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Homeostasis: thermoregulation and adaptation

UM2010 Integrated Science and Clinical Medical

Core block - Physiology

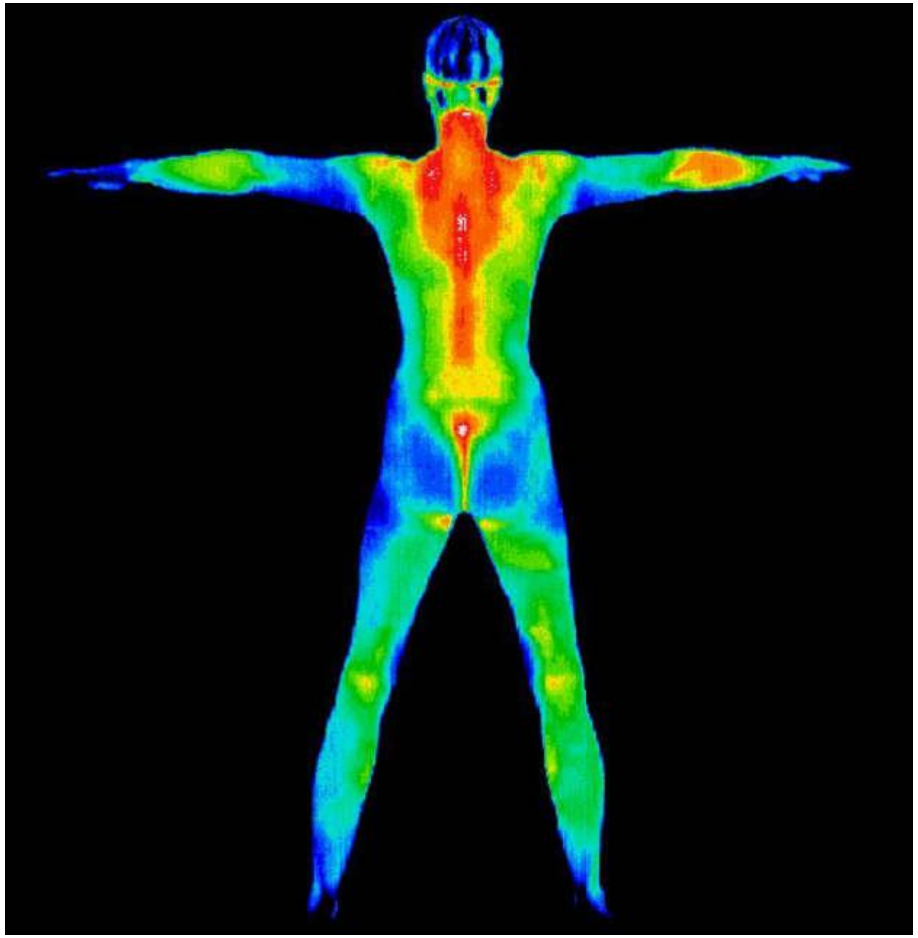
What we will be covering today:

- The limits of temperature tolerance in humans
- Methods by which body core temperature is maintained in hot and cold conditions
- Consequences of failure of temperature homeostasis
- Longer term adaptation to cold

Body Temperature

- Humans are homeothermic (i.e. body temperature is maintained independently of environmental temperature)

- Body temperature often described as either:
  - 'Core' (typically 36.1 - 37.8°C)
  - 'Shell' (ideally 33°C but up to 42°C in contracting muscle)



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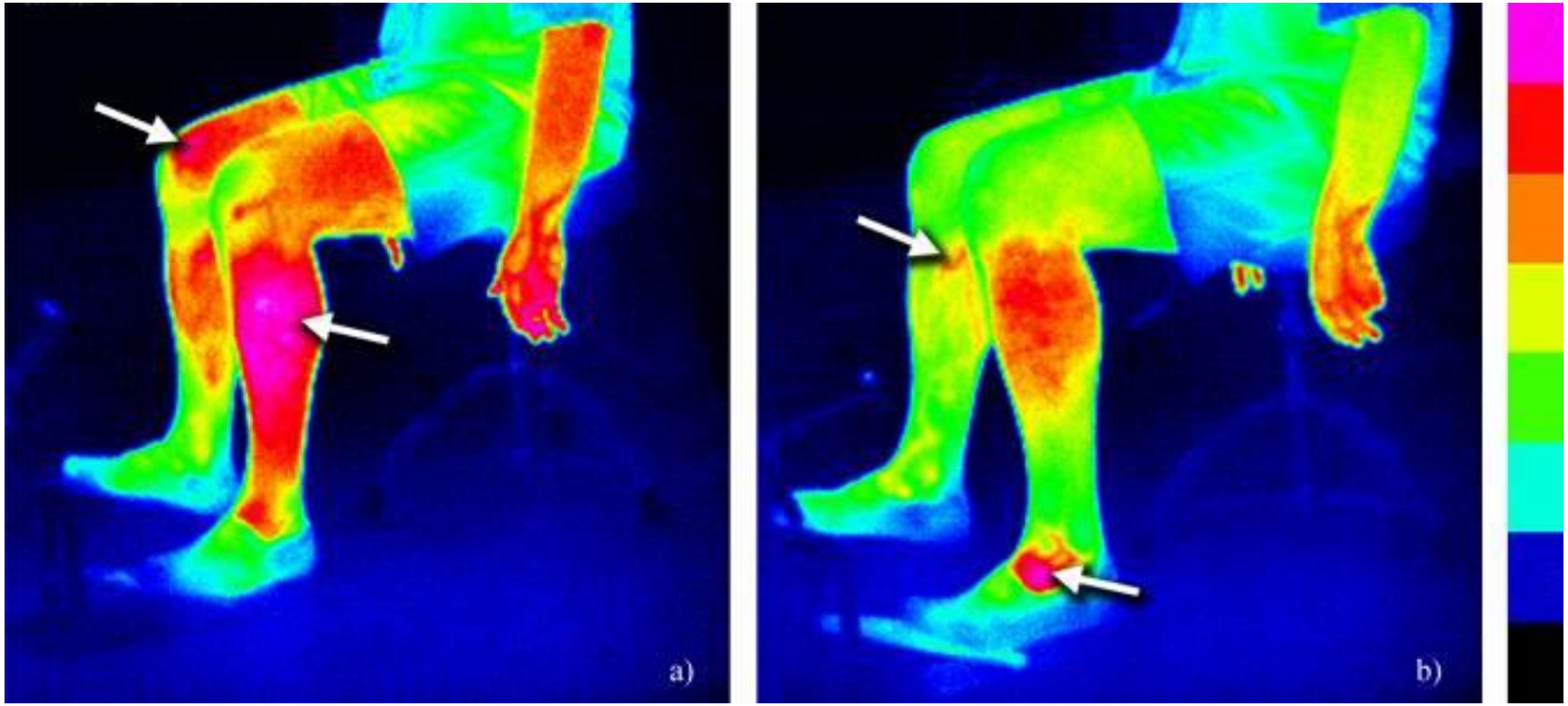
Muscle temperatures in different bass drum techniques



Limits of cold tolerance

36 °C – Feeling cold, mild to moderate shivering (not unusual during sleep)

35 °C – (Hypothermia is less than 35 °C – Intense shivering, numbness and bluish/greyness of the skin. There is the possibility of heart irritability.

34 °C – Severe shivering, loss of movement of fingers, blueness and confusion. Some behavioural changes

33 °C – Confusion, sleepiness, depressed reflexes, progressive loss of shivering, slow heart beat, shallow breathing. Shivering may stop. Subject may be unresponsive

32 °C – (Medical emergency) Hallucinations, delirium, confusion, extreme sleepiness that is becoming comatose. Shivering absent (subject may even think they are hot). Reflexes reduced

31 °C – Comatose, rarely conscious. No or slight reflexes. Very shallow breathing and slow heart rate. Possibility of arrhythmia is present, posing a serious risk to patient survival.

28 °C – Arrhythmia common at this level and cardiac arrest may occur. Patient may appear dead.

26 °C or less – Death usually occurs due to arrhythmia or cardiac arrest; however, some patients have been known to survive with body temperatures as low as 14.2 °C due to brain cells freezing and staying preserved for extensive periods of time

Limits of heat tolerance

44 °C or more – Almost certainly death will occur; however, people have been known to survive up to 46.5 °C

43 °C – Normally death, serious brain damage, continuous convulsions and shock. Cardio-respiratory collapse will likely occur.

42 °C – Subject may turn pale or remain flushed and red. They may become comatose, be in severe delirium, vomiting, and convulsions can occur. Blood pressure may be high or low and heart rate will be very fast.

41 °C – (Medical emergency) – Fainting, vomiting, severe headache, dizziness, confusion, hallucinations, delirium and drowsiness can occur. There may also be palpitations and breathlessness.

40 °C – Fainting, dehydration, weakness, vomiting, headache and dizziness may occur as well as profuse sweating. Starts to be life-threatening.

39 °C – Severe sweating, flushed and red. Fast heart rate and breathlessness. There may be exhaustion accompanying this. Children and people with epilepsy may be very likely to get convulsions at this point.

