

Physiological psychology

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1. Neuron, synapse, neurotransmitters and the nervous system
2. The brain, hemispheric specialisation and the endocrine system

1 Neuron, synapse, neurotransmitters and the nervous system

The neuron is the basic information-processing unit of the nervous system; it fires an all-or-none electrical impulse down its axon and passes the message across a synapse with chemical neurotransmitters; neurons form the central (brain, spinal cord) and peripheral (somatic, autonomic) nervous systems, and the autonomic system has a sympathetic (fight or flight) and a parasympathetic (rest and digest) branch.

Core facts

- **Neuron** = nerve cell = the **basic structural and functional (information-processing) unit** of the nervous system. The human brain has about **86 billion** neurons.
- **Parts of a neuron:** **dendrites** (receive messages), **cell body / soma** (holds the nucleus, keeps the cell alive, adds up incoming signals), **axon** (carries the impulse away from the cell body), **axon terminals / terminal buttons** (release neurotransmitters).
- **Myelin sheath:** fatty white coat on many axons; speeds the impulse; made by **Schwann cells** (PNS) and **oligodendrocytes** (CNS). Gaps in it = **nodes of Ranvier**.
- **Direction of a message:** dendrite → cell body → axon → axon terminal → synapse.
- **Kinds by function:** **sensory (afferent)** neurons carry messages **to** the CNS; **motor (efferent)** neurons carry commands **from** the CNS to muscles and glands; **interneurons (association neurons)** connect neurons inside the CNS and are the most numerous.
- **Kinds by shape:** unipolar, bipolar (e.g. in the retina), multipolar (most motor neurons and interneurons).
- **Glial cells (glia):** support, nourish, insulate and clean up neurons; textbooks say they outnumber neurons (recent counts put them at roughly equal numbers in the human brain).
- **Resting potential:** about **-70 mV** (inside negative). **Action potential (nerve impulse):** a brief reversal to about **+30 to +40 mV** when the neuron fires.
- **All-or-none law:** a neuron either fires fully or not at all; a stronger stimulus raises the **rate** of firing, not the size of each impulse.
- **Refractory period:** a short time after firing when the neuron cannot fire again (absolute) or needs a stronger stimulus (relative).
- **Synapse:** the junction between two neurons; term coined by **Charles Sherrington (1897)**. The tiny gap = **synaptic cleft**.
- **First neurotransmitter identified:** **acetylcholine**, by **Otto Loewi (1921)**, in frog-heart experiments.
- **CNS = brain + spinal cord.** **PNS = all nerves outside them:** **12 pairs of cranial nerves** and **31 pairs of spinal nerves**.
- **PNS divisions:** **somatic** (voluntary; skeletal muscles and senses) and **autonomic** (involuntary; heart, glands, gut, blood vessels).

- **Autonomic divisions: sympathetic** = arousal, emergency, **fight or flight** (Walter Cannon); **parasympathetic** = calming, **conserves energy, rest and digest**.

Neurotransmitter	Main role in behaviour	When it goes wrong
Acetylcholine (ACh)	muscle movement, attention, learning and memory	low in Alzheimer's disease
Dopamine	voluntary movement, reward, pleasure, motivation	low → Parkinson's disease ; excess linked to schizophrenia
Serotonin	mood, sleep, appetite, impulse control	low → depression
Norepinephrine (noradrenaline)	alertness, arousal, vigilance	low → depressed mood
GABA	main inhibitory transmitter; calms neurons	low → anxiety , seizures
Glutamate	main excitatory transmitter; learning and memory	excess → overstimulation, seizures
Endorphins	natural pain relief and pleasure	released in pain, stress, hard exercise

Explained

1. How a neuron is built and what each part does.

- **Dendrites** are short, branched fibres that pick up signals from other neurons or from sense receptors. More branches mean more connections.
- The **soma** adds up all the "fire" and "don't fire" signals it receives. If the total crosses the **threshold** (about -55 mV), the neuron fires.
- The **axon** is a single long fibre (from a fraction of a millimetre to about a metre, as in the nerves to the toes). Its start, the **axon hillock**, is where the impulse begins.
- **Myelin** insulates the axon. The impulse jumps from one node of Ranvier to the next (**saltatory conduction**), so myelinated axons conduct much faster (up to about 120 m/s) than bare ones. Loss of myelin in the CNS causes **multiple sclerosis**.
- **Terminal buttons** hold small sacs, the **synaptic vesicles**, filled with neurotransmitter.
- Myelinated axons look white (**white matter**); cell bodies look grey (**grey matter**).

