CHAPTER 1

ORIGINS OF BEHAVIORAL NEUROSCIENCE

1.1 Prehistoric

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- Complications arise because they thought the heart contained the soul–you need it to live and emotions effect it.

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1.4.1 *Hippocrates*

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- Galen is a physician to gladiators.
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- Noticed there were large spaces (called "ventricles," or "spaces") that were filled with fluid.
- From here, we get the four humors (fluids).
- Galen thought that these fluids are what control the brain, NOT the brain structure itself. Think of the purpose of canned vegetables. The tin container does not actively contribute to the liquid / vegetables; rather, it is disposable.
- These ideas were jumpstarted by the invention of aqueducts. The movement of water was so important from aqueducts, so the idea this idea was extended to the brain.

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- *French* developed hydraulically controlled machines.
- Again, this is adding to the idea that liquids (which can flow through things and cause movements) are responsible for the brain's functionality.

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- Believed that non-humans–what he called animals–are controlled by fluid.
- From this, he posited that the human body is a material entity functioning as a machine (like animals)–these are known as reflexes.
- But, the mind is nonmaterial and free from the laws of the universe and was uniquely human.
- Question: How does the nonmaterial part of the body (the mind) communicate with the material part of the body? Through the pineal gland! This gland would move around like a joystick and would manipulate the fluid that came from the third ventricle.

1.8 The Mind/Body Problem

- What is the basic relationship between mental events and physical events?
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- Strengths: Commonsense view.
- Weaknesses: The universe is composed of matter or energy.
- Modern neuroscientific explanation: Everything the body does rests on the events taking place in specific, definable parts of the nervous system–the "mind" is the product of the nervous system activity.

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- A new world view at the end of the Renaissance.
  - Replace *Rationalism* with *Scientific Method*.
- Closer look at the substance of the brain:
  - Gray and white matter change the way we look at the brain. That is, why would these parts of the brain that are clearly different, be different if the brain is used just to move fluids around.
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- *Isaac Newton* showed it is possible to electrically stimulate nerves.
- Then, *Luigi Galvani* and *Emil du Bois-Reymond* showed that electricity can make muscles contract.
- Later on, *Hermann von Helmholtz* showed that the speed of nerve conduction is not instantaneous.
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- *Bell* and *Magendie* showed that the dorsal nerve root and the ventral nerve root are different.
  - Specifically, Bell showed that the ventral nerve root is for motor information, and Magendie showed that the dorsal nerve root is for sensory information.
- The dorsal nerve root is for sensory information, and the ventral nerve root is for motor information.
- *Dorsal* = *Sensory*: Think of the dorsal fin of a shark sensing vibrations in the water.
- *Ventral* = *Motor*: Think of a vent (like a car exhaust) pushing out movement.

- *Johannes Müller* came up with the doctrine of *Specific Nerve Energies*.
  - This doctrine states that the nature of a sensation depends on which nerve is stimulated, not on how the nerve is stimulated.
  - For example, if you stimulate the optic nerve, you will see something. If you stimulate the auditory nerve, you will hear something.
- Spawned the *Great Debate*: Is the brain a homogenous mass or is it made up of different parts?

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- *Franz Joseph Gall* and *Johann Spurzheim* thought the bumps and groves on the head were due to the size of the brain parts.
- They concluded that the size of the brain parts was correlated to the use of that part.
- This is known as *phrenology*.
- *Localization of Functions*–brain function can be localized to regions, pathways, or neurons.
  - Basically, if you cut out a piece of brain, and the animal (a pigeon) is no longer able to do a specific task, then that part of the brain is responsible for that task.
  - However, it turns out that these pigeons were able to relearn the task, so the brain is not as localized as we thought (this research is from Flourens).
- *Aggregate Field Theory*–the brain is a homogenous mass.
  - Complex brain functions emerge from the collective interactions of numerous simple neuronal activities.
  - Unlike localizationist models, this theory emphasizes the distributed nature of cognitive processes across neural networks.
- *Pierre Flourens* (1794–1867)
  - Studied the effect of brain damage with pigeons and supported the Aggregate Field Theory.
- *Paul Broca* (1824–1880)
  - Found a patient who *could speak* but could *not understand language*.
  - After the patient died, Broca found a lesion in the *left frontal lobe*.
  - This area is now known as *Broca's area*.
  - This area is responsible for *speech production*.
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- Then, we have *Gustav Fritsch* and *Eduard Hitzig* (1870)
  - Similarly to *Luigi Galvani* and *Emil du Bois-Reymond*, they electrically stimulated the brain.
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1.12 Same Resolution?

- *Modified Aggregate Field Theory*
  - *Karl S. Lashley* (1890-1958)
    - *The Principles of Mass Action*
      - Complex behavior–such as learning–is dependent on the total mass of the brain.
    - *Equipotentiality*
      - Specialization of function is not tied to specific brain regions.
      - All parts of the cortex contribute equally to complex behavior.
    - *Vicarious functioning*
      - If one part of the brain is damaged, another part can take over.

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    Table 1.1: Key Figures in the Great Debate: Localization vs. Aggregate Theory

Localization	**Aggregate Theory**
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Paul Broca	
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Gustav Fritsch	
Eduard Hitzig	

12. **Modified Aggregate Theory**: Karl Lashley emphasized mass action and equipotentiality.