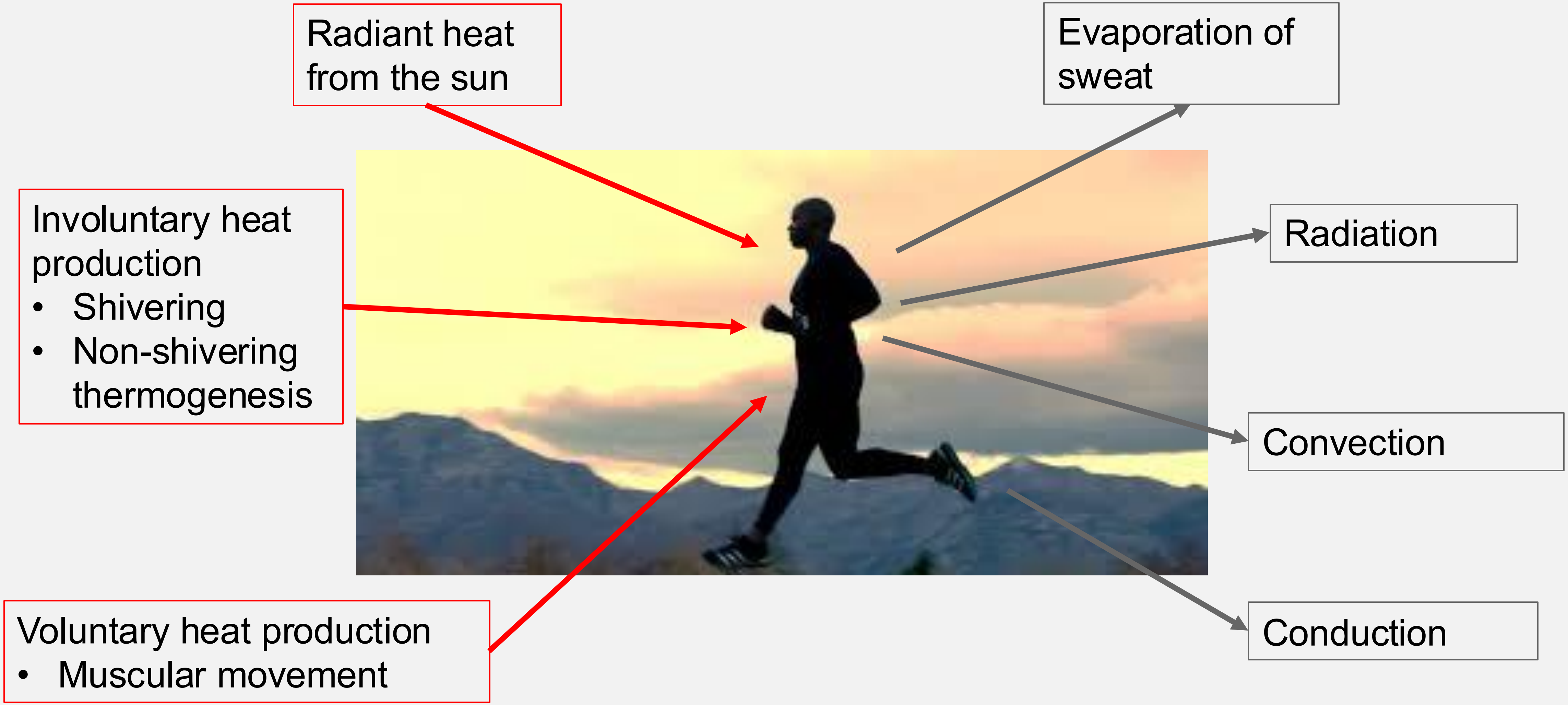
38 °C – (this is classed as hyperthermia if not caused by a fever) Feeling hot, sweating, feeling thirsty, feeling very uncomfortable, slightly hungry. If this is caused by fever, there may also be chills.

37 °C – Normal internal body temperature (which varies between about 36.12 – 37.8 °C)

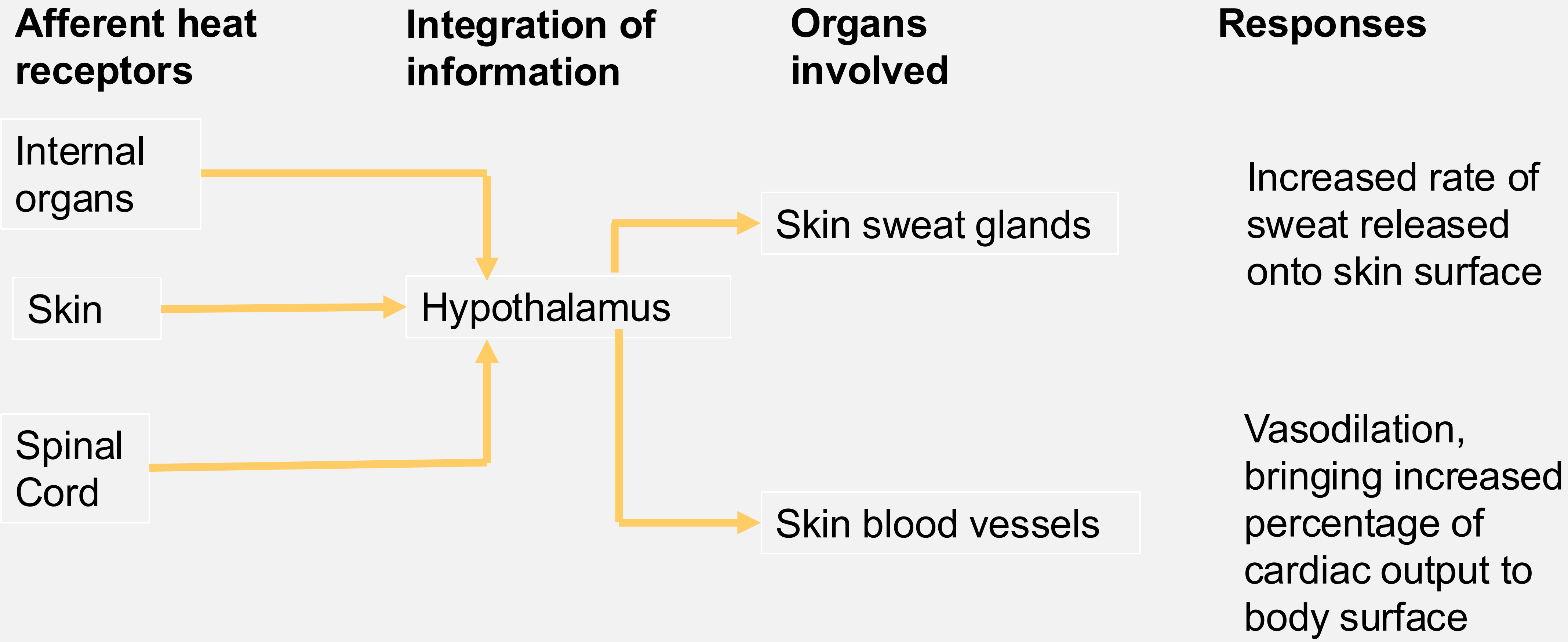
Temperature Balance

- Constant internal temperature requires a balance between heat gain and heat loss
- Even in a thermoneutral environment, basal metabolism produces 1 kcal/kg/h
- The specific heat of human tissue only requires 0.83 kcal/kg to raise internal temperature by 1°C
- Therefore, without heat loss processes, internal temperature would elevate by 1°C/h even at rest

Temperature Balance



Responses to heat



Methods of heat loss

Evaporation of sweat

- Heat from the skin raises the temperature of sweat causing it to evaporate
- As skin loses heat it is cooled
- Evaporation also depends on humidity gradient, so it happens much faster in dry conditions

Conduction

- When warm skin touches a colder surface, heat is transferred
- The rate of heat loss (or gain!) depends on the temperature gradient

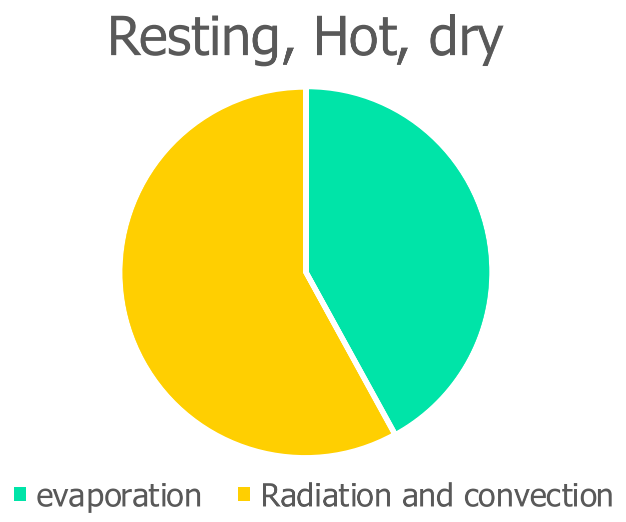
Radiation

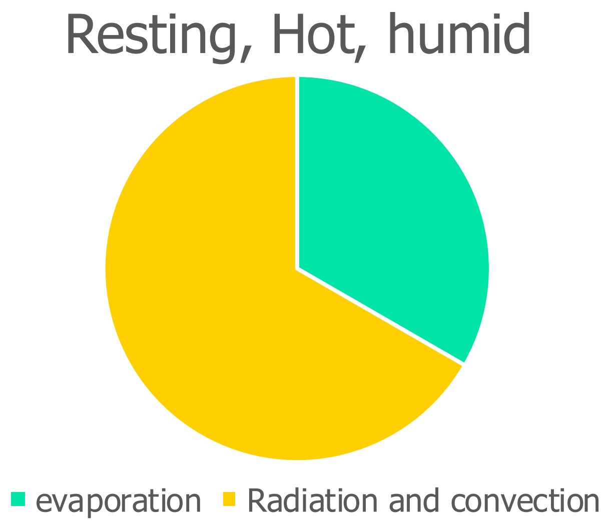
- This is the transfer of heat energy from one abject to another by infrared radiation. The objects are not in physical contact
- Radiation will occur whenever the skin is warmer than the surrounding air

