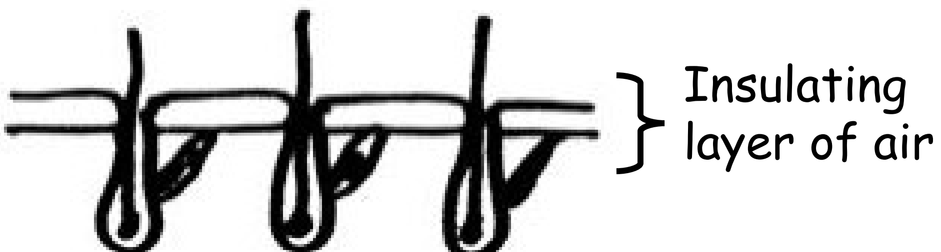


Preventing overcooling: Contraction of erector muscles

In a cold environment we need to reduce heat loss. This system is more efficient in furry animals than in humans.

Nerve impulses from the **hypothalamus** cause the **erector muscles** in our skin **contract** causing the hair (or feathers in birds) to rise up. This increases the layer of **insulating air** trapped by them so keeps the body warm.

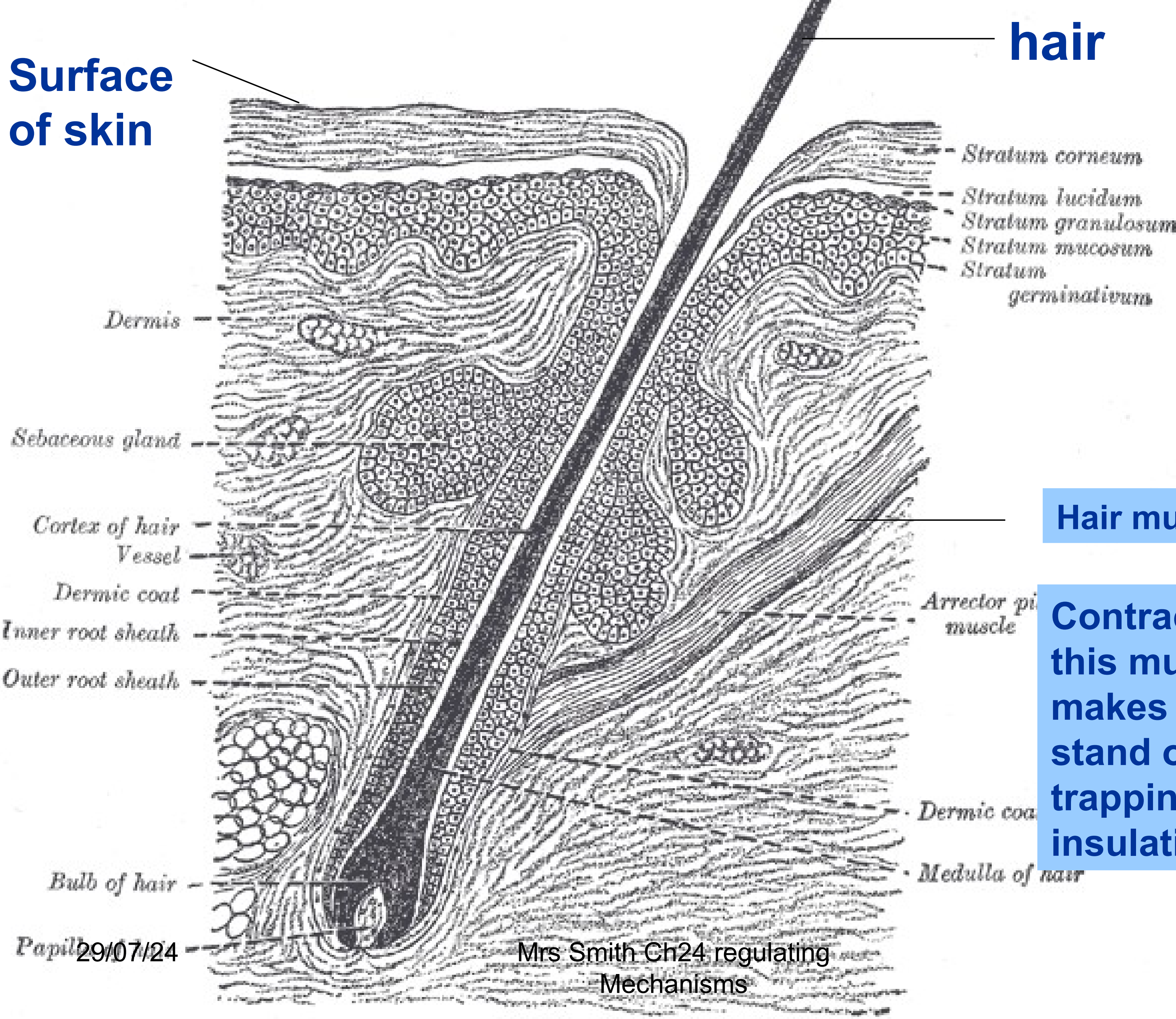