Table 1.2: Key Scientists and Contributions

Scientist	**Contributions**
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SKIP CHAPTER 2

Most of the content from Chapter 2 has been blended with Chapter 3.

CHAPTER 3

STRUCTURE OF THE NERVOUS SYSTEM

3.1 Neuroanatomy

Neuroscience is the study of the nervous system. Behavioral neuroscience is understanding the nervous system's underlying behavior.

3.1.1 Nervous System Structure

Structural Nervous System

How are neurons organized into systems?

- **Central Nervous System (CNS)**
  - Brain
  - Spinal Cord
- **Peripheral Nervous System (PNS)**

Functional Nervous System

What are the 'jobs' of the nervous system?

- *Somatic Nervous System*
  - Skeletal Muscles (Striated)
  - Sensory information in
  - Voluntary motion out
- *Autonomic Nervous System*
  - Uses smooth muscles
  - Glands
  - Sympathetic Nervous System
    - Fight or Flight
    - Heart rate, blood pressure, respiration, and alertness.
  - Parasympathetic Nervous System
    - Rest and Digest
  - *Enteric Nervous System*

- A mesh-like system of neurons that governs the function of the gastrointestinal system.
- AKA: 'Second Brain'
- GI problems are correlated with psychological disorders.
- The GI track houses a lot of our microbiota.
- Fecal Microbiota Transplant
  - Rat studies showed that when a skinny rat has a fecal transplant from a fat rat, the skinny rat becomes fat. This works in reverse too.
  - Therefore, the microbiota change the *behavior* of the rat.
- Elevated Plus Maze
  - A test to measure anxiety in rats.
  - The rats with the fecal transplant from the anxious rats were more anxious.
  - **This is huge!** This shows that the microbiota can change if a rat is anxious or not!

3.2 Meninges

- Cover the outside of the nervous system.
  - Three for the CNS and two for the PNS.
  - The PNS does not use the arachnoid mater.
- *Dura Mater*
  - "Hard Mother"
  - The outermost layer.
  - Tough and fibrous.
  - Contains blood vessels.
  - Early anatomists called it "pachymeninges" because similar to elephant skin.
- *Arachnoid Mater* = "Spider Mother"
  - Middle layer.
  - Web-like structure.
  - Contains blood vessels.
  - Subarachnoid Space
    - Between the arachnoid and Pia mater.
    - Contains cerebrospinal fluid (CSF).
  - Arachnoid trabeculae

        - Web-like structures that connect the arachnoid mater to the Pia mater.
        - Allows for the subarachnoid space to be filled with CSF.
- *Pia Mater* = "Soft Mother"
    - Innermost layer.
    - Thin and delicate.
    - Flows over every sulcus (grooves), fissure (deep indentations), and gyri (bumps).
    - Follows the contours of the brain and spinal cord.
- *Meningitis*
    - Inflammation of the meninges.
    - Can cause symptoms such as headache, fever, a stiff neck, or hallucinations.

3.3 Cerebrospinal Fluid (CSF)

- Similar to blood plasma.
- Functions of CSF
    - Protection
        - Failures:
            - Brain is injured.
            - AND even Contrecoup–when the brain is injured on the opposite side of the impact–injuries.
            - *Chronic Traumatic Encephalopathy (CTE)*
                - Old name: Dementia Pugilistica (boxer's dementia).
                - Symptoms (not exhaustive): Memory loss, confusion, impaired judgment, impulse control problems, aggression, depression, Parkinson's-like symptoms, insomnia, and progressive dementia.
                - Causes ventricular enlargement. In other words, the larger your ventricles, the less brain matter you have.
                - Also causes atrophy of the fornix. The fornix is a C-shaped bundle of nerve fibers in the brain that acts as the major output tract of the hippocampus.
                - Tau are abnormally phosphorylated aggregate into tangles. They accumulate both inside neurons and even released into extracellular space.
    - The CSF also moves neurotransmitters, waste, hormones, nutrients, and other substances from one place to another.
        - For example, the CSF moves β-amyloid (in-between cells) from the brain to the blood.

- *Choroid Plexus*
  - *Ependymal cells*
    - Lines the lateral ventricles.
    - These are the cells that produce the CSF.
  - If the choroid plexus is not working properly, it can cause hydrocephalus.
  - *Hydrocephalus*
    - "Water on the brain"
    - Swelling of the brain due to the accumulation of CSF.
  - Derives from the Pia mater.

3.3.1 Flow of CSF

- *Lateral ventricles*
  - CSF is produced here and flows through the interventricular foramen.
- *Third Ventricle*
  - Looks like a duck's head.
  - Is connected to the *pituitary gland* through the *infundibulum*.
- The CSF routed through the medial longitudinal fissure and into the *Superior Sagittal Sinus*.
- *Interperducular Fossa*
  - The space between the two cerebral peduncles.
- *Interventricular Foramen*
  - Connects the lateral ventricles to the third ventricle.
- *Cerebral Aqueduct*
  - Connects the third and fourth ventricles.
- *Central Canal*
  - Connects the fourth ventricle to the spinal cord.
  - For remembering purposes, the *cerebral* aqueduct is in the *brain* and the central canal is in the spinal cord.
- *Subarachnoid Space*
  - Foramen of Magendie (Medial) and Luschka (Lateral)
    - Two tiny little holes in the fourth ventricle.

