NEUROTECH 102 - THE BRAIN

INTRODUCTION TO NEUROTECH WORKSHOP SERIES

HALLOWEEN EDITION

IMPERIAL COLLEGE NEUROTECH SOCIETY

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Workshop Aims

1. APPRECIATION OF THE UNCONSCIOUS BRAIN
   - The computational complexity of what the brain does on a daily basis
2. BASICS OF NEUROSCIENCE
   - Terminology for navigating the brain
   - How brains are cross-sectioned (**sagittal, coronal, axial** planes etc.)
   - Basics of neuron biology and neural circuits
3. PHILOSOPHY OF MIND
   - A detour into the **mind / body** problem
   - Overview the schools of thought surrounding Philosophy of Mind

01 The Neuroscience of the Unconscious Brain

01 The Neuroscience of the Unconscious Brain

Picture a scenario:

- You are sitting with your friend together in a coffee shop.
- As you’re chatting you notice them lift their cup of coffee up to take a sip.
- The act is so unremarkable that it bears no mention in the slightest.

But.....

- **This simple act is underpinned by trillions of electrical impulses meticulously coordinated by the brain.**

01 The Neuroscience of the Unconscious Brain

- The **visual system** scans the scene and pinpoints the cup
- Years of experience **trigger memories** of coffee in other situations, causing the **frontal cortex** to trigger the premotor cortex
- The **premotor cortex** coordinates precise muscle contractions throughout the torso, arm, forearm, and hand to grasp the cup
- As the cup is touched, nerves carry back reams of information about the *cup's weight*, its *position in space*, its *temperature*, the *slipperiness of the handle* etc.. All this information streams up the **spinal cord** and into the brain
- Micro-adjustments in the *strength of the cup lift* and *force of the grip* are transmitted back down near instantaneously
- As the cup is moved in a smooth arc to the lips, the person tilts the cup - just enough to extract some liquid, but not burn them

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It would take dozens of the world's fastest supercomputers to match this computational feat

But your friend is doing it in total obliviousness

01 The Neuroscience of the Unconscious Brain

1. Visual Perception

a. Object Recognition

The brain processes visual input to recognise the cup using the **ventral stream** (the ‘what’ pathway). This involves:

- Light reflecting off the cup is detected by the retina
- The visual information is transmitted to the primary visual cortex (V1)
- The brain identifies the shape, colour, and size of the object
- The object is recognised as a ‘cup’ past on past experience and learned knowledge

b. Depth and Distance Perception

Simultaneously, the **dorsal stream** (the ‘where’ pathway) estimates the distance, position, and orientation of the cup relative to the body

This involves spatial and depth processing through binocular disparity, motion, and size perception

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2. Motor Planning

a. Premotor Cortex

The brain’s **premotor cortex** plans the movement required reflecting off the cup is detected by the retina

b. Motor Sequence Programming (Supplementary Motor Area - SMA)

The supplementary motor area sequences the required movements of the shoulder, elbow, wrist and fingers

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2. Motor Planning

a. Trajectory Planning

The brain’s **premotor cortex** plans the movement required to pick up the cup and determines a trajectory to reach, grasp, and lift

b. Motor Sequence Programming (Supplementary Motor Area - SMA)

The supplementary motor area sequences the required movements of the shoulder, elbow, wrist and fingers

3. Grasping Coordination

a. Finger Coordination

The **prefrontal cortex** coordinates decision-making about how to grasp the cup based on its size and shape

The **basal ganglia** smoothes out the sequence of muscle movements, ensuring grasp is fluid and efficient

b. Fine Motor Control

The **cerebellum** coordinates fine motor control, balance, and timing, ensuring that the cup is lifted steadily without spilling. It makes tiny adjustments to hand movements based on proprioceptive feedback from the muscles

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4. Proprioception

a. Somatosensory Cortex

Proprioceptive sensors in muscles and joints continuously send signals up the spinal cord to the **somatosensory cortex** about limb positioning

b. Multisensory Integration

As the hand nears the cup, sensory feedback from the fingers touching the cup informs the brain whether adjustments are needed. If the cup feels heavier or lighter than expected, the brain fine-tunes the grip strength.

01 The Neuroscience of the Unconscious Brain

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5. Lifting the cup

a. Posture Control (Brainstem)

The **brainstem** helps maintain postural control, ensuring that the rest of your body remains stable and balanced while your arm moves. The body makes small adjustments to balance, preventing the torso from swaying or tipping forward while lifting the cup.

01 The Neuroscience of the Unconscious Brain

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6. Sipping and Swallowing

a. Oral Motor Control

The brain controls the facial muscles, lips, and tongue through cranial nerves to bring the cup to the mouth and drink without spilling

Muscles in the mouth and throat coordinate to create the appropriate suction to draw the liquid in, while the tongue helps control flow.

The swallowing reflex is initiated by the brainstem, managing smooth coordination between breathing and drinking, so you don’t choke.

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7. Maintaining Awareness

a. Distraction Handling

While all this is happening, the brain's **prefrontal cortex** allows you to *carry on with conversation* or focus on *thinking about something* else

It is allocating attention to more relevant tasks, like **shaping the airflow through your throat** to facilitate speaking, which automating the motor task

b. Sensory Monitoring

The brain is subconsciously monitoring the environment for potential changes (e.g. temperature of the coffee, or external sounds) and can shift focus if something unexpected happens

02 Brain Terminology

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Let’s now learn to *navigate* the brain...

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Just as there is a north, south, east, and west for navigating around maps, there are conventional brain directions

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Front *Back*

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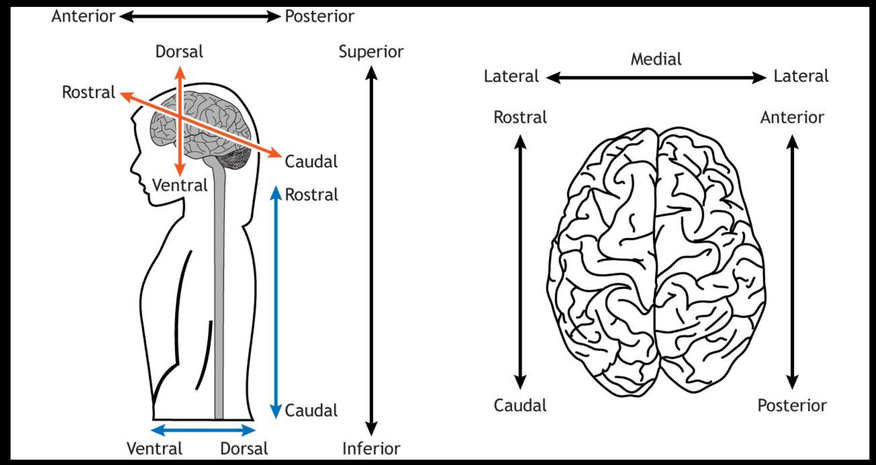
'Anatomical Directions' by Casey Henley



