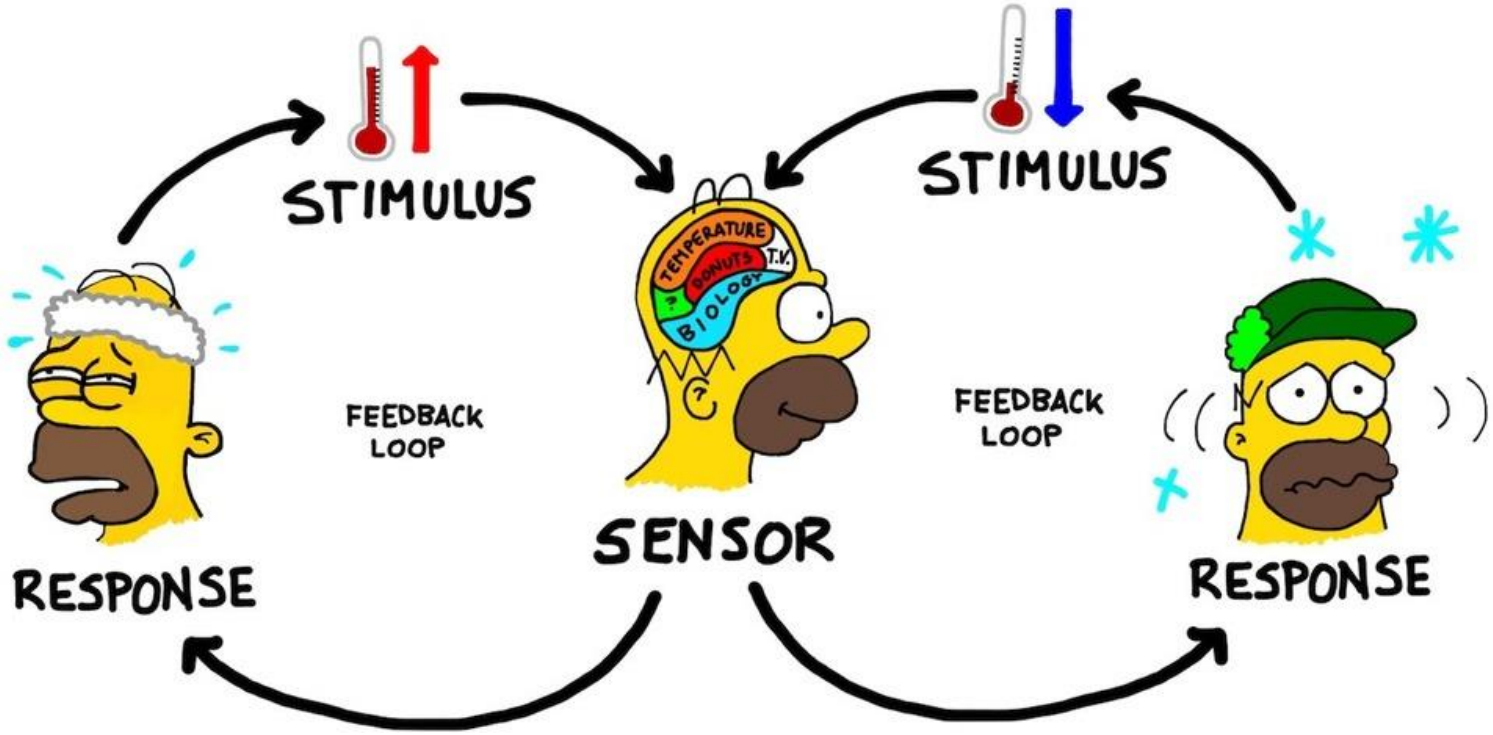
School of Physiology

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Temperature regulation

PHSL 2000



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Course outline

Lecture 1:

- Introduction to temperature regulation
  - Endotherm & Ectotherm
- Body temperature
  - Core temperature & outer shell temperature
  - Why thermoregulation is important
  - Factors that cause changes in body temperature
  - Measuring body temperature

Lecture 2:

- Mechanisms of heat loss/gain
- Neuronal control of temperature
- Factors affecting heat exchange
  - Heat loss mechanisms
  - Response to a warm environment

Lecture 3:

- Factors affecting heat exchange
  - Heat gain mechanisms
  - Response to a cold environment
- Neonatal thermoregulation
- Geriatric thermoregulation

Lecture 4:

- Altered thermoregulation
  - Fever
  - Hyperthermia
  - Hypothermia
- Thermoregulation during exercise
- Acclimatisation

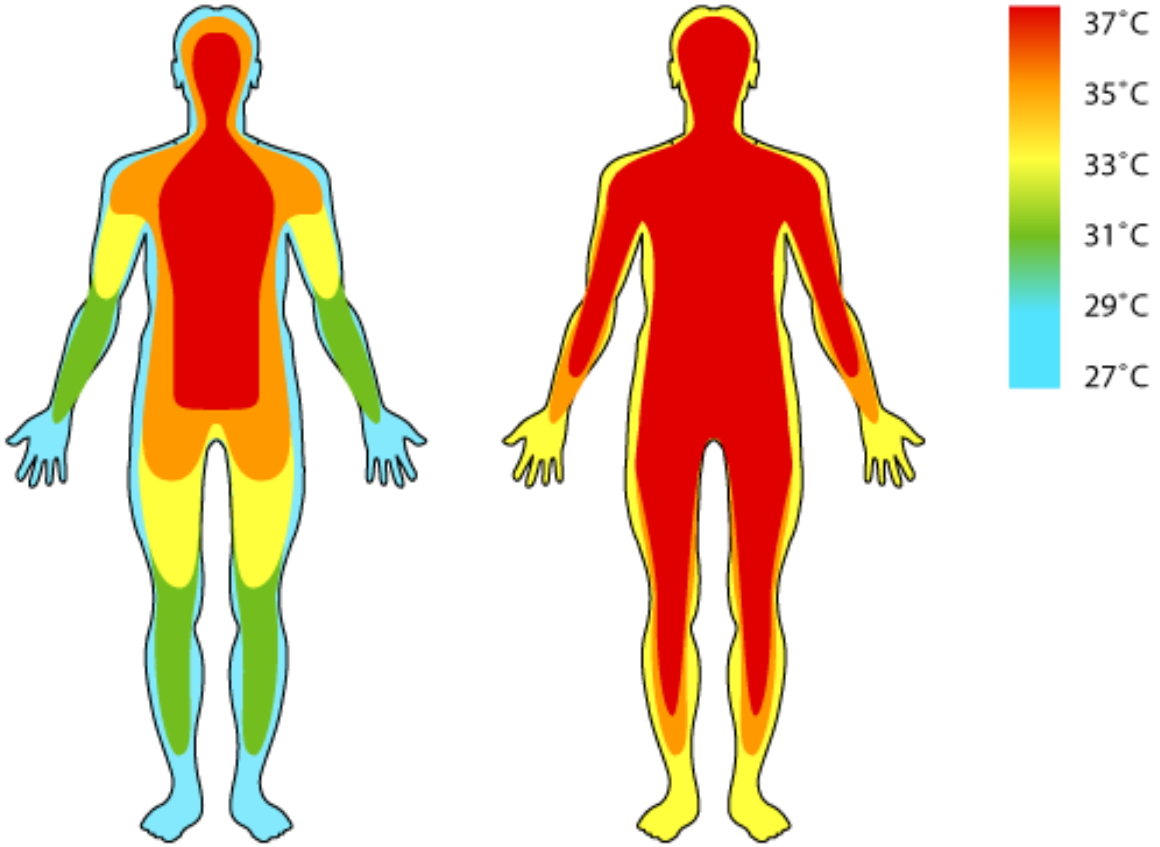
Temperature regulation

What is temperature?

Temperature is a measure of the average kinetic energy of molecules in a system.

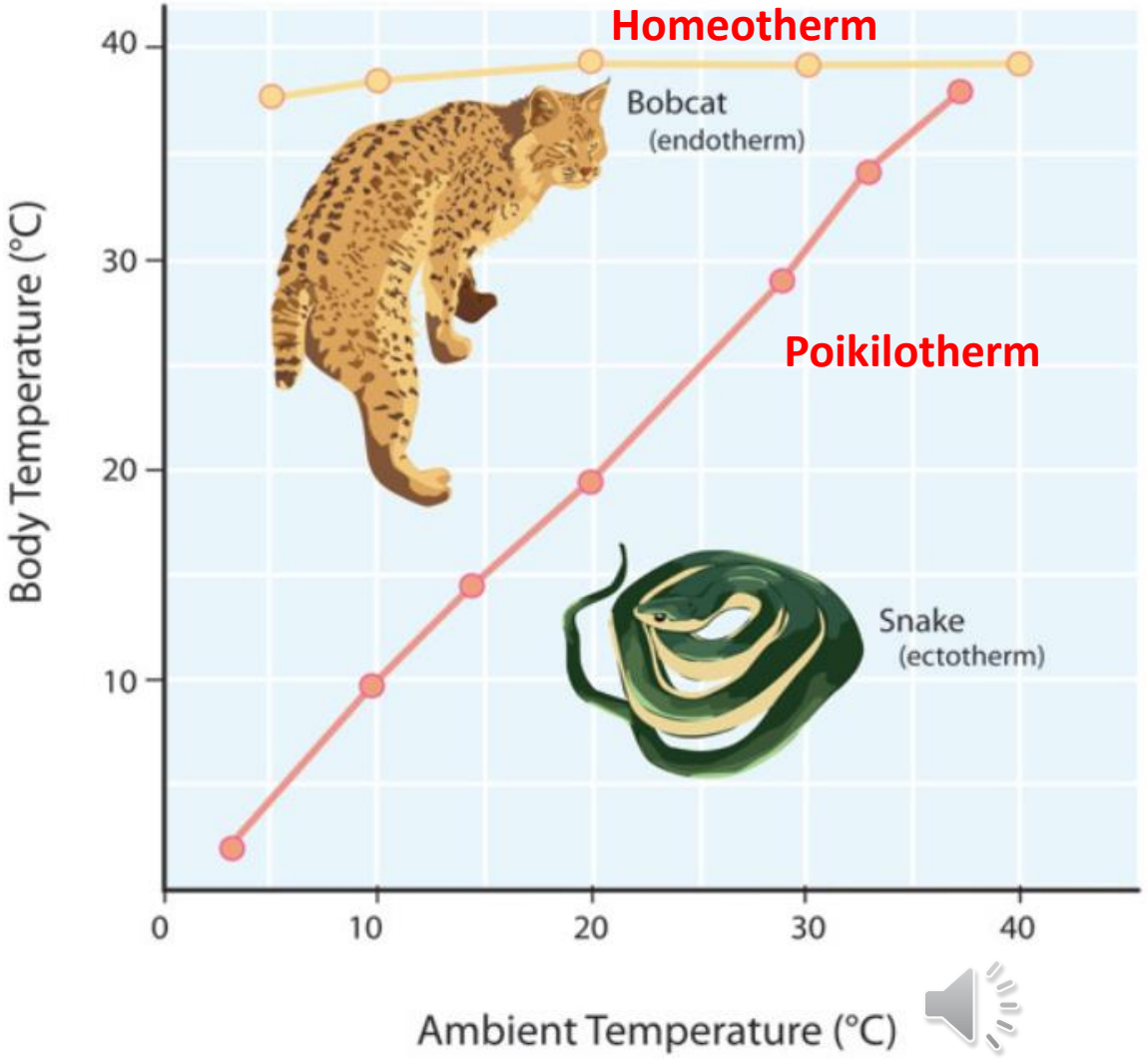
What is temperature regulation?

The ability of an organism to **regulate** its internal temperature to a particular level that provides optimal conditions for metabolic processes to occur.



