

Foundations of the Brain

Get these slides:

[link](#)

Dr Germano Gallicchio

Lecturer in Computational Psychophysiology

School of Sport Science, Bangor University, UK

[profile](#) | [learning resources](#) | [book meeting](#)

Attendance:

<https://checkin.bangor.ac.uk/>

Agenda

Describe structure and function of:

- Neuronal cells (microscopic level)
- Nervous system (macroscopic level)

In other words:

- Structure and function of neurons (**how** do neurons communicate?)
- The type of information sent and received (**what** do neurons communicate?)
- The higher-level functions that emerge from this communication (**why** do neurons communicate?)

Why study the brain, neurons, etc?

1. A fundamental principle in Biology: “structure determines function”
2. Psychology studies mental “functions”
3. Useful for psychologists to understand (at the least at a basic level) the biological substrate to the mental functions.

Structure of a neuron

Neuron’s three main structures:

- Soma
- Dendrites (neurite)
- Axon (neurite)

the three main neuronal structures:

- soma
- dendrites
- axon

Image: [Drawing of a neuron and its main structures](#)

The **soma**, or cell body, is the central part of a neuron that contains the *nucleus*, which houses the cell’s genetic material (DNA). The soma is responsible for maintaining the neuron’s health, regulating its metabolic functions, and synthesizing proteins necessary for the neuron’s structure and signaling processes.

Neurites are projections from the soma and include both dendrites and the axon.

Dendrites are branched extensions that receive signals from other neurons and transmit them toward the soma.

The **axon** is a long, singular projection that transmits signals away from the soma to other neurons, muscles, or glands.

Dendrites

Image: [Stellate neuron](#)

Dendrites are specialized structures that **receive information*** from other neurons (axons).

Each neuron typically has **many dendrites**, which are organized in a branching pattern known as the **dendritic tree**.

The **structure and shape** of dendrites vary across different types of neurons, enabling diverse functional roles in neural communication.

Axon

Image: [Neuron structure showing axon](#)

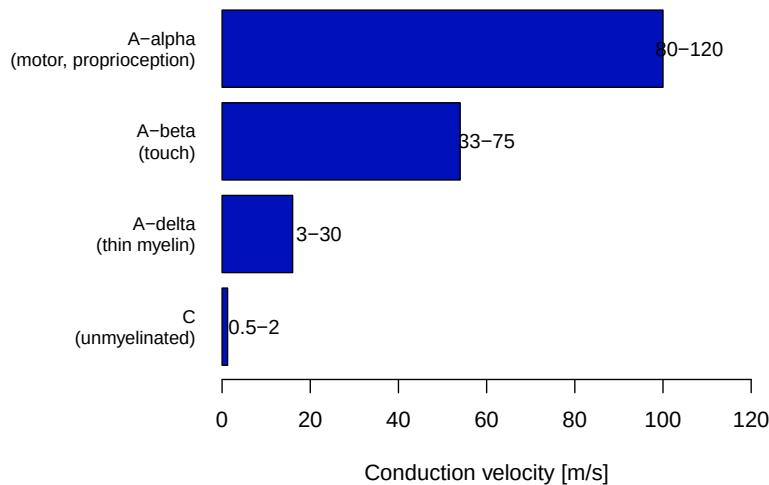
The **axon** is a singular, elongated projection that **transmits information** away from the soma to other neurons (dendrites or soma).

While each neuron has **only one axon**, it may branch into **collaterals** to communicate with multiple targets.

Many axons are **wrapped in myelin**, a fatty substance that enables **faster conduction** of electrical impulses by insulating the axon membrane.

How fast is a nerve signal?

Myelin does more than insulate: it changes conduction speed by **two orders of magnitude**.



Thickly myelinated fibres carry motor commands and limb-position information at up to about **120 m/s**.

Unmyelinated fibres — slow pain, temperature — travel at about **1 m/s**, roughly walking pace.

So why are our reactions not as fast?

