IB DP BIOLOGY

Theme C: Interaction and Interdependence

C3.1 Integration of Body Systems

Revision Notes · Standard and Higher Level

Fahad H. Ahmad

+92 323 509 4443 | Megalecture.com

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What the syllabus requires

C3.1 asks you to see the body not as a bag of separate organs but as one coordinated whole. Use this checklist to confirm you can explain each idea and, crucially, apply it to unfamiliar integrated examples in the exam.

Understanding	You should be able to...
Organisms as integrated systems	Explain why the activities of separate organs must be coordinated, and describe emergent properties of the whole organism.
Two coordinating systems	Compare nervous and endocrine (hormonal) coordination in terms of speed, duration, transmission and target specificity.
The nervous system	Outline the roles of the central and peripheral nervous systems and sequence a reflex arc.
The brain as integrator	Describe the brain as a processing centre and the hypothalamus–pituitary axis as the link between the two systems.
The endocrine system	Relate glands, hormones and target cells, and explain negative feedback maintaining a set point.
Integrated examples	Explain the coordination of heart rate, blood glucose and the fight-or-flight response.
(HL) Feedback and rhythms	Analyse feedback loops in detail, the pituitary–hypothalamus axis, epinephrine and melatonin in circadian rhythm.

> **Exam note:** Most of C3.1 is common to SL and HL. HL adds the detailed control of circadian rhythm by melatonin and deeper analysis of feedback and of the pituitary. Points that are HL-only are flagged with "(HL)" below.

1. Organisms as integrated systems

A multicellular animal is a hierarchy: cells build tissues, tissues build organs, and organs work together in organ systems. None of these parts functions in isolation. When you sprint for a bus, the muscular, skeletal, respiratory, circulatory, nervous and endocrine systems all adjust together in the same moment. If each organ acted independently the organism would fail; survival depends on **integration** — the coordination of many parts toward the needs of the whole.

Why coordination is essential

- Resources are shared. Blood delivers a limited supply of oxygen and glucose, so its distribution must be prioritised to whichever organs are most active.
- Conditions must be kept within narrow limits. Cells only function over a restricted range of temperature, pH and solute concentration, so many organs must cooperate to hold the internal environment steady (homeostasis).
- Responses must be timed and matched. A change detected in one place often requires action somewhere else — a fall in blood glucose sensed in the pancreas triggers glucose release by the liver.

Emergent properties

An **emergent property** is a characteristic of the whole system that none of its individual parts possesses on its own; it arises from the interactions between the parts. A single heart-muscle cell can contract, but only the integrated cardiovascular system produces a regulated blood pressure. No single neuron is conscious, yet the interacting network of billions produces memory, emotion and thought. Emergent properties explain why studying parts in isolation (reductionism) can never fully describe a living organism.

> **Key idea:** Integration means the outputs of one system become the inputs of another. The nervous and endocrine systems are the two great communication networks that make this coordination possible.

2. Nervous versus hormonal coordination

Animals coordinate their organs using two complementary systems that carry information in different ways. The **nervous system** sends fast electrical impulses along dedicated neurons; the **endocrine system** releases chemical hormones that travel more slowly in the blood. Comparing them is a favourite exam question, so learn the contrasts precisely.

Feature	Nervous coordination	Hormonal (endocrine) coordination
Signal	Electrical impulse (action potential), with chemical transmitters at synapses	Chemical hormone molecules
Transmission	Along neurons; a fixed wired pathway	Dissolved in blood plasma; carried throughout the body
Speed of action	Very fast (milliseconds)	Slower (seconds to hours, even days)
Duration of effect	Brief — stops when impulses stop	Longer lasting; persists while the hormone remains in the blood
Target specificity	Precise: a neuron signals specific cells at its endings	Widespread, but only cells with the matching receptor respond
Typical response	Rapid, localised (muscle contraction, gland secretion)	Slower, often whole-body or long-term (growth, metabolism)

The two systems are not rivals; they overlap and cooperate. The same stress can trigger both an instant nervous response and a slower, sustained hormonal one, and the hypothalamus physically links them (Section 4).

> **Exam tip:** If a question stresses a rapid, short-lived, precisely targeted response, argue for nervous control. If it stresses a slow, sustained or widespread change, argue for hormonal control — then note where both act together.