Types of thermoregulation

- Endotherms: primarily produces own body heat
- Ectotherm: primarily gains heat from the environment
- Homeotherm: maintains a constant body temperature
- Poikilotherm: body temperature varies according to the environment



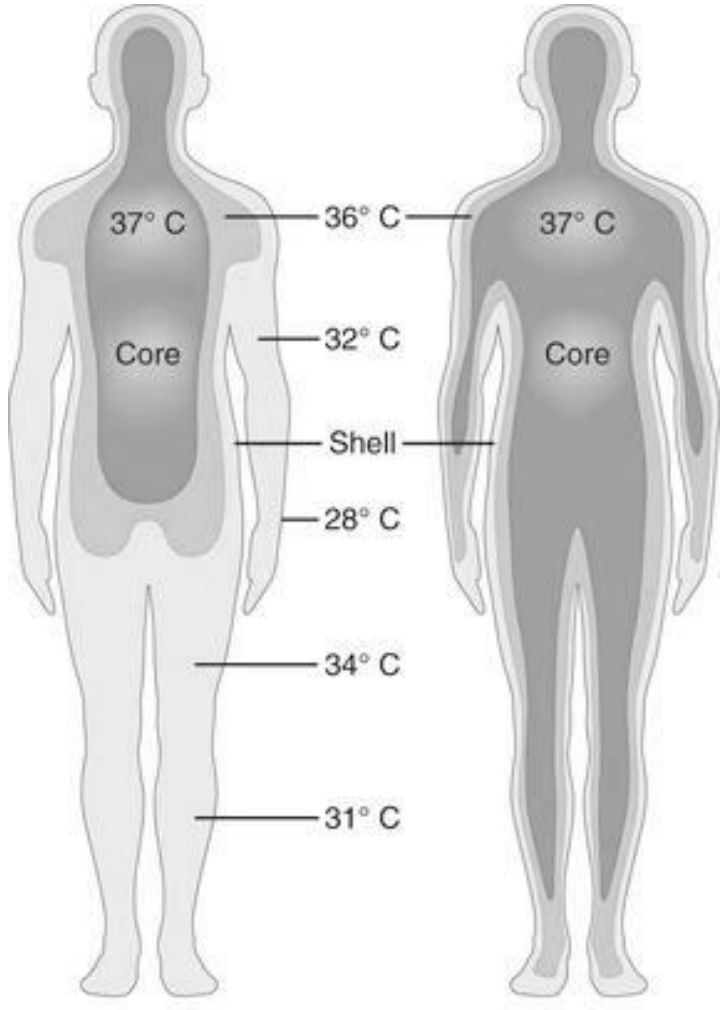
Body temperature

Outer shell temperature

- Temperature of skin, subcutaneous fat
- Rises and falls with changes in ambient temperature

Regulated through changes in skin perfusion:

- **↑ (vasodilation) or ↓ (vasoconstriction) of blood flow**
- **↑ or ↓ sweating**



Ambient temperature of **20° C**

Ambient temperature of **30° C**

Core temperature

- Temperature of intracranial, thoracic and abdominal regions
- Remains constant despite changes in ambient temperature

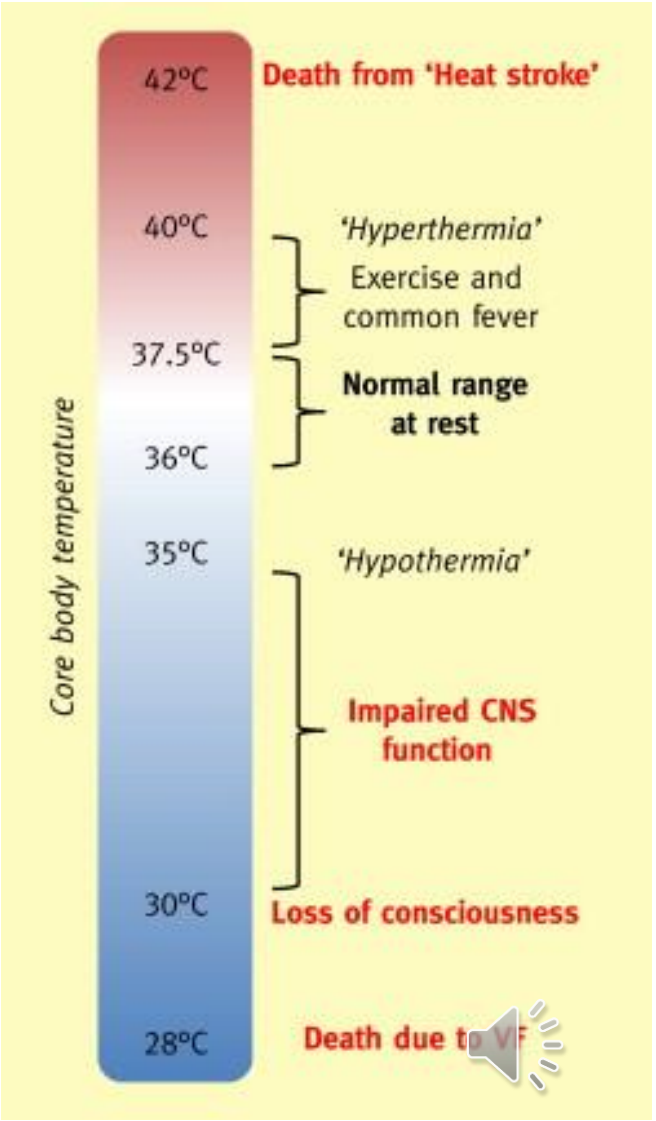
Regulated by ↑ or ↓ in heat transfer to shell

Why is thermoregulation important?

Changes in body temperature alters cellular activity

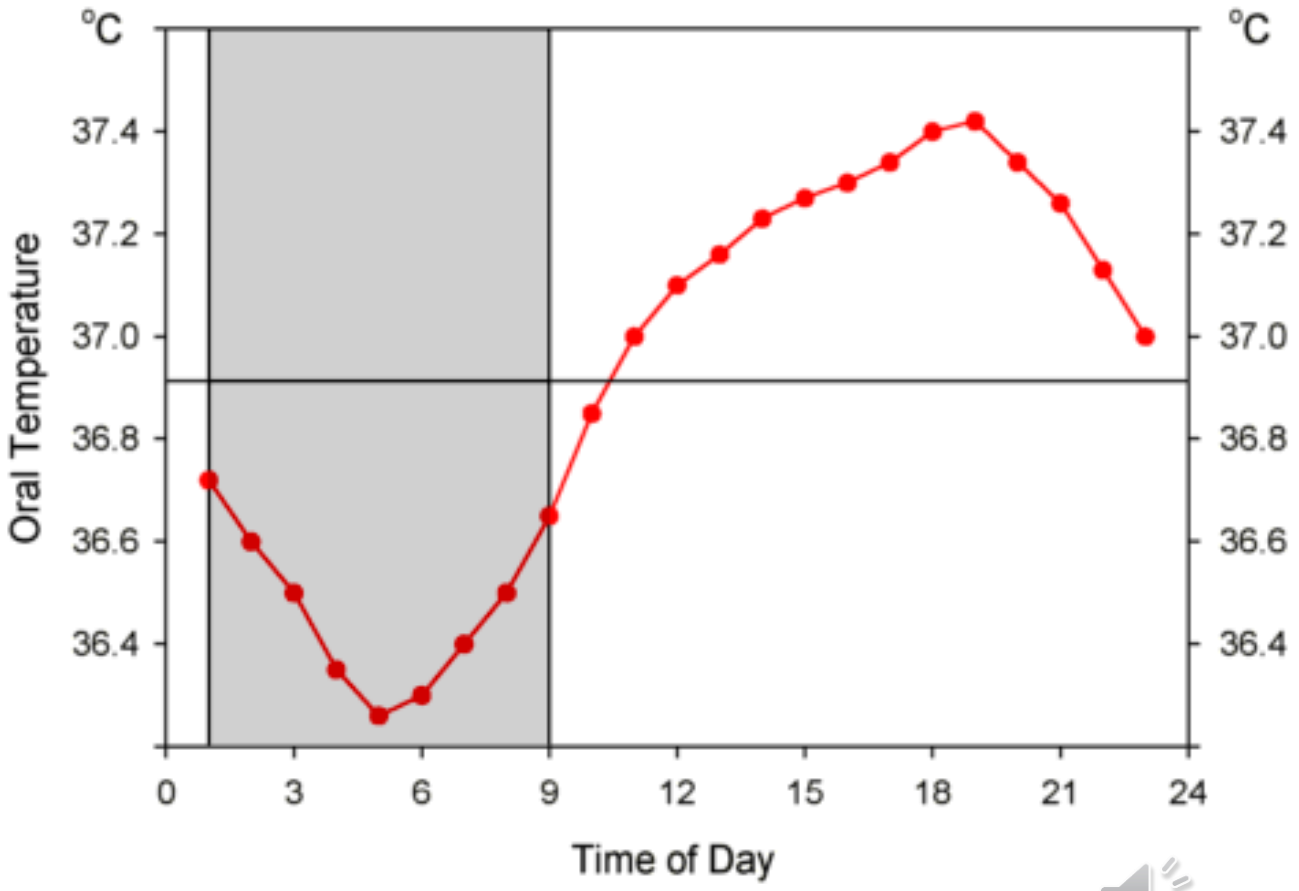
- Low (cold) temperatures
  - –Slows down cellular chemical reactions
  - –Hypothermia
    - › Rapture of cell membranes
    - › Slows down nerve conduction

- High (hot) temperatures
  - –Speeds up cellular chemical reactions
  - –Hyperthermia
    - › Nerve malfunction
    - › Irreversible protein denaturation



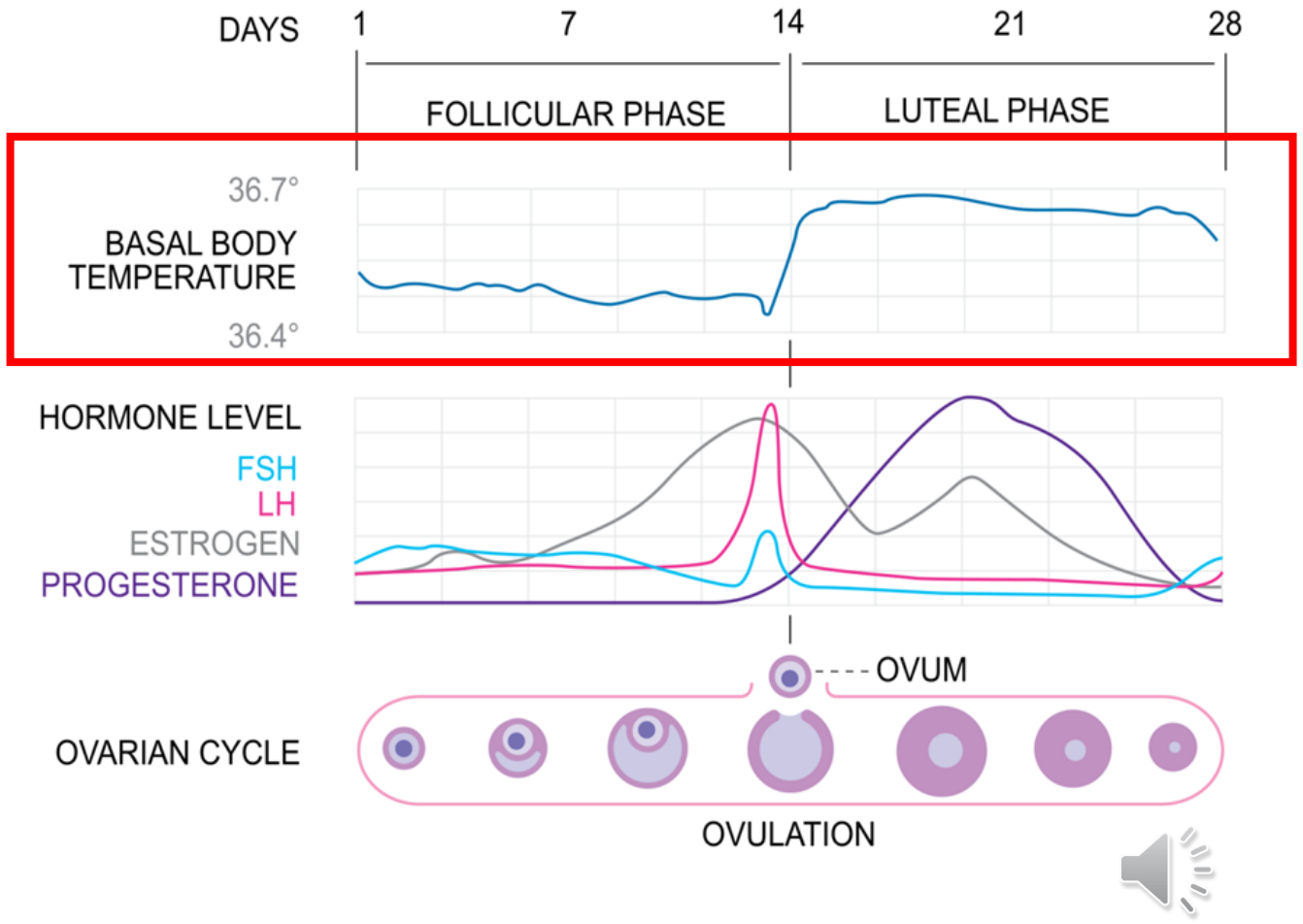
Circadian variations in temperature

- Varies by about 1°C during the day
- Lowest in the early morning
- Highest in the late afternoon/early evening