In an adult, a touch on the hand travels to the spinal cord and up to the brain—roughly **1.3 m**—and the command travels back out again.

Touch signals travel in on A fibres at around 50 m/s: about **25 ms**.

Motor commands travel out on A fibres at around 100 m/s: about **15 ms**.

Total conduction: roughly **40 ms**.

But a simple reaction to a touch takes about **155 ms**.

So conduction accounts for only about **a quarter** of it. The other three quarters is your brain detecting the signal, deciding what to do, and getting the muscle to contract.

Optional:

Fibre classes and velocities follow the Erlanger–Gasser scheme. Values as tabulated in Kandel, E. R., Koester, J. D., Mack, S. H., & Siegelbaum, S. A. (Eds.) (2021). *Principles of Neural Science* (6th ed.). McGraw Hill.

For the historical origin of the classification, see Manzano, G. M., Giuliano, L. M. P., & Nóbrega, J. A. M. (2008). A brief historical note on the classification of nerve fibers. *Arquivos de Neuro-Psiquiatria*, 66(1), 117–119.

<https://doi.org/10.1590/S0004-282X2008000100033> (open access)

Conduction is fast. **Deciding is slow.**

Reaction time, taken apart

Every reaction (e.g., a sprint start, a save, a swerve) is the sum of five stages.

The five stages of a reaction:

1. Transduction — stimulus becomes a neural signal
2. Afferent conduction — signal travels to the CNS
3. Central processing — detect, identify, select a response
4. Efferent conduction — command travels to the muscle
5. Muscle activation — force is produced, movement begins

Stages 2 and 4 are the conduction we just calculated: fast, and fairly fixed.

Stage 3 is where the variation lies. It is the stage that gets **slower when there are more options to choose between**, and **faster when you already know what is coming**.

Soma

Image: [Neuron cell body \(soma\)](#)

The soma, also known as the cell body, is the central part of a neuron. It contains the nucleus, which houses the cell's genetic material, and is responsible for regulating the neuron's activities, including protein synthesis and energy production.

The soma **integrates** incoming signals from the dendrites and determines whether to generate an action potential that travels down the axon.

Reaction times: touch 155 ms, sound 140–160 ms, light 180–200 ms. Compiled in Kosinski, R. J. (2013). *A literature review on reaction time*. Clemson University, drawing on Woodworth & Schlosberg (1954) and Welford, A. T. (Ed.) (1980). *Reaction Times*. Academic Press. Note that the tactile estimate traces to Robinson (1934) and is old; the ordering of the three modalities is the robust finding.

review questions

Which part of the neuron *mainly* receives information from other neurons?

- a) Axon
- b) Soma
- c) Myelin
- d) Dendrites

Correct response: d

Note the emphasis on *mainly* in the question: the soma can also receive information but it's not its main function

True or false: Each neuron has multiple axons.

Correct response: false

Synapse (Pronounced *s n.æps*)

Image: [Chemical synapse](#)

The synapse is the junction between the **axon terminal** of one neuron and the **dendrite** (or soma) of another neuron.

When an action potential reaches the axon terminal, it triggers the release of **neurotransmitters** into the **synaptic cleft**.

These chemicals bind to receptors on the post-synaptic neuron, causing changes in its electrical state.

It is the site where **neurotransmitters** are released to allow communication between neurons.