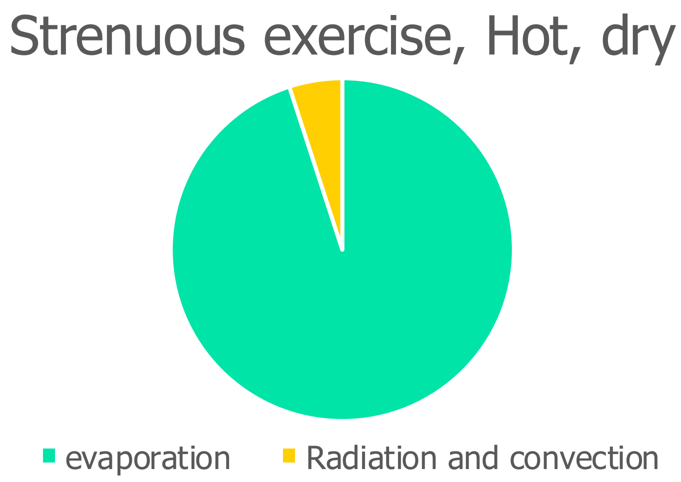
Convection

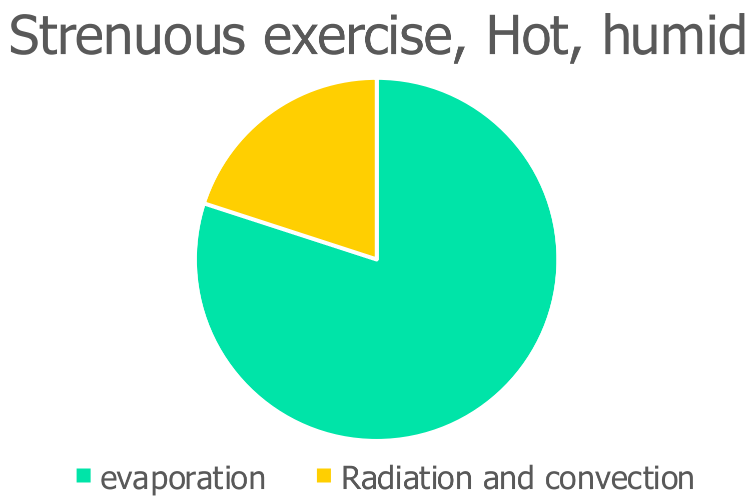
- Heat is transferred to a fluid (e.g. water or air) in contact with the body
- The increased thermal energy in the fluid reduces its density, and it rises away from the body
- Cooler air/water is more dense and it replaces the air/water that has risen

Methods of heat loss in different environmental conditions









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Sweat loss in hot conditions

- Evaporative heat loss is very important in hot conditions, especially during activity
- A person can lose up to 2 litres of sweat per hour under extreme conditions
- If evaporative heat loss is limited (e.g. when the air is very humid) then the body may not be able to lose enough heat to survive
- Above a core temperature of approximately 41°C, sweating stops and assistance is needed to cool the body, otherwise death occurs quickly (heat stroke)

Heat and humidity and the risk to health

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Relative Humidity %	Air temperature °C										
	21	24	27	29	32	35	38	41	43	46	49
0	18	21	23	26	28	31	33	35	37	39	42
10	18	21	24	27	29	32	35	38	41	44	47
20	19	22	25	28	31	34	37	41	44	49	54
30	19	23	26	29	32	36	40	45	51	57	64
40	20	23	26	30	34	38	43	51	58	66	
50	21	24	27	31	36	42	49	57	66		
60	21	24	28	32	38	46	56	65			
70	21	25	29	34	41	51	62				
80	22	26	30	36	45	58					
90	22	26	31	39	50						
100	22	27	33	42							

Serious risk to health - heatstroke imminent

Prolonged exposure and activity could lead to heatstroke

Prolonged exposure and activity may lead to fatigue

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Fever

- During a fever, bacteria cause bone-marrow macrophages to secrete substances called endogenous pyrogens
- The endogenous pyrogens are released into the blood stream and cause the hypothalamic set point to be increased
- This results in initiation of feedback mechanisms that increase body temperature
- Body temperature rises above normal

  - The above-normal temperatures are thought to help defend against microbial invasion because they stimulate the motion, activity, and multiplication of white blood cells and increase the production of antibodies.
  - At the same time, elevated heat levels may directly kill or inhibit the growth of some bacteria and viruses that can tolerate only a narrow temperature range.

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Responses to cold

Increase in heat production

- Non-shivering thermogenesis: hormones (adrenalin, noradrenalin and thyroxin) are released into the bloodstream – causes increased metabolic rate and therefore heat production by exothermic reactions

- Shivering thermogenesis: when skin temp falls quickly, or when core temp falls below shivering threshold, shivering ensues. No mechanical work is done by muscles so the majority of energy is converted to heat. Can increase heat production by 5 x resting value

Decrease in heat loss

- Vasoconstriction in the skin means that less heat comes close to the skin surface, and heat loss by all methods is reduced.

- As less blood is flowing in the subcutaneous fat layer, it becomes a very good insulator to heat loss

- Behavioural heat conservation: individuals exhibit behaviour that reduces the surface area to volume ratio, resulting in reduced heat loss by all methods

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Calculating surface to volume ratio

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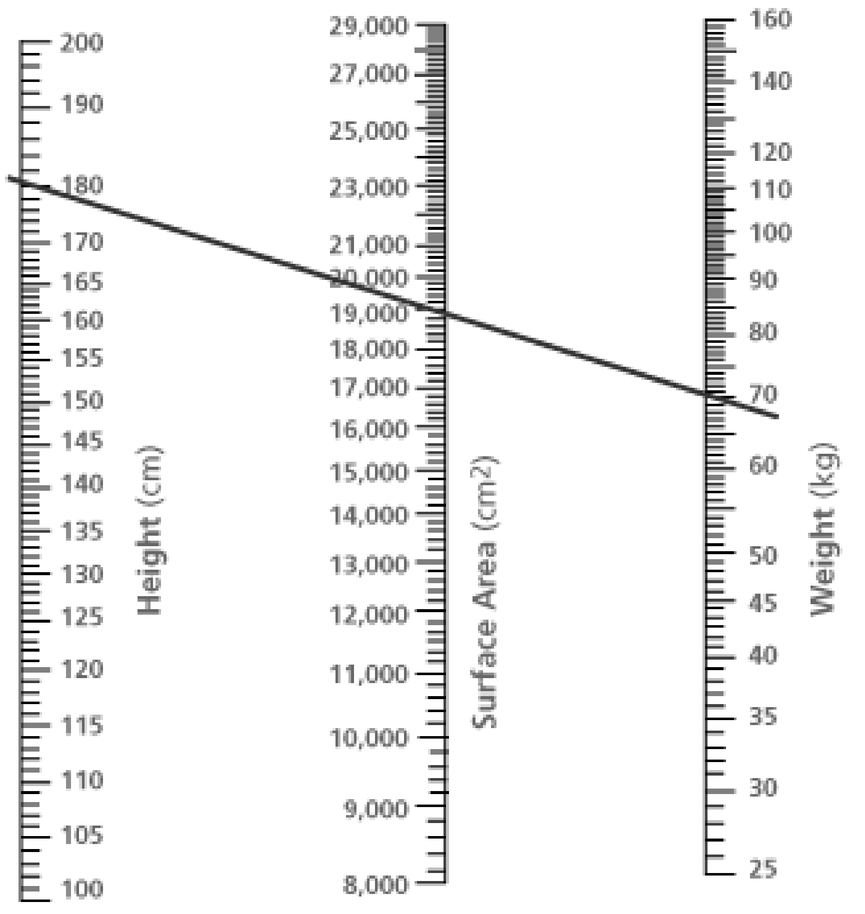


Nomograph for Estimating Body Surface Area from Height and Weight

The density of the human body is a little greater than the density of water because of our bones and organs. One kilogram of body mass occupies a volume of about 0.9 L. Determine the volume of your body by multiplying your weight in kilograms by 0.9.