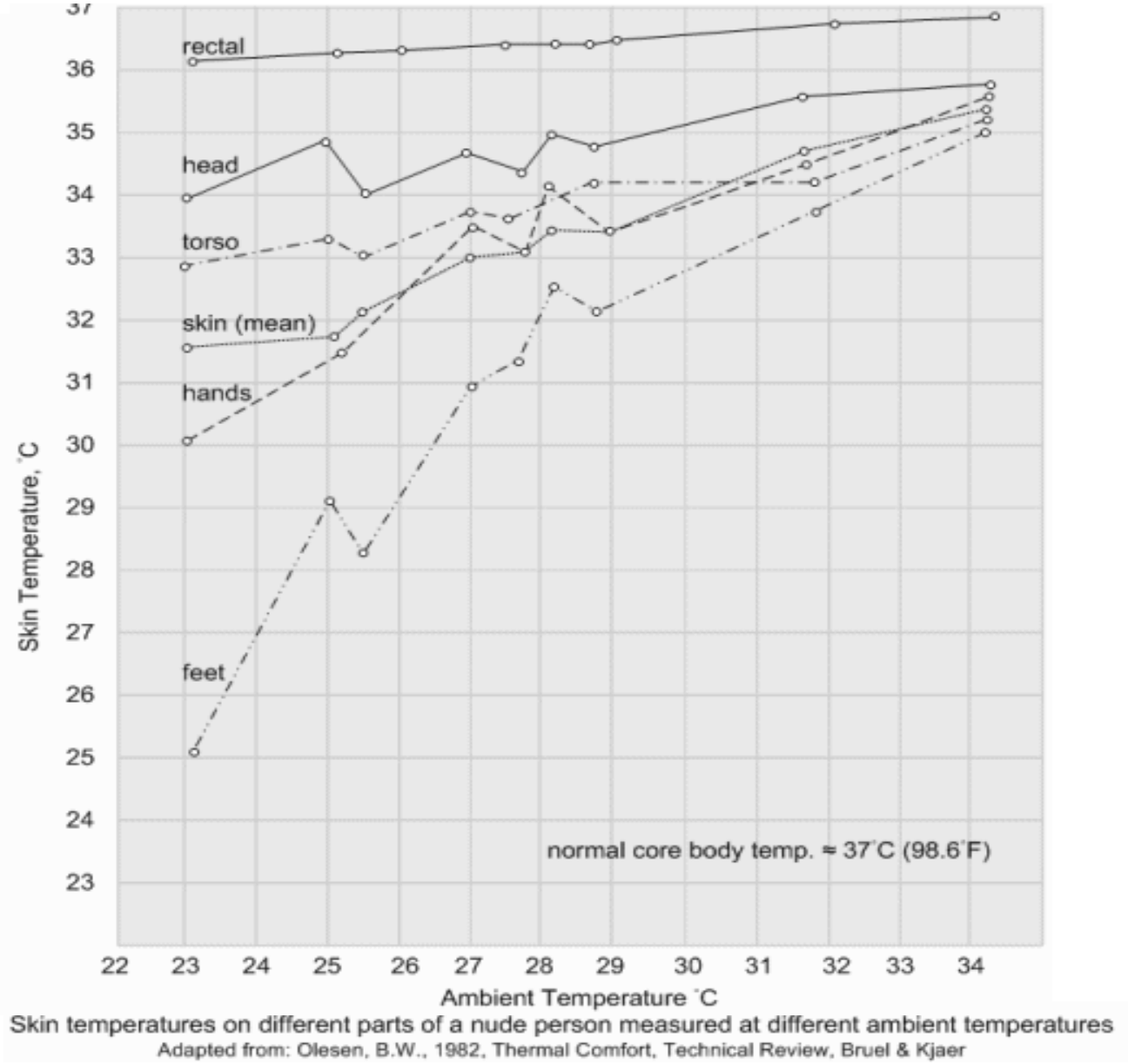


Temperature variations during menstrual cycle

- Low during follicular phase
- High during luteal phase
  - Progesterone increases body temperature
- Contraceptives suppress rhythm & ↑ body temperature



Measuring body temperature



Skin temperatures on different parts of a nude person measured at different ambient temperatures

Adapted from: Olesen, B.W., 1982, Thermal Comfort, Technical Review, Bruel & Kjaer

Measuring body temperature

Site of Measurement	Good measure of core body temperature?
Skin	No, varies with ambient temperature
Axilla	Practical but unreliable
Tympanic	Fast and convenient, but accuracy varies
Oral	Convenient but varies → should be taken in closed mouth for a minute
Rectal	Good but uncomfortable
Oesophageal	Very good but invasive
Mixed venous blood	Best measure but very invasive


Skin

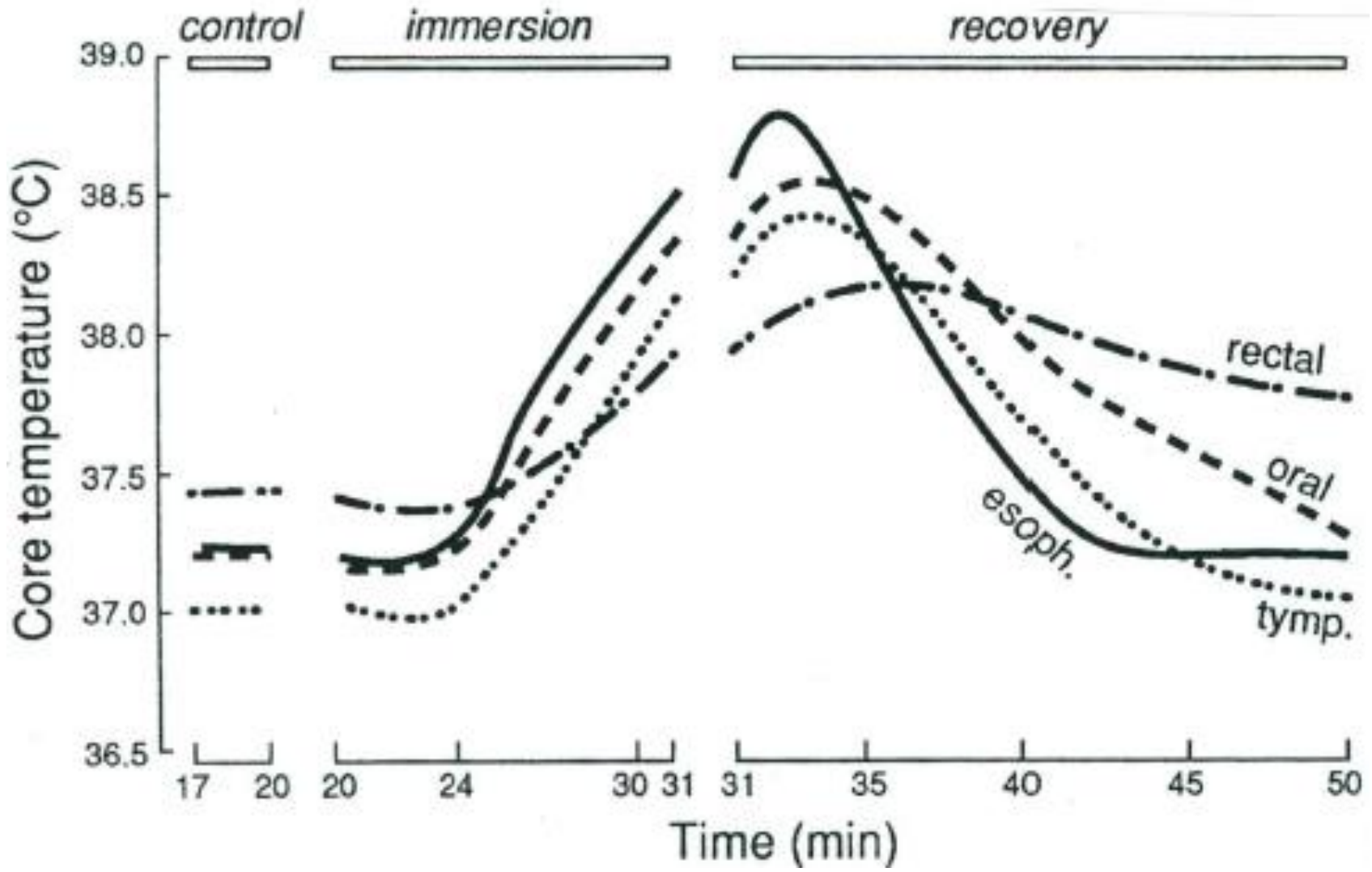

Axilla


Tympanic


Oral

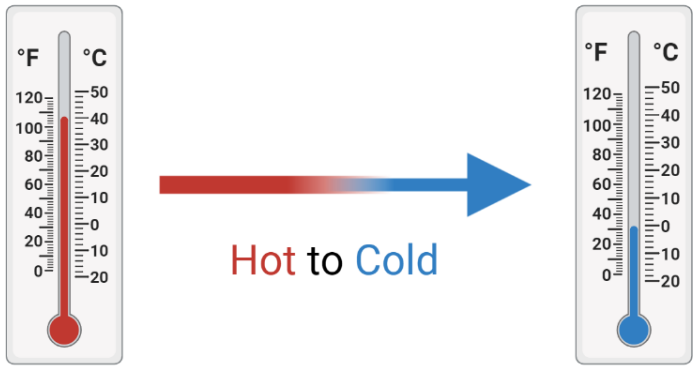

Oesophageal

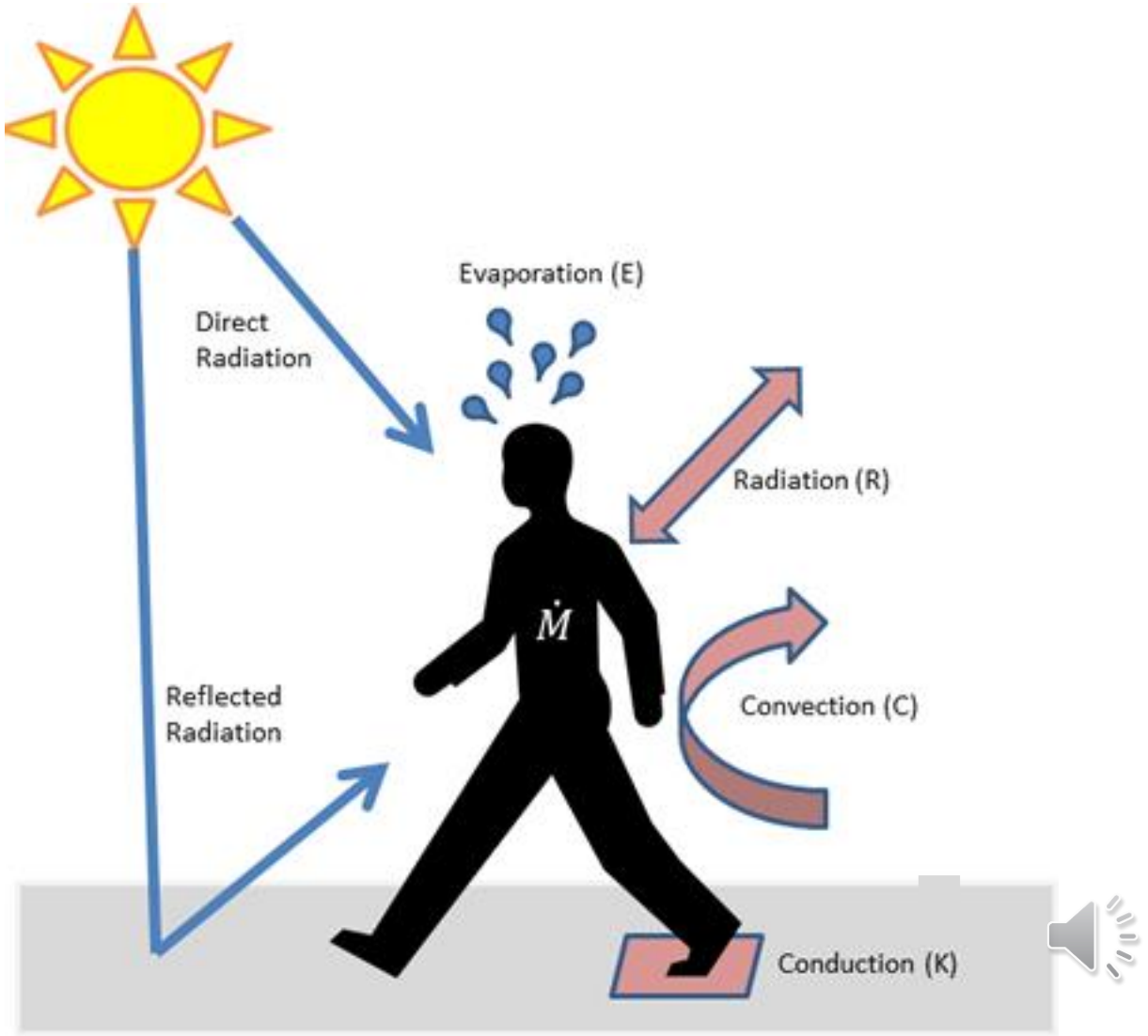
Where can we measure body temperature



Mechanism of heat loss/ gain

- Four mechanisms of heat loss/gain:
  - Conduction
  - Convection
  - Radiation
  - Evaporation
- Heat moves down it's concentration gradient