2. The nerve impulse, step by step.

- At rest the inside of the neuron is negative compared with the outside: there are more sodium ions (Na^+) outside and more potassium ions (K^+) inside. The **sodium-potassium pump** keeps it so. The membrane is **polarised**.
- When the threshold is reached, sodium channels open and Na^+ rushes in: **depolarisation**; the inside turns positive (the **action potential**).

- Potassium channels then open and K^+ flows out: **repolarisation**. A brief overshoot below -70 mV is **hyperpolarisation**.
- The action potential travels down the axon like a falling row of dominoes. It is **electrical within the neuron** and **chemical between neurons**.
- Because of the all-or-none law, the brain codes stimulus **intensity** by the **frequency** of impulses and by **how many** neurons fire.

3. What happens at the synapse.

- The impulse reaches the terminal → vesicles release neurotransmitter into the cleft → the molecules bind to **receptor sites** on the next neuron, like a key in a lock.
- The effect is either **excitatory** (makes the next neuron more likely to fire) or **inhibitory** (less likely).
- The transmitter is then cleared by **reuptake** (pumped back into the sending neuron) or broken down by **enzymes** (e.g. acetylcholinesterase breaks down ACh).
- **Drugs act at the synapse.** An **agonist** mimics or boosts a transmitter (morphine mimics endorphins; nicotine mimics ACh). An **antagonist** blocks it (curare blocks ACh receptors and causes paralysis). Many antidepressants (SSRIs) block the reuptake of serotonin.
- Most synapses are **chemical**; a few are **electrical** (direct contact, very fast).

4. Neurotransmitters and behaviour (more detail).

- **Acetylcholine:** carries the message from motor neurons to skeletal muscles; in the brain it helps memory (the hippocampus). The ACh-producing neurons decline in Alzheimer's disease.
- **Dopamine:** the brain's reward signal (food, praise, addictive drugs). The dopamine neurons of the **substantia nigra** die in Parkinson's disease (tremor, rigid slow movement; treated with L-dopa). Drugs that block dopamine reduce hallucinations in schizophrenia.
- **Serotonin:** steadies mood, sleep and appetite; low levels go with depression, aggression and impulsive behaviour.
- **Norepinephrine:** works with the sympathetic system for alertness and emergency arousal; also released as a hormone (noradrenaline) by the adrenal medulla.
- **GABA:** brakes neural activity; anti-anxiety drugs (benzodiazepines) and alcohol enhance GABA, which is why they calm and sedate.
- **Glutamate:** the accelerator; vital for forming memories (long-term potentiation).
- **Endorphins** ("endogenous morphine"): the body's own opioids; reduce pain and give the "runner's high".

5. Organisation of the nervous system.

Division	Made of	Job
Central (CNS)	brain, spinal cord	processes information, decides, stores
Peripheral: somatic	sensory and motor nerves to skin, muscles, joints	voluntary movement, sensation
Peripheral: autonomic	nerves to heart, lungs, gut, glands	automatic body functions, emotion

Division	Made of	Job
Autonomic: sympathetic / parasympathetic	two opposing branches	arouse / calm the body

- **Spinal cord:** carries messages between the brain and the body (ascending sensory tracts, descending motor tracts) and controls **reflexes**.
- **Reflex arc:** receptor → sensory neuron → interneuron in the spinal cord → motor neuron → muscle. The response (e.g. pulling the hand from a flame, the **knee-jerk**) happens before the brain is aware; the knee-jerk has no interneuron (monosynaptic).
- The **hypothalamus** is the chief brain centre that controls the autonomic nervous system.