3. The nervous system and the reflex arc

The nervous system is divided into two parts. The **central nervous system (CNS)** is the brain and spinal cord; it processes information and decides on responses. The **peripheral nervous system (PNS)** is all the nerves that carry signals to and from the CNS. **Sensory neurons** bring information in from receptors; **motor neurons** carry instructions out to effectors (muscles and glands); **relay (interneurons)** connect them within the CNS.

The reflex arc

A **reflex** is a rapid, automatic, involuntary response to a stimulus that protects the body before the conscious brain is even aware. The pathway followed is the **reflex arc**, the simplest example of nervous integration — input is converted straight into output through the spinal cord.

stimulus → receptor → sensory neuron → relay neuron → motor neuron → effector → response

Step	What happens (withdrawal from a hot object)
Stimulus	A harmful change is detected — heat from the object.
Receptor	Temperature/pain receptors in the skin convert the stimulus into a nerve impulse.
Sensory neuron	Carries the impulse from the receptor into the spinal cord.
Relay neuron	Within the spinal cord, passes the impulse to the motor neuron (and up to the brain).
Motor neuron	Carries the impulse out from the spinal cord to the effector.
Effector	A biceps (flexor) muscle receives the signal.
Response	The muscle contracts and the hand is pulled away.

Because the signal is processed in the spinal cord and acts before it reaches the conscious brain, the response is extremely fast. Impulses are still sent up to the brain, so you feel the pain a moment *after* you have already moved.

> **Common misconception:** A reflex does not "skip the brain entirely." The reflex arc bypasses conscious decision-making in the brain, giving speed, but the brain is still informed — which is why you feel the pain just after reacting.

4. The brain and the hypothalamus–pituitary link

The brain is the body's chief integration centre. It receives sensory input from receptors across the body, processes and compares it with stored information, and coordinates the outgoing motor and hormonal instructions. Different regions specialise: broadly, the cerebral hemispheres handle conscious thought and voluntary movement, the cerebellum fine-tunes balance and coordination, and the brain stem controls automatic vital functions such as breathing and heart rate.

The hypothalamus: the bridge between two systems

The **hypothalamus** is a small region at the base of the brain that is the single most important link between the nervous and endocrine systems. It receives nerve signals about the internal state of the body (temperature, blood solute concentration, and so on) and responds by controlling the **pituitary gland**, which sits just below it. In this way a nervous input is converted into a hormonal output.

- The hypothalamus makes hormones (for example ADH) that are released from the posterior pituitary.
- The hypothalamus makes releasing hormones that travel a short distance to the anterior pituitary and control its secretions.

The pituitary is often called the "master gland" because the hormones it releases (such as those controlling the thyroid, adrenal cortex, growth and reproduction) in turn control many other endocrine glands. The hypothalamus–pituitary axis therefore sits at the top of the endocrine hierarchy while remaining under direct nervous control.