Mechanisms of heat exchange

Conduction

- Direct transfer of heat from one substance to another
- Heat moves from warmer to cooler object
- Lose or gain heat from the layer of air in direct contact with the body

Mechanisms of heat exchange

Convection

- Transfer of heat energy by air currents
- Aids with conduction
  - Body loses heat by conduction to surrounding cooler air
- Depends on velocity of movement, surface area

Mechanisms of heat exchange

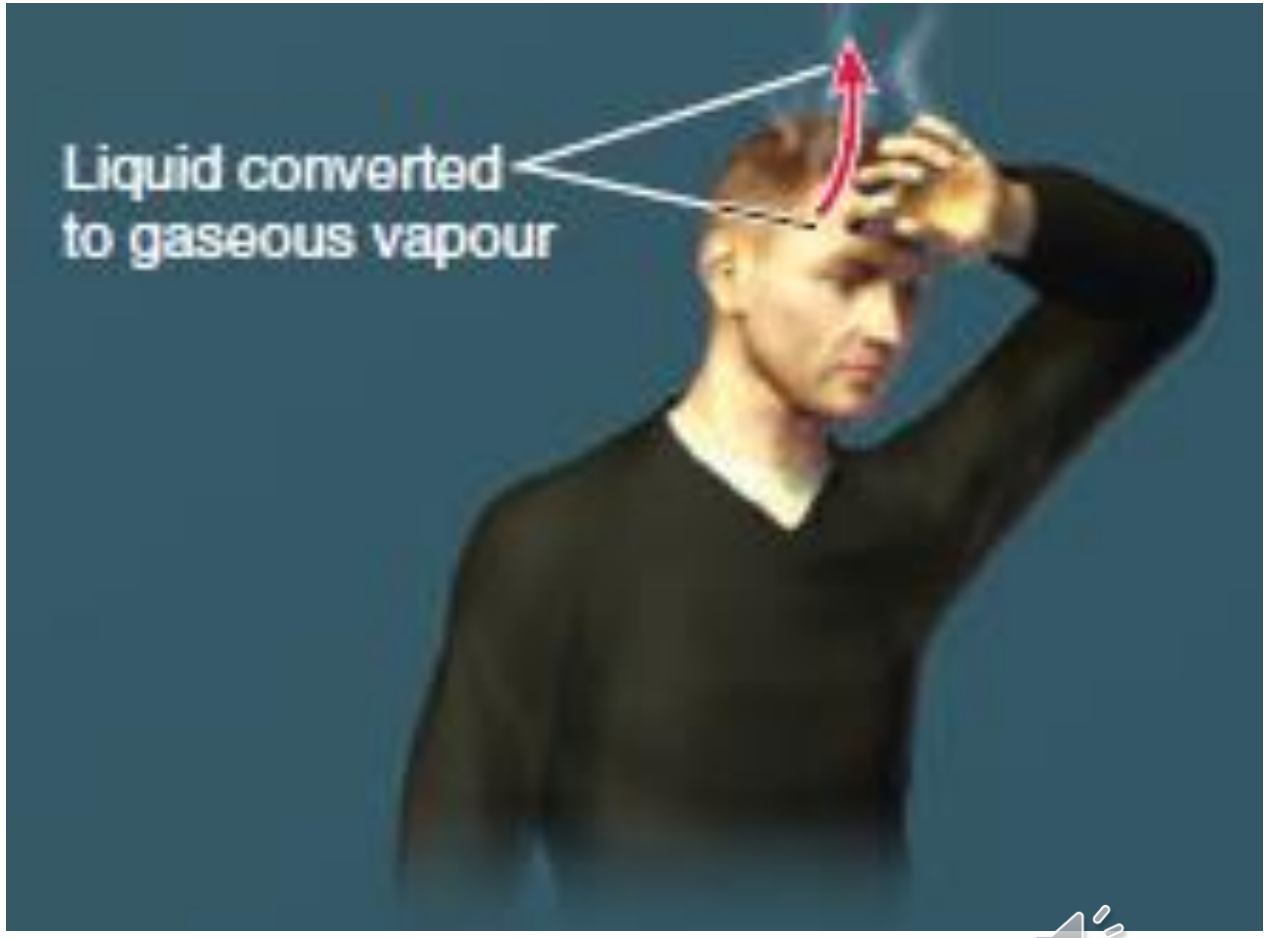
Radiation

- Is the transfer of heat from a warmer to a cooler object by infrared radiation
- Does not require direct contact
- Depends on surface area, colour

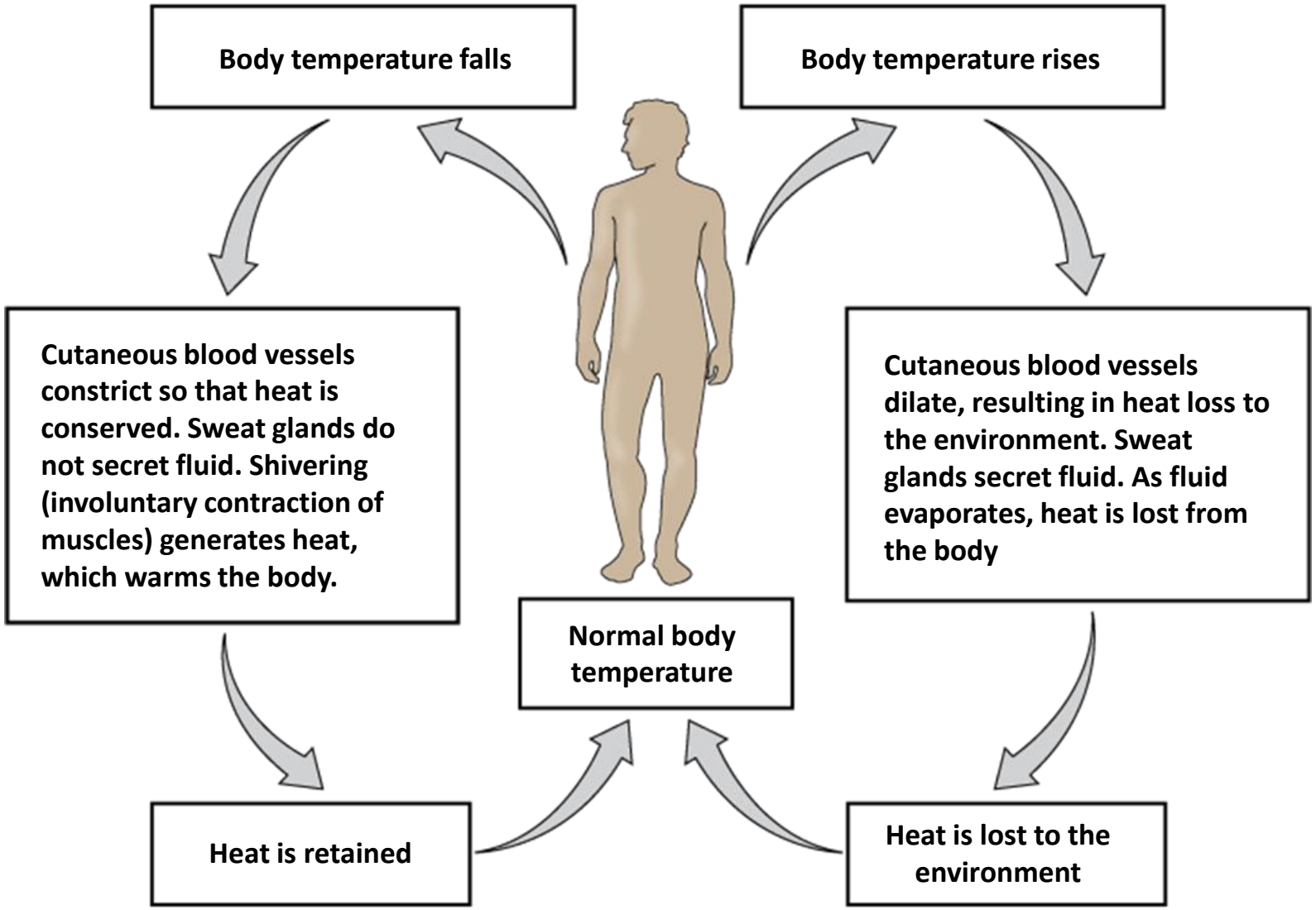
Mechanisms of heat exchange

Evaporation

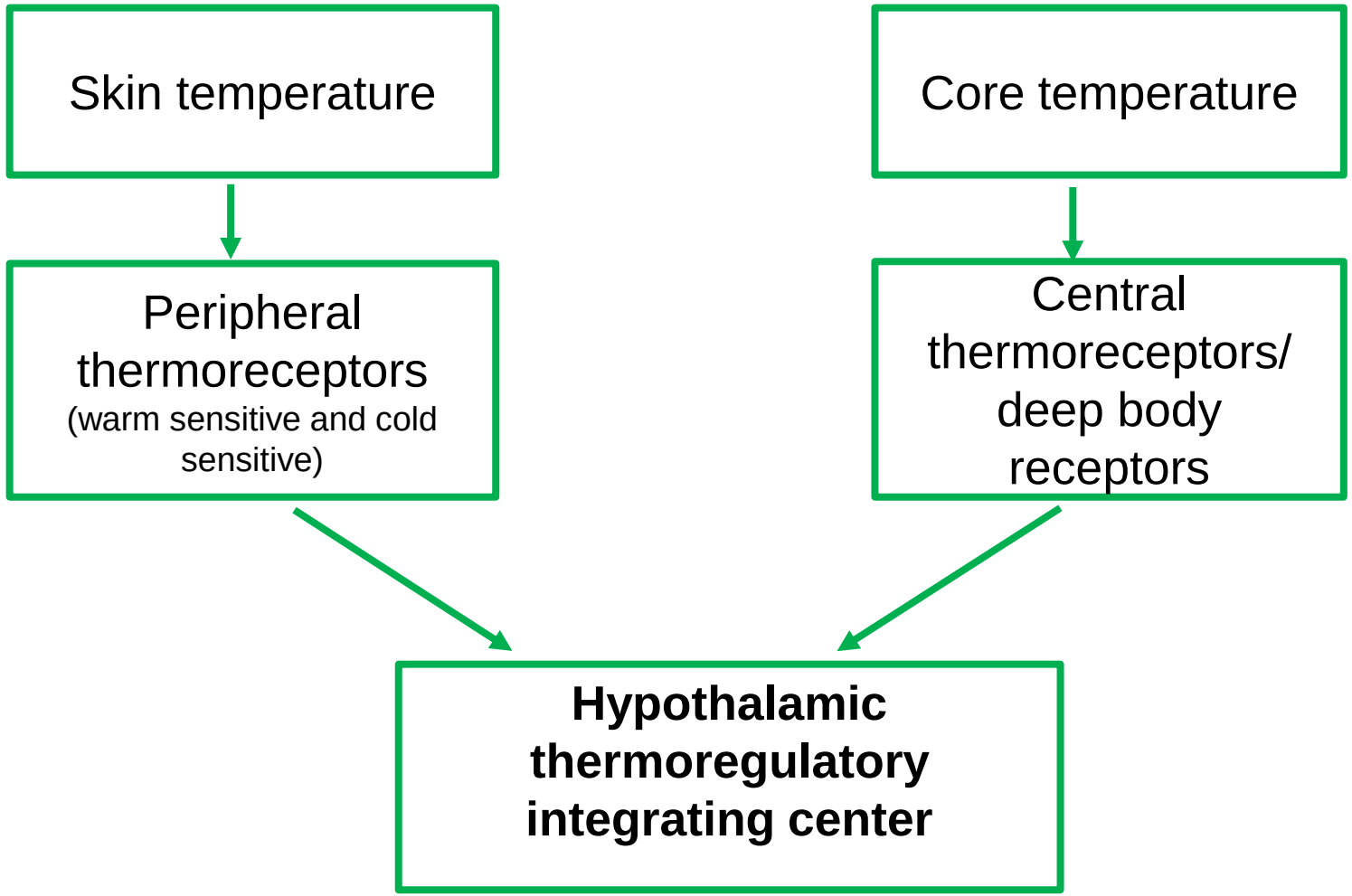
- Conversion of a liquids into gaseous vapour
- Depends on relative humidity
- Effective way of dissipating heat



