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1 The Brain and Behavior

1.1 The Brain Has Distinct Functional Regions

The Central Nervous System Has Seven Main Parts

- ▷ **Spinal cord:** most caudal part of the central nervous system. It is subdivided into cervical, thoracic, lumbar, and sacral regions.
- ▷ **Brain stem:** consists of the medulla oblongata, pons, and midbrain. Relays input from the spinal cord and back, and controls input to and from the head.
- ▷ **Medulla oblongata:** rostral to spinal cord and includes several centers responsible for vital autonomic functions.
- ▷ **Pons:** rostral to medulla and conveys information about movement.
- ▷ **Cerebellum:** lies behind pons, modulates force and range of movement, and involved in learning motor skills.
- ▷ **Diencephalon:** lies rostral to midbrain and contains two structures, thalamus (processes information reaching cerebral cortex) and hypothalamus (regulates autonomic, endocrine, and visceral functions).
- ▷ **Cerebrum:** comprises two cerebral hemispheres, each consisting of wrinkled outer layer (the cerebral cortex), and three deep lying structures (basal ganglia, the hippocampus, and the amygdaloid nuclei).
- ▷ **Cerebral cortex:** divided into four distinct lobes— frontal, parietal, occipital, and temporal. The frontal lobe is largely concerned with short-term memory and planning, as well as movement; the parietal lobe with somatic sensation, forming a body image, and relating it to extrapersonal space; the occipital lobe with vision; and the temporal lobe with hearing—combined with deeper structures—with learning, memory, and emotion.

2 Nerve Cells, Neural Circuitry, and Behavior

2.1 The Nervous System Has Two Classes of Cells

- ▷ There are two main classes of cells in the nervous system: nerve cells, or neurons, and glial cells, or glia.
- ▷ A neuron has four defined regions:
 - **Cell body**: or *soma*, is the metabolic center of the cell, containing normal cell organelles.
 - **Dendrites**: branch out in tree-like fashion and are main apparatus for receiving signals.
 - **Axon**: extends some distance from a cell and carries signals to other neurons.
 - **Presynaptic terminals**: specialized enlarged regions of its axon's branches and is responsible for transfer of signals.
- ▷ **Principle of dynamic polarization**: electrical signals only flow in one direction in neurons.
- ▷ **Connectional specificity**: nerve cells do not connect randomly with one another in these formation of networks.
- ▷ Neurons are classified into three groups:
 - **Unipolar**: simplest due to single primary process, which gives rise to many branches. One branch as axon and others as receiving structures. These cells predominate invertebrates; they occur in the autonomic nervous system in vertebrates.
 - **Bipolar**: oval soma that gives rise to two processes: a dendritic structure that receives signals and an axon that carries information towards the central nervous system. Many sensory cells are bipolar, and pain receptors are pseudo-unipolar.
 - **Multipolar**: predominate nervous system of vertebrates and vary greatly in shape; typically containing a single neuron and many dendritic points emerging from various points around the cell body.

- ▷ Glial cells support nerve cells and greatly outnumber neurons.
- ▷ Glial cells surround the cell bodies, axons, and neurons and can be divided into two major classes:
 - **Microglia**: immune system cells that become phagocytes during injury, infection, or degenerative diseases.
 - There are three main types of **macroglia**: oligodendrocytes, Schwann cells, and astrocytes. About 80% of all brain cells are macrogalia.

3 Genes and Behavior

This chapter has been intentionally left blank, see genetic notes for more information.

4 The Cells of the Nervous System

This chapter was intentionally left blank, see cell biology notes for more information.

5 Ion Channels

5.1 Rapid Signaling in the Nervous System Depends on Ion Channels

- ▷ Up to 100 million ions can pass through a single channel each second, comparable to the turnover rate of the fastest enzymes, catalase and carbonic anhydrase.
- ▷ Each channel allows only one or a few types of ions to pass.
- ▷ Many open and close, however, some remain open resulting in significant contribution to resting potential.
- ▷ Ion pumps maintain gradients and are 100 to 100,000 times slower than channels.
- ▷ Questions for this chapter:
 - Why do nerve cells have channels?
 - How can channels conduct ions at such high rates and still be selective?
 - How are channels gated?
 - How are properties of these channels modified by various intrinsic and extrinsic conditions?

5.2 Ion Channels are Proteins That Span the Cell Membrane

- ▷ Cells have channels in order to transport ions across lipid bilayer easily and eliminate the need to be stripped of waters of hydration.
- ▷ The smaller the ion, the greater attraction to water, and the lower its mobility. This partially explains selection, but how does the inverse selection, that selecting of lower mobility, occur?
- ▷ Some ions bind to proteins that can transport them, but this is far too slow for some cases.

- ▷ An extension of pore theory says that channels have narrow regions that act as molecular sieves, where the ion sheds most of its water and only is let through by a binding to a specifically charged selectivity filter.