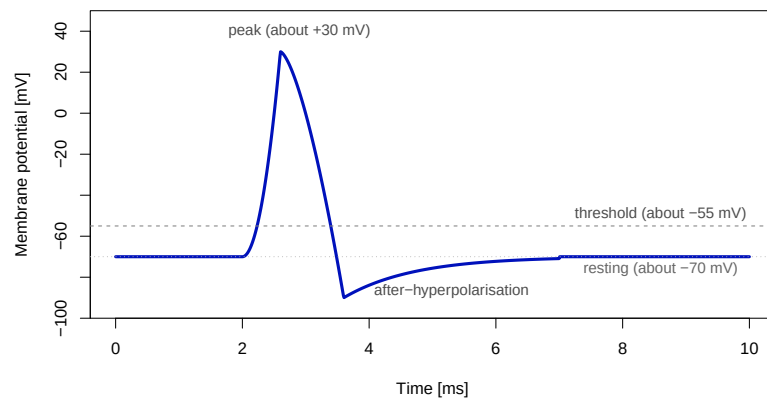
Synapses can be **excitatory** or **inhibitory**, depending on the type of neurotransmitter and receptor involved. This process is essential for all forms of **neural communication**, including learning, memory, and reflexes.

The **presynaptic neuron** (sender) releases **neurotransmitters** from its axon terminal into the synaptic cleft, whereas the **postsynaptic neuron** receives and processes the signal.

This interaction can either **excite** or **inhibit** the postsynaptic neuron, depending on the type of neurotransmitter and receptor involved.

The summation of multiple post-synaptic potentials will determine whether that neuron will, in turn, generate its own action potential.

Electrochemical communication: the action potential



The **action potential** is a rapid, self-propagating change in membrane potential that travels along the axon.

It is **all-or-nothing**: once threshold is crossed, the shape and size of the response are the same every time.

It ends at the **synapse**, the junction with the next neuron.

Electrochemical Communication: post-synaptic potential

Image: [Anatomy of neuron](#)

When stimulated, the **dendrites** change their chemicals, generating an electrical **post-synaptic potential**.

This potential is conducted **passively** towards the soma and then to the **axon hillock**.

The potentials generated by many dendrites are **summed** (some positive, some negative). If the resulting potential is **large enough**, it triggers an **action potential** in the axon.

Neurotransmitters

Image: [Synapse schematic](#)

Neurotransmitters are molecules that play a crucial role in synaptic communication. They are released by the **presynaptic neuron** into the synaptic cleft in response to an action potential.

Once released, neurotransmitters bind to specific receptors on the **postsynaptic neuron**, triggering changes in its electrical or chemical state.

Neurotransmitters: functions

Neurotransmitter types:

- Excitatory
- Inhibitory
- Modulatory

Neurotransmitters can either:

- excite
- inhibit
- modulate

the post-synaptic neuron

Excitatory neurotransmitters (e.g., glutamate) increase the likelihood of the postsynaptic neuron firing an action potential.

Inhibitory neurotransmitters (e.g., GABA) decrease the likelihood of the postsynaptic neuron firing.

Modulatory neurotransmitters adjust properties (e.g., excitability) of neural circuits.

The **interplay** between inhibition and excitation ensures precise and regulated communication among neurons, enabling complex processes such as learning, memory, and motor control.

Review questions

What is the gap between two neurons called?

Explain the difference between pre-synaptic and post-synaptic neurons in synaptic communication.

Types of Neurons

Neurons can be classified based on several characteristics, including:

- number of dendrites
- shape of dendrites
- axon length
- type of neurotransmitter they release

This classification highlights the *diversity* of neurons and their *specialized* roles in the nervous system.

Classification by Number of Dendrites

- **Unipolar:** Single projection (one neurite) from the soma that branches into dendrites and an axon. Examples: Sensory neurons
- **Bipolar:** One axon and one dendrite (two neurites) extending from the soma. Examples: Retinal neurons
- **Multipolar:** One axon and multiple dendrites, the most common type of neuron. Examples: Motor neurons, interneurons

Classification by Number of Dendrites

Image: [Neuron shape classification](#)

Illustration of **unipolar**, **bipolar**, or **multipolar** neurons, depending on the number of projections extending from the soma.

Classification by Neurotransmitter

In addition to **excitatory** (i.e., they activate the postsynaptic neuron and increase the likelihood of an action potential) and **inhibitory** (i.e., they suppress the activity of the postsynaptic neuron and reducing the likelihood of an action potential), some neurotransmitters are **modulatory**: they influence the overall activity of neural circuits by altering the strength or dynamics of synaptic communication.