Control of body temperature

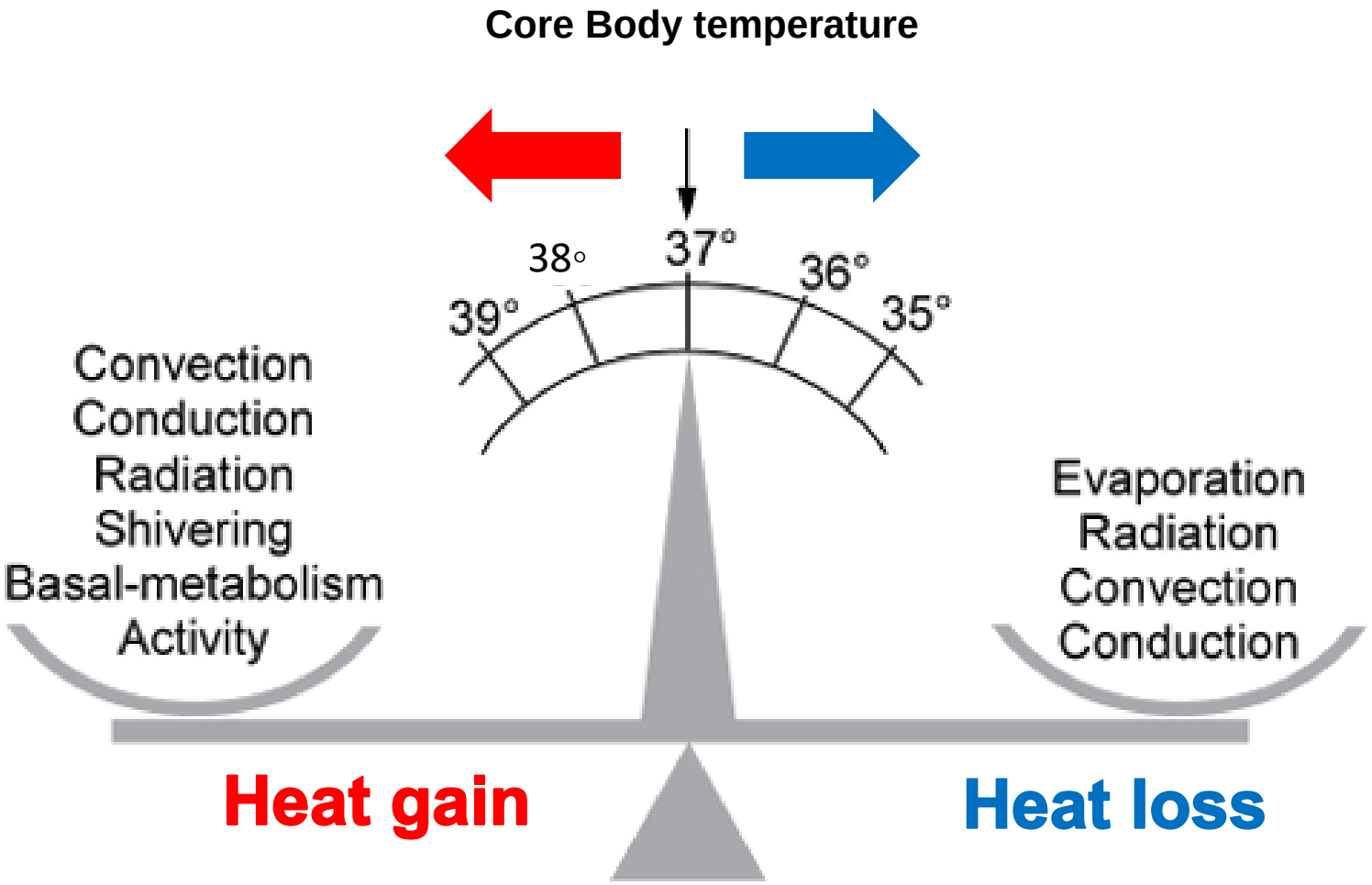


Neural control of temperature



Thermoreceptors: temperature sensitive receptors which inform the hypothalamus about changes in temperature at the surface of the skin and in the core

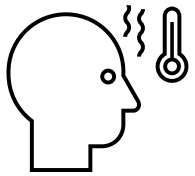
Regulating core temperature



Factors affecting heat transfer

Body size: Surface area to body ratio (SA:V) → ↓ body size = ↑ SA:V

Insulation: fat, hair, clothing



Blood flow to skin: carrying heat from core to shell

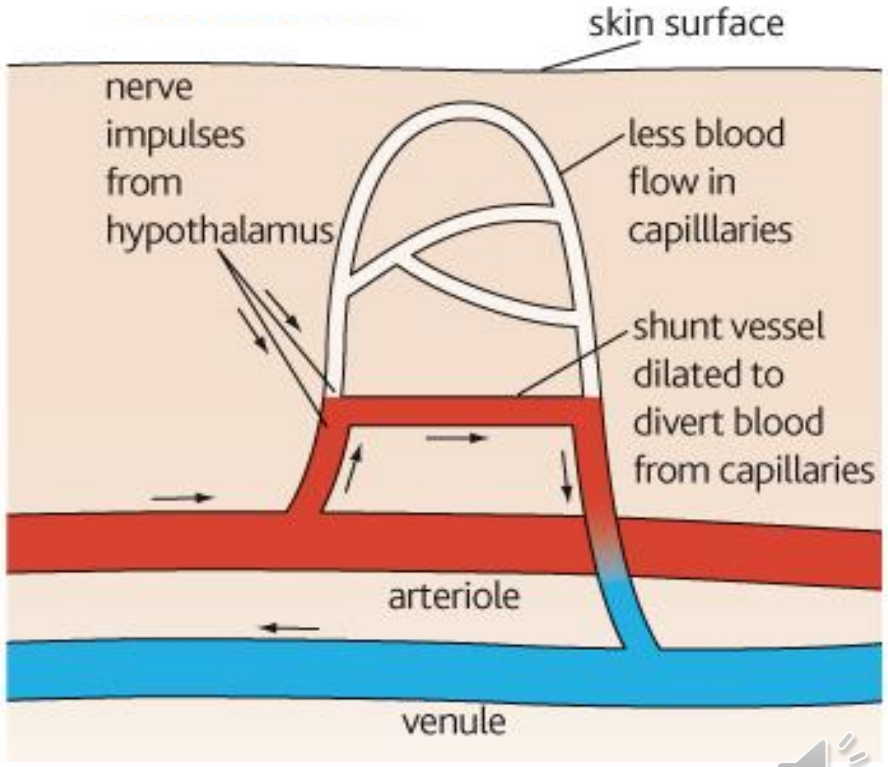
Behavior

Heat gain mechanisms (autonomic)

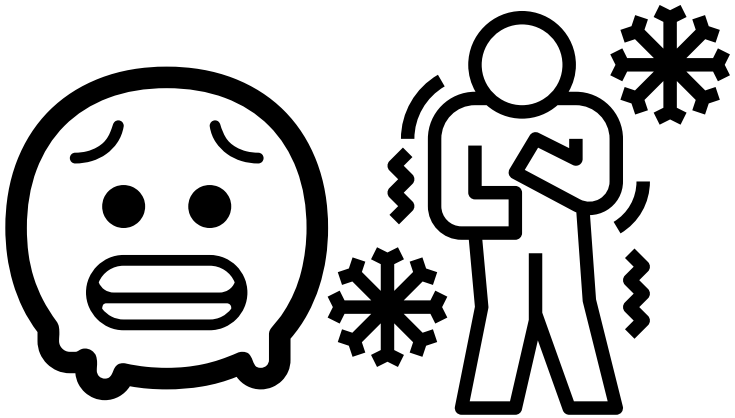
1. Skin blood flow: Vasoconstriction

- Arterioles constrict
  - ↓ blood flow to skin
  - ↓ heat loss

Cold conditions

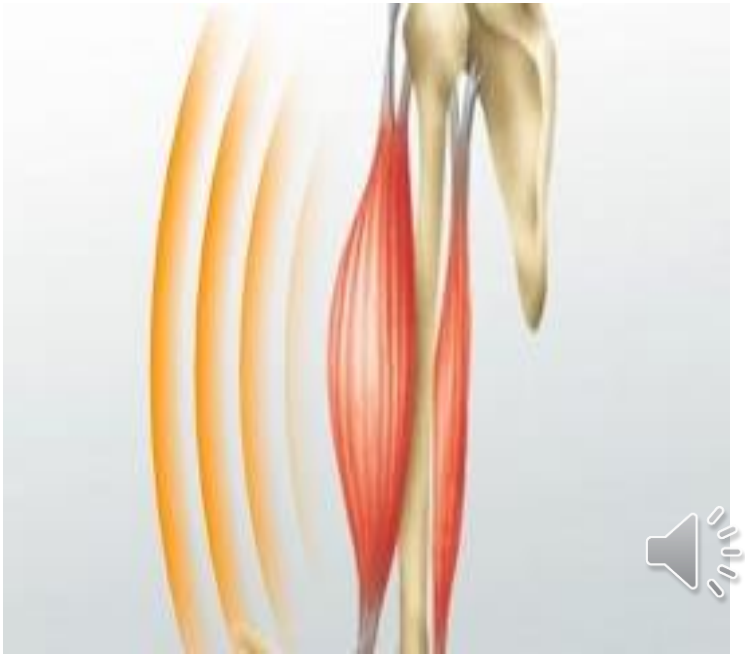


Heat gain mechanisms (autonomic)



2. Shivering

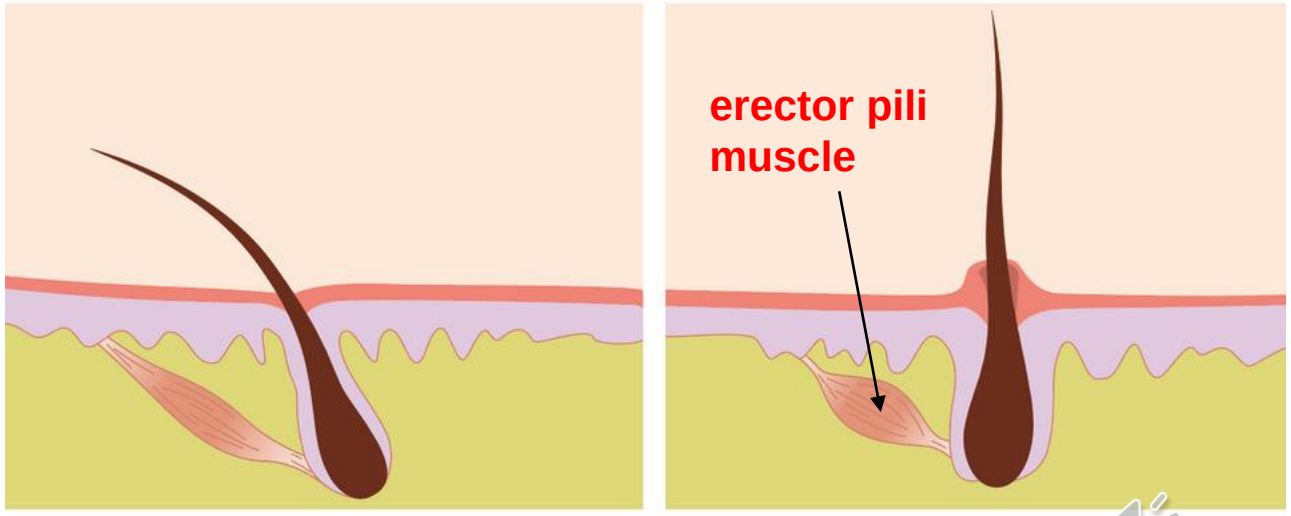
- Involuntary response where skeletal muscles contract
- Rhythmic, oscillating contractions of the skeletal muscle (10-20 per second)
- Produces energy
  - all energy converted to heat as no work is accomplished



Heat gain mechanisms (autonomic)

3. Piloerection

- Muscles attached to hair follicles contract
  - Hairs become erect
- More air trapped
  - More insulation
  - More heat generated



Relaxed erector pili muscle

Contracted erector pili muscle

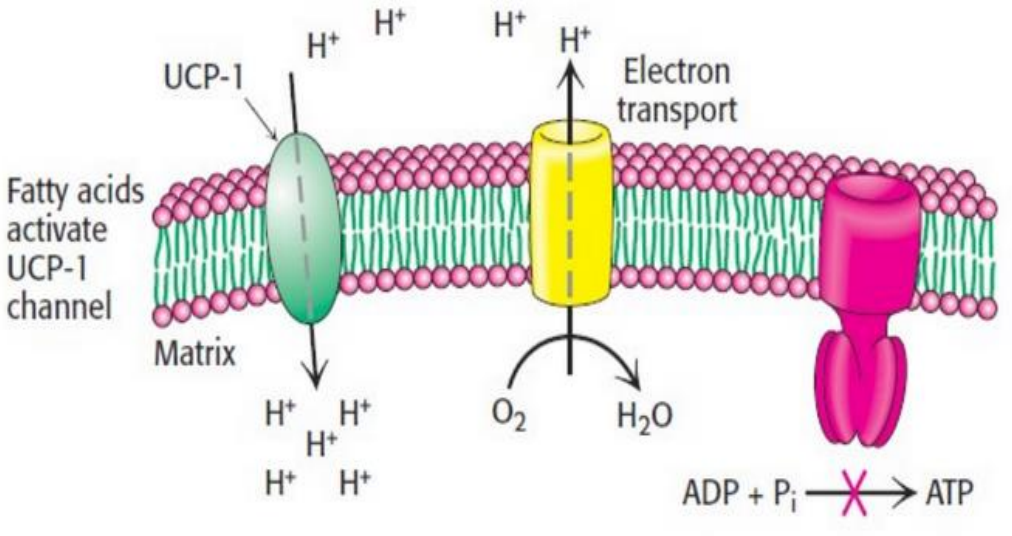
Heat gain mechanisms (autonomic)

4. Hormonal output

- More thyroxine and adrenaline produced
  - ↑metabolic heat production

5. Non-shivering thermogenesis

- Occurs in extreme cases in adults
- Brown adipose tissue
  - Uncoupling proteins produce heat rather than ATP
- Mediated through thyroxine and adrenaline



Heat gain mechanisms (behavioural)

6. Behavioural

- Become more active (↑physical activity)
- Changes in body position
- Selecting a different micro-climate
- Operant behaviour

selecting different micro-climate

operant behaviour

changes in body position

Response to a cold environment

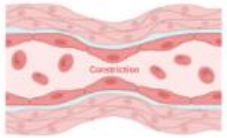
Cold environment with a decrease in skin and core body temperature

↑ firing of cold thermoreceptors in the skin and deep-body core

↓ firing of warm-sensitive thermoregulatory neurons in the hypothalamus

Activation of heat production/ conservation mechanism e.g.