Now calculate your surface area to volume ratio by dividing the volume by the surface area and expressing in the form 1: X

e.g. in this example, weight - 70 kg so volume is 63L; at height 180cm surface area is 19,000cm^2 or 1.9m^2

Surface area to volume ratio is therefore 1.9/1.9 : 63/1.9

= 1:33

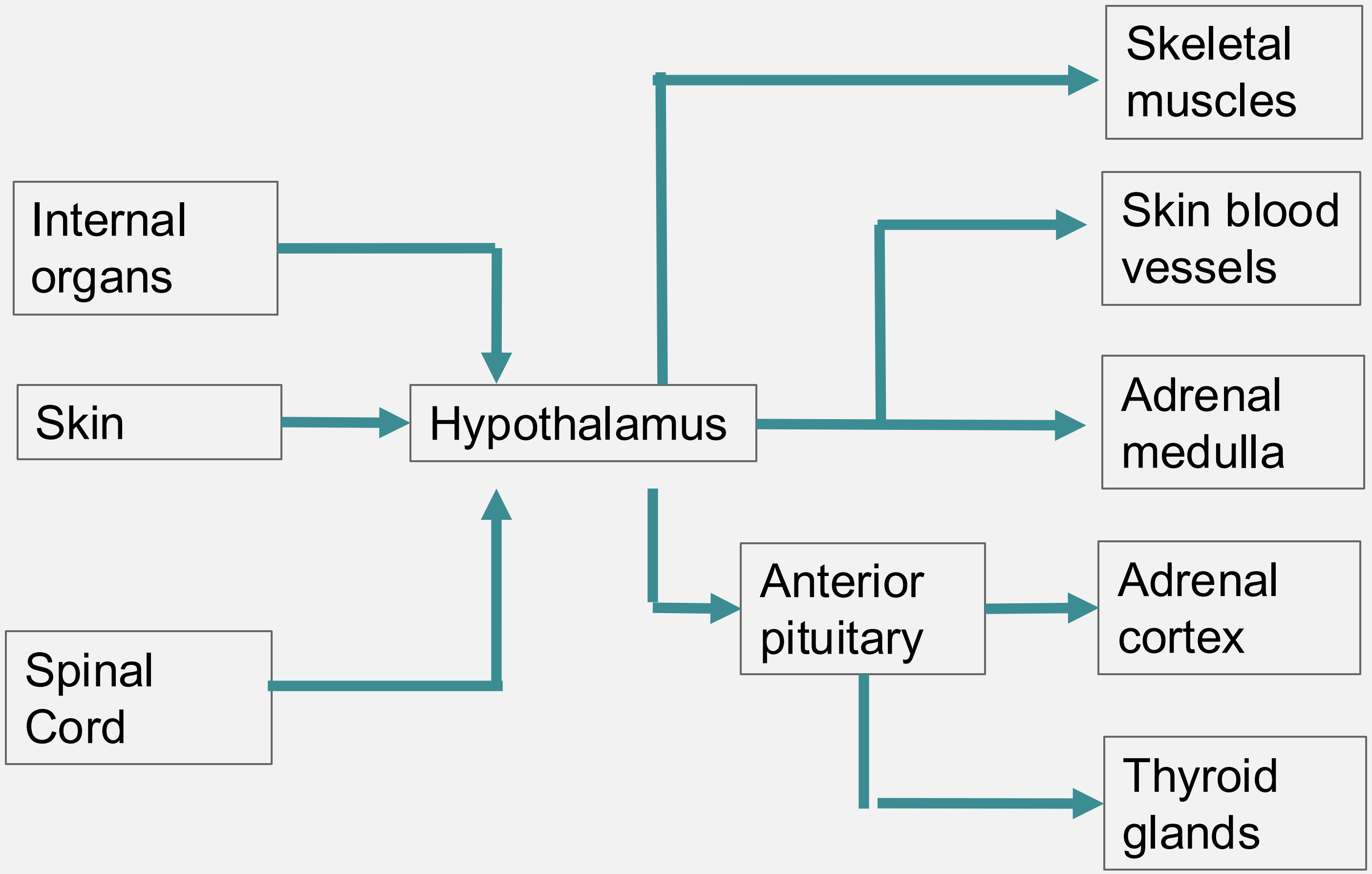
Responses to cold

Afferent cold receptors

Integration of information

Organs involved

Responses



Shivering: increased oxygen consumption and heat production

Vasoconstriction and increased cardiac stroke volume

Increased blood fatty acids and glucose, metabolic rate and stroke volume due to secretion of adrenalin and noradrenalin

Increased blood glucose due to secretion of cortisol and corticosterone

Increased metabolic rate due to secretion of thyroid hormone

What sort of conditions might be expected? NE

In UK:

a gale = wind 40mph (64kph)

highest recorded gust 173mph (276kph; Scotland)

lowest ever temp -27.2ºC (Scotland)

mean temp on Ben Nevis -0.3ºC

Lowest temp in Antarctica : -41ºC

Lowest temp in Norway : -18ºC

Temp falls at a rate of 1ºC every 150m height gained

Water temp - sea freezes at -1.9º

Below 11ºC swimming will result in significant fall in core temp

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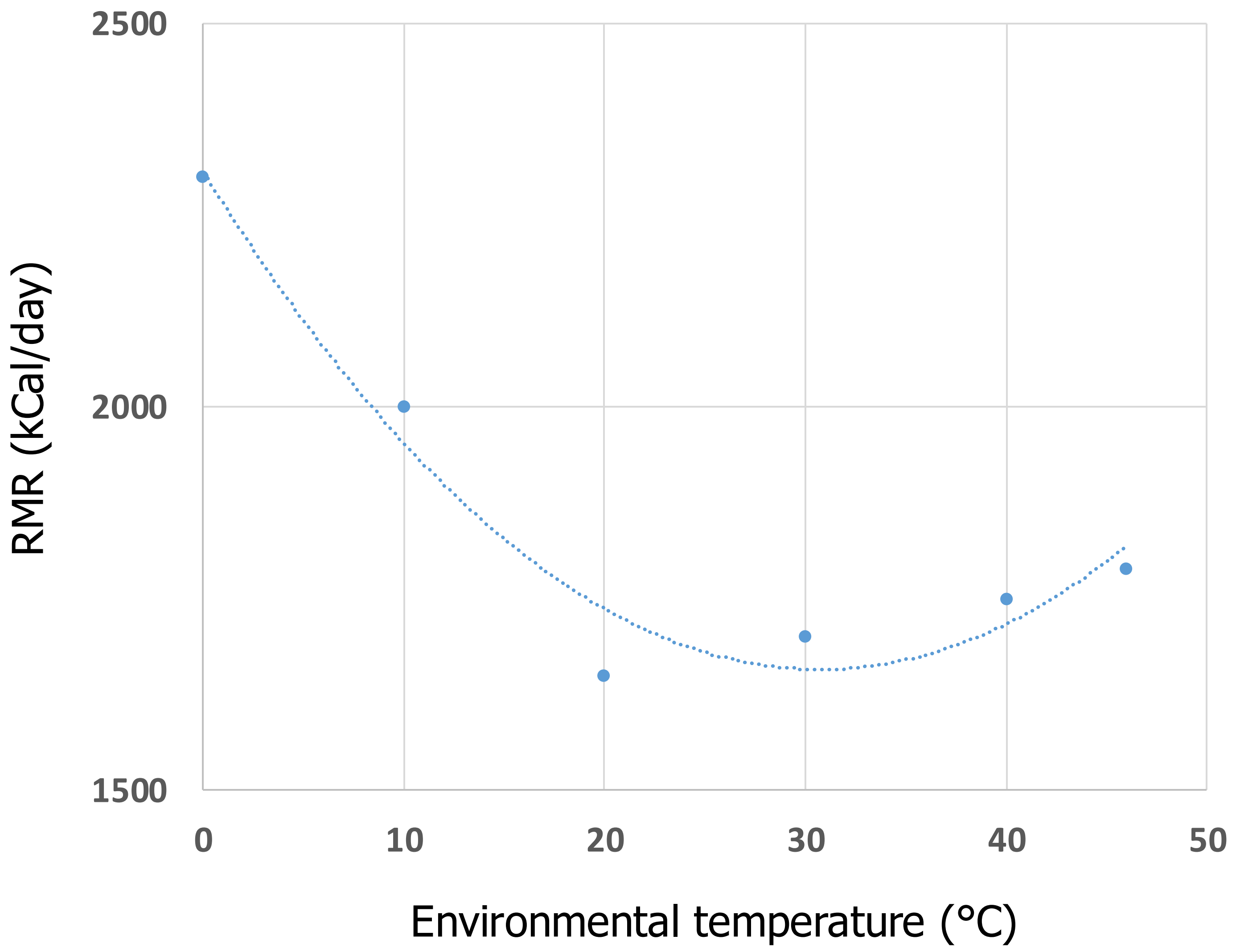
Resting metabolic rate and environmental temperature



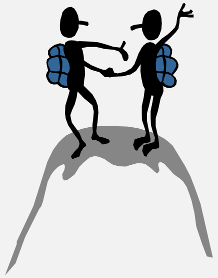
- Why is RMR greater at lower environmental temperatures?
- Why does it get higher at higher environmental temperatures?
- What is the consequence of a higher RMR in cold conditions?

