

Heat acclimatisation induces significant physiological changes, notably an increase in total body water and plasma volume. Data shows that over 8 to 22 days of heat exposure, total body water increases by 5-7%, primarily due to plasma volume expansion, without a corresponding increase in red blood cell volume. This expansion is likely due to increased albumin production in the liver and higher plasma protein levels, which elevate oncotic pressure and retain more water in the circulatory system.

This increase in plasma volume enhances venous return, stroke volume, and cardiac output, leading to a lower resting heart rate. The inverse relationship between plasma volume and resting heart rate indicates improved cardiovascular efficiency, which benefits exercise performance.

## **Effects of Plasma Volume on Cardiac Function and Exercise Performance**

Increased plasma volume results in higher stroke volume and cardiac output during exercise, as demonstrated in studies with participants before and after acclimation. Post-acclimation, participants show elevated cardiac output and stroke volume during 40-minute exercise sessions, compared to pre-acclimation conditions. This adaptation allows the heart to pump more blood per, reducing the need for higher heart rate and improving overall cardiovascular efficiency.

## **Summary of Heat Acclimation Adaptations**

Heat acclimation triggers rapid physiological adaptations that enhance thermoregulatory capacity and exercise performance. Key changes include:

- Rapid increase in plasma volume, leading to higher total body water and circulatory fluid volume.
- Decreased resting heart rate due to improved venous return and stroke volume.
- Enhanced sweating response, with increased sweat rate and reduced sweat electrolyte concentration, improving cooling efficiency.
- Better thermal comfort higher temperatures, as the body becomes more efficient at dissipating heat and maintaining core temperature.

These adaptations collectively improve the body's ability to perform in hot, reduce cardiovascular strain, and increase exercise endurance under heat stress conditions.

## **Age Related Impairment of Heat Defence**

### **Introduction to Heat Exposure and Plasma Volume Changes**

This presentation discusses how age influences the body's ability to regulate temperature and maintain plasma volume during acute heat exposure. The focus is on understanding age-related impairments in thermoregulation, especially under conditions of prolonged heat stress. The data

primarily examines plasma volume changes over a three-hour period of heat exposure, highlighting different physiological responses in young versus older individuals.

## Stages of Response to Heat Exposure

Researchers have identified three stages in the body's response to initial heat exposure:

1. **Initial Response (Hemodilation):** A surprising finding is a smaller increase in plasma volume, approximately 5%, contrary to expectations. This is due to mechanisms involving vasodilation and fluid shifts.
  - a. **Mechanisms Behind Plasma Volume Increase:** The increase results from vasodilation without concurrent vasoconstriction, leading to decreased venous pressure. This reduction in venous pressure lowers capillary filtration pressure, promoting fluid movement into tissues and expanding plasma volume.
2. **Prolonged Exposure Effects:** Continued heat exposure causes sweating, leading to water loss (~1 liter), which reduces plasma volume.
3. **Stage 3:** As plasma volume decreases, the body initiates responses to conserve water, including suppressing sweating, which impairs thermoregulation.

## Physiological Explanation of Vasodilation and Resistance

The dilation of veins (venodilation) rather than arteries (vasodilation) is hypothesized to occur due to a decrease in total peripheral resistance. This reduction causes a slight fall in mean arterial pressure, decreasing filtration in capillaries and aiding fluid retention in tissues. The decrease in resistance helps maintain blood pressure but also influences plasma volume dynamics during heat stress.

## Effects of Prolonged Heat Exposure

Extended heat exposure results in increased sweating, which causes significant water loss. Without rehydration, plasma volume continues to decline, eventually plateauing. The body responds by suppressing sweat production to conserve water, but this impairs cooling mechanisms, leading to potential overheating.

## Age-Related Differences in Thermoregulatory Response

### Comparison Between Young and Older Adults

The study compares young individuals (~26 years) with older adults (~64 years) during a three-hour heat exposure. Key observations include:

- Young individuals show a modest increase in core temperature, indicating effective thermoregulation.
- Older adults struggle to maintain their core temperature, which rises more slowly but reaches higher levels, indicating impaired thermoregulatory capacity.

## **Core Temperature and Relative Changes**

Absolute core temperature varies among individuals, so the focus is on temperature changes relative to baseline. The data shows a 1°C difference between young and older adults, with older individuals having a higher starting core temperature and a greater difficulty in temperature regulation.

## **Plasma Osmolarity and Volume in Aging**

Older adults tend to start with higher plasma osmolarity, suggesting slight dehydration even before heat exposure. This initial dehydration limits their capacity for plasma volume expansion, which is crucial for cooling and fluid balance during heat stress.

- Young individuals exhibit plasma volume expansion within the first 30 minutes, aiding in thermoregulation.
- Older adults do not show this (hemodilation) expansion, and their plasma volume decreases more during heat exposure.