erector muscles relaxed



erector muscles contracted

Surface of skin

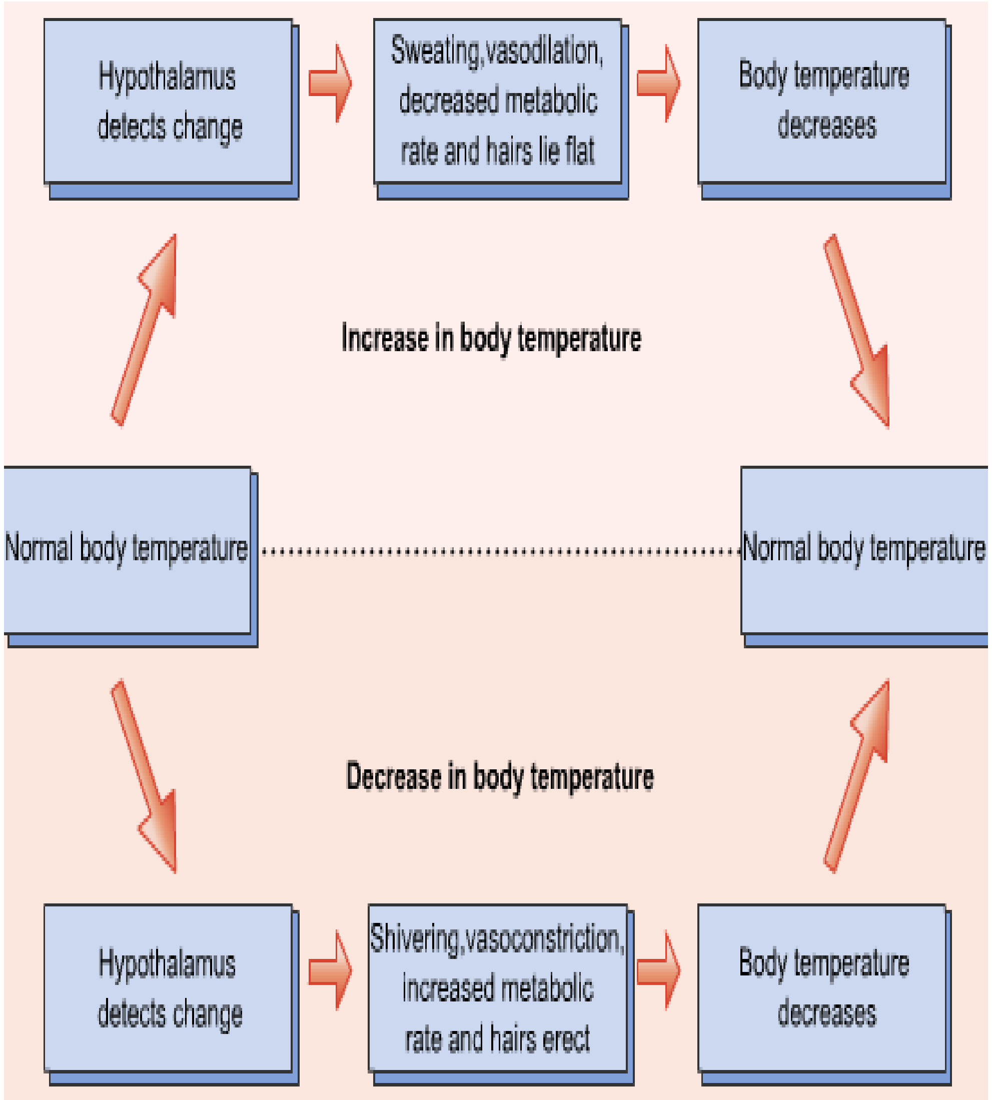
hair

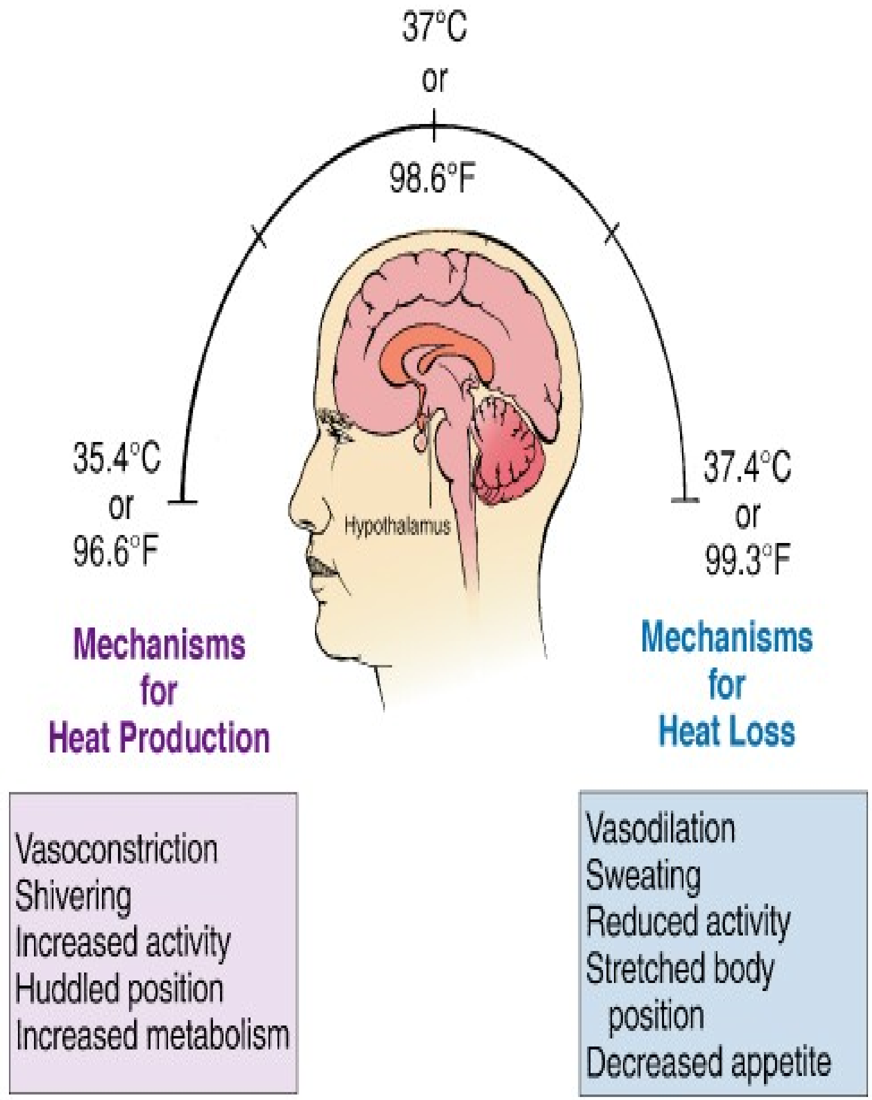


Hair muscle

Contraction of this muscle makes the hair stand on end, trapping more insulating air.

