PL3232 Biological Psychology

Spring 2021

Section 1

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1.1. Nerve Cells and Impulses.

1.1.1. *Neurons and glia.*

(1) The nervous system is conposed of **neurons** and **glia**.

Glia cells include:

- astrocytes,
- radial glia,
- oligodendrocytes,
- Schwann cells, and
- microglia.

(2) Our brain contains many ($\sim 100+$) billions of neurons.

(3) A neuron has a **soma** (or cell body), **dendrites** (that receive input from other neurons), and **axons** (that send output to other neurons).

(4) Neurons communicate with each other using **synapses** (chemical signals are sent from the presynaptic cell to the postsynaptic cell).

- **Afferent** axons bring information *into* a structure.
- **Efferent** axons carry information *away* from a structure.
- **Interneurons** or **intrinsic neurons** have dendrites and axons which are completely contained within a single structure.

1.1.2. *Resting potential.*

(1) **Ohm's law** is given by $V = IR$.

(2) **Equilibrium potential** refers to the membrane potential that leads to zero net ionic current (i.e. equilibrium), given certain ionic concentrations.

- Chemicals can only pass through the neuronal membrane via certain channels embedded in it.
  - Uncharged molecules may cross freely through open channels.
  - Charged ions cross through membrane channels that only open sometimes (i.e. protein channels).
  - The **sodium-potassium pump** transports 3 Na^+ out of the cell and draws 2 K^+ into it.
- At rest, the neuronal membrane has **selective permeability** to K^+.
- The equilibrium/reversal potentials of different ions are different because of both *concentration* and *charge* differences,

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(3) **Resting membrane potential** refers to the membrane potential at which there is a zero net ionic current, when considering all ions.

At rest, the membrane potential is dominated by K^+. Because the conductance of K^+ is high (due to having many open channels), the membrane approaches the reversal (Nernst) potential of K^+, around -70 mV.

(4) The resting potential is advantageous because it prepares the cell for producing an AP quickly following a stimulus.

1.1.3. *Action potential.*

(1) **Action potential** is the rapid change in membrane voltage when a neuron depolarizes past its firing threshold.

- The **all-or-none law** states that the *amplitude* and *velocity* of an action potential are independent of the intensity of the stimulus that initiated it, provided that the stimulus reaches the threshold.
- However, note that subthreshold stimulation does produce a response, which quickly decays.

(2) **Depolarization** is driven by the opening of voltage-gated Na^+ channels.

(3) **Repolarization** is driven by the closing of voltage-gated Na^+ channels, and the opening of voltage-gated K^+ channels.

- After repolarization, the neuron **hyperpolarizes** slightly beyond the resting membrane potential, due to the voltage-gated K^+ channels being still open.

1.1.4. *Propagation of the AP.*

(1) The action potential propagates down the axon due to the diffusion of ions that enter during the depolarization phase.

- It also back-propagates into the soma and dendrites at its start.

(2) After the action potential, there is a **refractory period** over which it is impossible or harder to fire another action potential.

- The **absolute refractory period** is the period following an action potential, in which the neuron *cannot* fire another action potential (due to the closure of voltage-gated Na^+ gates).
- The **relative refractory period** is the period following an action potential, in which it is *harder* for the neuron to fire another action potential (due to hyperpolarization of neuron).

(3) **Myelin** insulates axons to increase their conduction speed for action potentials.

- It allows action potentials to jump from node to node down the axon, in a process called **saltatory conduction**.

1.2. **Synapses and neurotransmitters.**

1.2.1. *Properties of synaptic communication.*

(1) Most information from neuron to neuron is relayed through *chemical signals* across **synapses**.

(2) Presynaptic inputs can be **spatially** and **temporally** summed to activate the postsynaptic neuron. These inputs can be **inhibitory** (IPSP) or **excitatory** (EPSP).

- **Temporal summation** refers to the situation whereby repeated stimuli have a cumulative effect, and can produce a nerve impulse when a single stimuli is too weak.

- **Spatial summation** refers to the situation whereby synaptic input from several locations can have a cumulative effect and trigger a nerve impulse.
- Signaling across the synapse can produce a *localized graded change* in the post-synaptic membrane potential.
  - This can be an **excitatory post-synaptic potential (EPSP)**, i.e. a depolarization that makes the cell more likely to fire (due to Na^+).
  - It may also be an **inhibitory post-synaptic potential (IPSP)**, i.e. a hyperpolarization that makes the cell less likely to fire (due to K^+ or Cl^-).