Anterior
Front

Posterior
Back

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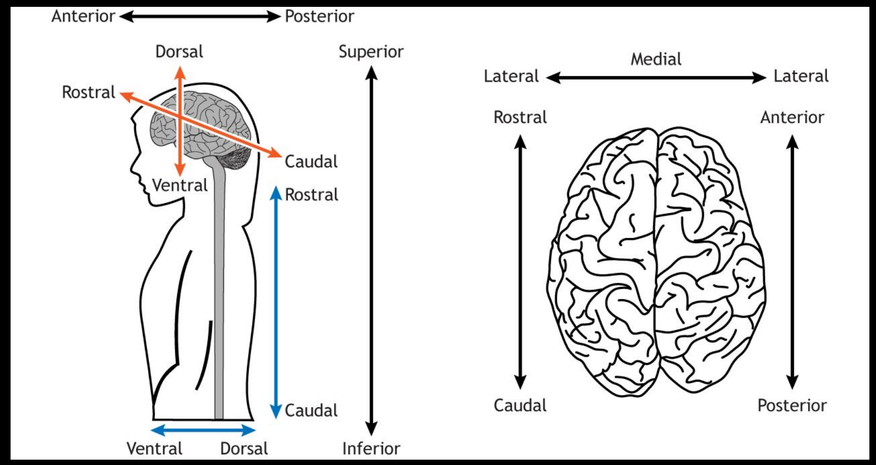

Anterior — *Front*

Posterior — *Back*

Rostral

Caudal

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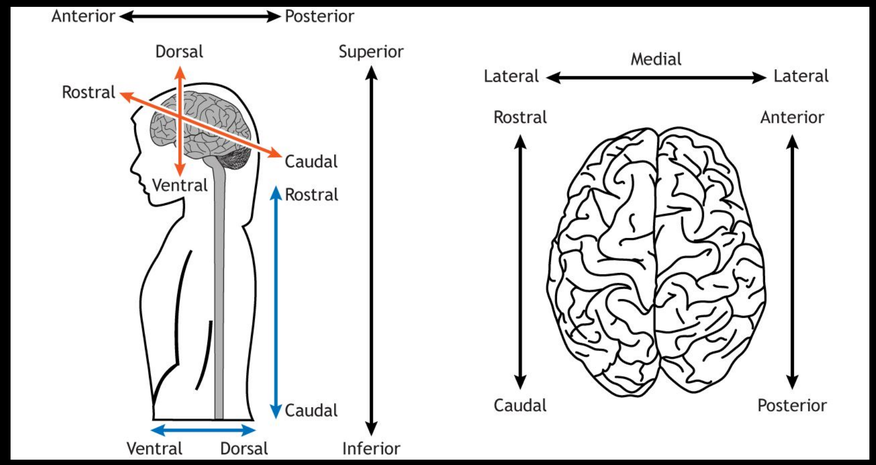

Anterior	Posterior	*Top*	*Bottom*
Front	*Back*		
Rostral	Caudal		

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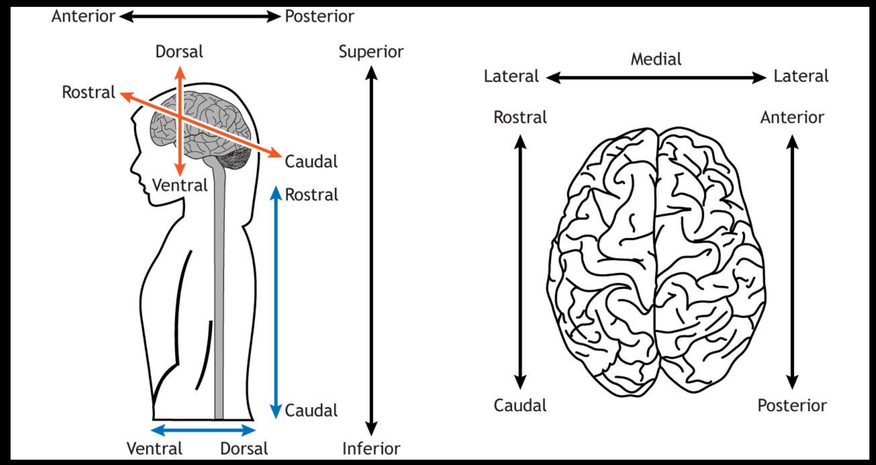

Anterior	Posterior	Superior	Inferior
Front	*Back*	*Top*	*Bottom*
Rostral	Caudal	Dorsal	Ventral

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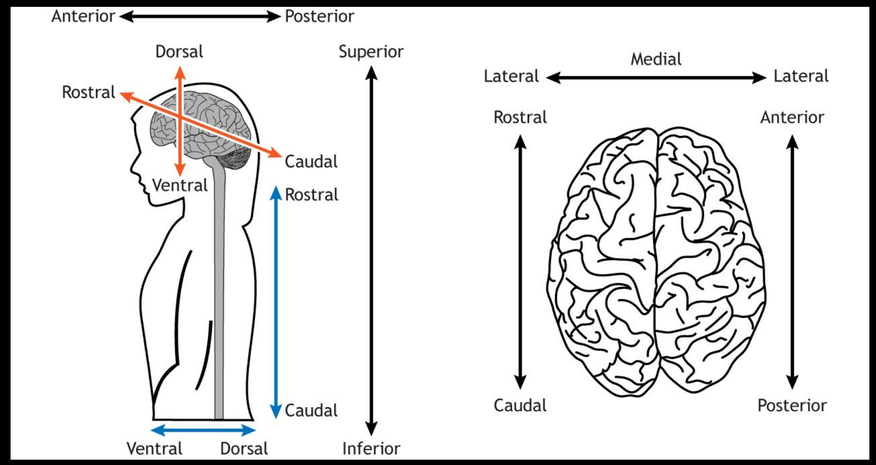