For example, a modulatory neurotransmitter can influence the excitability of a postsynaptic neuron.

- **Excitatory:** Release neurotransmitters that increase the likelihood of action potentials in the postsynaptic neuron. Examples: Glutamatergic neurons

- **Inhibitory:** Release neurotransmitters that decrease the likelihood of action potentials in the postsynaptic neuron. Examples: GABAergic neurons
- **Modulatory:** Release neurotransmitters that modulate the activity of other neurons. Examples: Dopaminergic, serotonergic neurons

Why so many kinds of neuron?

Neurons differ in **shape**, **size**, the **length of their axon**, and the **neurotransmitter** they release.

Structure determines function.

A neuron with a long, thick, heavily myelinated axon is built to carry signals **fast over distance** — for example from your spinal cord to your calf muscle.

A neuron with a short axon and a dense dendritic tree is built to **integrate many local signals** — for example within a small patch of cortex.

Dual Nature of Neural Information Communication

Dendrites receives information.

The soma receives and integrates information.

The axon sends information.

But what information are we talking about?

Electro-chemical potentials

Electrico-chemical potentials

Neural Communication types:

- Electrical communication (within neuron)
- Chemical communication (between neurons)

Within a neuron, information is transmitted *electrically* (post-synaptic potentials, action potential).

Between neurons (in the synapse), information is transmitted *chemically* via neurotransmitters.

Neurons communicate information using both **electrical** and **chemical** mechanisms.

Spiking Rate and Neural Coding

The action potential is a all-or-nothing event (either sent or not sent): same voltage and same duration for each neuron under stable conditions.

So how do neurons communication different information?

Through **spiking rate**: the *number* of action potentials sent *per second*. The frequency at which action potentials are sent (i.e., how often they are sent) can vary.

The **spiking rate** encodes meaning in neuronal communication.

For example, a neuron may exhibit a high spiking rate during specific activities, such as processing auditory information during speech, indicating its **specialization** in that domain.

Neurons that respond to similar types of information are often spatially **grouped together**, reflecting **regional functional specialization**.

Review questions

Explain the dual nature of neural communication (electrical vs. chemical)

If all action potentials are the same, how do neurons communicate different types or intensities of information?

Not just neurons

Image: [Types of neuroglia](#)

Glial cells, or **glia** (pronounced *li .ə*), are *non-neuronal* cells in the nervous system that provide support, protection, and nourishment to neurons. They play a critical role in maintaining the homeostasis of the neural environment and facilitating efficient neural communication.

This illustration shows **different types of glial cells** and their roles.

Types of glia

Brief overview of some glial cells

- **Astrocytes:** Maintain the blood-brain barrier, regulate nutrient supply, and support synaptic function.
- **Oligodendrocytes:** Produce myelin sheaths that insulate axons in the CNS, enabling faster signal transmission.
- **Schwann Cells:** Produce myelin sheaths in the peripheral nervous system (PNS)
- **Microglia:** Act as immune cells in the CNS, clearing damaged cells and protecting against pathogens

Neurons and glia

Until recently, it was believed that the **ratio of neurons to glial cells** in the human brain was approximately **1:10**, meaning there were ten times as many glial cells as neurons. However, recent research has revised this estimate, suggesting a ratio closer to **1:1**.

This ratio is not uniform across the nervous system; different regions exhibit varying proportions of neurons and glial cells. For example:

- The **cerebral cortex** has a higher density of neurons relative to glial cells.
- The **white matter** contains more glial cells due to the abundance of myelinated axons.

White and gray matter

Image: [Gray and white matter of the cerebrum](#)

The brain is composed of **gray matter** and **white matter**, each playing distinct roles in neural function.

- **Gray matter** consists primarily of **neuronal cell bodies**, **dendrites**, and **glial cells**. It is involved in processing and integrating information.
- **White matter** is made up of **myelinated axons**, which facilitate the rapid transmission of signals between different brain regions.