6. Sympathetic vs parasympathetic.

Body part	Sympathetic (fight or flight)	Parasympathetic (rest and digest)
Pupils	dilate	constrict
Heart rate, blood pressure	increase	decrease
Breathing, bronchi	faster, bronchi widen	slower, bronchi narrow
Salivation	decreases (dry mouth)	increases
Digestion	slows down	speeds up
Blood sugar	rises (liver releases glucose)	falls; energy is stored
Sweating	increases	no direct effect
Adrenal medulla	stimulated (adrenaline)	not stimulated
Bladder	relaxes (holds urine)	contracts (empties)
Overall	spends energy	conserves and restores energy

- Sympathetic nerves leave from the **thoracic and lumbar** spinal cord (**thoracolumbar**); parasympathetic from the **brainstem and sacral** cord (**craniosacral**); the **vagus nerve** is the main parasympathetic nerve.
- The two usually **work in opposition** (one speeds up an organ, the other slows it), which keeps the body in balance (**homeostasis**). In strong emotion such as fear or anger the sympathetic branch dominates; after the danger passes the parasympathetic branch restores calm.

Common traps

✗ "Dendrites carry the impulse away from the cell body." ✓ Dendrites **receive**; the **axon** carries the impulse away.

✗ "A stronger stimulus produces a bigger impulse." ✓ All-or-none: the impulse is the same size; stronger stimuli raise the **firing rate**.

✗ "Sensory neurons are efferent." ✓ Sensory = **afferent** (to the CNS); motor = **efferent** (from the CNS).

✗ "The synapse was named by Loewi." ✓ **Sherrington** (1897) named the synapse; **Loewi** (1921) found the first transmitter, **acetylcholine**.

✗ "Parkinson's disease is due to too little acetylcholine." ✓ **Dopamine** loss → Parkinson's; ACh loss → **Alzheimer's**.

✗ "GABA is excitatory." ✓ GABA is the main **inhibitory** transmitter; **glutamate** is the main excitatory one.

✗ "The CNS includes the cranial and spinal nerves." ✓ CNS = **brain and spinal cord** only; the nerves belong to the **PNS**.

✗ "The sympathetic system conserves energy." ✓ The **parasympathetic** conserves energy; the sympathetic **spends** it (raises heart rate and blood sugar).

✗ "Sympathetic activity increases digestion and salivation." ✓ It **slows** digestion and **reduces** saliva; the parasympathetic increases them.

✗ "The autonomic system controls voluntary movement." ✓ Voluntary movement = **somatic** system.

Quick revision

- Neuron = basic information-processing unit; dendrite → soma → axon → terminal.
- Myelin speeds conduction; nodes of Ranvier; saltatory conduction.
- Sensory = afferent; motor = efferent; interneurons most numerous.
- Resting -70 mV; action potential: Na⁺ in, then K⁺ out; all-or-none.
- Synapse: Sherrington 1897; first transmitter ACh: Loewi 1921.
- ACh: memory, muscles (Alzheimer's); dopamine: movement, reward (Parkinson's, schizophrenia).
- Serotonin: mood, sleep (depression); GABA inhibitory; glutamate excitatory; endorphins pain relief.
- CNS = brain + spinal cord; PNS = 12 cranial + 31 spinal nerve pairs.
- PNS: somatic (voluntary) and autonomic (involuntary).
- Sympathetic: fight or flight, spends energy; parasympathetic: rest and digest, conserves energy.

2 The brain, hemispheric specialisation and the endocrine system

The brain has three parts, hindbrain (life support, balance), midbrain (reflexes, relay) and forebrain (thalamus, hypothalamus, limbic system, cerebral cortex); its two hemispheres do partly different jobs (left: language and analysis; right: space, faces, holistic processing) joined by the corpus callosum; and the endocrine glands shape behaviour slowly through hormones carried in the blood.