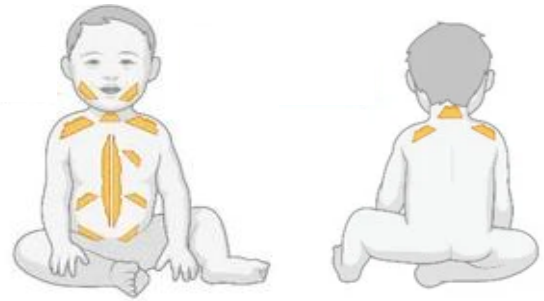
- Shivering thermogenesis
- Brown adipose tissue thermogenesis
- Cutaneous vasoconstriction



Thalamus relays to cerebral cortex → feeling cold

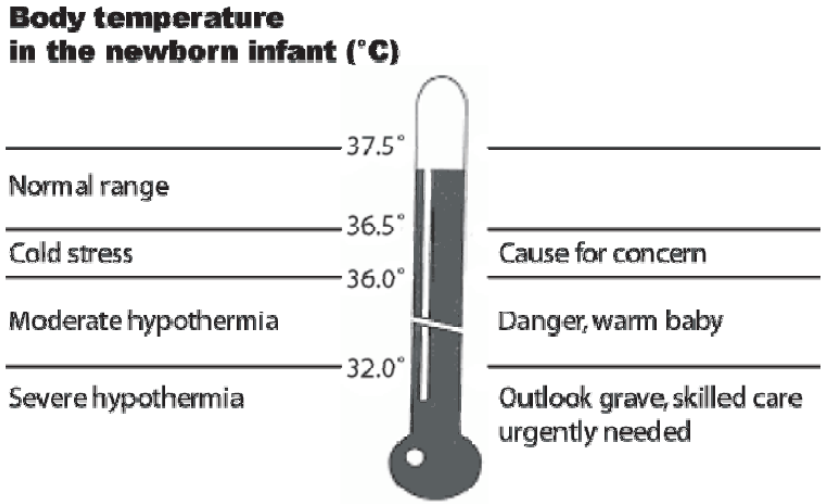
Neonatal thermoregulation

Neonates have ↑ surface area to body mass ratio → ↑ Heat loss



Heat gain mechanisms

1. ↑ metabolic rate	• Metabolic processes
2. Non-shivering thermogenesis	• Metabolism of brown adipose tissue found around kidneys, scapula, axilla, neck and sternum • chemical process generate heat instead of ATP
3. Peripheral vasoconstriction	• ↓blood flow to the skin
4. Shivering	• ↓shivering responses (in severe hypothermia)
5. Behavioural responses	• Conservation of heat by assuming flexed position to decrease surface area • Voluntary muscle activity: restlessness and crying

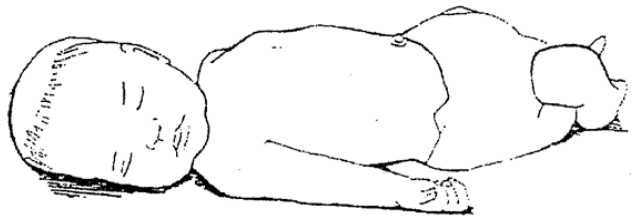


Hypothermia in the newborn infant

Neonatal thermoregulation

Heat loss mechanisms

1. Sweating	• ↓sweating responses (immature cholinergic receptors)
3. Peripheral vasodilation	• ↑blood flow to the skin
4. Behavioural responses	• Lying on their backs to increase surface area



Geriatric thermoregulation

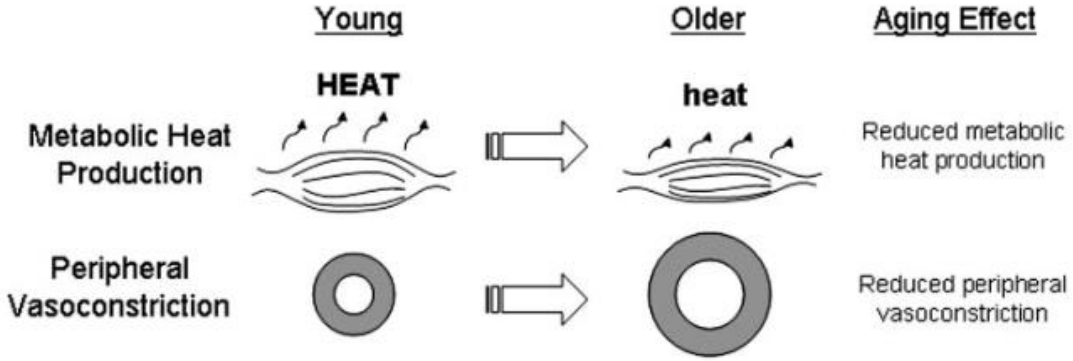
Thermoregulatory competence declines with age

↓sensitivity to temperature changes in environment → ↓autonomic AND behavioural responses

↓insulation, ↓shivering, ↓BMR → ↓heat production

↓sweat output per gland

↓ability to vasoconstrict

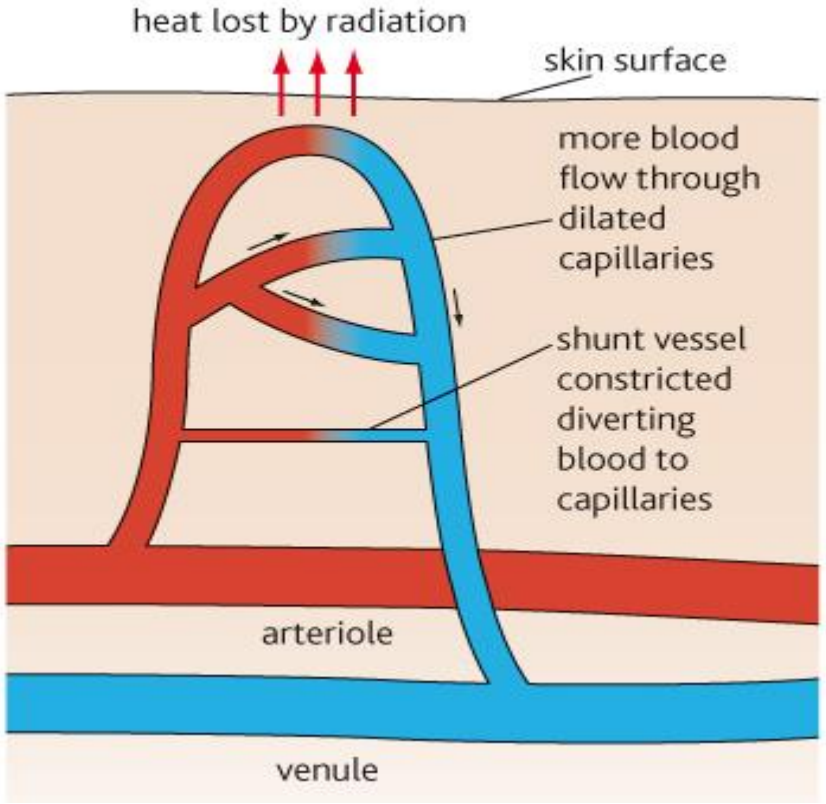


Heat loss mechanisms (autonomic)

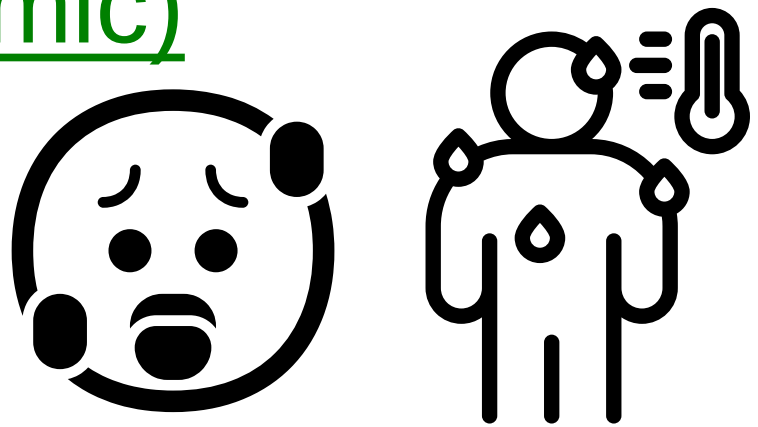
1. Skin blood flow: Vasodilation

- Arterioles dilate
  - ↑blood flow to skin
  - ↑ heat loss

Warm conditions

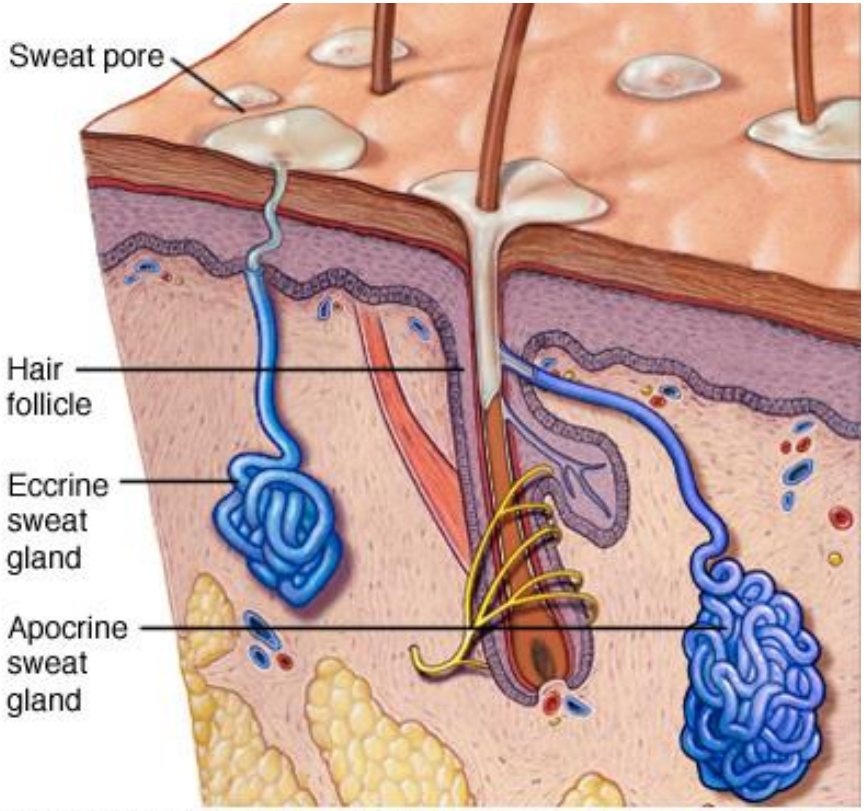


Heat loss mechanisms (autonomic)