3.3.2 Dumping of CSF

- Arachnoid Villi/Granulations
  - Absorbed into blood stream from the superior sagittal sinus.

3.3.3 Getting Some CSF Out -or- Putting Something Into It

- Where would you have them stick that needle?
  - *Dural Sac*
    - Enlarged space in the lumbar region.
    - Testing and introduction of anesthetic agents.
    - Epi = Something in
  - *Lumbar Puncture*
    - AKA: Spinal Tap.
    - Tap = Taking something out

3.4 Cranial Nerves

#	Name	Type	Information Carried
I	Olfactory	S	Smell
II	Optic	S	Vision
III	Oculomotor	M	Eye movement, pupil constriction
IV	Trochlear	M	Eye movement
V	Trigeminal	B	Touch to face, motor control of mandibles
VI	Abducens	M	Eye movement
VII	Facial	B	Taste and facial expression
VIII	(Vestibulocochlear)	S	Hearing
IX	Glossopharyngeal	B	Taste and swallowing
X	Vagus	B	Taste and sensation from neck, thorax, abdomen, swallowing, control of larynx, parasympathetic nerves to heart and viscera
XI	Spinal Accessory	M	Movement of shoulders
XII	Hypoglossal	M	Movement of tongue

3.4.1 Mnemonic for Cranial Nerves

Old **Op**ie **oc**casionally **tr**ies **tr**igonometry **a**nd **f**eels **ve**ry **glo**omy, **vagu**e, **a**nd **hypo**active.

3.5 Terms

- Santiago Ramon y Cajal (1911)
  - Used the Golgi stain to show that neurons are separate cells.
- *Soma* – Cell Body
- *Dendrites* – "Branches"
  - Purpose is to increase the surface area of the neuron, so it can receive the most amount of information.
- *Axon terminal botton* – The ends of the neuron that send information.
- *Glial cells* – Support cells by insulating the axon for better communication.
- *Myelin sheath* – Insulates the axon.
- *Nodes of Ranvier* – Gaps in the myelin sheath.
- *Unmylinated axons* are called grey matter.
- *Ganglion* – A collection of cell bodies in the PNS.
- *Nerve* – A collection of axons in the PNS.
- *Nucleus* – A collection of cell bodies in the CNS.
- *Tract* – A collection of axons in the CNS.

Grey Matter	**White Matter**
Cell bodies Dendrites Unmyelinated axons	Myelinated axons

Table 3.1: Gray vs. White Matter

	Gray Matter	**White Matter**
Location	**Cell Bodies**	**Axons**
CNS	Nucleus	Tract
PNS	Ganglion	Nerve

Table 3.2: Differentiation of Gray and White Matter in the CNS and PNS

3.6 Brainstem

3.6.1 Hindbrain

- *Myenlencephalon*
  - *Medulla Oblongata*
    - Enlargement of the cord.
    - Lots of gray matter.
    - *Reticular Formation*
      - A network of nuclei.
      - Regulates sleep, wakefulness, and arousal.
      - Also regulates heart rate, blood pressure, respiration, and skeletal muscle tone.
    - *Pyramids*
      - Two ridges on the ventral surface.
        - Voluntary motor system.
    - *Olives*
      - Audition and motor learning.
      - Located on the lateral surface.
- *Metencephalon*
  - *Pons* – "Bridge"
    - White matter on the outside and gray on the inside.
    - *Locus Coeruleus*
      - Produces norepinephrine.
      - The norepinephrine is sent to the forebrain.
  - *Cerebellum*
    - Caudal portion of the brain.
    - Balance, hand/eye coordination, soothes movements.
    - Shifting attention between vision and hearing, sensory timing (judging rhythms), language, emotional control, and reward valuation.
    - Cerebellar agenesis – the cerebellum is not developed.

3.6.2 Midbrain

Mesencephalon

- *Techtum* = "Roof"
  - *Superior Colliculus* – Visual Reflexes
    - Pupils opening and closing in response to light.

- *Inferior Colliculus* – Auditory Reflexes
- Colliculus = "Little Hill"
- *Pineal Gland* – Melatonin

- *Tegmentum* = "Floor"
  - *Substantia Nigra* = "Black substance."
    - Get its black coloring from the creation of dopamine.
    - Clearly, this brain structure makes a majority of dopamine (1 of 3).
  - *Red Nucleus* – Motor coordination.
    - Get its red color from iron oxidation.
    - Connects to the cerebellum for that motor coordination.
  - *Periaqueductal Gray Area* – Opioids.
    - Peri = around, so peri-aqueductual = around-the cerebral aqueduct.
    - Handles endogenous pain relief.