Adaptation responses

What we would normally think of as a homeostatic response

Accommodation: *immediate physiological change in sensitivity of cells to changes in the external environment*

Acclimation; *long term physiological adaptations in response to exposure to artificial or simulated changes in environment*



Acclimatisation: *long term physiological changes resulting from exposure to natural changes in environment*

Acquired responses

Genetic adaptation: *physiological or morphological changes that occur as a result of 'survival of the fittest', following long term exposure to changes in the environment*

Inherited responses

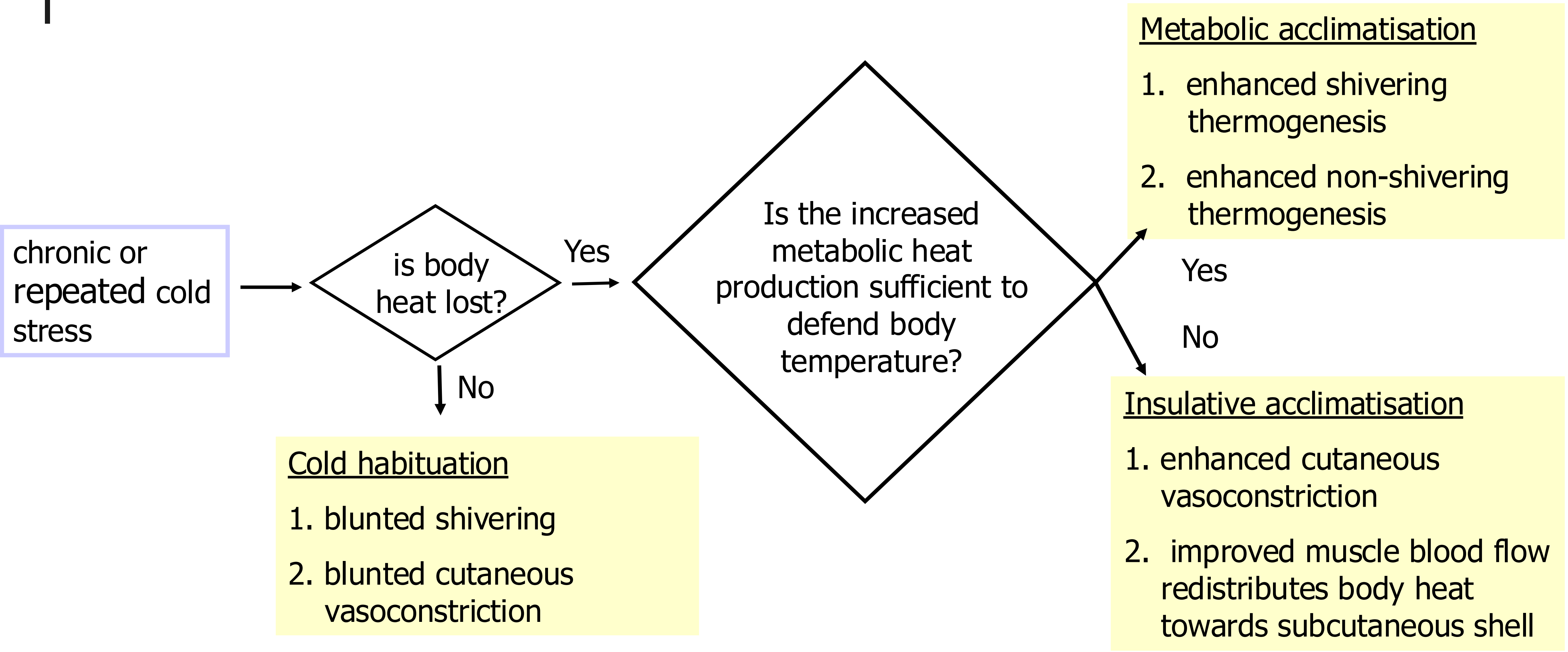
Acquired and Inherited Adaptations

Mode	Site	Affect	Time to develop	Example
Aquired	Cells	chemical reactions	mins-hours	Change in metabolic rate when cold
	tissues and organs	structure	days	increase in number o red blood cells at altitude
	organ systems	function	days-weeks	increase in sweat rat
Inherited	population	traits	years-generati ons	high body fat in Inuit populations (cold)

Acclimatisation to cold

- the body's response to cold varies between individuals
- factors that may affect the response to cold include:
  - duration of cold exposure
  - intensity of cold
  - length of acclimatisation period
  - inherited characteristics

Young's Model of Cold Acclimatisation



(adapted from Armstrong 2000 p102)

further observations on cold acclimatisation:

1. individuals can exhibit combinations of the three responses

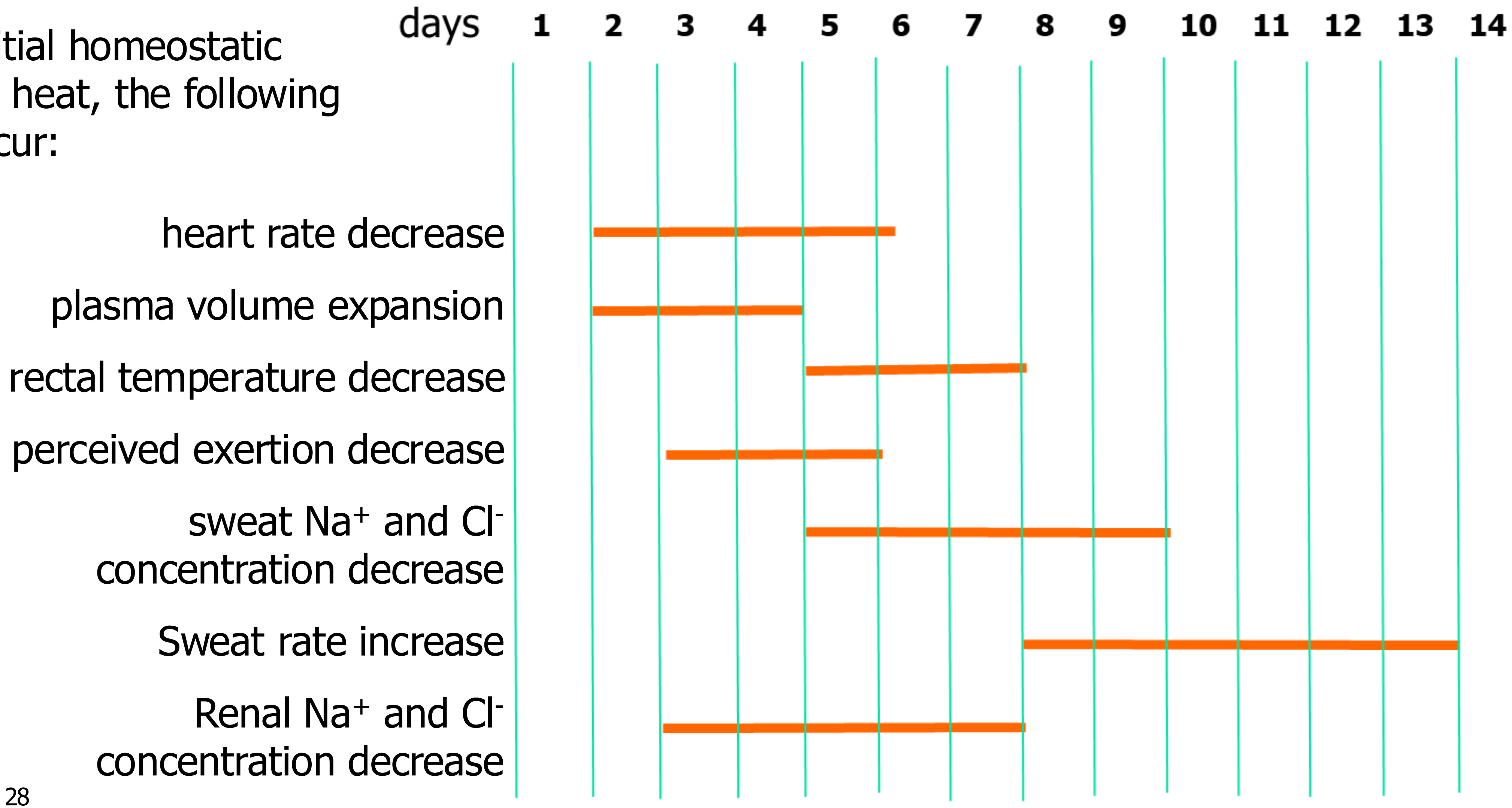
- people may progress from one stage to the next

2. initial cold exposure may result in strong sympathetic response, replaced by a a parasympathetic response after approx 21 days

- this is a controversial theory - there is no clear cut explanation for adaptive responses to cold

Heat Acclimatisation

After the initial homeostatic response to heat, the following changes occur:



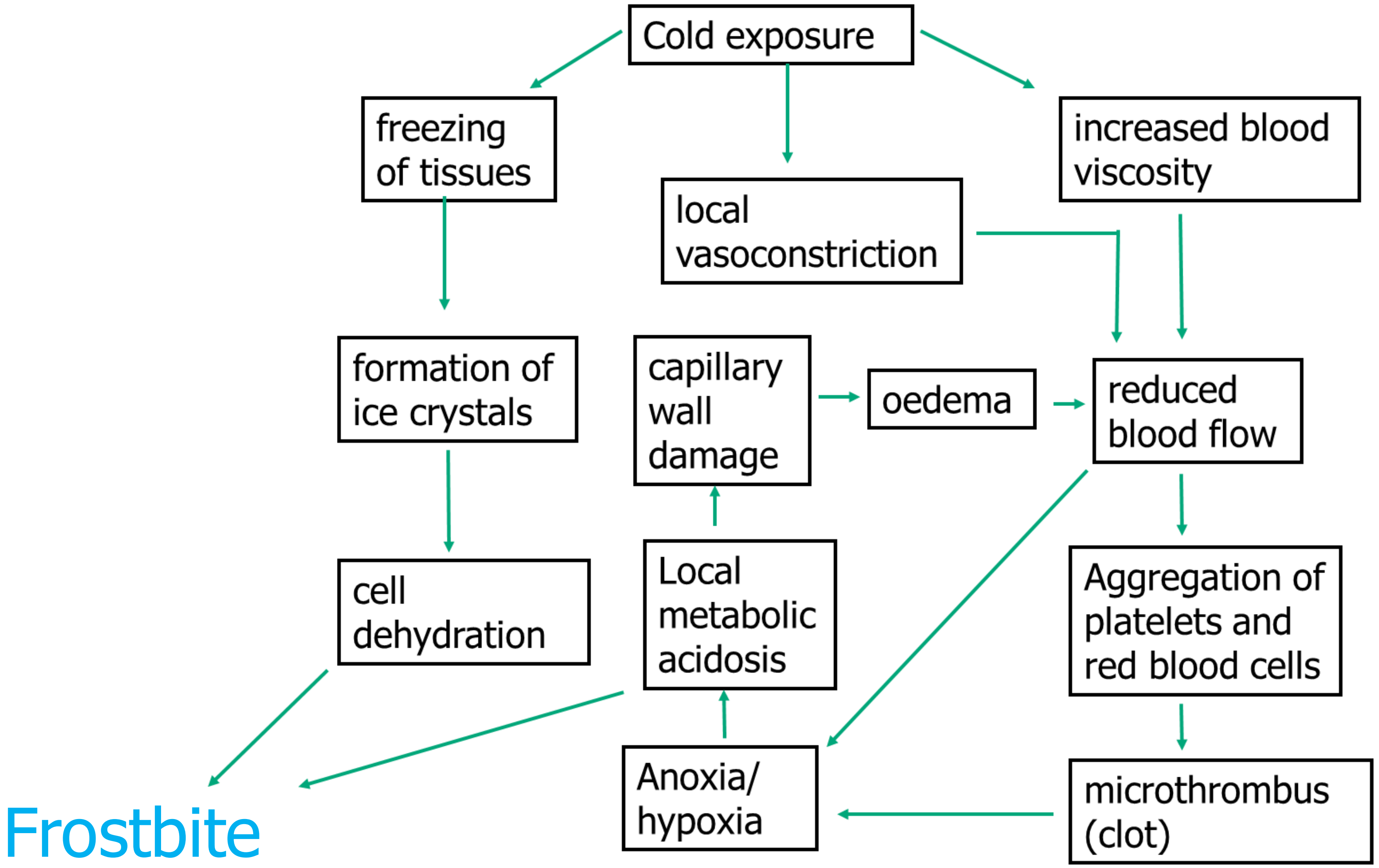
ref. Armstrong (2000) p 28

Problems when temperature homeostasis fails

Freezing injuries

Frostnip	→	freezing of outer skin layer	- usually due to contact with cold surfaces or severe windchill
superficial frostbite	→	freezing of outer skin layer plus some underlying tissue	- prolonged exposure to cold
severe frostbite	→	formation of ice crystals in interstitial fluid or within cells	- rapid or prolonged exposure to very severe cold

Problems when temperature homeostasis fails



Problems when temperature homeostasis fails

Severe frostbite

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Problems when temperature homeostasis fails

- Can occur when ambient temperature is above freezing
- With rapid cooling (e.g. immersion) energy reserves are relatively intact and casualty will often rewarm once removed from cold
- With less severe cold, body temp only falls when energy reserves are depleted (e.g. elderly in cold house); worse prognosis

Hypothermia

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Problems when temperature homeostasis fails

- Cold induced vasoconstriction increases BP and results in diuresis
- Cold reduces kidney tubules' ability to reabsorb water and reduces sensitivity to ADH; further increases diuresis
- Fluid shifts from intravascular → extravascular → intracellular space

Increased BP increases fluid shift into extravascular space; combination of osmotic and hydrostatic pressure causes shift into intracellular space

- This reverses on rewarming so that if the individual has ingested fluids, increasing the blood volume, the intravascular volume increases by up to 30% above normothermic volume

Fluid balance

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Vascular responses when immersed in cold water

- When an individual falls into cold water, cold induced vasoconstriction (CIVC) occurs – cool outer shell, warmer core protected
- Removal from cold relaxes CIVC; vascular volume increases
- Removal from water relaxes "squeeze"; vascular volume increases but fluid volume does not – "distributive shock"
- Distal half of limbs may show the 'Hunter reflex' This is a cyclical vasoconstriction and vasodilation, which may reduce risk of cold injury but increase rate of heat loss

Reduces the thermal gradient between the skin and the cold water, reducing rate of heat loss

The water pressure 'squeezes' the body, reducing the vascular volume

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Speed of cooling

Acute – typically immersion.

- Energy reserves intact, very little fluid shift
- Rewarm if can be removed from cold

Subacute (exhaustion) – e.g. lost hill walker

- Cold is less severe, hypothermia does not develop until energy reserves deplete
- Spontaneous rewarming less likely to be effective

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Speed of cooling

Subchronic (urban)

- Cold is not extreme but is prolonged
- Fluid shifts extensive
- Loss from vascular space may have been replaced with oral intake
- Rapid rewarming may reverse fluid shifts more quickly than kidneys can manage, resulting in pulmonary oedema

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Classification of hypothermia

I. Clear consciousness with shivering
II. Impaired consciousness and/or no shivering
III. Unconscious or cardiovascular instability
IV. Apparently dead
V. Death due to irreversible hypothermia

- Oxygen consumption decreases, and the CNS depresses further
- Patients become at risk for significant arrhythmias.

- Lethargy
- Loss of fine motor coordination
- Cold diuresis
- may develop altered judgment, amnesia, and dysarthria.
- Respiratory rate may increase
- At 33°C, ataxia and apathy are seen typically.

- Very cold skin
- Unresponsive
- Rigidity
- Apnoea, no pulse
- Areflexia
- Unresponsiveness
- Fixed pupils
- susceptibility to ventricular fibrillation and further depression of myocardial contractility

Heat exhaustion and heat stroke

Heat exhaustion

- inability to continue exercising in the heat
- may be due to water depletion or salt depletion
- readily reversible by replacement of water or salt as appropriate

Heatstroke

- fatigue and weakness, related to a high core temperature
- potentially life-threatening

Distinction between heat exhaustion and heat stroke

Diagnostic factors	Mild heat Exhaustion	Severe heat exhaustion	Exertional heatstroke
Blood enzymes	normal	elevated	elevated
Rectal temp	up to 39-40°C	variable	over 39-40°C
Spontaneous body cooling	present	variable	Absent
mental acuity	normal	impaired	Disorientation coma, bizarre behaviour

Detailed pathphysiological changes

Blood enzymes - plasma levels rise because excess heat damages cell membranes

Rectal temperature – up to about 40ºC, homeostatic mechanisms may have some effect in thermoregulation, above this level, thermoregulatory ability is impaired

Spontaneous body cooling - in mild heat exhaustion the rate of metabolic heat production is approx the rate of heat loss. In severe heat exhaustion and in heat stroke, the CNS function is impaired, and thermoregulation no longer functions

Mental acuity - when it becomes hot enough for the CNS to be affected, then the individual may become confused and act strangely

Clinical applications and mechanisms

- UM 2010
- DR K Taylor

Definitions

- As defined by the International Union of Physiological Sciences
- The term adaptation is used to describe "changes that reduce the physiological strain produced by stressful components of the total environment".
- The terms acclimation and acclimatization are often used interchangeably to refer to any adaptive change which occurs due to prolonged or repeated exposure to a stressful environment, and which reduces the strain or enhances endurance of strain in that environment
- The terms differ slightly in that acclimation refers to experimentally driven or lab-based exposures, while acclimatization refers to natural exposures due to climate, season, or location.
- Habituation is defined as a "reduction of responses to or perception of a repeated stimulation."

Clinical Manifestations of Insufficient Heat Loss

- **Heat Stroke:**
  - Central nervous system dysfunction
  - Lack of sweat
  - Core body temperature above 40 C
  - Skin: Red, hot, dry
  - Nausea/vomiting
  - Rapid, strong pulse
  - Heat syncope

Heat Exhaustion:

- Dizzy or possibly syncope
- Core body temperature between 37 to 40°C
- Excessive sweating
- Skin: Cool, pale, clammy
- Nausea/vomiting
- Rapid, weak pulse
- Heat-associated muscle cramping

What is happening at the cellular level

- Heat is generated on a cellular level by metabolism. The basal metabolic rate increases by thyroid hormone, sympathetic stimulation, muscle activity, and chemical activity within cells. When cell metabolism is high, there is a great demand for ATP. During hydrolysis of high energy ATP bonds, part of the derived energy dissipates as heat.
- in a state of hypothermia (core body temperature lower than 35 degrees C), the rate of cellular heat production decreases by 2-fold per 10 degrees reduction in body temperature
- In hyperthermia, protein denaturation occurs resulting in impaired cellular function and release of inflammatory mediators increases gastrointestinal permeability allowing a release of endotoxins into circulation. Heat loss and production must remain balanced to avoid this pathophysiology. The rate of heat loss is determined by the rate of heat conduction from body tissues to the skin via the blood and the rate of heat transfer from the skin to the surroundings by one of the four mechanisms of heat loss.