  Most neurons have a *spontaneous firing rate*; EPSPs increase that frequency whereas IPSPs decrease it.

1.2.2. *Synapses and neurotransmitters.*

(1) **Electrical synapses** occur at specialzed sites called **gap junctions**, and they allow ions to pass directly from the cytoplasm of one cell to another.
   - They have relatively large pores.
   - They are bidirectional and fast-acting (i.e. often associated with escape reflexes).

(2) **Neuromuscular junctions** are large synapses that occur at axons that terminate on motor neurons in muscles and the spinal cord.
   - They are fast and reliable, and always generate an action potential.
   - They have a **motor end plate**, which increases their surface area.

(3) Neurotransmitters are packaged in the presynaptic axon terminal, and released (via exocytosis) to the synaptic cleft after an action potential reaches the presynaptic axon terminal.

(4) Receptors present in the membrane of postsynaptic cells bind to specific neurotransmitters. The binding causes:
   - the opening of ion channels in **ionotropic receptors**, or ligand-gated ion channels (these receptors mostly use glutamate and GABA), or
   - the activation of "second-messengers" in **metabotropic receptors**, or G-protein-coupled receptors (these receptors use a range of neurotransmitters).

(5) Neurotransmitters are removed from the synaptic cleft by **reuptake** into the presynaptic neuron, or **inactivation**.

1.2.3. *Neurotransmitter functions.*

(1) **Glutamate (Glu)** and **GABA** are amino acids that act as the primary excitatory and inhibitory neurotransmitters in the CNS, respectively.
   - However, note that Glu may inhibit neurons and GABA may excite neurons, albeit rarely.

(2) **Neuromodulatory systems** modulate the activity of the CNS by influencing larger groups of neurons in a more diffused manner (as compared to the 1-to-1 effect of classic synaptic transmission of Glu and GABA), and for a longer period.
   - **Noradrenaline** is produced by neurons in the **locus coeruleus**, and is thought to increase arousal and alertness (and is strongly associated with wake/sleep).
   - **Dopamine** is produced by neurons in the **substantia nigra** and **ventral tegmental area (VTA)**, and is thought to be important for the reward system (in terms of predicting rewarding outcomes), motor system, and cognition.
   - **Serotonin** is produced by neurons in the **dorsal raphe nuclei**, and is thought to be important for regulating mood and sleep.

- **Acetylcholine (ACh)** is produced by neurons in the **basal forebrain** and **pons**, and is thought to be important for learning, memory, reward, and arousal (and motor functions – it is found on motor endplates). It binds to nicotinic and muscarinic[1] receptors.

(3) **Neuropeptides** and **hormones** are other ways that the nervous system can transfer information, through release and diffusion around the neuron (neuropeptides) or through release into the bloodstream (hormones).

- Neuropeptides are often called *neuromodulators*.
- Their release requires repeated stimulation.
- They trigger other neurons to release the same neuropeptide.
- They diffuse widely and affect many neurons via metabotrophic receptors.

	Neuropeptides	**Neurotransmitters**
Place synthesized	Cell body	Presynaptic terminal
Place released	Mostly from dendrites, also cell body and sides of axon	Axon terminal
Released by	Repeated depolarization	Single AP
Effect on neighbouring cells	Release neuropeptide as well	No effect on neighbours
Spread of effects	Diffuse to wide area	Affects mostly receptors of adjacent postsynaptic cell
Duration of effects	Minutes	Milliseconds to seconds

FIGURE 1.1. Comparison between neuropeptides and neurotransmitters.

1.3. **Neuroanatomy and Research Methods.**

1.3.1. *Definitions.*

(1) **Anatomical planes** are hypothetical planes that transect (cut through) the body. They can be *sagittal/longitudinal*, *coronal/frontal*, or *horizontal/traverse*.

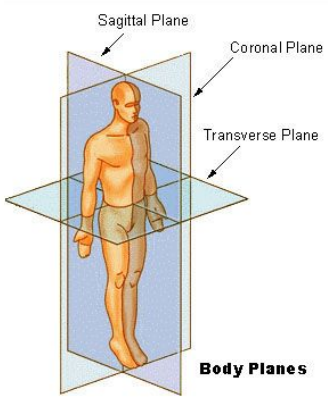

FIGURE 1.2. Anatomical planes of the human body.