3.6.3 Forebrain

Diencephalon

- *Thalamus*
  - Massa Intermedia = intermediate mass. This connects the two halves together.
  - Made up of many specific relay nuclei.
    - *Lateral Geniculate Nucleus* – Vision
    - *Dorsal Medial Nucleus* – Pain
      - Routes the pain from the thalamus to the prefrontal cortex.
  - . . . and of non-specific relay nuclei.
    - *Nucleus Reticularis* – Promotes wakefulness.
      - Goes to different parts of the brain, not just one specific part like the specific relay nuclei.
- *Hypothalamus*
  - Irregular shape, size of a thumbnail.
  - Encases the ventral part of the third ventricle.
  - **Survival of the individual**
    - Eating
    - Drinking (water)
      - Salt regulation
    - *Suprachiasmatic Nucleus*

        - Circadian rhythms
        - Daily fluctuations of temperature
    - **Survival of the species**
        - Territoriality
        - Sexual activity
        - Reproduction
    - **Integration of information**
        - Endocrine system
        - Autonomic nervous system

Telencephalon

- *Corpus callosum*
    - Connects the two hemispheres.
    - Remember that the neurons in this structure go from lateral to lateral, and not from dorsal to ventral.
    - Creates the roof of the lateral ventricles.
    - Agenesis of the cc
        - AKA: Callosal Agenesis
        - Vision impairments,
        - hypotonia,
        - poor motor coordination,
        - delays in motor milestones,
            - (Such as sitting and walking.)
        - cognitive disability,
            - (Disability in complex problem solving.)
        - and social difficulties.
            - (Missing subtle social cues maybe cause of impaired fair processing.)
    - *Corpus Callosotomy* – Split brain surgeries.
        - Used to treat epilepsy.
        - Gives information about lateralization of hemispheres.
        - **Left Hemisphere**
            - language
            - serial events
        - **Right Hemisphere**
            - creativity
            - synthesis

- *Basal Ganglia*
  - **Function:**
    - Initiation of Voluntary Movements.
    - Click here for Parkinson's continuation.
  - Curls laterally around the thalamus.
  - *Striatum*
    - *Caudate Nucleus* = "Nucleus with a Tail"
      - Obsessive Compulsive Disorder (OCD)
        - MIXED RESULTS
          - Too much activity, too large.
      - Romantic Love
        - Fisher, Aron, and Brown
          - Anthropologist used fMRI with a picture of neutral and romantic partners.
          - The CN activity was increased for loved one.
      - Larger in folks with incredible episodic memories (superior autobiographical memory).
        - How large? 7-8 SDs larger.
    - *Putamen* = "Shell"
    - *Nucleus Accumbens*
      - Nucleus Accumbens Septi = "Nucleus leaning against the septum."
        - Where the head of the caudate and the most anterior portion of the putamen come together.
        - Plays an important role in reinforcement, pleasure, and addiction.
  - *Globus Pallidus* = "Pale Globe"
  - *Note:* When people mention the putamen and the globus pallidus, they call it the lentiform nucleus.
- *Limbic System*
  - *Hippocampus*
    - In charge of moving memories from short-term to long-term.
    - Emotion, selective attention, learning, and memory.
  - *Amygdala*
    - In charge of emotions.
    - Fear and aggression, territoriality, odor processing, and sexual activity.
    - **Amygdala and Fear**
      - 1930's.

- Lesions to amygdala in monkeys.
- Many things happened...
  - Exploratory behavior of objects (put in mouth–hyperorality).
  - Hypersexuality.
  - Loss of fear.
    - Freezing, increased heart rate, hair standing on end, etc.
    - Lost their fear of the human experimenters.
- *Kluver-Bucy Syndrome*
  - Damaging the anterior temporal lobes.
  - Herpes encephalitis and trauma.
  - Loss of normal fear and anger responses.
- Facial mimicry
  - Seeing fear in others lead to fear expression.
  - AND has amygdala activity.
- **Other things**
  - Social networks (Bickart et al., 2010)
    - Size and complexity of social network + correlated with amygdala size.
    - MAYBE: More effectively identify, learn about, and recognize socioemotional cues.
  - Political views (Rees et al., 2011)
    - Took extreme liberals and extreme conservatives and found that the more extreme conservatives had a larger amygdala than the extreme liberals.
- **How burnout is related to your brain...**
  - Worse at suppressing negative emotions.
  - Big amygdala & weak connection to frontal lobe.

- *Cingulate Gyrus*
  - Selective attention.
  - Love (like the cingulate gyrus)
    - Same studies show increased activity for loved ones.
  - Pain.
    - Serves as alarm for distress
    - Association of the emotional components and the sensory components of pain.
    - Sympathetic pain (empathy).
    - Social rejection.
      - Eisenberger (1990s)
      - Cyberball

        - A computer game where you play catch.
        - The other players stop throwing the ball to you.
        - The cingulate gyrus lights up.
    - *Fornix*
    - *Mammillary Bodies*
    - *Septal Nucleus*

Cerebral Cortex

- Cortex = "bark"
- Many convolutions
    - Sulci/fissures
    - Gyri
- Gray matter.
- 6 Layers
- Four lobes
    - *Frontal Lobe*
        - Executive functions, motor control, and language production (Broca's area).
    - *Parietal Lobe*
        - Lips, toes, and spacial awareness.
    - *Temporal Lobe*
        - Memory, hearing, and language comprehension (Wernicke's area).
    - *Occipital Lobe*
        - Vision
    - **How they are separated:**
        - Frontal ↔ Parietal: *Central Sulcus*
        - Parietal ↔ Occipital: *Parieto-Occipital Sulcus*
        - Temporal ↔ Frontal/Parietal: *Lateral Sulcus (Sylvian Fissure)*
- *Nucleus Accumbens*

3.7 Parkinson's Disease

- *Bradykinesia*
  - Slowness of movement.
- *Akinesia*
  - Difficulty initiating voluntary movements.
- *Rigidity*
  - Increased muscle tone.
- *Tremors*
  - Involuntary shaking of hands and jaw most prominent at rest.