Interestingly, plasma protein levels remain stable in young individuals but decrease in older adults over the exposure period. This reduction in plasma proteins can impair oncotic pressure, reducing fluid reabsorption into the bloodstream and exacerbating dehydration.

## **Implications for Older Adults in Hot Environments**

Older individuals are less capable of thermoregulation in high-temperature environments (e.g., 45°C with 25% humidity). Their impaired ability to maintain core temperature and plasma volume increases the risk of heat-related illnesses such as heat stroke. The decline in plasma volume and protein levels further compromises their cooling capacity, making them more vulnerable to serious health consequences during heat waves.

## **Heat Defence and Sleep**

### **Introduction to Circadian and Body Temperature**

Circadian rhythm is a biological process that regulates various physiological functions over a 24-hour cycle. A key aspect of this rhythm is the fluctuation of core body temperature, which correlates closely with our alertness and sleep propensity. During the decline phase of core temperature, the body prepares for sleep, making us more drowsy and increasing the likelihood of falling asleep.

### **Core Body Temperature and Sleep Propensity**

As core temperature decreases, our readiness for sleep increases. This decline in temperature is a natural signal that promotes sleep onset. Conversely, if the body's ability to lower its core

temperature is impaired, it can negatively affect sleep quality and duration. This explains why hot nights, where ambient temperature remains high, can make falling asleep more difficult.

## **Environmental Factors Affecting Thermal Comfort and Sleep**

Environmental conditions, particularly temperature and humidity, significantly influence sleep quality by affecting thermal comfort. The interaction between these factors determines how easily the body can dissipate heat and maintain a comfortable sleep state.

## **Effects of Temperature and Humidity on Core Temperature During Sleep**

Studies compare two environmental conditions with the same heat index but different temperature and humidity levels:

- Condition 1: 32°C with 80% humidity
- Condition 2: 26°C with 50% humidity

In these conditions, rectal (core) temperature and skin temperature are monitored throughout the sleep period. The data shows that in the more humid environment (32°C, 80%), there is little to no significant change in core body temperature during sleep. In contrast, in the more temperate environment (26°C, 50%), core temperature drops by over one degree Celsius from the start to the end of sleep.

## **Impact of Humidity and Temperature on Sleep Quality**

The quality of sleep is assessed using a sleep deficiency index, which considers various sleep stages, including REM sleep. Results indicate that sleep quality is higher in the temperate environment compared to the hot and humid one. The inability to effectively lose core body heat in hot, humid conditions impairs sleep quality.

## **Mechanisms Behind Impaired Sleep in Hot and Humid Conditions**

High ambient temperature and humidity hinder the body's capacity to dissipate heat, preventing the normal decline in core temperature that facilitates sleep onset. This disruption in thermoregulation interferes with the circadian rhythm, leading to poorer sleep quality and increased difficulty in falling asleep or maintaining restful sleep.

# Stress and the Body: How Does the Body Respond to Stressful Challenges

## Learning Outcomes

- Define and explain Homeostasis
- Compare the different levels of regulation in the maintenance of homeostasis
- Explain how set point operates in normal homeostasis and in adaptive homeostasis and the role of feedback mechanisms in maintaining homeostasis
- Explain the difference between stressor and stress response
- Summarise the three different types of stress response, and provide examples of the responses
- Explain the difference between autonomic and automatic responses
- Describe the importance of time course in the adaptive response

## Homeostasis

### Definition of Physiology

Physiology is derived from the ancient Greek words "physikos" meaning nature or origin, and "logia" meaning study. It is the scientific study of the functions and mechanisms in living systems. In simple terms, physiology is about understanding how living organisms work together, often described as the "life logic." It explores the processes that sustain life and how various systems coordinate to maintain normal functioning.

### Importance of Terms and Definitions in Science

Grasping key terms and their precise definitions is crucial in science, especially in physiology, to ensure clear communication and understanding of complex concepts. Accurate terminology helps in understanding how biological systems operate and adapt.

### Understanding Homeostasis

Homeostasis is a fundamental concept in physiology that refers to the body's ability to maintain a stable internal environment despite external changes. The term was first coined by Walter Cannon in the 1930s, a prominent figure in physiology often called the father of experimental physiology. Cannon derived the term from Greek roots "homoios" meaning similar, and "stasis" meaning standing still, emphasizing the idea of maintaining stability.

## **Historical Background and Origin of the Term**

Walter Cannon's interest in homeostasis was influenced by the work of Claude Bernard, a French physiologist who introduced the concept of the "milieu intérieur," meaning a stable internal environment. Bernard emphasized that despite external fluctuations, internal conditions remain relatively constant, which is vital for survival.

## **What Homeostasis Is and Is Not**

Homeostasis does not imply that conditions are unchanging or stagnant. Instead, it involves dynamic processes that constantly adjust to maintain a set of optimal conditions. Physiology is inherently about change and adaptation, and homeostasis is a mechanism that ensures internal stability through these adjustments.