[1] Related to sea-sickness.

(2) Anatomical terms of location indicate where, with respect to a landmark or a plane, is a region located.

Term	Definition
Dorsal	Toward the back, away from the ventral side.
Ventral	Toward the stomach, away from the dorsal side.
Anterior	Toward the front end.
Posterior	Toward the rear end.
Superior	Above another part.
Inferior	Below another part.
Medial	Toward the midline.
Lateral	Toward the sides.
Proximal	Located close to the point of origin/attachment.
Distal	Located more distant from the point of origin/ attachment.
Ipsilateral	On the same side of the body.
Contralateral	On the opposite side of the body.

(3) **Brodmann areas** were created based on *cytoarchitecture* (i.e. the cellular composition of brain tissue).

(4) Gross anatomical structures in the CNS may be described accordingly:

Term	Definition
Gyrus (Gyri)	Protuberance on the surface of the brain.
Sulcus (Sulci)	Fold or groove that separates one gyrus from another.
Fissure	Long, deep sulcus.
Nerve	Set of axons in the periphery of the CNS.
Tract	Set of axons within the CNS.
Ganglion	Cluster of neuron cell bodies, usually outside the CNS.
Nucleus	Cluster of neuron cell bodies within the CNS.

1.3.2. *CNS anatomy.*

(1) **Central Nervous System (CNS)** consists of the brain and the spinal cord, while the **Peripheral Nervous System (PNS)** consists of the ganglia and nerves outside the CNS.

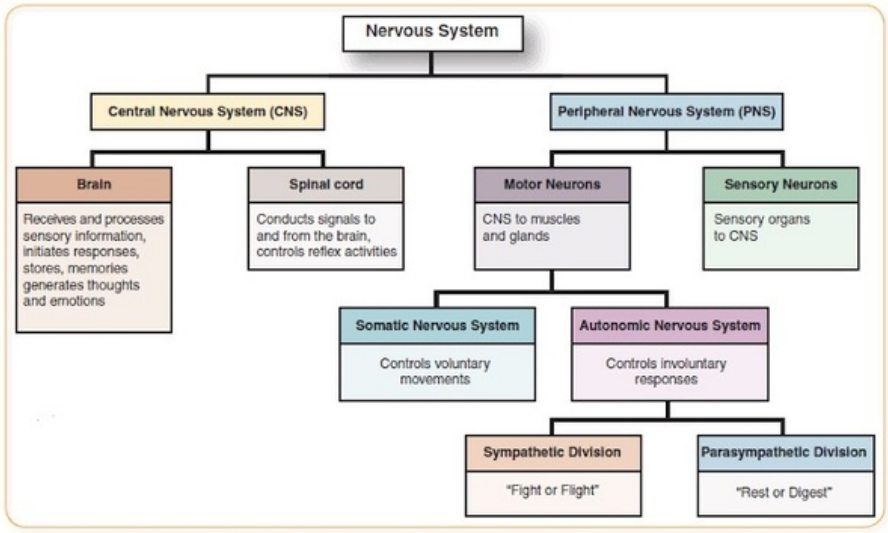

FIGURE 1.3. Flowchart summarizing the parts of the nervous system.

(2) **Gray matter** is where cell bodies are located, whereas **white matter** is where axonal fibers are located.

- Gray matter is located in the outermost part of the brain and the inner part of the spinal cord, whereas white matter is located in the inner part of the brain and outermost part of the spinal cord.

(3) The brain is divided into three sections: **forebrain**, **midbrain**, and **hindbrain**.

1.3.3. *Hindbrain and midbrain anatomy.*

(1) The **brainstem**, consisting of the **medulla**, **pons**, and **reticular formation**, is the most posterior section of the hindbrain, and is involved in the control of autonomous (involuntary) functions.