5.3 Ion Channels in ALL Cells Share Several Characteristics

- ▷ The opening and closing of a channel involve conformational changes.
- ▷ *Gating*: the transition of a channel between these stable functional states.
- ▷ Three major gating mechanisms:
 - Ligand: binding of chemical ligands known as agonists at either cellular site; transmitters on the extracellular; others that activate signaling cascades; and more.
 - Voltage-gated: changes in electrochemical changes as often as temperature sensors.
 - Mechanical stretch or physical changes in the membrane.

6 Electrical Properties of the Neuron

This chapter was intentionally left blank. No alternative notes, but may need to review chemistry and physics if this chapter is needed.

7 Propagated Signaling

7.1 Personal Notes

- ▷ The variety of voltage-sensitive ion channels and the influence of cytoplasmic factors may be analogous to bias/weights or other hyperparameters in neural networks.
- ▷ Genetic changes thus change these networks and may be how transfer learning takes place instead of starting from complete scratch for every organism.
- ▷ Innate abilities could represent earlier layers in the network and heavily genetically programmed, while later layers are given more time to develop based on environment.
- ▷ Can epigenetics have a relatively fast acting change on inherited intelligence?

The rest of this chapter has been left blank, as it is more of an extension of molecular genetics, which I may need to return to later to answer questions like those listed above.

8 Overview of Synaptic Transmission

8.1 Synapses Are Either Electrical or Chemical

- ▷ Average neuron forms and receive several thousand synaptic connections each, with the Purkinje cell of the cerebellum receiving up to 100,000.
- ▷ Both forms of transmission can be enhanced or diminished by cellular activity.
- ▷ Electrical synapses are used to send rapid stereotyped depolarizing signals.
- ▷ Chemical synapses are capable of more complex behaviors due to variable signaling.
- ▷ Most synapses are chemical.

8.2 Electrical Synapses Provide Instantaneous Signal Transmission

- ▷ Presynaptic terminals must be big enough for its membrane to contain many ion channels to trigger initial depolarization.
- ▷ Postsynaptic terminals must be relatively small in due to Ohm's law.
- ▷ Even weak subthreshold depolarizing currents can be carried to the postsynaptic neuron and depolarize it.
- ▷ Electrical synapses have a specialized region of contact called the gap junction, with separation of only 4 nm, bridged by gap-junction channels specialized to conduct ionic current.
- ▷ Electrical transmission can be used to orchestrate actions of large groups of neurons.
- ▷ Groups of electrically coupled cells allows for explosive reactions.
- ▷ Gap junctions are formed between glial cells as well as neurons.

8.3 Chemical Synapses Can Amplify Signals

- ▷ Chemical synapses are used to amplify or inhibit signals.
- ▷ The synaptic cleft is 20-40 nm wide and depend on the diffusion of neurotransmitters to carry out signaling.
- ▷ Neurotransmitters are clustered at speclized regions called *active zones*, which allow for selective activate of nearby postsynaptic receptors, which lead to the opening or closing of ion channels.
- ▷ Chemical synapses can be as short as 0.3 ms but often last several ms.
- ▷ Weak activations of chemical synapses can activate larger electrial synapses.
- ▷ The action of a transmitter depends on the properties of the postsynaptic receptor, not the chemical properties of itself.
- ▷ Neurotransmitters control the opening of ion channels in the postsynaptic cell either directly or indirectly.
- ▷ Indirect effects tend to last seconds to minutes and often modulate behavior due to alterations in the excitability of neurons and their synaptic connections.

9 Directly Gated Transmission

This chapter has been intentionally left blank. Unlikely to return to this chatper.

10 Synaptic Integration in CNS

10.1 Central Neurons Receive Excitatory and Inhibitory Inputs

- ▷ Generation of an action potential often requires the near-synchronous firing of a number of sensor neurons.
- ▷ Small inhibitory postsynaptic potential (IPSP), if strong enough, can counteract the sum of the excitatory actions and prevent membrane potential from reaching threshold potential.
- ▷ **Sculpting** function of synaptic inhibition that exerts control over action potentials in neurons that are spontaneously active due to intrinsic pacemaker channels, often completely shaping the firing patterns of cells.
- ▷ Most transmitters usually are inhibitory or excitatory despite being able to be either type.

10.2 Inhibitory Synaptic Action

- ▷ Inhibitory synapses play an essential role in the nervous system both by preventing too much excitation and by helping coordinate activity among networks of neurons.
- ▷ Inhibitory inputs that hyperpolarize the cell perform subtraction on the excitatory inputs, where those that *shunt* perform division.
- ▷ Adding or removing nonshunting inhibitory inputs results in summation, while the combination or excitatory with the removal of inhibitory shunt produces a multiplication.

11 Second Messengers

This chapter has been intentionally left blank. Molecular focused chapters may be reviewed later when a more narrow question needs to be answered.