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Front	*Back*	*Top*	*Bottom*	*Outer Surface*	*Center*
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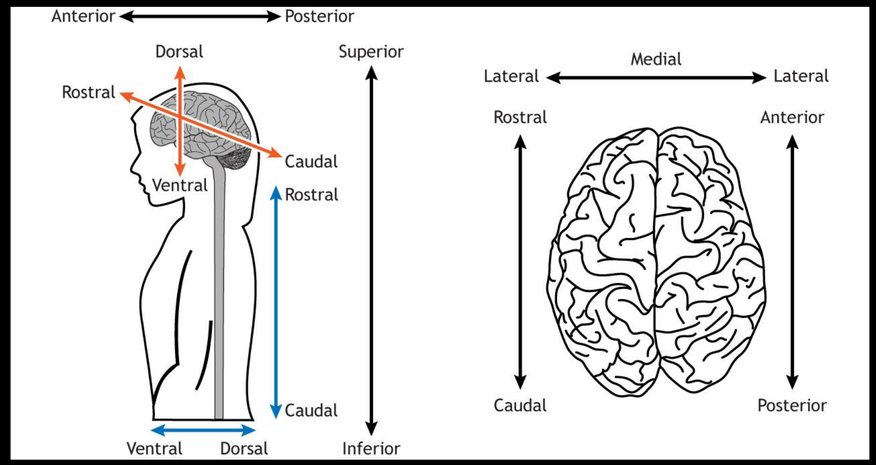

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Anterior	Posterior	Superior	Inferior	Lateral	Medial
Front	*Back*	*Top*	*Bottom*	*Outer Surface*	*Center*
Rostral	Caudal	Dorsal	Ventral		

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The brain can also be cross-sectioned (sliced in 2D) in a number of ways

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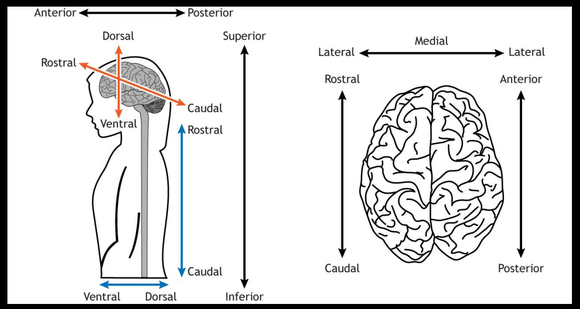

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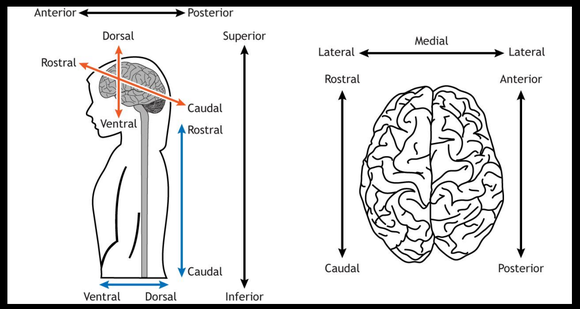

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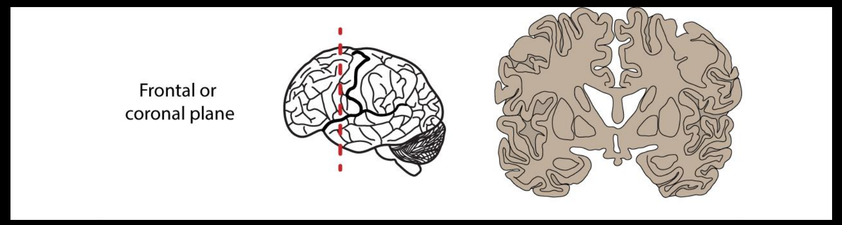

Anterior	Posterior	Superior	Inferior	Lateral	Medial
Front	Back	Top	Bottom	Outer Surface	Center
Rostral	Caudal	Dorsal	Ventral		

Coronal

Slice in the vertical plane, through **both hemispheres**

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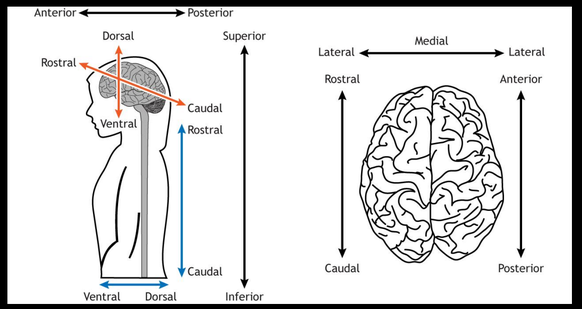

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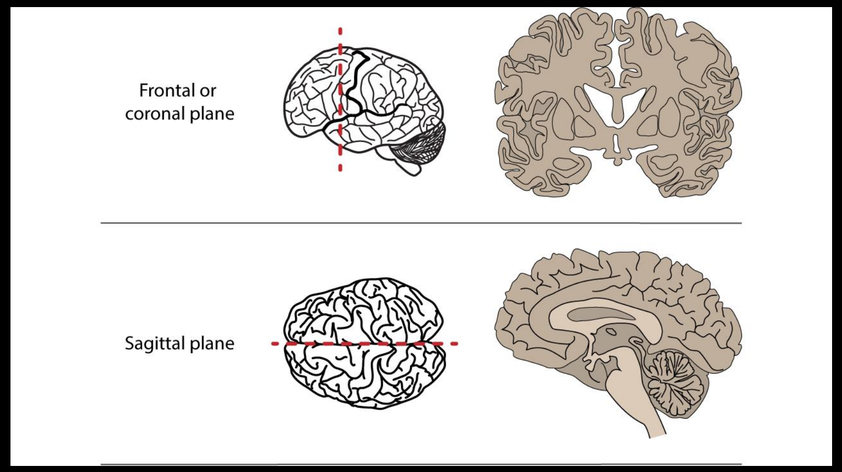

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Front	Back	Top	Bottom	Outer Surface	Center
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Coronal

Slice in the vertical plane, through **both hemispheres**

Sagittal

Slice in the vertical plane, through **one of the hemispheres**, or in the medial

02 Brain Terminology

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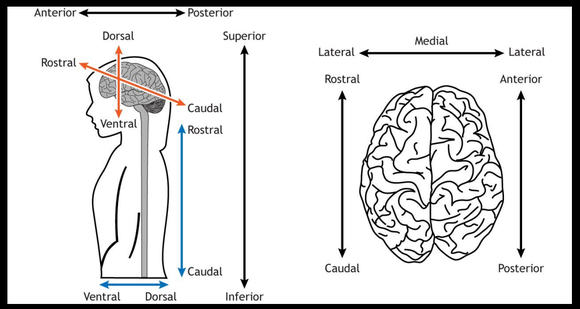