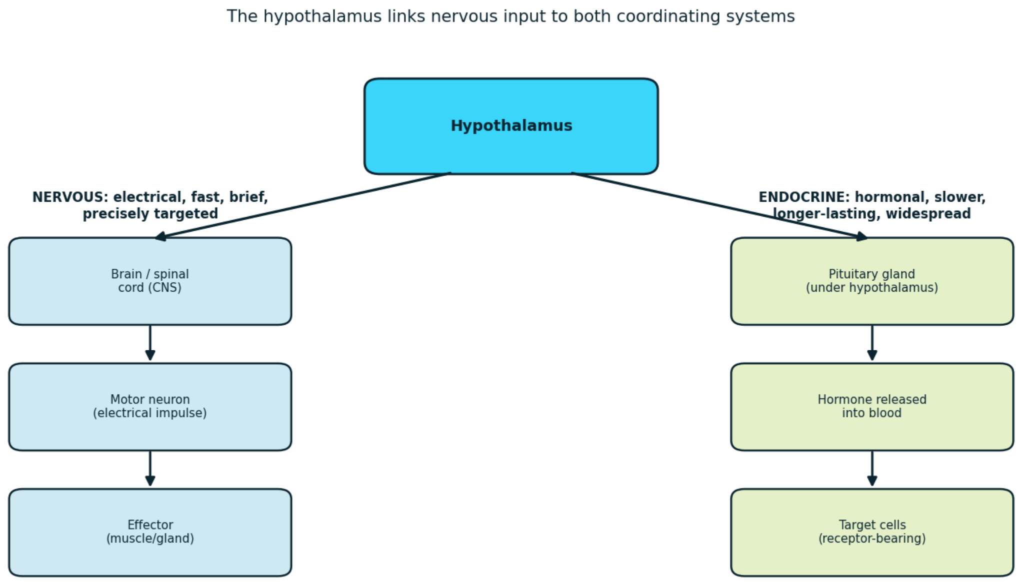

Figure 2. The hypothalamus is the physical link between the two coordinating systems: it drives a fast, brief, precisely targeted nervous pathway and a slower, longer-lasting, widespread endocrine pathway from the same nervous input.

> **Key idea:** The hypothalamus is where the wiring meets the plumbing — electrical nerve signals in, hormonal signals out. It is the physical proof that the nervous and endocrine systems are integrated, not separate.

5. The endocrine system and negative feedback

The **endocrine system** is a collection of ductless **glands** that secrete **hormones** directly into the blood. A hormone is a chemical messenger that travels in the blood and alters the activity of specific **target cells**. Although a hormone reaches almost every cell, only cells carrying the matching **receptor** can bind it and respond — this is what gives hormones their specificity despite their wide distribution.

Gland	Example hormone	Main effect
Pancreas (islets)	Insulin / glucagon	Lower / raise blood glucose concentration
Adrenal medulla	Adrenaline (epinephrine)	Prepares body for fight or flight
Thyroid	Thyroxine	Raises metabolic rate
Pituitary	Many (e.g. ADH, growth hormone)	Controls other glands, water balance, growth
Pineal	Melatonin	Signals darkness; regulates the sleep–wake cycle (HL)

Negative feedback and set points

Most hormones act within **negative feedback loops**, the central mechanism of homeostasis. A regulated variable (such as body temperature or blood glucose) has a normal value called the **set point**. A change away from the set point is detected and triggers a response that opposes the change and restores the set point. Because the response counteracts the original deviation, the variable is held stable around the set point rather than drifting.

A control loop always contains the same components:

- a **receptor / sensor** that detects the change,
- a **control (integrating) centre** that compares the value with the set point, often the hypothalamus or an endocrine gland,
- an **effector** that carries out the corrective response,
- and negative feedback, so that once the set point is restored the correction is switched off.

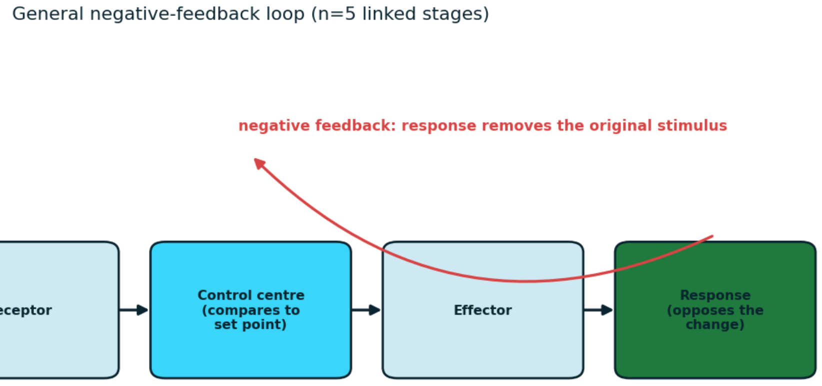

Figure 1. A negative-feedback loop always has the same five linked stages: stimulus → receptor → control centre → effector → response. The response feeds back to remove the original stimulus, restoring the set point.

> **Contrast:** In rare **positive** feedback the response amplifies the original change (as in oxytocin during childbirth). This is the exception — for homeostasis, think negative feedback restoring a set point.

6. Integrated examples of coordination

The examiner rewards you for showing how several systems act together in one response. Three classic examples follow.

6.1 Control of heart rate

The heart beats on its own because it is myogenic — the sinoatrial node (SAN) sets a basic rhythm without nervous input. But the rate must match the body's demand, so it is adjusted by both systems. The **medulla** of the brain stem monitors blood pressure and carbon dioxide/pH, then sends nervous signals to the SAN: sympathetic nerves speed the heart up, parasympathetic (vagus) nerves slow it down. At the same time the hormone **adrenaline** released during exercise or stress raises the rate for longer. Here fast nervous control and slower hormonal control combine on a single effector.