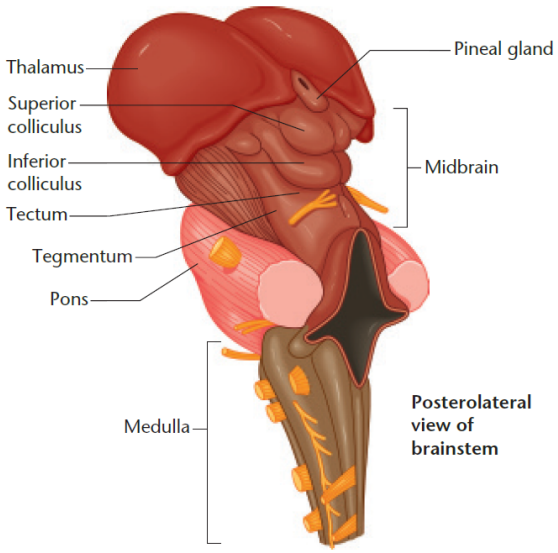

FIGURE 1.4. Anatomy of the brainstem.

We have 12 cranial nerves which are also involved in the control of autonomous functions; their nuclei are mostly located in the pons and medulla.

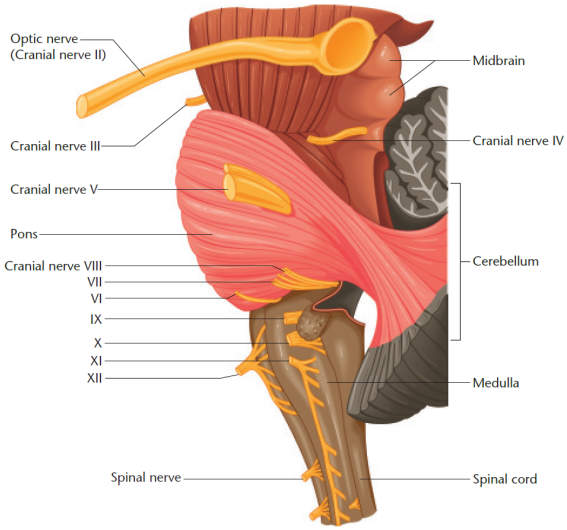

FIGURE 1.5. Cranial nerves in the human brain.

Name	Major functions
I. Olfactory	Smell
II. Optic	Vision
III. Oculomotor	Control of eye movements and pupil constriction
IV. Trochlear	Control of eye movements
V. Trigeminal	Skin senstations from most of the face and control of jaw muscles
VI. Abducens	Control of eye movements
VII. Facial	Taste from the anterior two-thirds of the tongue and control of facial expressions
VIII. Statoacoustic	Hearing and equilibrium
IX. Glossopharyngeal	Taste and other sensations from the throat and posterior third of the tongue, as well as control of swalling, salivation, and throat movements
X. Vagus	Sensations from neck and thorax and control of various parasympathetic nerves
XI. Accessory	Control of neck and shoulder movements
XII. Hypoglossal	Control of muscles of the tongue

(2) The **cerebellum** is primarily involved in motor control, but may also be involved in cognitive control.

(3) The **midbrain** is involved in visual, auditory, and oculomotor (i.e. eye motion) processing. It is also where **dopaminergic** ascending modulatory signals are generated.

- **Premotor nuclei:** generation of eye movements.
- **Superior colliculus:** processing of visual information relating to visual reflexes.
- **Inferior colliculus:** processing of auditory information.
- **Substantia nigra and VTA:** ascending modulatory source of dopamine.

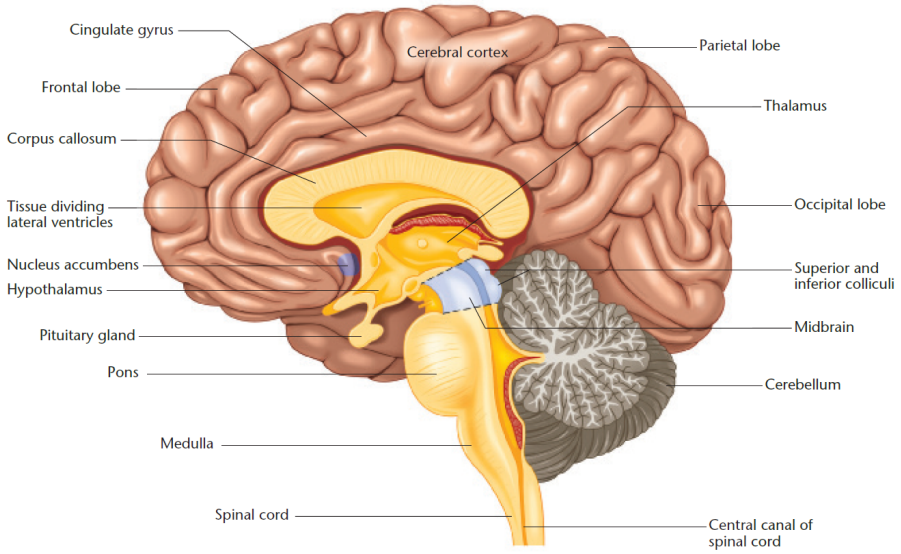

FIGURE 1.6. Sagittal view of the brain.