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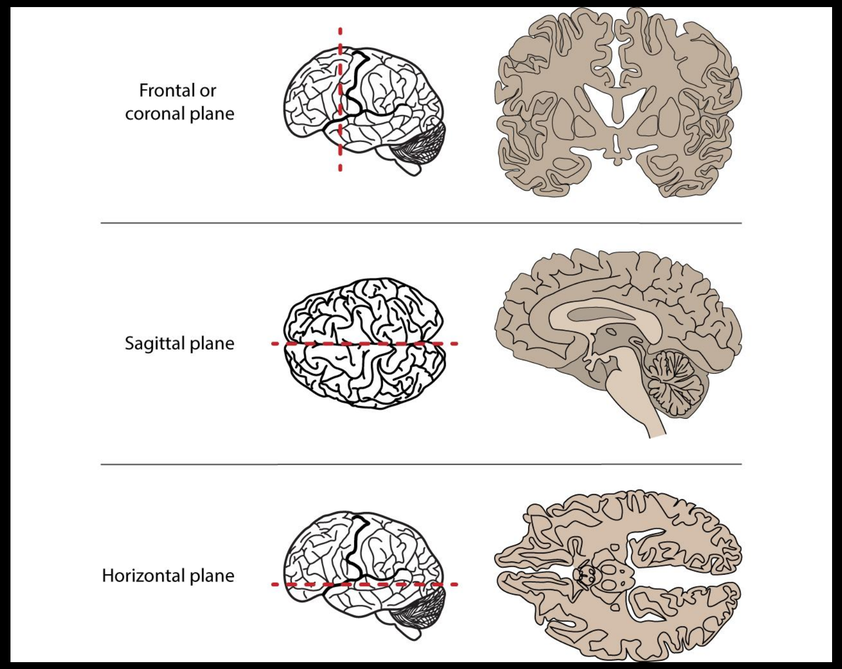

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Coronal

Slice in the vertical plane, through **both hemispheres**

Sagittal

Slice in the vertical plane, through **one of the hemispheres**, or in the medial

Axial or Horizontal

Slice in the horizontal plane

03 Brain Structures

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Knowledge Difficulty Scale

1

Novice

No prior knowledge of Neuroscience

- Minimal or no technical knowledge

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Novice

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Enthusiast

High-School Level Biology knowledge

- Basic understanding of neuron structure and brain regions, with simple explanations of how neurons communicate

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3

Undergraduate

Introductory Level Neuroscience knowledge

- Familiar with neural anatomy, synaptic transmission, basic brain regions and functions

03 Brain Structures

Knowledge Difficulty Scale*

And some more audiences

3

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Introductory Level Neuroscience knowledge

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Knowledge Difficulty Scale*

And some more audiences

3

Undergraduate

Introductory Level Neuroscience knowledge

- Familiar with neural anatomy, synaptic transmission, basic brain regions and functions

4

Postgraduate

Formal Neuroscience education

- Deep understanding of neural circuits, functional connectivity, neurotransmitter pathways, and experimental neuroscience techniques.

03 Brain Structures

Knowledge Difficulty Scale*

And some more audiences

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Undergraduate

Introductory Level Neuroscience knowledge

- Familiar with neural anatomy, synaptic transmission, basic brain regions and functions

4

Postgraduate

Formal Neuroscience education

- Deep understanding of neural circuits, functional connectivity, neurotransmitter pathways, and experimental neuroscience techniques.

5

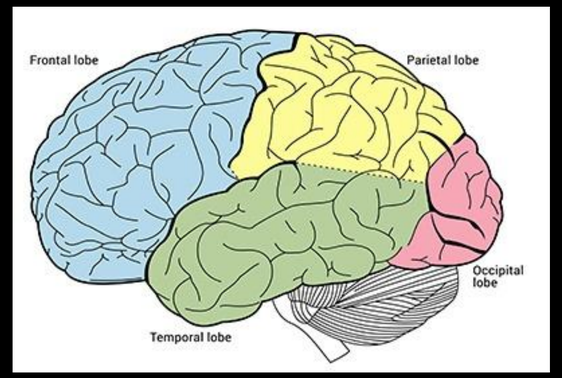
PhD Researcher

Extensive expertise and established Neuroscientist

- Proficient in neuroanatomy, neurophysiology, and neurochemistry, with in-depth knowledge of specialized techniques and data interpretation.

03 Brain Structures

Cerebrum



1

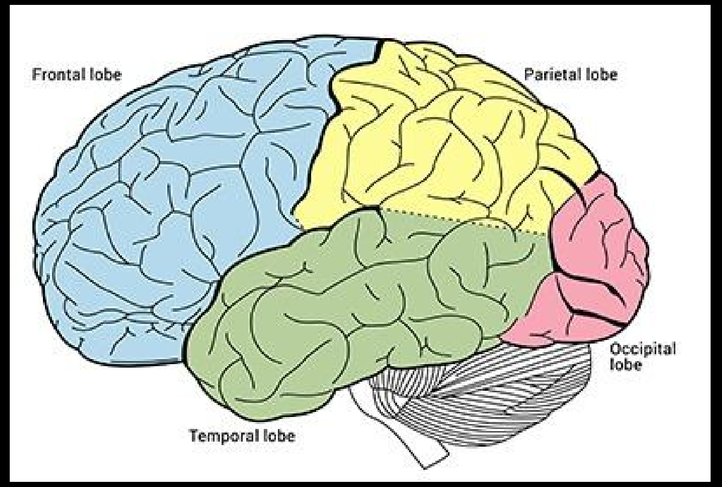
Structure

The largest part of the brain, divided into two hemispheres (left and right) and further subdivided into lobes.

Function

Responsible for higher cognitive functions, sensory processing, voluntary motor control, and complex thought.