6.2 Control of blood glucose

Blood glucose concentration is held near a set point by two antagonistic hormones from the pancreas, a clear negative feedback system.

If blood glucose...	Detected by / hormone released	Effect on target cells (mainly liver)
rises (after a meal)	Pancreas releases **insulin**	Liver and muscle take up glucose and store it as glycogen; glucose falls back to the set point.
falls (during fasting/exercise)	Pancreas releases **glucagon**	Liver breaks glycogen down to glucose and releases it; glucose rises back to the set point.

Each correction removes the stimulus that caused it — textbook negative feedback. Failure of this loop (for example insufficient insulin) is diabetes mellitus.

6.3 The fight-or-flight response

A frightening or threatening stimulus is a striking example of full integration. The brain (via the hypothalamus) stimulates the **adrenal medulla** to release **adrenaline (epinephrine)** into the blood. Adrenaline acts on many target organs at once to prepare the body for vigorous action:

- heart rate and breathing rate increase, delivering more oxygen and glucose to muscles;
- the liver breaks down glycogen, raising blood glucose for energy;
- blood is redirected from the gut and skin to the skeletal muscles;
- the pupils dilate and the airways widen.

Nervous signals produce the instant reaction while adrenaline sustains it — the two coordinating systems working on the same goal.

> **Movement coordination:** Ordinary movement is also integrated: the brain plans it, motor neurons trigger contraction, antagonistic muscle pairs move the skeleton, and smooth-muscle **peristalsis** — waves of contraction coordinated by the nervous system — pushes food along the gut.

7. Receptors, processing and effectors

Every coordinated response, nervous or hormonal, follows the same general model. Sensory **input** is gathered, the CNS **processes** it, and a motor **output** is sent to effectors. Holding this three-part model in mind lets you analyse any unfamiliar example in the exam.

input (receptors) → processing (CNS / control centre) → output (effectors)

Component	Role	Examples
Receptor	Detects a stimulus and converts it into a nervous impulse (transduction)	Photoreceptors (light), chemoreceptors (CO_2, glucose), thermoreceptors (heat), mechanoreceptors (pressure)
Processing centre	Integrates information and decides the response	Spinal cord (reflexes), brain, hypothalamus, endocrine glands
Effector	Carries out the response	Muscles (contract) and glands (secrete)

Receptors are the body's windows on both the external world and the internal environment; effectors are the only means by which the body acts on the outcome. Everything in between is integration.

8. (HL) Feedback, the pituitary axis and circadian rhythm

(HL) At higher level you must analyse how feedback holds systems stable over time and how several controls interact. A negative feedback loop is inherently **self-limiting and self-correcting**: the size of the corrective response is proportional to the size of the deviation, so a large disturbance triggers a large correction and a small one a small correction. The variable therefore oscillates gently around the set point rather than being held at an exact fixed value — dynamic equilibrium, not rigid constancy.