Interim summary

End of the brief “microscopic” view of the brain

Video to watch in your own time, summarizing some of the content covered so far.

Video: 2-Minute Neuroscience: The Neuron - <https://youtube.com/watch?v=6qS83wD29PY>

Nervous system

Nervous System structure:

- Central Nervous System: Brain (Cerebrum, Cerebellum, Brainstem) and Spinal Cord
- Peripheral Nervous System: Somatic (Sensory Afferent, Motor Efferent) and Autonomic (Sympathetic, Parasympathetic, Enteric)

The central nervous system includes the brain and the spinal cord.

How the nervous system is organised

Nervous system:

- **Central:** brain + spinal cord
- **Peripheral:** nerves outside the CNS
 - **Somatic:** voluntary movement and sensation
 - **Autonomic:** involuntary control of organs
 - * Sympathetic (“mobilise”)
 - * Parasympathetic (“recover”)

Everything covered so far — neurons, synapses, transmitters — is common to **all** of it.

Most of this module concerns the **central** nervous system.

The cerebrum

A useful check: the sympathetic branch raises heart rate before a race; the parasympathetic branch brings it back down afterwards.

Cerebrum structure:

- Cerebral Cortex: Frontal, Parietal, Temporal, Occipital Lobes
- Subcortical Structures: Basal Ganglia, Thalamus, Hypothalamus

The cerebrum includes multiple structures

The brain is more than the cerebrum

Beyond the cerebrum:

- **Cerebellum:** coordination, timing, movement accuracy
- **Brainstem:** arousal, breathing, heart rate
- **Spinal cord:** reflexes, and the route to and from the body

The **cerebellum** holds more neurons than the rest of the brain combined, despite its size.

It does not initiate movement. It **refines** it — comparing what you intended with what actually happened, and correcting the difference.

The cerebral cortex

The outermost layer of the brain, responsible for cognitive functions such as **perception**, **decision-making**, **language**, and **conscious thought**. It is divided into four lobes:

Image: [Lobes of cerebral cortex](#)

- **Frontal Lobe:** Involved in reasoning, planning, and voluntary movement.
- **Parietal Lobe:** Processes sensory information like touch and spatial awareness.
- **Temporal Lobe:** Handles auditory processing and memory.
- **Occipital Lobe:** Dedicated to visual processing.

Cerebral cortex and cognitive functions

The cerebral cortex enable complex **cognitive functions** such as:

- **Perception:** processing sensory input from various modalities (e.g., hearing, vision, touch, taste) to create a coherent representation of the environment.

- **Attention:** it allows to select relevant stimuli while filtering out distractions
- **Memory:** encoding, storing, and retrieving of memories.
- **Language:** speech production and comprehension.
- **Decision-Making:** reasoning, problem-solving, and planning, which are essential for making informed decisions.
- **Conscious Thought:** self-awareness and the ability to reflect on one's thoughts and actions.

Frontal lobe

The **frontal lobe** is the largest of the brain's lobes and is responsible for a wide range of functions, including:

- **Executive Functions:** Planning, decision-making, problem-solving, and goal-setting.
- **Motor Control:** Houses the **primary motor cortex**, which controls voluntary movements.
- **Language Production:** Includes Broca's area, essential for speech production.
- **Attention and Focus:** Regulates concentration and the ability to shift focus between tasks.
- **Emotional Regulation:** Plays a role in managing emotions and social behavior.
- **Working Memory:** Supports short-term memory and the manipulation of information.
- **Personality:** Influences traits such as self-awareness, motivation, and social interactions.

Temporal lobe

The **temporal lobe** is located on the sides of the brain, near the ears, is responsible for functions including:

- **Auditory Processing:** Houses the **primary auditory cortex**, which processes sounds and enables hearing.
- **Language Comprehension:** Includes Wernicke's area, essential for understanding spoken and written language.