03 Brain Structures



Cerebrum
Lobes

Frontal Lobe
Involved in decision-making, problem-solving, planning, and motor function

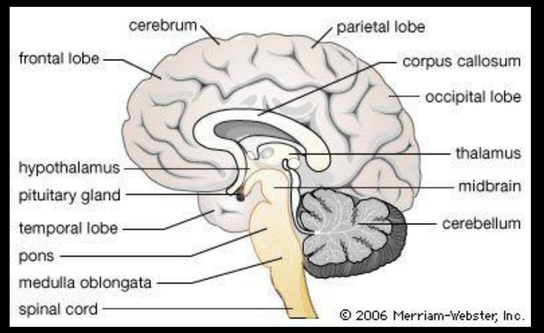
Parietal Lobe
Processes sensory information such as touch, temperature, and pain; involved in spatial orientation

Temporal Lobe
Associated with auditory processing, memory, and language comprehension

Occipital Lobe
Primarily responsible for visual processing

03 Brain Structures

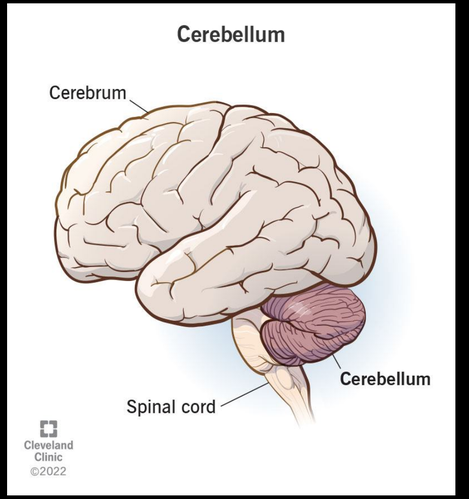
Cerebellum



1

Structure

Located at the back of the brain, beneath the cerebrum

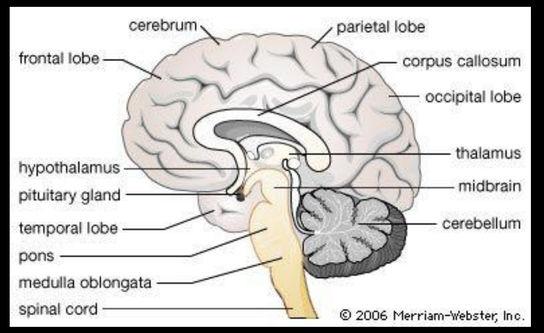


Function

Coordinates voluntary movements, balance, and posture; involved in motor learning

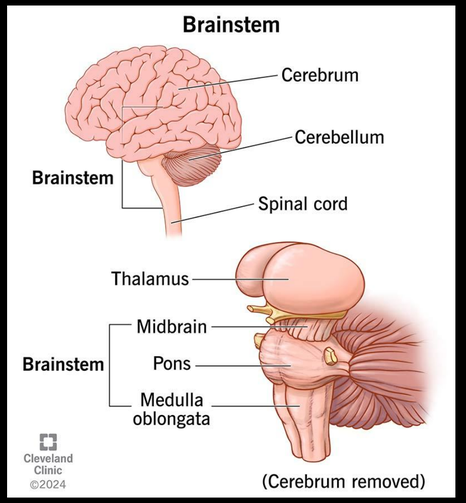
03 Brain Structures

Brainstem



1 **Structure**

Comprised of the midbrain, pons, and medulla oblongata

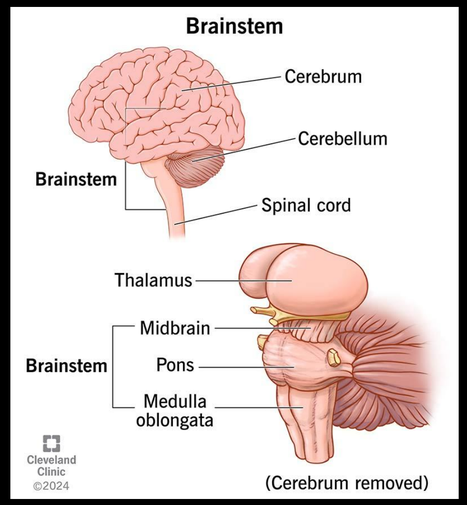


Function

Regulates essential life functions such as breathing, heart rate, and blood pressure; serves as a pathway for nerve fibres between the brain and spinal cord

03 Brain Structures

Brainstem



1

Structure

Comprised of the midbrain, pons, and medulla oblongata

Function

Regulates essential life functions such as breathing, heart rate, and blood pressure; serves as a pathway for nerve fibres between the brain and spinal cord

2 Components

Midbrain

Involved in visual and auditory processing; plays a role in motor control

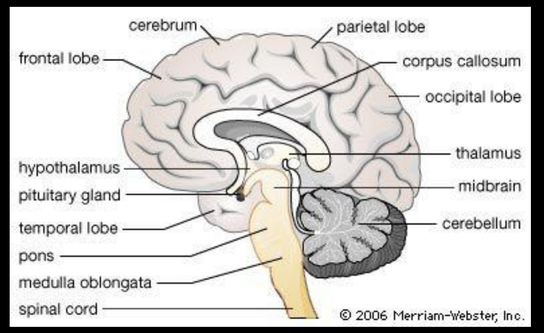
Pons

Connects different parts of the brain and regulates sleep and arousal

Medulla Oblongata

Controls autonomic functions and reflexes such as swallowing and heart rate

03 Brain Structures

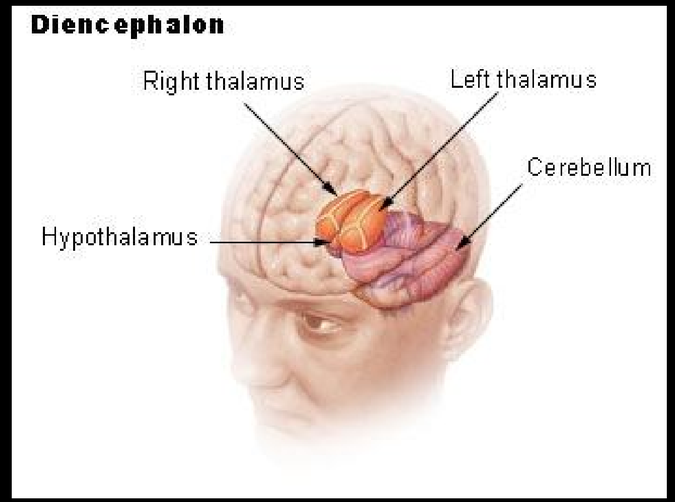


Diencephalon

1

Structure

Located beneath the cerebrum, includes the thalamus and hypothalamus



Function

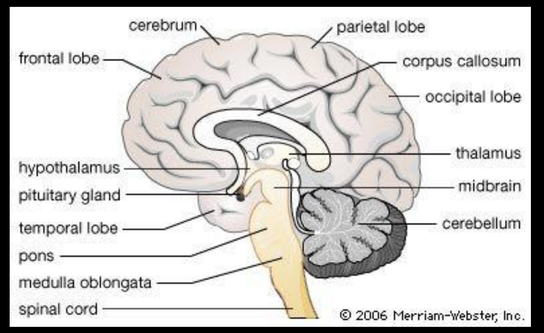
Thalamus

Acts as a relay station for sensory information; involved in consciousness and alertness