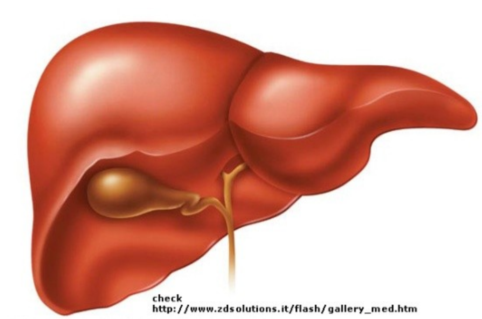
Summary: Body Temperature

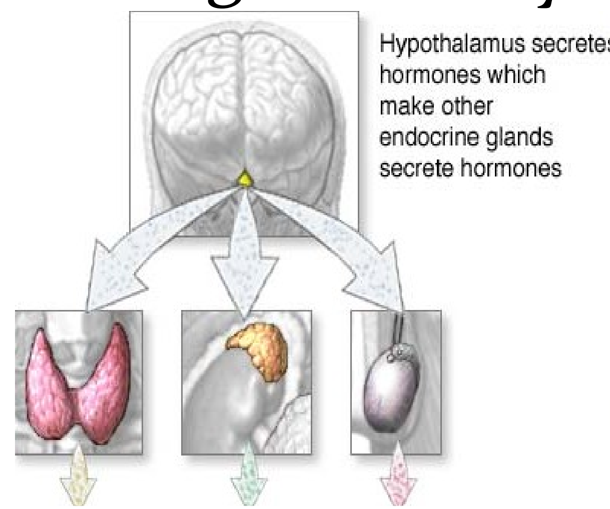




Role of other effectors in temperature regulation

These other effectors help temperature regulation by generating heat when it is needed:





Shivering by skeletal muscles: muscle contractions which generate heat energy, helping return temperature to normal

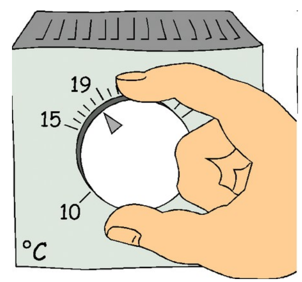
Liver:
high metabolic activity produces heat and helps to maintain body temperature

Hormones: *increase metabolic rate*
- release of adrenaline during sudden exposure to cold temperatures
- release of thyroxin

Voluntary Responses

However body temperature is also controlled by voluntary responses e.g.

putting on a jumper

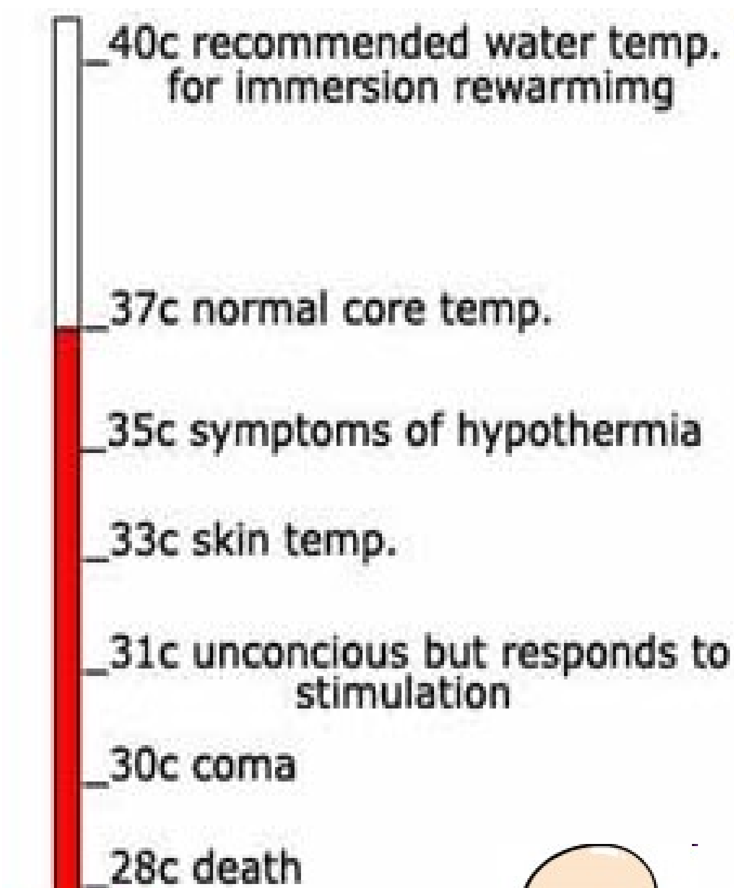


turning on the heating

drinking a warm drink

When body temperature drops (or rises) nerve impulses pass the information to the thinking part of the brain (the cerebrum), which makes the person feel cold (or hot) and react.

Hypothermia



Hypothermia is caused when the body’s core temperature drops to a dangerously low temperature.

Uncontrollable shivering and blue lips are early signs of hypothermia

Babies and the elderly are the most susceptible to hypothermia

Breakdown of homeostasis

Homeostasis only works in certain limits!!

If exposed to an extreme environmental condition for a long time the **negative feedback control breaks down**.

For example, the elderly often fail to realise the signs of hypothermia so don't take corrective action (e.g. turning up the heating). If their homeostatic temperature control has broken down their body can't recover on its own. They become hypothermic and need urgent medical attention.

THANK YOU