3.8 Alzheimer's Disease

- Progressive memory loss.
- Affects the cortex and hippocampus.
- Suffers from both retrograde and anterograde amnesia.

CHAPTER 5

METHODS AND STRATEGIES OF RESEARCH

Behavioral neuroscience research involves the efforts of science in many disciples, including physiology, neuroanatomy, biochemistry, psychology, endocrinology, and histology. An enormous array of research methods is available to researchers in behavioral neuroscience. The goal of this chapter is to provide an overview of the most common methods used in the field.

This chapter will mainly focus on the following research methods:

- Experimental Ablation
- Recording and Stimulating Neural Activity
- Neurochemical Methods
- Genetic Methods

Each research method has a multitude of techniques that we will explore in detail for each section.

5.1 Experimental Ablation

5.1.1 Terms

EVALUATING THE BEHAVIORAL EFFECTS OF BRAIN DAMAGE

- *Experimental Ablation* – Destroying a part of the brain and evaluating an animal's subsequent behavior. (Synonymous with *lesion study*)
- *Lesion* – The damaged tissue.

PRODUCING BRAIN LESIONS

- *Kainic Acid* – An excitatory amino acid that kills neurons by stimulating them to death.
- *Cannula* – A small metal tube.
- *Excitotoxic Lesions* (*ek sigh tow tok sik*) – A brain lesion produced by intracerbral injection of an excitatory amino acid, such as kainic acid.
- *Sham Lesions* – A placebo procedure that duplicates all the steps of producing a brain lesion except the one that actually causes the brain damage.

STEREOTAXIC SURGERY

- *Sterotaxic Surgery* (*stair ee oh tak sik*) – Brain surgery using a stereotaxic apparatus to position an electrode or cannula in a specified position of the brain.
- *Steotaxic Atlas* – A collection of drawings of sections of the brain of a particular animal with measurements that provide coordinates for stereotaxic surgery.
- *Bregma* – The junction of the sagittal and coronal structures of the skull; often used as a reference point for stereotaxic brain surgery.
- *Stereotaxic Apparatus* – A device that permits a surgeon to position an electrode or cannula into a specific part of the brain.
- *Deep Brain Stimulation* – A technique using sterotaxic surgery to implant a permanent electrode in the brain; used to treat chronic pain, movement disorders, epilepsy, depression, and OCD.

HISTOLOGICAL METHODS

- *Histological Methods* – Methods of preparing and examining brain tissue to determine the effects of behavior, injury, or disease.
- *Formalin* (*for mal lin*) – The aqueous solution of formaldehyde gas; the most commonly used tissue fixative.
- *Fixative* – A chemical such as formalin; used to prepare and preserve body tissue.
- *Microtome* – An instrument that produces very thin slices of body tissue.
- *Cryostat* – An instrument used to prepare very thin slices of body tissue inside a freezer chamber.
- *Immunocytochemical Method* – A histological method that uses radioactive antibodies or antibodies bound with a dye molecule to indicate the presence of particular proteins of peptides.
- *Transmission Electron Microscope* – A microscope that passes a focused beam of electrons through thin slices of tissue to reveal minuscule details.
- *Scanning Electron Microscope* – A microscope that provides three-dimensional information about the shape of the surface of a small object by scanning the object with a thin beam of electrons.
- *Confocal Laser Scanning Microscope* – A microscope that provides high-resolution images of various depths of thick tissue that contains fluorescent molecules by scanning the tissue with light from a laser beam.

TRACING NEURAL CONNECTIONS

- *Anterograde Labeling Method* – A histological method that labels the axons and terminal buttons of neurons whose cell bodies are located in a particular region.

- *Retrograde Labeling Method* – A histological method that labels cell bodies that give rise to the terminal buttons that form synapses with cells in a particular region.

STUDYING THE STRUCTURE OF THE LIVING HUMAN BRAIN

- *Computerized Tomography (CT)* – The use of a device that employs a computer to analyze data obtained by a scanning beam of X-rays to produce a two-dimensional picture of a "slice" through the body.
- *Magnetic Resonance Imaging (MRI)* – A technique whereby the interior of the body can be accurately imaged; involves the interaction between radio waves and a strong magnetic field.
- *Diffusion Tensor Imaging (DTI)* – An imaging method that uses a modified MRI scanner to reveal bundles of myelinated axons in the living human brain.

5.1.2 Evaluating the Behavioral Effects of Brain Damage

An example of experimental ablation (or lesion study) would be if, after part of the brain is destroyed, an animal can no longer perform tasks that require vision, we can conclude that the damaged area plays some role in vision. (See Johannes Müller and the doctrine of specific nerve energies for relevant information.)