Hypothalamus

Regulates homeostasis, including temperature, hunger, thirst, and circadian rhythms; controls the endocrine system via the pituitary gland

03 Brain Structures



Limbic System

1

Structure

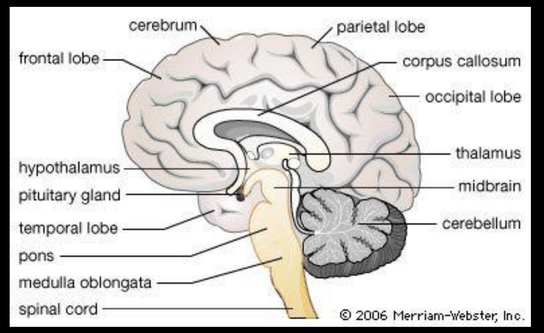
A complex system of structures including the hippocampus, amygdala, and parts of the thalamus and hypothalamus

Function

Plays a key role in emotions, memory, and motivation. The hippocampus is crucial for forming new memories, while the amygdala is involved in emotional responses

03 Brain Structures

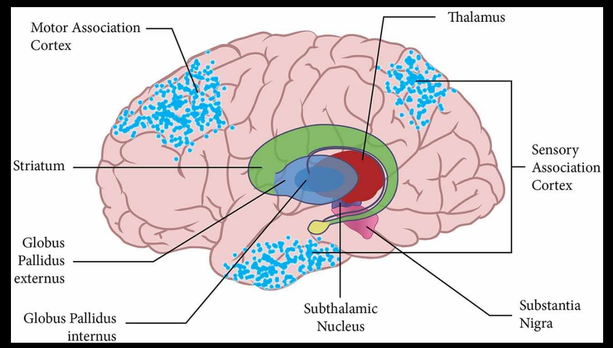
Basal Ganglia



2

Structure

A group of nuclei located deep within the cerebral hemispheres

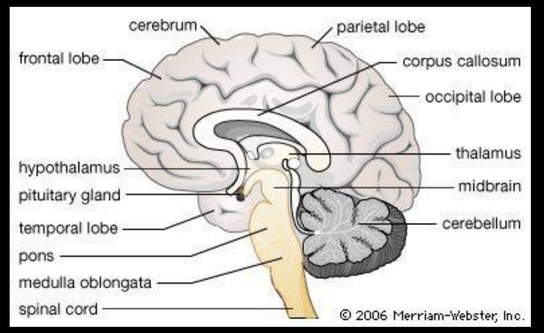


Function

Involved in the control of movement and coordination, as well as the regulation of voluntary motor movements, procedural learning, and routine behaviours

03 Brain Structures

Corpus Callosum



2

Structure

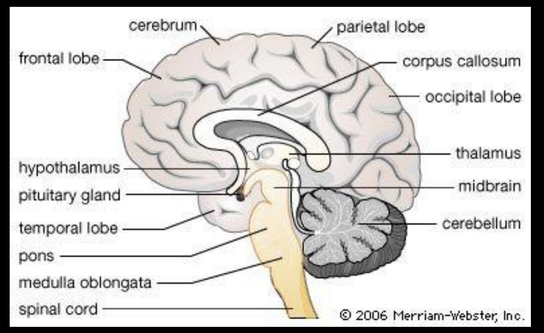
A large bundle of neural fibres connecting the left and right hemispheres

Function

Facilitates communication between the two hemispheres, allowing for coordinated functions and information sharing

03 Brain Structures

Ventricular System



2

Structure

Comprises interconnected cavities filled with cerebrospinal fluid (CSF)

Function

CSF cushions the brain, removes waste, and provides a stable chemical environment

1

Fun Fact: The ventricular system was incorrectly revered for 1,500 years as being the seat of thought, emotions, reasoning, and memory

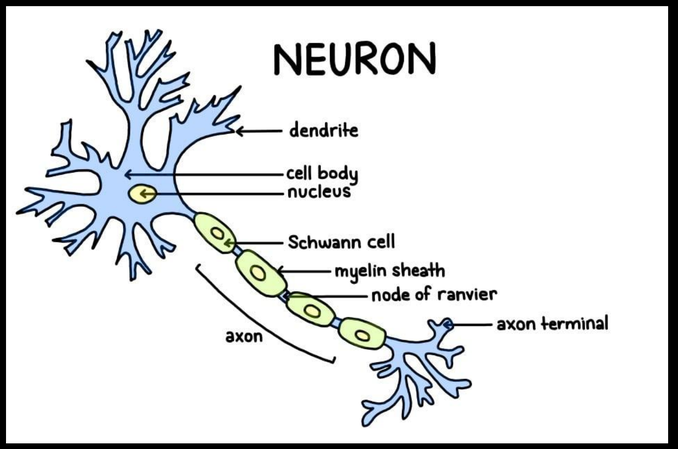
03 Brain Structures

The Structure of the Brain

03 Brain Structures

The Neuron

1 The neuron is the functional unit of the nervous system, responsible for transmitting information throughout the body via electrical and chemical signals



All neurons share a few main features

Dendrites
Branch-like structures that receive signals from other neurons

Cell Body (Soma)
Contains the nucleus and organelles, processing incoming signals

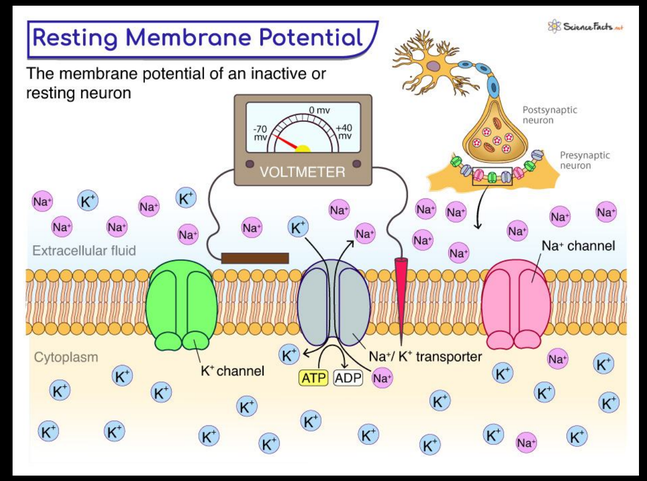
Axon
A long, slender projection that transmits electrical impulses away from the cell body

03 Brain Structures

Resting Potential

2

Resting potential is the electrical charge across a neuron's membrane when it is not actively sending a signal. Typically, this charge is around -70 millivolts (mV).