1.3.4. *Forebrain anatomy.*

(1) The **cerebral cortex** is a folded sheet which is divided into 4 lobes: *frontal*, *temporal*, *parietal*, and *occipital*. It is involved in sensory (perception), motor (action), and cognitive processing.

- Frontal lobe:
  - Movement (posterior)
  - Working memory and cognitive control (middle)
  - Value calculations and decision making (anterior)
- Parietal lobe:
  - Body sensations
  - Advanced visuospatial processing
- Temporal lobe:
  - Auditory processing
  - Advanced visual processing
- Occipital lobe:
  - Early visual processing

The central sulcus lies in between the frontal and parietal lobes, whereas the Sylvian fissure occurs nearby the temporal lobe.

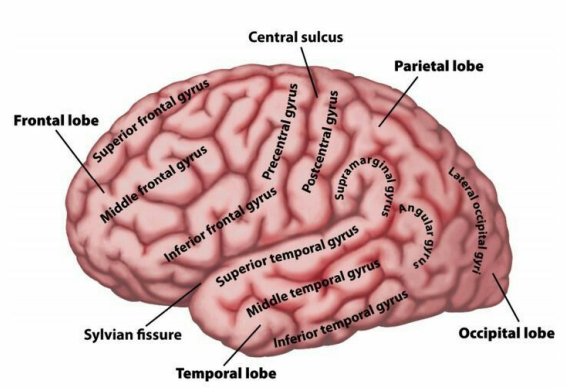

FIGURE 1.7. Positions of various gyri and sulci on the human brain.

(2) The **hippocampus**, **basal ganglia**, and **olfactory bulb** are parts of the forebrain involved in multiple functions, including learning, memory, sensation, movement control, and emotional processing.

- Hippocampus:
  - Memory consolidation
  - Spatial navigation
- Basal ganglia: major structures include the *caudate nucleus*, *putamen*, and *globus pallidus*.
  - Control of voluntary motor movements
  - Procedural learning
  - Cognitive control
  - Emotional processing

(3) The **thalamus**, **subthalamus**, **epithalamus**, and **hypothalamus** are a number of nuclei at the center of the brain, which (1) connect the cerebral cortex with other brain and peripheral regions, and (2) control the connections between the cerebral cortex and the rest of the nervous system.

- The thalamus is composed of multiple nuclei including:
  - **Lateral geniculate nucleus:** the first region to receive input from the retina.
  - **Medial geniculate nucleus:** receives auditory information.
  - **Pulvinar**
  - **Mediodorsal nucleus**
  - etc.

1.3.5. *Research methods in neuroscience.*

(1) **Neuroanatomical** methods that study the *structure* of the nervous system, range from subcellular to whole-brain for different levels of analysis, e.g.:

- Electron microscopy to study the connectome
- Staining techniques (Golgi) to study neuronal morphology
- Neuronal tracers to study the connectivity between areas
- MRI to study whole-brain axonal paths

(2) **Neurophysiological** methods that study the *function* of the nervous system, range from cellular to whole-brain for different levels of analysis, e.g.:

- Intracellular recording to study excitation and inhibition in single neurons
- Photon calcium imaging to study neuronal populations
- Lesion studies
  - However, as areas of the brain are not normally highly specialized, brain damage to a particular area does not usually produce specific impairments.
- EEG to study cognitive processing (via measuring average activity of cells in a given region of the brain)
- fMRI to study cognitive processing (via measuring the **Blood-Oxygen-Level Dependent (BOLD)** contrast)

(3) **Brain stimulation** techniques range from specific neurons to whole brain areas, to control or manipulate the activity of the brain, e.g.:

- Intracortical microstimulation:
  - Deep brain stimulation (DBS) to treat motor symptoms of Parkinson's Disease
- Non-invasive stimulation:
  - Transcranial magnetic stimulation (TMS) alters arm movements
  - Transcranial direct current stimulation (tDCS) to help patients with brain injuries or psychiatric conditions