2. Sweating

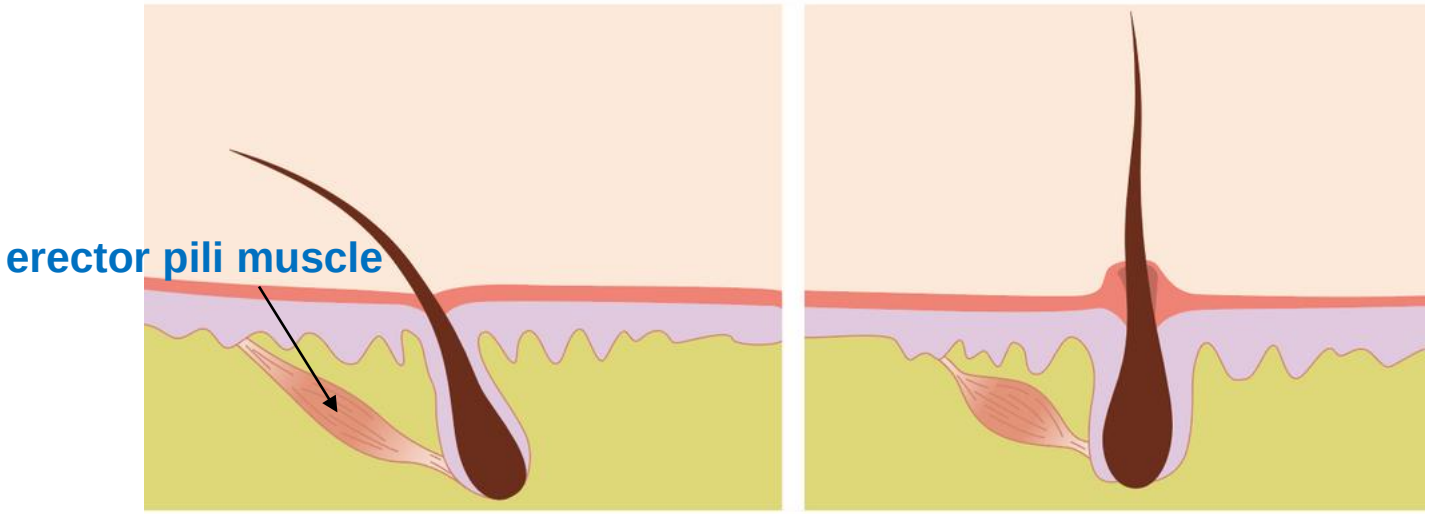
- Heat loss by evaporation
- Two types of sweat glands
  - Eccrine glands
    - › generalised sweat
  - Apocrine glands
    - › localised sweat
- Also called evaporative cooling



Heat loss mechanisms (autonomic)

3. Pilorelaxation

- Muscles attached to hair follicles relax
  - Hair lie flat
- Less air trapped next to skin
  - less insulation
- Little effect



Relaxed erector pili muscle

Contracted erector pili muscle

Heat loss mechanisms (behavioural)

4. Behavioural

- Changes in body position
- Selecting a different micro-climate
- Operant behaviour

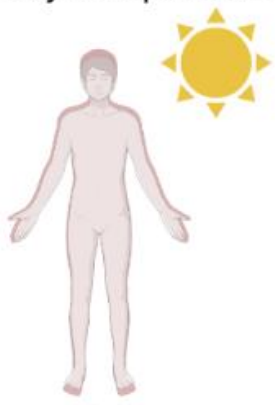
selecting different micro-climate

changes in body position

operant behaviour

Response to a warm environment

Warm environment with an increase in skin and core body temperature

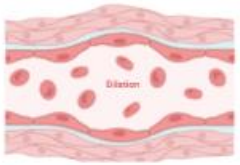


↑ firing of warm thermoreceptors in the skin and deep-body core

↑ firing of warm-sensitive thermoregulatory neurons in the hypothalamus

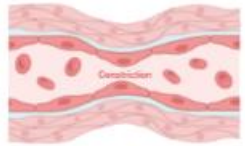
Activation of heat loss mechanisms e.g.

- Eccrine sweating
- Cutaneous vasodilation



Inhibition of heat production/ conservation mechanism e.g.

- Shivering thermogenesis
- Brown adipose tissue thermogenesis
- Cutaneous vasoconstriction



Thalamus relays to cerebral cortex → feeling hot

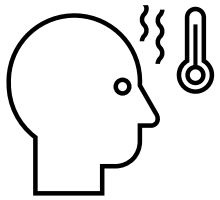
Altered thermoregulation

Setpoint temperature: Temperature at which core body temperature is maintained. The setpoint is controlled by the hypothalamus.

Normal: $T_{core} = T_{setpoint}$

1. Fever: $T_{setpoint} \uparrow$ above T_{core}
2. Hyperthermia: $T_{core} \uparrow$ above $T_{setpoint}$
3. Hypothermia: $T_{core} \downarrow$ below $T_{setpoint}$

Fever

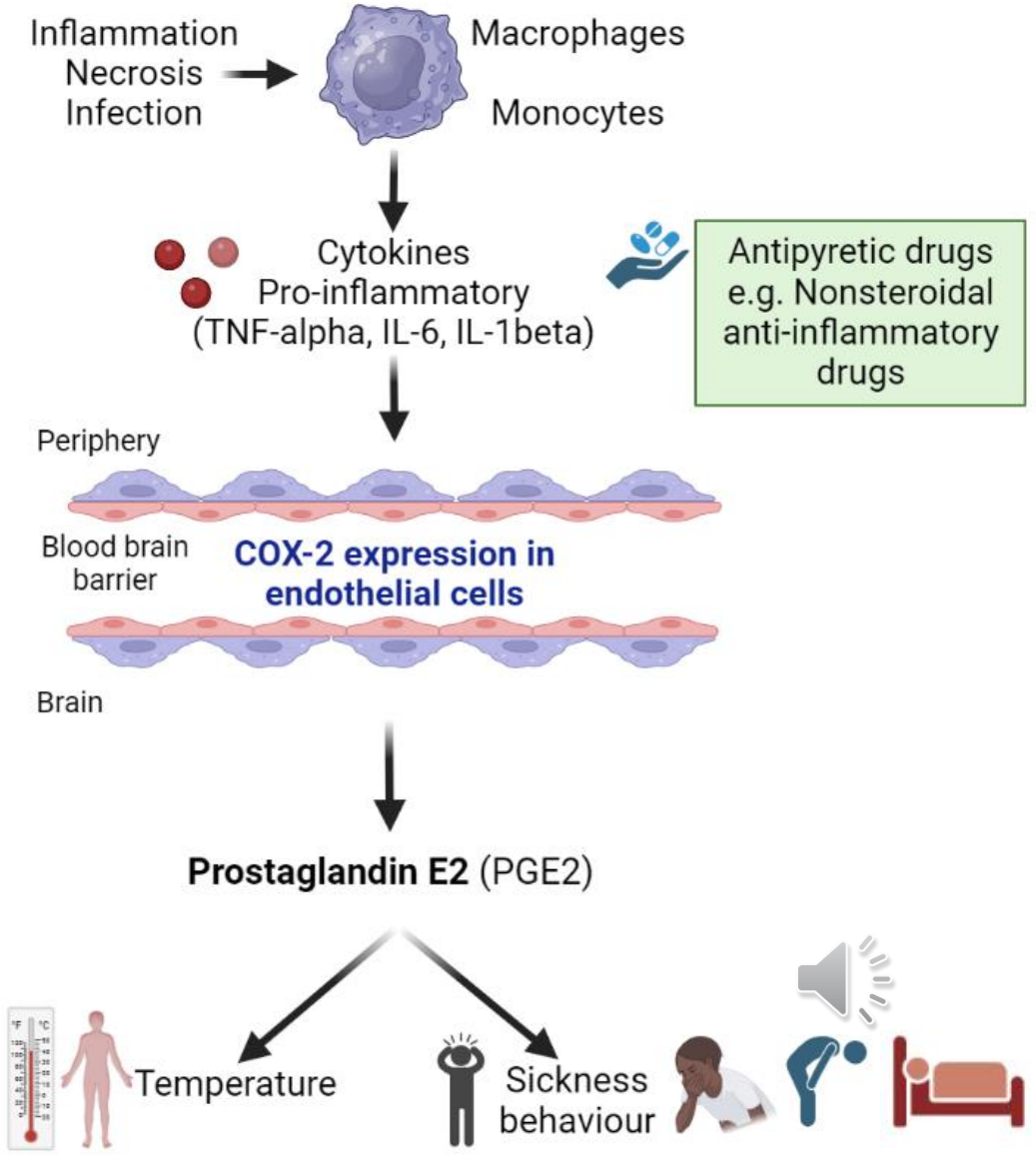


- Can be caused by bacterial & viral infections, immunological reactions and malignancies.
- Characterised by an ↑ in core body temperature due to resetting of the hypothalamic thermoregulatory set point.
- Pyrogens cause **↑ in setpoint temperature**

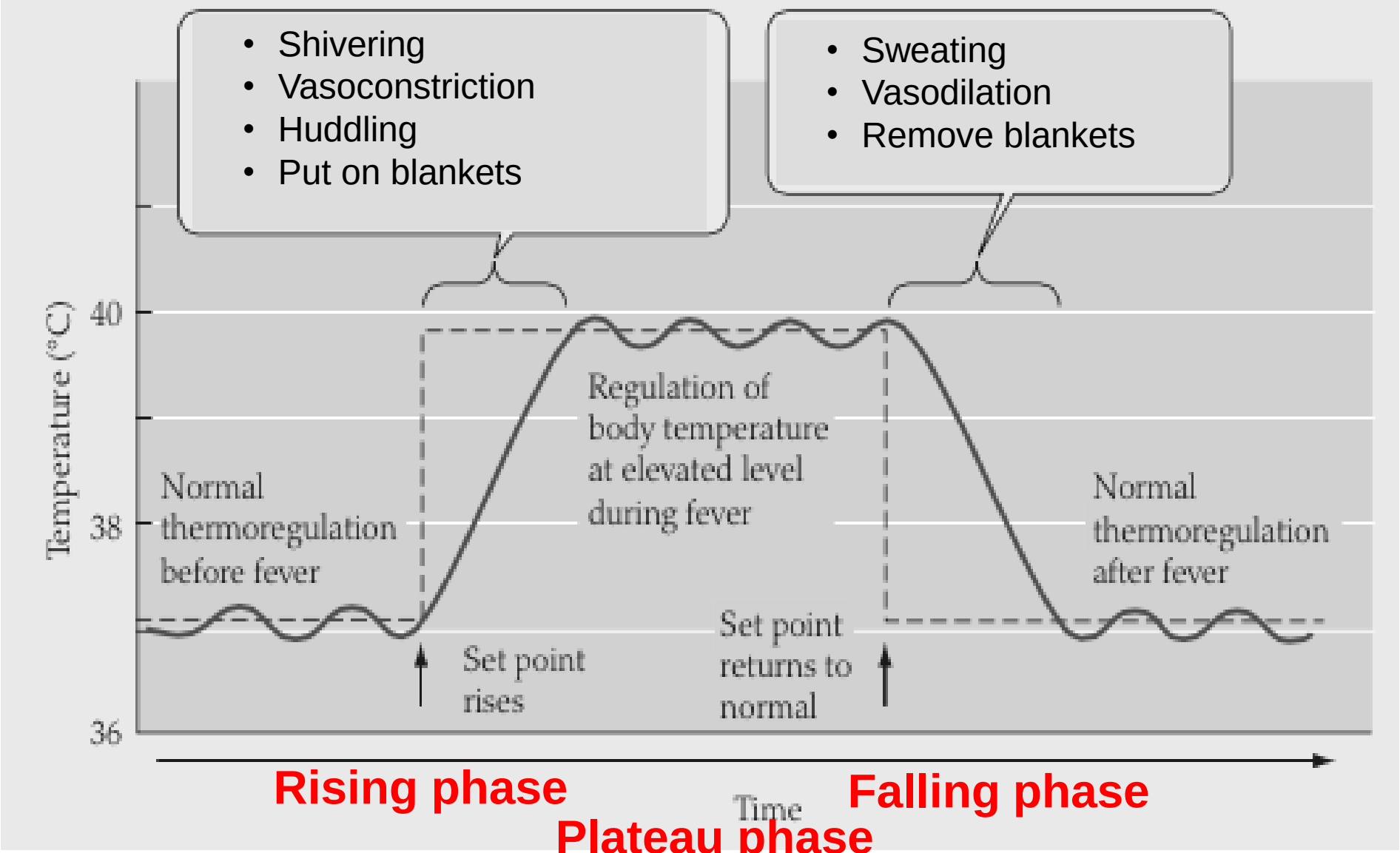
Pyrogens = fever inducing substances

Biochemistry of the fever pathway

- Cytokines activate hypothalamic-pituitary-adrenal (HPA) axis
  - CRH → ↓ appetite
  - Cortisol → anti-inflammatory
- Cytokines transported to the liver
  - Release acute phase proteins
    e.g. C-reactive protein
- Cytokines cross blood-brain barrier
  - Activate prostaglandins
    - ↑ temperature
    - Sickness behaviour