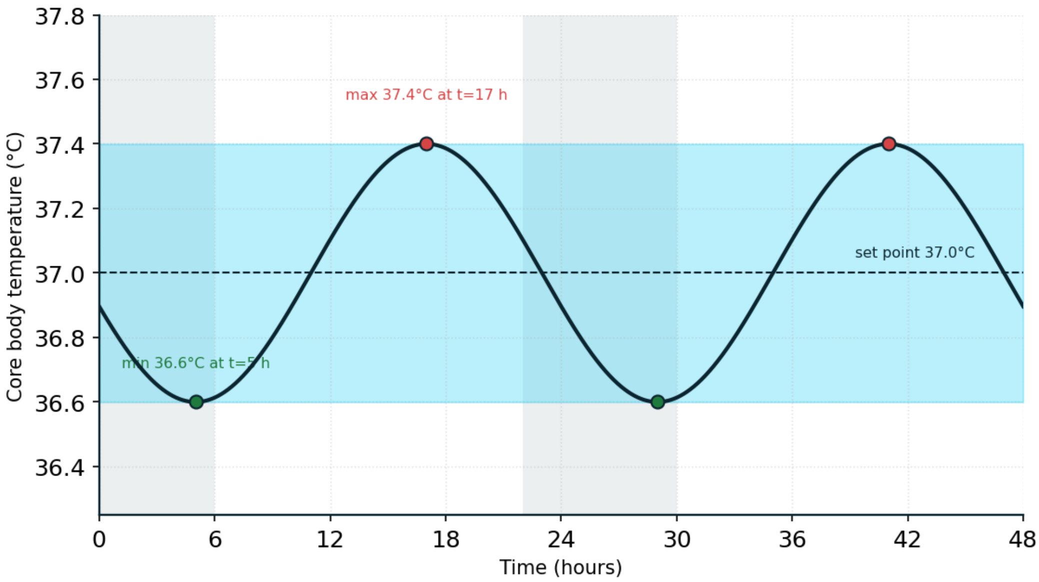

Figure 3. (HL) A controlled variable, here core body temperature, oscillates around its set point (37.0°C) rather than staying fixed. The shaded band spans set point ± 0.4°C; grey bands mark night. The computed peak and trough are 12 h apart, showing dynamic equilibrium produced by continuous negative feedback.

The hypothalamus–pituitary axis in detail

(HL) Many hormonal systems are controlled by a cascade with feedback at several levels. The hypothalamus releases a releasing hormone; this stimulates the anterior pituitary to release a stimulating hormone; this stimulates a target gland to release its own hormone. The final hormone then feeds back to inhibit both the hypothalamus and the pituitary, keeping its own level steady. This three-tier negative feedback is the general pattern for thyroid, adrenal-cortex and reproductive hormones.

hypothalamus → anterior pituitary → target gland → hormone → (negative feedback back to the top)

Epinephrine and integrated stress control

(HL) The rapid pathway uses **epinephrine (adrenaline)** from the adrenal medulla under direct nervous stimulation, giving the near-instant fight-or-flight response. A slower parallel pathway runs through the hypothalamus–pituitary axis to the adrenal cortex, sustaining the response for longer. Two pathways — one fast and nervous, one slow and hormonal — illustrate integration for a single purpose.

Melatonin and circadian rhythm

(HL) A **circadian rhythm** is a biological cycle of roughly 24 hours. In humans it is coordinated by the hormone **melatonin**, secreted by the **pineal gland**. Light detected by the eyes is signalled to the hypothalamus, which controls the pineal gland:

- In darkness, melatonin secretion rises, promoting sleep and lowering body temperature and alertness.
- In daylight, melatonin secretion is suppressed, promoting wakefulness.

(HL) Melatonin thus sets the sleep–wake cycle to the day–night cycle, and its disruption helps explain jet lag when travel suddenly shifts the timing of light. This is another case of nervous input (light) driving a hormonal output through the hypothalamus.

> **(HL) Exam tip:** For any feedback question, name the stimulus, the receptor, the control centre, the effector and the corrective response — then state explicitly that the response opposes the change and restores the set point.

9. Worked examples and skills

Worked example 1 — choose the coordinating system

A person is startled and their heart begins to pound and keeps pounding for several minutes. Explain which coordinating systems are involved and why.

The initial jump is too fast to be hormonal, so it is **nervous**: sympathetic nerves from the medulla speed the SAN almost instantly. The pounding that *persists* for minutes is **hormonal**: adrenaline released into the blood keeps the heart rate high after the nerve signals fade.

Conclusion: both systems act on the same effector — nervous control for speed, hormonal control for duration.

Worked example 2 — sequence a reflex arc

You tread on a sharp stone and lift your foot before you feel pain. Put the events in order and name the neurons.

Stimulus (sharp pressure) → receptor in skin → sensory neuron → relay neuron in spinal cord → motor neuron → effector (leg muscle) → response (foot lifted).

The pain is felt *after* the movement because impulses reach the conscious brain only after the spinal reflex has already acted — evidence that the reflex bypasses conscious processing to gain speed.

Worked example 3 — explain a negative feedback loop

Describe how blood glucose is returned to normal after a sugary meal.

Stimulus: blood glucose rises above the set point. Receptor/control centre: cells in the pancreas detect the rise. Effector response: the pancreas secretes **insulin**, which makes liver and muscle cells take up glucose and store it as glycogen.

As glucose falls back to the set point, the stimulus is removed and insulin secretion decreases. The response **opposed** the original change — negative feedback.

Worked example 4 — interpret an integrated response

During a race, a sprinter's blood glucose stays adequate, breathing deepens and the heart races. Identify the coordination at work.