Core facts

- **Three main divisions: hindbrain** (medulla, pons, cerebellum), **midbrain**, **forebrain** (thalamus, hypothalamus, limbic system, cerebrum). **Brainstem** = medulla + pons + midbrain.
- **Medulla oblongata**: breathing, heart rate, blood pressure, swallowing; the **vital centre**.
- **Pons** ("bridge"): links the cerebellum and cerebrum; sleep, dreaming, breathing rhythm.
- **Cerebellum** ("little brain"): **balance, posture, coordination** of movement, motor skills.
- **Reticular formation / reticular activating system (RAS)**: network through the brainstem; **arousal, attention, sleep-wake**.
- **Midbrain**: visual and auditory reflexes (turning towards a flash or a sound); **substantia nigra** makes dopamine.
- **Thalamus**: **relay station** for all senses **except smell**.
- **Hypothalamus**: hunger, thirst, body temperature, sex drive, emotion; controls the **autonomic nervous system** and the **pituitary**.
- **Limbic system**: emotion, motivation, memory. **Hippocampus** = forming new long-term memories; **amygdala** = fear and aggression.
- **Cerebral cortex**: thin, folded outer layer (grey matter) of the cerebrum; higher mental processes. Two **hemispheres** linked by the **corpus callosum**.
- **Four lobes: frontal** (planning, reasoning, personality, movement; Broca's area), **parietal** (touch, pain, temperature, body position, space), **temporal** (hearing, language comprehension; Wernicke's area), **occipital** (vision).
- **Broca's area** (left frontal) → speech **production**; **Wernicke's area** (left temporal) → speech **comprehension**.
- **Contralateral control**: each hemisphere controls and senses the **opposite** side of the body.
- **Hemispheric specialisation (lateralisation)**: the two hemispheres differ in the tasks they handle best.
- **Split-brain studies: Roger Sperry** and **Michael Gazzaniga** (1960s), on patients whose corpus callosum was cut to control epilepsy; Sperry won the **Nobel Prize (1981)**.
- **Endocrine glands** = **ductless** glands that pour **hormones** straight into the **blood**.
- **Pituitary** = **master gland** (controlled by the hypothalamus).

Gland	Hormone	Effect on body and behaviour
Pituitary	growth hormone, TSH, ACTH, FSH/LH, prolactin, oxytocin, ADH	growth; directs other glands; milk; bonding
Thyroid	thyroxine	metabolism , energy, activity level
Adrenal medulla	adrenaline (epinephrine), noradrenaline	emergency , fight or flight
Adrenal cortex	cortisol , aldosterone	stress, blood sugar, salt balance
Pancreas (islets of Langerhans)	insulin , glucagon	blood sugar level
Pineal	melatonin	sleep–wake (circadian) rhythm
Gonads (testes / ovaries)	testosterone / estrogen, progesterone	sex characteristics, sex drive
Parathyroid	parathormone	calcium level, nerve excitability
Thymus	thymosin	immunity (T-cells), active in childhood

Explained

1. Hindbrain and midbrain: the old brain.

- These parts are shared with lower animals and keep us alive without thought. Damage to the medulla can stop breathing; this is why a blow to the base of the skull is dangerous.
- The **cerebellum** stores skills that become automatic (cycling, typing). Alcohol impairs it early, causing the unsteady walk and slurred movements that police roadside tests look for.
- The **RAS** filters incoming stimuli and keeps the cortex awake; a sleeping parent wakes to the baby's cry but not to traffic. Damage to it can cause coma.

2. Forebrain structures below the cortex.

- **Thalamus**: sorts sensory messages (vision, hearing, taste, touch) and sends them to the right area of the cortex. Smell goes directly to the olfactory areas.
- **Hypothalamus**: small (about the size of an almond; the pituitary below it is pea-sized) but powerful. It keeps **homeostasis**: it starts eating, drinking and shivering or sweating as needed, and it is a centre for **emotional and sexual behaviour** and aggression. It links the nervous and endocrine systems by controlling the pituitary.
- **Limbic system** (a ring of structures around the brainstem; Broca named the "limbic lobe" in 1878, Papez described an emotion circuit in 1937, and MacLean named the "limbic system" in 1952): includes the **hippocampus**, **amygdala**, **cingulate gyrus**, and is linked with the hypothalamus.
 - Hippocampus damage (the famous patient H.M., 1953) leaves old memories but prevents new long-term ones (anterograde amnesia).
 - Amygdala damage makes animals tame and fearless; stimulation can trigger rage or fear.