How it works

Ion Distribution

There are more sodium ions (Na^+) outside the neuron and more potassium ions (K^+) inside. This difference in ion distribution creates a negative charge inside the cell

Sodium-Potassium Pump

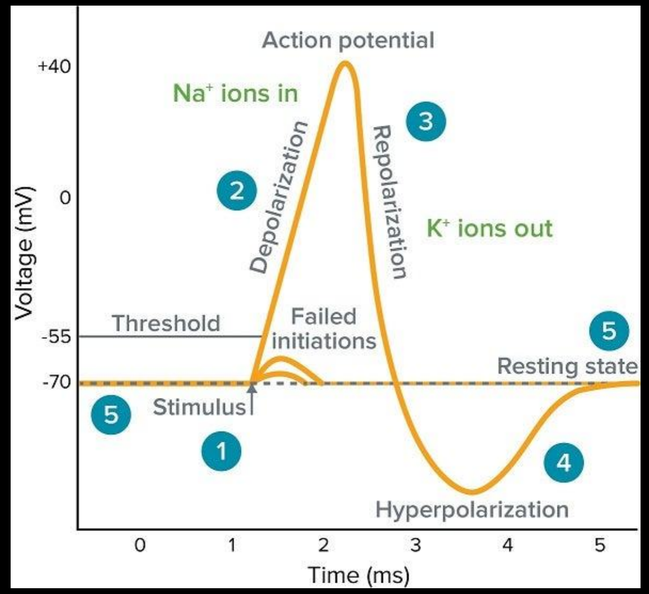
This pump actively moves Na^+ out of the cell and K^+ into the cell, helping maintain the resting potential

03 Brain Structures

Action Potential

2

An action potential is a rapid change in the electrical charge of the neuron that occurs when it sends a signal. It travels along the axon to communicate with other neurons



1. Stimulus

When a neuron receives a strong enough signal (above the threshold, usually around -55 mV), it triggers an action potential.

2. Depolarisation

Sodium channels open, allowing Na^+ to rush into the cell. This causes the inside of the neuron to become more positive (up to about +30 mV).

3. Repolarisation

After a brief moment, sodium channels close and potassium channels open, allowing K^+ to exit the cell. This restores the negative charge inside the neuron.

4. Hyperpolarisation

Sometimes, too much K^+ exits, making the inside of the neuron even more negative than the resting potential. This is a brief state before returning to resting potential.

03 Brain Structures

Synapse

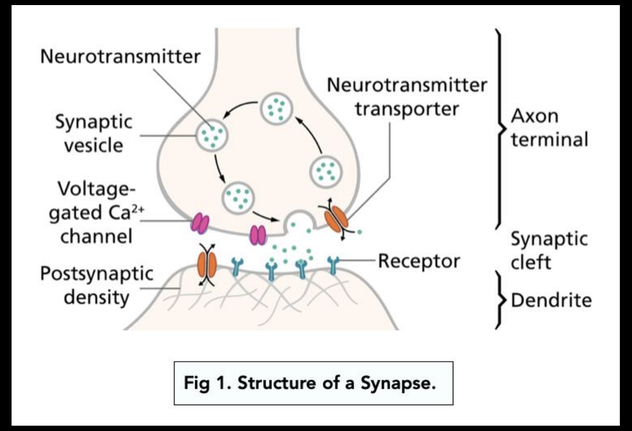


Fig 1. Structure of a Synapse.

2 A synapse is the junction between two neurons or between a neuron and another type of cell (like a muscle cell). It is where communication occurs, allowing signals to be transmitted from one cell to another

Stucture

Presynaptic Neuron
The neuron that sends the signal. It has a terminal known as the presynaptic knob or terminal

Synaptic Cleft
The small gap between the presynaptic neuron and the postsynaptic neuron (or target cell)

Postsynaptic Neuron
The neuron that receives the signal, which has receptors on its membrane

03 Brain Structures

3

Steps at a Synapse When an Action Potential Reaches the Presynaptic Knob

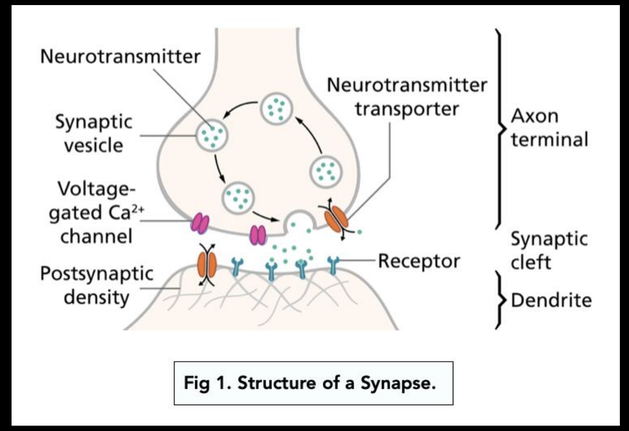


Fig 1. Structure of a Synapse.

1. Action Potential Arrival

When an action potential travels down the axon and reaches the presynaptic knob, it causes depolarization of the knob's membrane.

2. Opening of Voltage-Gated Calcium Channels

The depolarization triggers the opening of voltage-gated calcium (Ca^{2+}) channels in the presynaptic membrane.

3. Calcium Influx

Calcium ions rush into the presynaptic knob due to the concentration gradient (more Ca^{2+} outside than inside the cell).

4. Neurotransmitter Release

The influx of calcium causes synaptic vesicles (small membrane-bound sacs filled with neurotransmitters) to move toward the presynaptic membrane. They fuse with the membrane and release their contents into the synaptic cleft through a process called **exocytosis**.

03 Brain Structures

3

Steps at a Synapse When an Action Potential Reaches the Presynaptic Knob continued

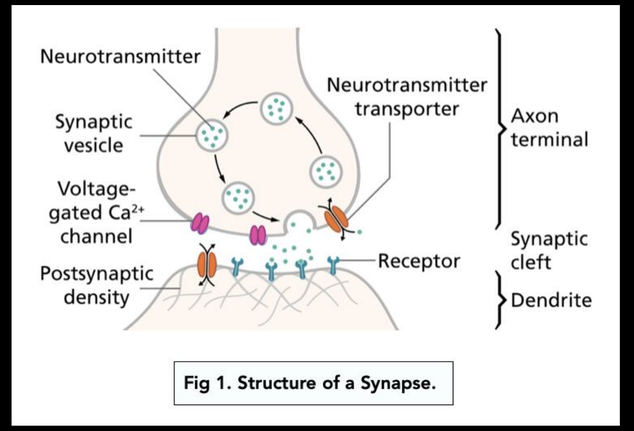


Fig 1. Structure of a Synapse.