Nervous: the medulla raises heart and breathing rate through sympathetic nerves. Hormonal: adrenaline sustains these effects and, with glucagon, stimulates the liver to release glucose so the concentration holds near its set point.

Several systems — nervous, endocrine, circulatory, respiratory and muscular — are integrated toward one outcome: sustained vigorous activity. This is an emergent, whole-organism response.

Common pitfalls

- Writing that a reflex "does not involve the brain at all." It bypasses *conscious* processing; impulses still travel to the brain, which is why pain is felt.
- Saying negative feedback "stops" a variable changing. It *reverses* a deviation and restores the set point, allowing small oscillations around it.
- Claiming hormones are simply "slower and worse" than nerves. They are slower but longer-lasting and can act on the whole body at once — different jobs, not worse.
- Forgetting that a hormone reaches all cells but only target cells with the correct receptor respond.
- Treating the nervous and endocrine systems as separate. The hypothalamus–pituitary axis links them directly.

Quick reference

Idea	One-line summary
Integration	Organs coordinated so the whole organism meets its needs; gives emergent properties.
Nervous control	Fast, brief, precise; electrical impulses along neurons via the CNS.
Hormonal control	Slower, longer, widespread; hormones in blood act on receptor-bearing target cells.
Reflex arc	stimulus → receptor → sensory → relay → motor → effector → response.
Hypothalamus–pituitary	Bridge between nervous and endocrine systems; nerve input, hormone output.
Negative feedback	Change detected → response opposes it → set point restored.

Idea	One-line summary
Blood glucose	Insulin lowers it, glucagon raises it (antagonistic, pancreatic).
Fight or flight	Adrenaline prepares the body; nervous speed plus hormonal duration.
(HL) Melatonin	From the pineal gland; rises in darkness to set the circadian sleep–wake rhythm.

10. Test yourself

Attempt these without notes, then check against the full answers below.

1. Define an emergent property and give one example from the human body.

2. State three differences between nervous and hormonal coordination.

3. List, in order, the components of a reflex arc.

4. Explain how the hypothalamus links the nervous and endocrine systems.

5. Describe how negative feedback returns a raised blood glucose level to its set point.

6. Explain how heart rate is controlled by both nervous and hormonal means.

7. Outline three effects of adrenaline in the fight-or-flight response and say why so many organs respond at once.

8. (HL) Explain how melatonin coordinates the circadian rhythm.

Answers

1. An emergent property is a feature of a whole system that none of its parts has alone, arising from their interactions — for example consciousness emerging from the interacting neurons of the brain, or a regulated blood pressure from the whole cardiovascular system.

2. Nervous signals are electrical impulses along neurons; hormonal signals are chemicals in the blood. Nervous responses are fast and brief; hormonal responses are slower and longer-lasting. Nervous signals are precisely targeted along wired pathways; hormones spread through the body but act only on receptor-bearing target cells. (Any three.)

3. Stimulus → receptor → sensory neuron → relay neuron → motor neuron → effector → response.

4. The hypothalamus receives nervous signals about the body's internal state and responds by controlling the pituitary gland — making hormones released from the posterior pituitary and releasing hormones that regulate the anterior pituitary. It thereby converts a nervous input into a hormonal output, linking the two systems.

5. A rise above the set point is detected by the pancreas, which secretes insulin. Insulin makes liver and muscle cells take up glucose and store it as glycogen, so blood glucose falls. As the set point is restored the stimulus is removed and insulin secretion decreases — the response opposed the change (negative feedback).

6. The SAN sets a myogenic rhythm. The medulla adjusts it through nerves — sympathetic nerves speed it up, the vagus (parasympathetic) slows it down — for rapid change. The hormone adrenaline raises the rate for longer during stress or exercise. Fast nervous control and slower hormonal control act on the same effector.

7. Adrenaline raises heart and breathing rate, stimulates the liver to release glucose, and redirects blood to skeletal muscles (also dilating pupils and airways). So many organs respond at once because adrenaline is carried in the blood to every organ, and all cells bearing its receptor react — giving a coordinated whole-body response.

8. (HL) Light is detected by the eyes and signalled to the hypothalamus, which controls the pineal gland. In darkness the pineal secretes more melatonin, promoting sleep; in daylight melatonin is suppressed, promoting wakefulness. This entrains the roughly 24-hour sleep–wake cycle to the day–night cycle; sudden shifts in light timing cause jet lag.