3. The cerebral cortex and its lobes.

- About 2–4 mm thick, but folded into ridges (**gyri**) and grooves (**sulci**) so that a large area fits inside the skull. The cerebrum (cortex plus the white matter under it) makes up about 80% of the brain's weight.
- Landmarks: the **central sulcus** (fissure of Rolando) separates the frontal and parietal lobes; the **lateral sulcus** (Sylvian fissure) sets off the temporal lobe.

Lobe	Key areas	Functions
Frontal	motor cortex (in front of the central sulcus), prefrontal cortex, Broca's area	planning, decisions, judgement, personality, voluntary movement, speech production
Parietal	somatosensory cortex (behind the central sulcus)	touch, pressure, pain, temperature, body position, spatial attention
Temporal	auditory cortex, Wernicke's area	hearing, understanding language, memory (with the hippocampus)
Occipital	visual cortex	seeing, recognising shapes and colours

- The motor and sensory strips are laid out like an upside-down map of the body (the "homunculus"); hands, lips and tongue get the largest areas because they need the finest control and sensitivity.
- Association areas** (most of the cortex, especially the prefrontal) combine information for thinking, planning and language.
- Phineas Gage (1848)**: an iron rod damaged his frontal lobe; he survived but became impulsive and irresponsible, showing the frontal lobe's role in personality and self-control.
- Aphasias**: damage to Broca's area → slow, effortful speech with good comprehension (expressive aphasia). Damage to Wernicke's area → fluent but meaningless speech with poor comprehension (receptive aphasia).

4. Hemispheric specialisation.

Left hemisphere (most people)	Right hemisphere
language: speaking, reading, writing, grammar	spatial relations, maps, drawing, puzzles
logical, analytical, step-by-step (sequential) thinking	holistic, whole-picture (parallel) processing
arithmetic calculation, details	face recognition, music, art, imagination
controls the right side of the body	recognising and expressing emotion , tone of voice; controls the left side

- Lateralisation** = the differing roles of the two sides of the brain in a task. It is **relative**, not absolute: both hemispheres take part in almost every task, sharing information through the corpus callosum (about 200 million fibres).
- Language** is in the left hemisphere in about 95% of right-handers and in most (roughly 70%) of left-handers.

- **Vision crosses too:** what we see to the **left of the fixation point** (left visual field) reaches the **right** hemisphere, and vice versa.

5. The split-brain experiments.

- Cutting the corpus callosum (**commissurotomy / callosotomy**) stopped severe epileptic seizures spreading from one hemisphere to the other. Patients seemed normal in daily life.
- In the laboratory, a word or picture was flashed to one visual field. Shown "spoon" in the **right** field (left hemisphere), the patient could **say** "spoon". Shown it in the **left** field (right hemisphere), he said he saw nothing, yet his **left hand** could pick out the spoon by touch.
- Conclusion: the left hemisphere controls speech; the right understands simple words and objects but cannot name them; each hemisphere can work with its own knowledge when disconnected.

6. Hemisphericity.

- **Hemisphericity** = an individual's tendency to rely more on one hemisphere's mode of processing information: **left** (verbal, logical, analytical), **right** (non-verbal, intuitive, holistic) or **integrated** (both equally). It is described as a person's **style of learning and thinking**.
- It is measured by tests such as **Torrance's "Your Style of Learning and Thinking" (SOLAT)**, used in Indian educational research (Indian adaptation by D. Venkataraman).
- Caution: "left-brained" and "right-brained" people are a popular simplification; in normal people the two hemispheres always work together.