1. Action Potential Arrival
2. Opening of Voltage-Gated Calcium Channels
3. Calcium Influx
4. Neurotransmitter Release

5. Neurotransmitter Diffusion

The released neurotransmitters diffuse across the synaptic cleft toward the postsynaptic neuron.

6. Binding to Receptors

The neurotransmitters bind to specific receptors on the postsynaptic membrane. This binding can either excite (depolarize) or inhibit (hyperpolarize) the postsynaptic neuron, depending on the type of neurotransmitter and receptor.

7. Generation of Postsynaptic Potential

If the binding of neurotransmitters results in enough depolarization, it can lead to the generation of a new action potential in the postsynaptic neuron.

8. Termination of Signal

The action of the neurotransmitters is terminated through:

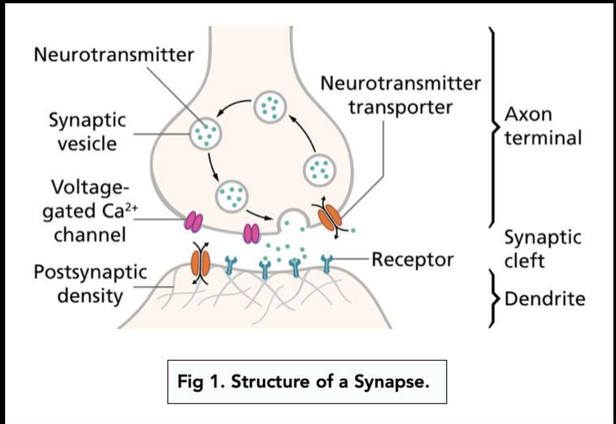
- Reuptake: Neurotransmitters are taken back into the presynaptic neuron for reuse.
- Enzymatic Degradation: Enzymes in the synaptic cleft break down neurotransmitters.
- Diffusion: Some neurotransmitters simply diffuse away from the synapse.

03 Brain Structures

3

Steps at a Synapse When an Action Potential Reaches the Presynaptic Knob

Quick Summary



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8. Termination of Signal

04 Philosophy of the Mind

04 Philosophy of Mind

Introduction to the Mind-Body Problem

At heart of the mind-body problem are two core questions:

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04 Philosophy of Mind

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The relationship between the **mental world** and the **physical world** is an open question in neuroscience and in all of human knowledge

04 Philosophy of Mind

Introduction to the Mind-Body Problem

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The relationship between the **mental world** and the **physical world** is an open question in neuroscience and in all of human knowledge

It has been debated for millennia, and has sprouted countless schools of thoughts

04 Philosophy of Mind

Dualism

Substance Dualism

Key Philosopher: René Decartes

The mind and body are fundamentally different substances

Reading: Meditations on First Philsophy
René Decartes

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Property Dualism

Key Philosopher: David Chalmers

Mental states are non-physical properties of physical substances

Reading: The Conscious Mind
David Chalmers

04 Philosophy of Mind

Monism

Reductive Physicalism

Key Philosopher: U. T. Place, J. J. C. Smart

Mental phenomena are fully reducible to physical processes

Reading: Is Consciousness a Brain Process?
U. T. Place

04 Philosophy of Mind

Monism

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Mental phenomena are fully reducible to physical processes

Reading: Is Consciousness a Brain Process?
U. T. Place

Eliminative Materialism

Key Philosopher: Patricia Churchland

Some mental states (e.g. beliefs) do not actually exist

Reading: Mental Events and the Brain
Paul Feyerabend

Monism (continued)

Idealism

Key Philosopher: George Berkley

Reading: Philosophical Works *George Berkley*

Only mental states really exist; the physical world is a construction of the mind

Functionalism

Functionalism

Key Philosopher: Hilary Putnam

Reading: The Nature of Mental States
Hilary Putnam

Mental states are defined by their functional roles rather than their physical make-up

04 Philosophy of Mind

Emergentism

Consciousness emerges from complex physical systems but cannot be reduced to them

Weak Emergentism

Key Philosopher: John Searle

Reading: The Rediscovery of the Mind (1992)
John Searle

Consciousness emerges from physical processes but remains dependent on the brain's structure

Strong Emergentism

Key Philosopher: C.D. Broad

Reading: The Mind and its Place in Nature (1925)
C. D. Broad

Consciousness emerges with unique properties that influence physical processes

Panpsychism

Panpsychism

Key Philosopher: Galen Strawson, David Chalmers

Reading: Is Consciousness Universal?
Christof Koch

Consciousness is a fundamental feature of the universe, present at some level in all things

Epiphenomenalism

Epiphenomenalism

Key Philosopher: Thomas Huxley

Reading: Epiphenomenal Qualia (1982)
Frank Jackson

Mental states are byproducts of physical processes and do not influence physical states

04 Philosophy of Mind

Why does philosophy of mind matter to Neurotech enthuasiasts?

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Questions from dualism or physicalism, for example, push us to ask whether machines might one day capture subjective experience, while functionalism and emergentism offer frameworks for designing and interpreting brain-computer systems

04 Philosophy of Mind

Resources

Stanford Encyclopedia of Philosophy: *https://plato.stanford.edu/*

The Blackwell Guide to Philosophy of Mind: *Available here*

Oxford Journal Online (database):

- ***Philosophy Quarterly***
- ***Mind***

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Interesting Topics and Reads

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- *Heidegger: Being In The World*
- *Gilbert Ryle: The Concept of Mind* (***The Category Mistake***!)

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Modern Approaches to Consciousness Research

Theories of consciousness[1]*, Seth. A & Bayne. T*

1. ***Integrated Information Theory (IIT)***
2. ***Global Workspace Theory (GWT)***

05 Thank you for joining us

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On The Mind Episode 1
ANDREAS SCHAEFER

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Fri **01 NOV** — Mind-Controlled Wheelchair Project brief
Dyson Level One, 6pm

Tue **05 NOV** — Onboarding Project Week 1
Dyson Level One, 6pm

Thu **07 NOV** — ARIA talk - Precisely interfacing with the human brain at scale: unlocking the next frontier in neurotechnologies
Jacques Carolan, Programme Director of ARIA Precision Neurotechnologies
Gillian Koehl, ARIA Neurotechnology Technical Specialist, ex-MRes Neurotech
RSM 1.31 (right here), 6pm

Advanced Research + Invention Agency ARIA