## **Key Aspects of Homeostasis**

- Maintains normal conditions or setpoints for various physiological parameters.
- Is a self-regulating process involving coordinated responses to environmental changes.
- Allows organisms to adapt to external challenges while preserving internal stability.

## **Analogy of Homeostasis: The Steam Train**

To understand homeostasis, consider a steam train. The train's smooth operation depends not just on the driver but also on various supporting systems. These include maintaining adequate water levels, sufficient coal supply, proper fire temperature, and functioning mechanical parts. Each system must be checked and maintained to keep the train running efficiently. Similarly in living organisms, multiple systems work together, constantly adjusting to keep internal conditions within optimal ranges.

## **Complexity and Coordination in Physiology**

Just like the steam train requires a team of engineers and systems working in harmony, the physiology of living organisms involves complex, coordinated responses. These responses ensure that despite external changes, internal conditions as temperature, pH, and fluid balance remain within a certain range.

# Regulatory Systems

## Introduction to Regulatory Systems

Regulatory systems are essential mechanisms that maintain homeostasis, ensuring the body's internal environment remains balanced despite external and internal challenges. These systems involve complex feedback and feedforward processes that operate at multiple organizational levels, from cellular to systemic and even higher cognitive functions. Proper regulation allows for normal functioning and adaptation, while failure to maintain this balance can lead to pathology and dysfunction.

- **Adaptation:** shifts from 'set point' but function is maintained
- **Pathology:** sustained upset in 'balance' resulting in dysfunction

## Feedback and Feedforward Systems

Feedback systems are the primary focus, involving a loop where a change in a variable triggers a response to restore it to its set point. Feedforward systems, which will be discussed later with specific examples, anticipate changes to adjust responses proactively. Feedback mechanisms are fundamental in maintaining stability across various physiological processes.

## Components of a Feedback System

A typical feedback system includes several key components:

- **Challenge or Stimulus:** External or internal factors that disturb the variable.
- **Variable:** The physiological parameter that is being regulated.
- **Sensor:** Detects changes in the variable.
- **Integrator or Comparator:** Compares the current value to the set point.
- **Effector:** Executes responses to correct deviations.

## Levels of Regulation in Organisms

Regulatory mechanisms operate at multiple levels:

1. **Cellular level:** Regulation of biochemical pathways within cells.
2. **Organ and tissue level:** Control of organ functions affecting systemic variables.
3. **System level:** Integration of multiple organs and systems to maintain overall balance.
4. **Central nervous system and higher cognitive functions:** Influence behavior and decision-making, impacting regulation indirectly.

External environmental factors can influence all these levels, creating a dynamic and interconnected regulatory network.

## **Example: Glucose Regulation During Eating**

When food is ingested, digestion begins, leading to absorption of nutrients like glucose. This increase in blood glucose acts as a stimulus, triggering pancreatic beta cells to release insulin. Insulin promotes glucose uptake by cells, especially muscle cells, reducing plasma glucose levels back toward the set point.

Digestion and absorption involve feedback mechanisms that regulate the rate of digestion and glucose entry into the bloodstream. The process is complex, involving cellular regulation within muscle cells, including the activity of like glucokinase, which phosphorylates glucose, and the regulation of glucose transporters.

## **Cellular Regulation of Glucose Uptake**

Within muscle cells, glucose uptake is controlled by several factors:

- Presence of insulin, which translocates glucose transporters to the cell membrane.
- Blood flow or perfusion to the tissue, affecting glucose delivery
- Glucose concentration gradient between blood and cells.
- Intracellular regulation, such as phosphorylation by glucokinase, which is itself regulated by glucose-6-phosphate levels.

High levels of glucose-6-phosphate inhibit further phosphorylation, slowing glucose entry and metabolism, exemplifying cellular feedback regulation.

## **Role of the Brain and Behavior in Regulation**

The brain plays a crucial role in regulating food intake and energy balance. Hormonal signals like insulin and sensors in the digestive tract send information to the hypothalamus, which influences appetite and energy expenditure. The limbic system, including reward pathways, also contributes to the pleasurable aspect of eating, affecting behavior and food choices.

This multi-layered regulation involves both physiological signals and behavioral responses, demonstrating the integration of cellular, systemic, and cognitive regulation in maintaining homeostasis.

## **Maintaining Homeostasis: Set Points and Feedback**

Regulatory systems rely on the concept of a set point—a target value for a physiological parameter. The integrator compares the current value to this set point, activating feedback mechanisms when deviations occur. These mechanisms work within an acceptable range, allowing for natural fluctuations but correcting when parameters go outside this range.

For example, blood pressure is maintained within a range through feedback involving the sympathetic and parasympathetic nervous systems. When blood pressure rises above the