7. The endocrine system and behaviour.

- Hormones act **more slowly** than nerve impulses but their effects **last longer** and spread through the whole body. The nervous system is like a phone call; the endocrine system is like a broadcast.
- The **hypothalamus** → **pituitary** → **target gland** chain controls most glands; hormones in the blood feed back to switch the chain off (**negative feedback**).
- **Pituitary.** Anterior lobe: **growth hormone** (too much in childhood → gigantism; in adults → acromegaly; too little → dwarfism), **TSH** (thyroid), **ACTH** (adrenal cortex), **FSH/LH** (gonads), **prolactin** (milk production). Posterior lobe releases two hormones made in the hypothalamus: **ADH / vasopressin** (water balance) and **oxytocin**.
- **Oxytocin:** uterine contractions in childbirth and milk let-down in breastfeeding; also **bonding, trust, social recognition** between mother and child and between partners (the "love" or "bonding" hormone).
- **Thyroid (thyroxine):** sets the body's **metabolic rate**. **Too little** (hypothyroidism): sluggish, tired, slow thinking, weight gain, depression; in infancy it causes **cretinism** (stunted growth and intellectual disability). **Too much** (hyperthyroidism): restless, anxious, irritable, sleepless, losing weight. Iodine deficiency → **goitre**.
- **Adrenal glands** (above the kidneys). The **medulla** releases **adrenaline** and noradrenaline in emergencies: faster heart, more blood sugar, alertness; it backs up the sympathetic nervous system. The **cortex** releases **cortisol**, the main long-term **stress hormone** (raises blood sugar, reduces inflammation; prolonged high levels weaken immunity).
- **Pancreas:** **insulin** lowers blood sugar, **glucagon** raises it. Too little insulin → **diabetes**; too much (low blood sugar) → anxiety, irritability, confusion, fainting.

- **Pineal gland:** releases **melatonin** in darkness; it makes us sleepy and keeps the body's daily (circadian) rhythm. Jet lag and night shifts upset it.
- **Gonads: testosterone** (testes) → male secondary sex characteristics, sex drive, linked to aggression and dominance; **estrogen and progesterone** (ovaries) → female sex characteristics, menstrual cycle, pregnancy. The adrenal cortex also makes small amounts of sex hormones in both sexes.
- **Parathyroid:** keeps blood calcium normal; too little parathormone → muscle twitching (tetany), irritability.
- **Thymus:** helps the immune system mature; large in childhood, shrinks after puberty.

Common traps

✗ "The cerebellum controls breathing and heart rate." ✓ The **medulla** does; the cerebellum controls **balance and coordination**.

✗ "The thalamus relays all senses, including smell." ✓ All senses **except smell**.

✗ "The hypothalamus is the master gland." ✓ The **pituitary** is the master gland; the hypothalamus controls it.

✗ "The hippocampus is the fear centre." ✓ **Amygdala** = fear; **hippocampus** = forming new memories.

✗ "Broca's area handles language comprehension." ✓ Broca = speech **production** (frontal); **Wernicke** = comprehension (temporal).

✗ "The left hemisphere controls the left hand." ✓ Control is **contralateral**: the left hemisphere controls the **right** side.

✗ "Face recognition and spatial skills are left-hemisphere tasks." ✓ They are mainly **right**-hemisphere tasks; language and analysis are left.

✗ "In split-brain patients an object seen in the left visual field can be named." ✓ It reaches the **right** hemisphere, which cannot name it; the **left hand** can pick it out.

✗ "The pineal gland makes thyroxine / adrenaline." ✓ Pineal → **melatonin** (sleep); thyroid → thyroxine; adrenal medulla → adrenaline.

✗ "Cortisol is made by the adrenal medulla." ✓ Cortisol comes from the adrenal **cortex**; adrenaline from the **medulla**.

Quick revision

- Hindbrain: medulla (vital centre), pons (sleep), cerebellum (balance, coordination).
- RAS: arousal and attention; thalamus: relay of all senses except smell.
- Hypothalamus: hunger, thirst, temperature, emotion; controls ANS and pituitary.

- Limbic: hippocampus (new memories), amygdala (fear, aggression).
- Lobes: frontal (planning, movement, Broca), parietal (touch), temporal (hearing, Wernicke), occipital (vision).
- Left hemisphere: language, logic, sequential; right: spatial, faces, music, holistic; contralateral control.
- Split-brain: Sperry and Gazzaniga, corpus callosum cut; Sperry Nobel 1981.
- Hemisphericity: preferred processing mode (left / right / integrated); a style of learning and thinking.
- Endocrine glands are ductless; pituitary = master gland; thyroxine = metabolism.
- Adrenaline = emergency; cortisol = stress; melatonin = sleep; oxytocin = bonding, childbirth, milk.