Thermoregulation during a fever



Hyperthermia: Heat exhaustion

- Heat production/gain exceed heat loss
- ↑ core body temperature above set point temperature

	Heat exhaustion
How does it occur?	Consequence of over activity of the heat-loss mechanisms
Cause	Exposure to hot/humid environments Response to medication→ dehydration Exercising in hot humid weather without drinking water→ dehydration
Core body temperature	< 40°C
Signs/symptoms	Sweating Decreased blood pressure→ Faint

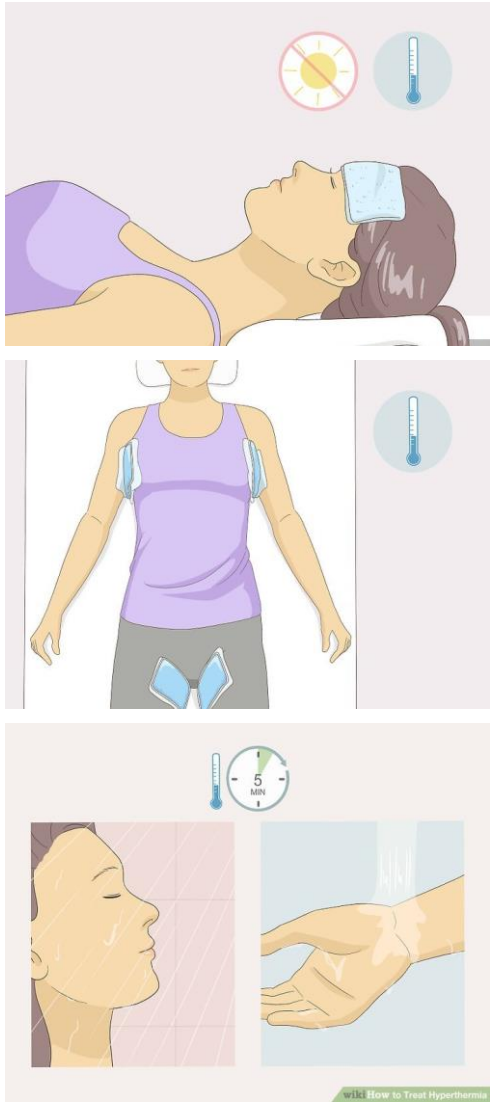
Hyperthermia: Heat stroke

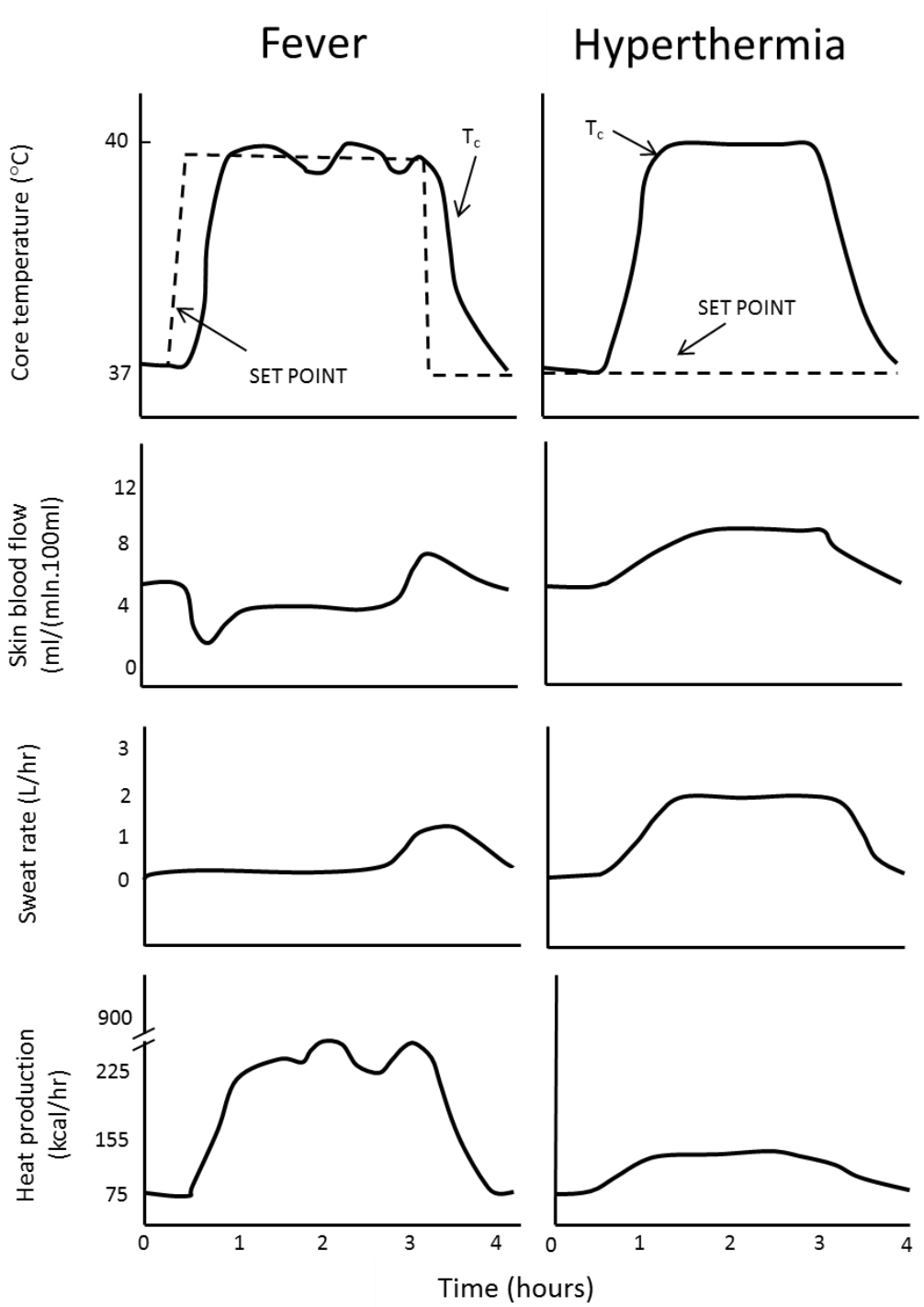
- Heat production/gain exceed heat loss
- ↑ core body temperature above set point temperature

	Heat stroke
How does it occur?	Preceded by heat exhaustion→ Results in the breakdown in thermoregulatory mechanisms
Cause	Preceded by heat exhaustion→ More likely to occur with overexertion in hot humid weather without drinking water
Core body temperature	> 40°C
Signs/symptoms	No sweating (dry skin)/ vasodilation Nerve malfunction→ CNS abnormalities ↑ Tbody →↑ chemical reactions →↑ metabolic rate →↑ heat production →↑ tissue damage

Treating hyperthermia

- Moving individual to a cooler environment
- Apply wet clothes
- Application of ice packs
- Spray the body with water
- Switch on fan to ↑ evaporative heat loss
- Immerse individual in cool bath (10-20^{o}C)





Core temp

Fever: ↑ set point temp, ↑ core temp

Hyperthermia: ↑ heat load, ↑ core temp

Skin blood flow

Fever: ↓ during rising phase, ↑ during falling phase

Hyperthermia: ↑ due to vasodilation to ↑ heat loss

Sweat rate

Fever: ↑ during falling phase

Hyperthermia: ↑ to ↑ evaporation to ↑ heat loss

Heat production

Fever: ↑ during rising & plateau phases, ↓ during falling phase

Hyperthermia: ↑ heat load ↑ heat loss mechanisms

Hypothermia

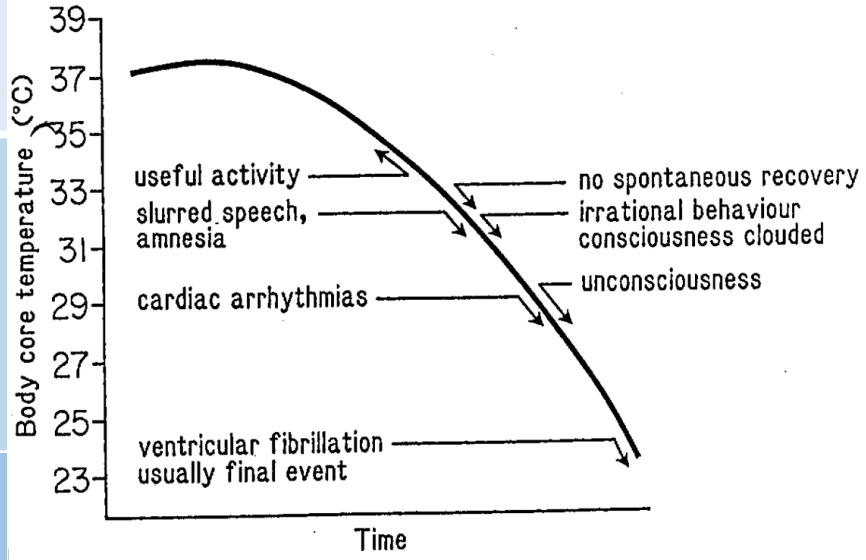
- Heat loss exceeds heat production/gain
- ↓ core body temperature (<35°C) below set point temperature

Primary (accidental) hypothermia	**Secondary hypothermia**
Unanticipated exposure to cold environments in an inadequately prepared person	Any condition that predisposes thermoregulatory failure under cold conditions • Malnutrition • Hypothyroidism • Alcohol intoxication

Hypothermia

- Heat loss exceeds heat production/gain
- ↓ core body temperature (<35°C) below set point temperature

Mild	Core body temperature: 35°C-32 °C ↑ metabolic rate→ shivering Excessive vasoconstriction
Moderate	Core body temperature: 32°C-28 °C Shivering ceases→ no spontaneous recovery Progressive depression of mental functions between (decreased cerebral blood flow), slurred speech
Severe	Core body temperature < 28 °C Unconsciousness Cardiac arrhythmias 26-25°C physical activity is impossible Death ~ 25 °C



Thermoregulation during exercise

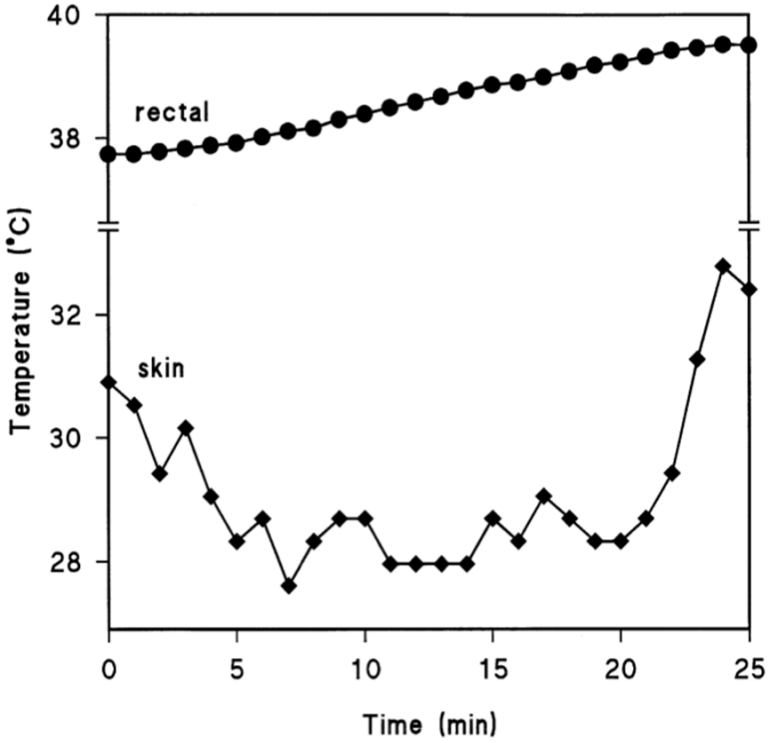
↑ metabolic heat production

Rise in core body temperature activates heat loss mechanisms → blood flow to both muscles and skin

When heat loss = heat production, body temperature constant

SNS → vasoconstriction, but ↑ core body temperature → vasodilation

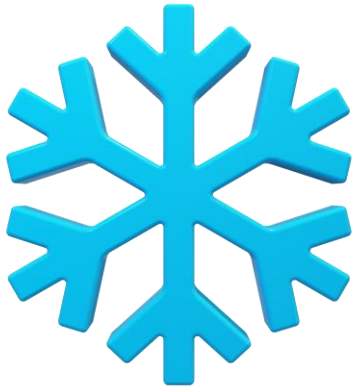
Thermal limit to exercise



Acclimatisation

Heat acclimatisation

- ↑sweat rate
- ↓threshold Tb for sweat activation
- Production of dilute sweat
- Expanded plasma volume



Cold acclimatisation

- ↑BAT and non-shivering thermogenesis
- ↓shivering
- Blunted cutaneous vasoconstriction