SYSTEM REGULATION

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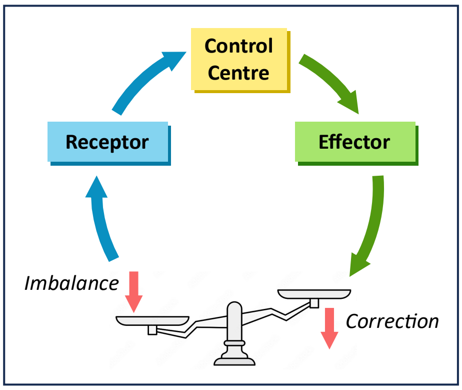
HOMEOSTASIS

Organisms must maintain certain physiological conditions in order to ensure the continuation of essential metabolic reactions needed for survival. Examples of conditions that must maintain an internal equilibrium include body temperature, blood glucose concentrations, blood pH levels and the osmotic concentration of the blood. **Homeostasis** is the tendency for a cell or organism to maintain a constant internal environment within physiological tolerance limits. A failure to maintain internal conditions within preset limits will result in the development of disease. Homeostatic regulation involves the use of communication systems (nerves and hormones) to detect and then respond to changing internal conditions via feedback loops.

NEGATIVE FEEDBACK

Physiological variations are detected by a variety of receptors within the body. Different receptor types detect different specific stimuli – for example, chemoreceptors detect chemicals while baroreceptors detect pressure changes. These receptors convert the stimulus into biological signals that can be processed. In order to maintain internal equilibrium, an organism must enact physiological responses that will function to negate the change detected – so as to restore conditions to within the required preset limits. This process, whereby a response is the *reverse* of the detected change, is known as **negative feedback**.



All homeostatic mechanisms involve negative feedback. Positive feedback will not promote homeostasis as it involves a response that acts to *reinforce* the stimulus (it will amplify the variation). Any unregulated condition that disrupts normal physiology will cause a **disease**. Conditions that must be regulated include blood sugar levels (normally between 75 – 95 mg/dL) and body temperature (between 36 – 38°C). Certain physiological activities produce predictable changes to internal conditions and need to be regulated. These include circadian rhythms, vigorous physical exercise and digestive movement in response to eating a meal.

BLOOD GLUCOSE REGULATION

Blood glucose concentrations are controlled by a set of antagonistic hormones secreted by the pancreas. **Insulin** (secreted by β cells) lowers blood sugar levels by increasing the uptake of glucose by the liver and adipose tissue (stored as glycogen). **Glucagon** (secreted by α cells) raises blood sugar levels by increasing the release of glucose by the liver and adipose tissue. Blood sugar levels may be increased following a meal and will decrease as a response to vigorous exercise (glucose is used in aerobic and anaerobic respiration).

⬆ blood sugar levels → Insulin released → Liver takes up glucose → ⬇ blood sugar levels

⬇ blood sugar levels → Glucagon released → Liver releases glucose → ⬆ blood sugar levels

DIABETES

Diabetes mellitus is a metabolic disorder that occurs when the body is unable to regulate its blood glucose concentrations. The body is unable to either produce or respond to insulin, resulting in hyperglycaemia. There are two types of diabetes that differ in their physiological consequences, risk factors and treatment:

	Type I (IDDM)	Type II (NIDDM)
Cause	β cells are destroyed (autoimmunity?)	Insulin receptors are down-regulated
Effect	The body does not *produce* insulin	Body does not *respond* to insulin
Risk Factors	Genetics (family history, ethnicity)	Obesity (poor diet, physical inactivity)
Onset	Early onset (childhood)	Late onset (adulthood)
Treatment	Insulin injections are required	Controlled by dietary management

THERMOREGULATION

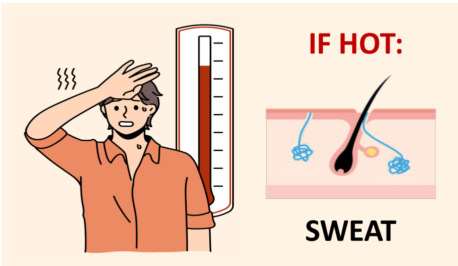
Homeotherms are animals that maintain a stable body temperature. Changes to core body temperature are detected by thermoreceptors in the skin and hypothalamus. These trigger a variety of mechanisms (either cooling or heating) to restore equilibrium. Responses include:

Cooling Mechanisms:

- *Vasodilation* – The arterioles widen to allow more heat to be lost
- *Sweating* – The production of sweat enables evaporative cooling
- *Behavioural changes* – Burrowing or decreasing physical activity

Heating Mechanisms:

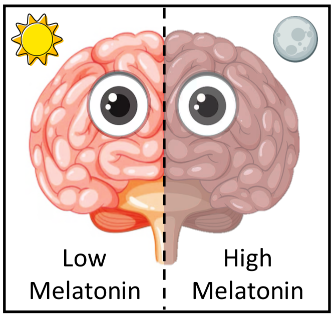
- *Vasoconstriction* – The arterioles will narrow to retain more heat
- *Shivering* – Repetitive muscular contractions will generate heat
- *Piloerection* – Bristling hairs act to trap warm air against the skin



Body temperature is also regulated by the hormone **thyroxin**. The hypothalamus triggers the production of thyroxin by the thyroid gland by stimulating the pituitary to secrete TSH (thyroid stimulating hormone). This hormone increases metabolic activity, producing heat as a by-product. **Brown adipose tissue** is particularly proficient at generating heat, as these cells have an uncoupling protein that prevents the energy released from aerobic respiration from being transferred to ATP. Instead, the released energy is converted into heat.

CIRCADIAN RHYTHMS

Circadian rhythms are the body's physiological responses to a 24-hour cycle of day and night. Circadian rhythms are regulated by the hormone **melatonin**. Light exposure (i.e. day time) is detected by the suprachiasmatic nucleus in the hypothalamus, which suppresses melatonin secretion. This means that levels are lower during the day and higher at night. Melatonin functions to promote activity in nocturnal animals and conversely promotes sleep in diurnal animals. Over a prolonged period, melatonin secretion becomes entrained to anticipate the onset of darkness and the approach of day. Melatonin levels will naturally decrease with age, leading to changes in the sleeping patterns of the elderly.



Melatonin expression

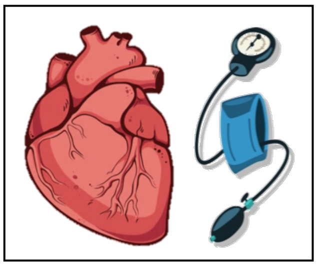
EXERCISE INTENSITY

Physiological changes occur when an organism performs vigorous physical activity. The active cells must undertake aerobic respiration in order to produce large quantities of ATP. This requires both oxygen and glucose, while carbon dioxide is produced as a by-product. Gases are exchanged at the lungs (respiratory system), while all materials are transported in the bloodstream (vascular system). To prepare for vigorous activity, the amygdala (an area of the brain involved in emotional processing) sends stress signals to the hypothalamus to initiate a 'fight or flight' response. The hypothalamus then stimulates the release of **adrenaline** (also called epinephrine) from the adrenal glands. Adrenaline will trigger a variety of responses:

- Cardiac output (heart rate and stroke volume) will increase to allow for greater systemic blood flow
- Ventilation rate will increase and bronchioles will widen to improve the exchange of respiratory gases
- Sugars will be released from storage organs and blood flow will be redirected to active tissues (muscles)

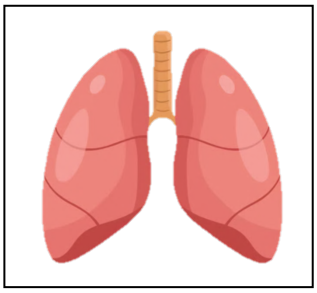
Cardiac Output

Cardiac output is autonomically controlled by the medulla oblongata (brainstem). Baroreceptors in the aortic arch and carotid sinuses detect any changes in blood pressure and send signals to the medulla to trigger adjustments to either heart rate or vessel diameter. Additionally, chemoreceptors in the blood vessels, along with central chemoreceptors in the medulla, may regulate heart rate according to changes in blood pH levels (a build-up of carbon dioxide lowers the pH of blood).



Ventilation Rate

Ventilation rate is regulated according to the changes in blood pH (which reflects the concentration of carbon dioxide in the blood). The chemoreceptors will send signals to the medulla to make adjustments that reflect the body's requirements (vigorous activity will increase the levels of carbon dioxide in the blood and will trigger an increase in the ventilation rate to enable the removal of this gas). The brainstem controls ventilation by signalling to the diaphragm and the intercostal muscles within the chest cavity to increase the depth and frequency of breaths.



DIGESTIVE CONTROL

Consuming a meal prompts certain physiological adjustments to allow for the transit of food through the digestive tract and its subsequent assimilation into the body. The initiation of swallowing and the egestion of faeces are under voluntary control by the CNS, however the passage of food between these points is involuntary. The enteric nervous system (ENS) coordinates the sequential contraction of longitudinal smooth muscles to move the food distally through the alimentary canal (via a process called **peristalsis**).