What makes lesion studies so important, is that, we can distinguish between brain function and behavior. For example, reading involves functioned required for controlling eye movements, focusing the lens of the eye, perceiving and recognizing words and letters, comprehending the meaning of words, and so on. Some of these functions also participate in other behaviors; for example, controlling eye movement and focusing are required for any task that involves looking, and brain mechanisms used for comprehending the meanings of words also participate in comprehending speech.

CHAPTER 6

HOW NEURONS PROCESS INFORMATION

NEW NOTES FOR 02/26/25

6.1 The Neuron

- Definition: Basic information processing unit of the NS.
- Similarities to an animal cell:
  - *Cell membrane*: Separates the inside of the cell from the outside environment.
  - *Nucleus*: Contains the genetic material of the cell.
  - *Organells*: Carry out the basic functions of the cell.
    - *Mitochondria*: Produce energy for the cell.
    - *Endoplasmic Reticulum*: Synthesizes proteins.
    - *Golgi Apparatus*: Packages proteins for transport.
    - *Lysosomes*: Break down waste products.
  - Basic cellular processes.
- Differences:
  - Special "morphology" (shape).
  - Communicate through an electrochemical process.

6.1.1 Structure of the Neuron

(Mostly a recap of Terms)

- *Soma*
- *Dendrite*
- *Axon*
- *Terminal Arboriza* – Branches at the end of the axon.
- *Terminal Buttons* – End of the terminal arboriza.
- *Axon Hillock*
- *Myelin*

- Not all axons have it.
- Glial cells / 70% Lipid / Nodes of Ranvier.
- Mutliple Sclerosis (MS) – Demyelination.

6.1.2 Support cells in the Nervous System

- Glia/Glial Cells/ Neuroglia – Support cells.
  - Capable of cell division after birth/communication.
  - Make up half of the volume, but are 10-50 times more numerous. (The other half is made up of neurons.)
  - CNS:
    - *Macroglia* – Large glial cells.
      - *Astrocytes* – Star-shaped cells that provide physical support to neurons, clean up debris, and provide nutrients to neurons.
        - *Note* that these cells do not help neurons grow when they are damaged. In fact, they inhibit growth by proliferating and forming a scar.
      - *Oligodendrocytes* – "few branches (in contrast to Astrocytes)" – *Form* myelin sheath around multiple axons in the CNS.
    - *Microglia* – Small cells that remove debris from injured or dead cells.
    - *Ependymal Glia* – Line the ventricles of the brain and spinal cord. (Remember the CSF?)
  - PNS:
    - *Satellite Cells* – Provide nutrients and physical support to neurons.
    - *Schwann Cells* – Form myelin sheath around axons in the PNS. These cells are monogamists; they wrap their arms around one axon.
      - Neuronal Regeneration.
  - The Myelin Sheath is composed of Oligodendrocytes in the CNS and Schwann Cells in the PNS.
  - *Phagocytosis* – When an injury occurs, the glial cells divide and eat the dead cells. (Done by Microglia and Schwann Cells.)
  - Maintenance of Internal Consistency.
    - When neurons undergo rapid firing, they release potassium ions. Astrocytes absorb these ions to maintain the internal consistency of the neuron, and dump them into the blood stream.

NEW NOTES FOR 02/28/25

6.1.3 Are Glial Cells Contributing to Alzheimer's Disease?

- Normally,
  - Beta amyloid cleared away through microglia.
- IF beta amyloid builds up too much, Tau INSIDE cells builds up.
- This leads to inflammation, which maybe leads to the problems of Alzheimer's.

6.2 Different Kinds of Neurons

- Based on Structure
- Based on Function

6.2.1 Structural Classification of Neurons

- *Unipolar/Pseudounipolar*
  - *The difference:* The axon and dendrite are fused together.
- *Bipolar*
- *Multipolar*

6.2.2 Functional Classification of Neurons

- Sensory Neurons (Afferent)
  - Carry information from the sensory receptors to the CNS.
  - Unipolar.
  - "Afferent" – "bearing or conducting inward"
- Interneurons
- Motor Neurons (Efferent)
  - Carry information from the CNS to the muscles and glands.
  - Multipolar.
  - "Efferent" – "conducting outward"
- Remember: Ad = towards Ex = from Ferro = I carry.

6.3 Neural Communication

- **2 Systems of Neuronal Communication:**
  - *Binary* – All or none (literally only 2 options).
  - *Analogue* –Graded, matter or degree.

NEW NOTES FOR 03/03/25 (kinda)
We added a lot to the notes that we already had, so there is new material springled throughout this section.

6.3.1 Binary System ("Off" and "On")

- *The Resting Membrane Potential (RMP)*: "OFF"
  - Click here for a diagram.
  - *Note:* Where the arrows land on either side of the cell membrane is supposed to represent the relative permeability of the cell membrane to different ions.
  - -70 mV (relative to the outside).
  - Understand the cell membrane.
    - *Phospholipid Bilayer* – Hydrophobic tails and hydrophilic heads.
    - *Semipermeability* – Some things can cross, others cannot.
      - Lipid, lipid soluble, small, and neutral.
    - *Embedded Proteins* – Channels and pumps.
      - **4 Jobs We Care About:**
        - *Receptors*
          - High specificity and affinity.
          - "Places where things can bind to the cell and cause a change."
        - *Channels*.
          - *Gated Channels*:
            - Passive movement. The cell itself does not expel any energy to move the ions.
            - Chemical (ligand) gated channels.
            - Voltage gated channels.
        - *Pumps* – Active transport.
        - *Enzymes* – Facilitates chemical reactions.
          - Breaking neurochemicals down or putting them back together.
  - **3 Determinants of the RMP**
    - *Differential Permeability* – The cell membrane is more permeable to some ions than others.