- **Memory Formation:** Plays a key role in forming and retrieving long-term memories, particularly through the **hippocampus**.
- **Emotional Processing:** Involved in interpreting emotions and social cues, with contributions from the **amygdala**.
- **Object Recognition:** Helps identify and categorize objects and faces through visual processing pathways.
- **Learning:** Supports the acquisition of new information and skills.

Parietal lobe

The **parietal lobe** is located near the top and back of the brain and is involved in various sensory and integrative functions:

- **Sensory Processing:** Interprets sensory information such as touch, temperature, pain, and pressure.
- **Spatial Awareness:** Helps in understanding spatial relationships and navigating the environment.
- **Proprioception:** Processes information about the position and movement of the body.
- **Integration of Sensory Input:** Combines information from different senses to create a coherent perception of the world.
- **Attention and Focus:** Plays a role in directing attention to relevant stimuli.
- **Mathematical and Logical Reasoning:** Supports numerical processing and problem-solving tasks.

Occipital lobe

The **occipital lobe** is located at the back of the brain and is primarily responsible for visual processing. Its functions include:

- **Visual Perception:** Processes visual information received from the eyes.

- **Color Recognition:** Interprets and distinguishes different colors.
- **Motion Detection:** Identifies and tracks movement within the visual field.
- **Spatial Processing:** Helps in understanding spatial relationships and depth perception.
- **Object Recognition:** Assists in identifying shapes, patterns, and objects.
- **Visual Memory:** Stores and retrieves visual information for future reference.

Review question

An athlete suffers a concussion affecting the frontal lobe. Based on the functions of this lobe, what cognitive or motor difficulties might they experience?

Layers of the cerebral cortex

The cerebral cortex is highly **folded**, increasing its surface area, and organised into **six layers** that differ in the neurons they contain and where those neurons send their connections.

The six cortical layers (surface to white matter):

- I molecular
- II external granular
- III external pyramidal
- IV internal granular (main input layer)
- V internal pyramidal (main output layer)
- VI multiform

Layer **IV** is the main **input** layer: it receives signals arriving from the thalamus.

Layer **V** is the main **output** layer: its large pyramidal neurons send signals away from the cortex, including to the spinal cord.

The layers vary in thickness across the cortex, and that variation reflects **functional specialisation**.

For example, primary visual cortex has a very thick layer IV (lots of incoming information), whereas primary motor cortex has a very thick layer V (lots of outgoing commands).

Brodmann areas

Image: [Brodmann areas](#)

The cerebral cortex is divided into distinct zones based on differences in cytoarchitecture. These zones, known as **Brodmann areas**, identified in the early 20th century by Korbinian Brodmann.

Generally, each area is associated with specific functions, such as sensory processing, motor control, or higher cognitive tasks.

For example:

- **Primary motor cortex (Brodmann area 4)**: Contains large pyramidal neurons critical for voluntary *movement*.
- **Broca's area (Brodmann areas 44 and 45)**: Located in the frontal lobe, it is critical for speech *production* and language processing.

Optional: Exploration of the brain

Interactive 3D brain explorer (online only):

<https://www.brainfacts.org/3d-brain#intro=false&focus=Brain>

Review questions

A simple reaction to a touch on the hand takes about 155 ms. Roughly how much of that is signals travelling along nerves?

- a) Almost all of it
- b) About three quarters

Do not confuse this with the **cerebellar** cortex, which has a different organisation of only three layers.

- c) About a quarter
- d) None — conduction is effectively instantaneous

Correct response: c. Around 40 ms of conduction; the rest is detection, decision and muscle activation.

True or false: a thicker, more heavily myelinated axon conducts more slowly, because there is more tissue for the signal to cross.

Correct response: false. Myelination *increases* conduction velocity.

Which layer of the cerebral cortex sends the main output to the spinal cord?

Correct response: layer V, the internal pyramidal layer.