Clinical Manifestation of Excessive Heat Loss

- Hypothermia:
  - Core body temperature below 35°C
  - Severe hypothermia: less than 28°C
  - Altered mental status
  - Loss of consciousness
  - Malignant cardiac arrhythmias
  - Inability to shiver

- **Other Causes of Impaired Heat Loss:**
- Hypohydrotic Ectodermal Dysplasia
  - Congenital absence or malfunctioning of sweat glands
  - Reduced tolerance of high temperatures that require evaporative cooling
  - Rely on environmental modifications to control heat exposure

Behaviour

- Behaviour is the most effective response to changes in temperature. Behavioural changes initiated by excessive heat loss include adding layers of clothing, curling up to minimize exposed surface area, or standing near a heat source to enhance heat gain via radiation. To minimize heat production if overheated, the behavioural response would be to reduce physical activity and enhance heat loss by convection by standing near a fan
- Other changes made by the hypothalamic efferent output include adjusting sympathetic outflow through the intermediolateral column to subcutaneous vessels. There is decreased sympathetic outflow to vessels causing vasodilation to avoid heat loss. Vasodilation results in the opening of arterioles and arteriovenous anastomoses which markedly increases blood flow to facilitate a greater transfer of heat to the skin surface.

Summary :Heat loss occurs through four mechanisms:

- **Conduction, convection, evaporation, and radiation.**
- The heat generated by the core body tissues travels to the vasodilated skin surface capillaries, and the temperature gradient between the limbs and environment drives transfer of heat to the surrounding air, mainly by radiation.

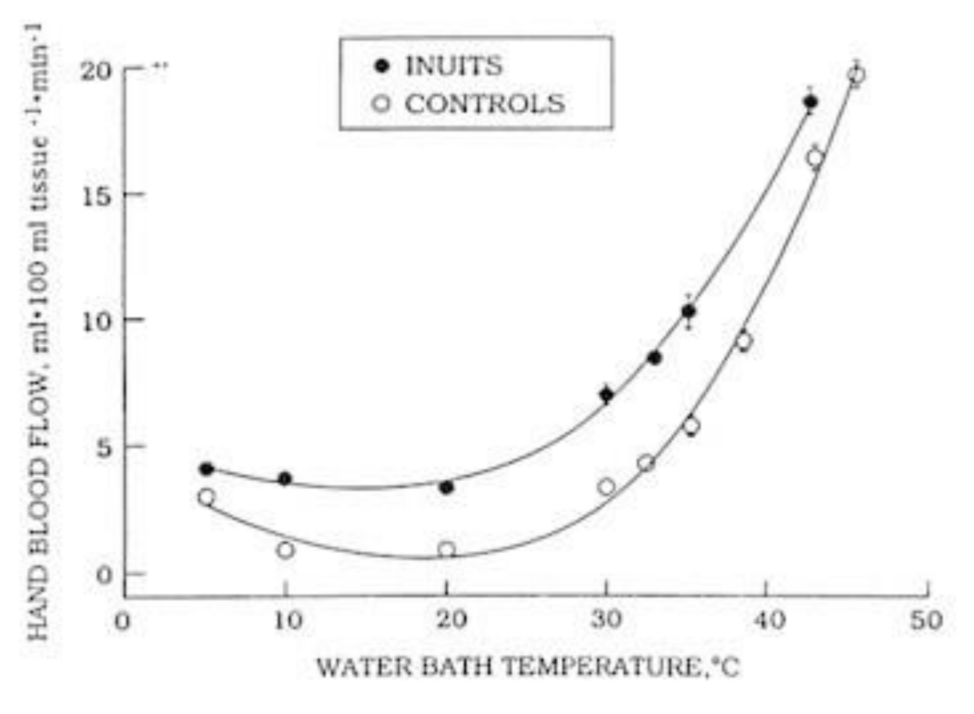
Mechanisms

- ***Radiation is the most significant source accounting for approximately 60% of heat loss.***
- Core body tissues transfer heat in subcutaneous blood vessels which emit infrared rays from the skin surface to lose heat by radiation.
- *Evaporation is the next major source accounting for about 22% of heat loss.*
- Water vaporization requires energy and consumes heat facilitating heat loss. This process occurs even when the body is not sweating. The body depends on evaporation for heat dissipation when the environmental temperature is warmer than the skin or when convection and radiation are insufficient.

Mechanisms

- Conduction and convection contribute roughly 15% of heat loss.
- Conduction is the loss of molecular kinetic energy in the form of heat from the skin to the surroundings.
- Different mediums transfer heat by conduction at different rates. For example, the conductive transfer of water is 100 times that of air. Radiation and conduction can facilitate heat loss as long as skin temperature is greater than the surroundings.
- At extremely high skin temperature (over 43°C), evaporation is the only mechanism of heat dissipation.

Adaptation



Peripheral vasoconstriction is one important physiological response exhibited by humans exposed to cold.
Blood flow decreases as water temperature becomes colder, as shown in Figure 7-1, which depicts blood flow in the hand decreasing in response to immersion in water of decreasing temperature.
During whole-body cold exposure, the vasoconstrictor response is not limited to the hands, but is widespread throughout the peripheral shell. The decrease in peripheral blood flow reduces convective heat transfer between the body's core and shell (skin, subcutaneous fat, and skeletal muscle) and increases insulation. Heat is lost from the body surface faster than it is replaced. As a result, whole-body cold exposure causes skin temperature over the entire body surface to decline). Insulation begins to increase when skin temperature falls below about 95°F (35°C), and becomes maximal when skin temperature is about 89°F (31°C) or less (Veicsteinas et al., 1982).So, during cold exposure, central core temperature defense occurs at the expense of a decline in skin temperature.

Summary

- Acute physiological responses to cold exposure include cutaneous vasoconstriction and shivering thermogenesis which, respectively, decrease heat loss and increase metabolic heat production.
- Vasoconstriction is elicited through reflex and local cooling. In combination, vasoconstriction and shivering operate to maintain thermal balance when the body is losing heat. Factors such as anthropometry, sex, race, fitness, thermoregulatory fatigue)that influence the acute physiological responses to cold exposure.
- . Three physiological responses to chronic cold exposure, also known as cold acclimation/acclimatization are thought to occur.
- a) habituation, b) metabolic adjustment, and c) insulative adjustment.

Changes in response in elderly

- Thermogenesis has reduced due to reduced skeletal muscle mass involved in shivering, atrophy of brown tissue mass, endocrine deficiencies, and cardiopulmonary problems restricting the available oxygen for consumption in heat production.
- Peripheral nerve fibre loss and lower conduction velocity contribute to reduced thermal sensitivity that develops in a distal to proximal fashion.
- For uncertain reasons, behavioural thermoregulation seems to be impaired in the elderly as well, and they tend to favour warmer environments.

Changes in response in elderly

- The expected increase in cardiac output in response to heat has decreased in the elderly due to reduced sensitivity of the beta adrenoreceptors in the heart. Less renal and splanchnic blood flow is redirected to the skin as well due to the reduced sympathetic tone. The dermal thinning that occurs with age reduces vascularization and limits the efficacy of the skin as an insulator or heat exchanger. Sweat glands are less productive, and the morbidity of dehydration exacerbates this problem in the elderly population.

Diminished Thermoregulatory Capacity of the Elderly

- During the aging process, the sympathetic response to a cold environment is blunted reducing the discharge rate of sympathetic nerves to the cutaneous vasculature.
- Additionally, the sympathetic neurotransmitter itself is in shorter supply.
- Vasodilatory response to heat is also impaired due to ROS which may limit nitric oxide synthase function. The elderly are therefore at risk for both hypothermia and hyperthermia.