- For sodium, the membrane only allows a trickle of Na^+ into the cell.
- Conversely, the membrane is more permeable to K^+ and CL^-. (K^+ is the most permeable.)

- **Driving Forces**:
  - *Diffusion* – Ions move from high to low concentration (Concentration Gradient).
    - *Note:* The cell membrane is more permeable to potassium ions than sodium ions.
  - *Electrostatic Pressure* – Ions move towards the opposite charge (Electrical Gradient).
  - *Equilibrium Potential* – The charge the ion "perfers" if it were the only one and could pass freely through the membrane.
    - This answers the question: "Why doesn't the cell get more and more negative?"
    - Driving force in (influx) = Driving force out (efflux).
    - $K^+ = -80$ mV and $Na^+ = +55$ mV.
- *Sodium-Potassium Pump* (Na^+/K^+ Pump)
  - 3 Na^+ out for every 2 K^+ in.
  - Costs 1 ATP.

- *The Action Potential (AP)*: "ON"
  - Click here for a diagram.
    - *Note:* The above diagram neglects to show that there can be *failed* attempts at an action potential wherein the threshold is not reached. In these cases, the charge of the cell can increase or decrease, but if it does not reach -55 mV, it will quickly settle back to its resting potential of -70 mV.
  - +40 mV (relative to the outside).
  - Thus, during an action potential, there is a total of 110 mV difference between the inside and outside the cell.

NEW NOTES FOR 03/05/25

- **Electrical Current**
  - *Depolarization*
    - A little
    - A lot
      - *Threshold of Excitation* = +15 mV.
      - Action potential
    - Even more.
  - *Repolarization*

        - A little
        - A lot
        - Even more.
    - *Refractory Period*
        - Cell is resistant to reexciation for a period after the AP peak.
            - *Absolute Refractory Period* – No amount of stimulation will cause another AP.
            - *Relative Refractory Period* – A stronger than normal stimulus is required to cause another AP. (This is because of hyperpolarization.)
    - **Three Questions:**
        - Why don't the Na^+ channels reopen during repolarization?
            - *Answer:* Because of the refractory period.
        - How can an all or none signal convey analog information?
            - *Answer:* The frequency of the APs can convey the intensity of the stimulus.
            - *Rate Law* – Variations in the intensity of a stimulus are represented by variations in the rate of firing.
        - Where does that signal come from that meets the threshold of excitation?
            - Refer to Conduction of Electrical Activity.

6.4 Conduction of Electrical Activity

6.4.1 Conduction of Hyper and (subthreshold) Depolarizations

- *Decremental Conduction* – The further the signal travels, the weaker it gets. (cable properties)
    - Analogue communication.
        - Degrading because for resistance and leakage.
    - *Passive Conduction* – No energy is expended.

6.4.2 Conduction of Action Potential in Unmyelinated Axons

NEW NOTES FOR 03/07/25

- *All or Nothing Law* – AP occurs or not once triggered, always the same size.
- *Active Regeneration* – The AP is regenerated at each point along the axon.
    - Takes a lot of time (< 1 - 10 meters/second).
    - Takes a lot of energy.

6.4.3 Conduction of Action Potential in Myelinated Axons

- *Saltatory Conduction* = "To jump" – AP jumps from node to node.
  - Decremental conduction in the myelinated portions.
    - No extracellular fluid.
    - Almost absent Na^+ channels.
  - Active regeneration at Nodes of Ranvier.
    - High density of Na^+ channels.
    - AP is regenerated.
  - **Advantages:**
    - Economic
      - Much less work for the Na^+/K^+ pump.
    - Speed
      - in excess of 100 m/s (225 mph) (not as fast as electricty's 300 million m/s).
    - So why not evolve 1 long myelin sheath?
      - *Answer:* The AP would be too weak from the decremental conduction by the time it reached the end.
  - Think of how this applies to multiple sclerosis: The myelin sheath is destroyed, and the AP can no longer jump from node to node. This results in a loss of sensation and motor control.

6.5 Conversion from Electrical to Chemical Signals

- Occurs at the synapse (Greek: "syn" = together, "haptein" = to clasp).
  - Synaptic cleft (200 angstroms (Å) across). *Note:* 10^7 Å = 1 mm.
  - Pre-synaptic membrane
    - *Golgi bodies* – Synthesize neurotransmitters and package them into vesicles.
    - *Synaptic vesicles* – Contain neurotransmitters.
      - In the pre-synaptic cell, the golgi bodies
    - *Docking proteins* – Hold the vesicles in place.
      - Full synaptic vesicles migrate to membrane and attach.
    - Voltage gated *Ca^{+2} channels* open.
    - Once the AP arrives at the synapse, the docking proteins release the vesicles and the neurotransmitters are released into the synaptic cleft (this is due to the Ca^{+2} channels opening).
  - Post-synaptic membrane
    - *Receptors* – Bind to the neurotransmitters.