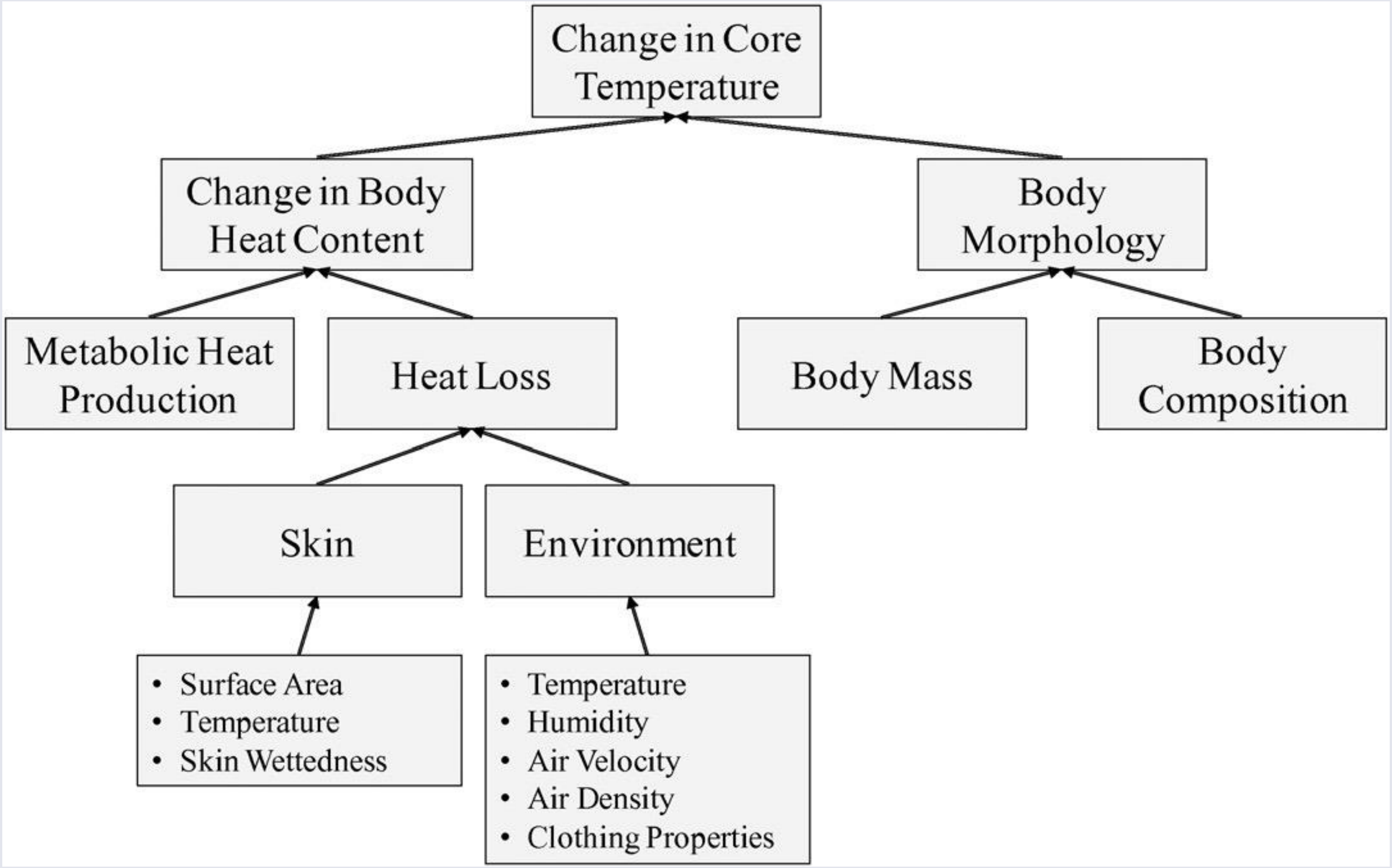
Heat loss at Birth

- The most significant heat loss occurs immediately after birth.
- The greatest source of heat loss at birth is when the amniotic fluid evaporates from the skin.
- Conductive heat loss occurs when the baby gets placed on a cooler surface like a scale or table.
- The baby can reflexively curl in the fetal position to reduce the surface area in contact with the cooler surface to minimize heat loss. Air flow through the room cases convective heat loss.
- Radiation is the most significant source of heat loss after birth and throughout the rest of development. If proper measures are not taken to mitigate heat loss immediately after birth, the temperature of the newborn could drop by 2 to 4 degrees C within the first 20 minutes.

Clinical significance

- The average difference between the core body temperature of a young adult and a geriatric adult is approximately 0.4°C;
- This is an important clinical consideration when evaluating an older adult for fever since their baseline temperature is lower.
- One study of nursing home patients found an increase in the incidence of infectious fever in the elderly when the fever threshold was lowered to 37.2 degrees C/99 degrees F, or 1.1 degrees C/2 degrees F above baseline.
- It is therefore clinically relevant to keep in mind the physiologic differences in thermoregulation between the elderly and young adults patient populations.

Biophysical factors affecting the change in core temperature during exercise and environmental heat exposure.



The pathophysiology of heatstroke: Overview

- The pathophysiology of heatstroke involves ***the insufficiency of the body's heat loss mechanism***s.
- At extremes of heat, the body relies on evaporative cooling because an insufficient thermal gradient exists between the skin and environment to facilitate conduction or radiation.
- However, if the humidity is also extremely high, evaporation is also limited.
- The amount of work exerted in a given environment is another contributor to heat stroke risk. For example, when a person is doing heavy work, the environmental temperature can be as low as 29.4 degrees C to cause heat stroke. Therefore, heat stroke results from an unfavoUrable balance of environmental temperature, humidity, and level of physical work..

Heatstroke

- **Heat Stroke**
- Heat stroke is an emergent clinical condition that requires immediate removal of the patient from the heat, ATLS protocol activation, and implementation of cooling measures while awaiting transportation. External cooling methods include evaporative cooling with misting water on the patient’s skin while fanning warm air. Immersion in an ice bath or application of ice packs on the axilla, groin, neck, and head are also effective. Considerations when performing immersive cooling include induction of shivering when the skin cools below 30 C and difficulty in accessing the patient if the cold water induces reflexive bradycardia.
- Internal cooling methods include gastric, bladder, and rectal lavage or even cardiopulmonary bypass. Cooling measures should terminate when the core temperature is 38 degrees C.

Heat acclimatization

- Humans who live in tropical regions demonstrate a higher heat tolerance than those living in more temperate regions.
- Their core body temperature is similar, but their threshold for a thermoregulatory response to heat is about 0.5°C higher; this is due to the adaptation of the sweat glands.
- Heat loss by evaporation gradually increases, and so does aldosterone secretion.
- The result is an increased level of less salty sweat and resultant thirst from the increased NaCl plasma concentration.

Heat Loss in the Newborn

- Minimizing heat loss in the newborn is central to reducing morbidity and mortality in the neonatal period and is one of the most critical strategies for the optimal development of the infant.
- Several characteristics of newborn physiology contribute to their increased risk of heat loss.
- The smaller the size of an infant, the larger the surface area-to-body mass ratio which promotes greater heat loss via conduction.
- Newborns also have less subcutaneous fat to provide insulation and more body water content.
- The blood flow in newborns is also altered resulting in peripheral cyanosis. Newborns are unable to activate their muscles to shiver and must rely on the non-shivering thermogenesis in brown fat.

Cold exposure in humans causes specific acute and chronic physiological responses

- Acute physiological responses to cold exposure include cutaneous vasoconstriction and shivering thermogenesis which, respectively, decrease heat loss and increase metabolic heat production.
- Anthropometry, sex, race, fitness, and thermoregulatory fatigue impact vasoconstriction, shivering, and thermal balance.
- Three primary patterns of cold acclimatization have been observed, a) habituation, b) metabolic adjustment, and c) insulative adjustment.
- The pattern of acclimatization is dependent on changes in skin and core temperature and the exposure duration.

Physiology of Cold Exposure

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- The reduction in blood flow and consequent fall in skin temperature contribute to the etiology of cold injuries (Purdue and Hunt, 1986). The hands and fingers are particularly susceptible to cold injury (Boswick et al., 1979) and to a loss of manual dexterity due to cold-induced vasoconstriction (Gaydos, 1958). In these areas of the body, another vasomotor response to cold, cold-induced vasodilation, modulates the effects of vasoconstriction.
- Periodic oscillations (rise and fall) of skin temperature follow the initial decline in skin temperature during prolonged cold exposure. These skin temperature oscillations are the result of transient increases in blood flow to the cooled finger. Originally thought to be a local effect of cooling (Burton and Edholm, 1955), recent evidence suggests the hunting reaction may involve a centrally-mediated mechanism (Lindblad et al., 1990). A similar cold-induced vasodilation occurs in the forearm (Clarke et al., 1957; Ducharme et al., 1991). This effect may reflect the operation of a different physiological mechanism, since the forearm response appears to be the result of vasodilation in muscle vasculature rather than in skin (Ducharme et al., 1991).

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- ‵In humans exposed to environments colder than body temperature, heat flows from the body core toward the environment, primarily via dry (i.e., conductive and convective) heat-loss mechanisms.
- Wind increases convective heat loss from the body surface (Santee and Gonzalez, 1988), thus providing the basis for the concept of wind chill (Siple and Passel, 1945). Because water has a much higher thermal capacity than air, convective heat transfer is greater (perhaps 70-fold) during immersion in water than in air of the same temperature (Gonzalez, 1988).
- Clothing provides insulation between the body and the environment, thus limiting convective and conductive heat loss, but wet clothing provides considerably less insulation than dry. Thus, environmental characteristics besides temperature influence the potential for heat loss and the resulting physiological strain of defending body temperature.’

Hypothalamic temperature regulation

- https://www.ncbi.nlm.nih.gov/books/NBK507838/
- The hypothalamic thermoregulatory centre sets the body's set point and regulates temperature homeostasis.
- The hypothalamus contains temperature sensors, which receive information via nerve cells called thermoreceptors. The body has peripheral and central thermoreceptors.
- The peripheral thermoreceptors are located in the skin and sense surface temperatures, while central thermoreceptors are found in the viscera, spinal cord, and hypothalamus and sense the core temperature.
- Variations in body temperature activate these thermoreceptors, which inform the preoptic area of the hypothalamus. This area then activates heat regulation mechanisms to increase or decrease body temperature and return it to baseline

The human body's thermostat is the hypothalamic thermoregulatory re which, more specifically, is located in the preoptic area of the hypothalamus.

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