NEW NOTES FOR 03/10/25

6.6 Conversion from Chemical Back to Electrical Signal

6.6.1 Two Kinds of Post Synaptic Potentials

- *Excitatory Post Synaptic Potentials* (ESPSs)
  - Bring the cell closer to firing.
  - i.e., opening of Na^+ channels.
- *Inhibitory Post Synaptic Potentials* (ISPSs)
  - Take the cell further from firing.
  - i.e., opening of K^+ channels (and potassium leaves).
- Thus, post synatpic into action potential by summing up of the EPSPs and IPSPs at the axon hillock.

6.6.2 What Happens to Excess or Used Neurotransmitters?

- **Three things can occur:**
  - *Active Reuptake* – The neurotransmitter is taken back up into the pre-synaptic cell.
  - *Metabolism* – The neurotransmitter is broken down by enzymes.
  - *Bound to Autoreceptors* – The neurotransmitter binds to autoreceptors on the pre-synaptic cell.
    - This inhibits the release of more neurotransmitters.

6.6.3 Two Types of Chemically Gated Channels

2 Kinds of Synapse: *ionotropic* and *metabotropic*.

6.6.4 *Ionotropic Synapse*

- No change in metabolism. (No ATM expended.)
- Direct change of ions.
- Fixed duration (rapid and short).
- 1 neurotransmitter binds to 1 receptor.
- **Example:** Acetylcholine (ACh) binds to a receptor and opens a Na^+ channel.

6.6.5 *Metabotropic Synapse*

- Actual change in cellular metabolism.
- Indirect exchange of ions.
- Variable duration (can be very long).
- At least 2 neuromodulator molecules bind to a receptor.
- **Example:** Dopamine binds to a receptor, which activates a G-protein, which activates an enzyme, which produces a second messenger, which opens a K^+ channel.
- **At the Metabotropic Synapse:**
  - Neuromodulator binds and initates process.
  - Alpha subunit of G-protien binds to *Adenylate Cyclase*.
    - Activating adenylate cyclase to convert ATP to *cAMP* (cyclic adenosine monophosphate).
  - cAMP activates *Protein Kinase A*.
    - Causing 2 subunits to dissociate.
    - Catalytic portion is no longer inhibited.
    - Allowing it to convert ATP to ADP.
      - This produces a phosphate group.
    - To end this process:
      - Neuromodulator dissociates to end cAMP production.
      - Enzymes
        - *Phosphodieterase* – Metabolizes residual cAMP
        - *Phosphoprotein phophatase* – Removes the phosphate and resets the channel.

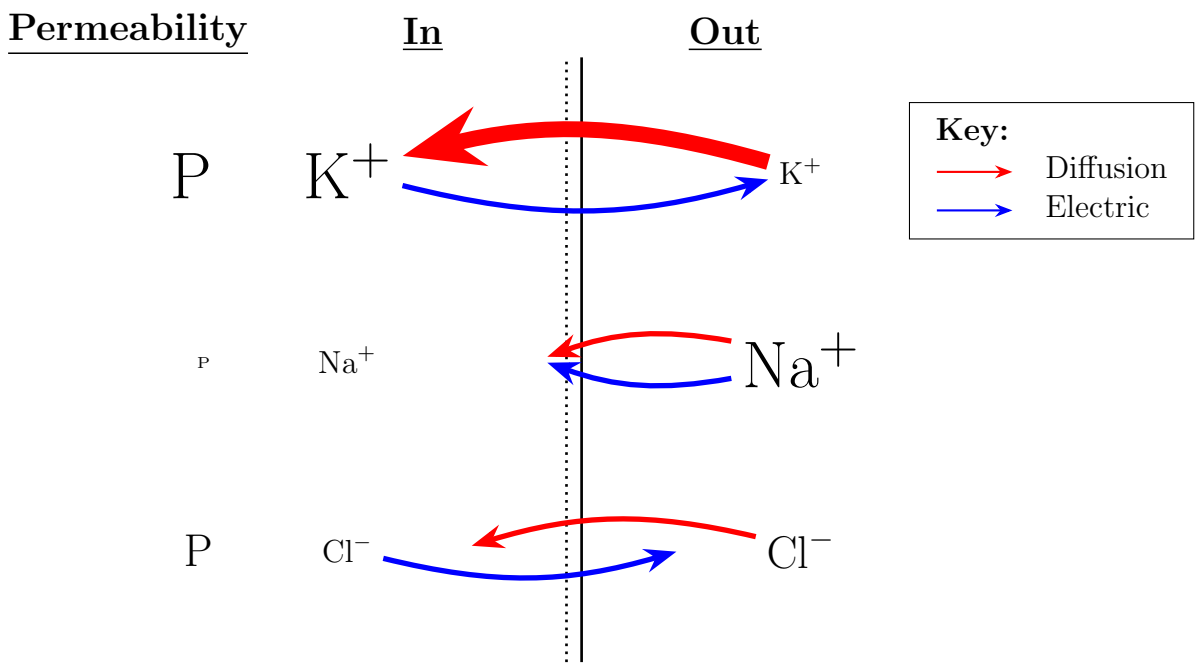

Figure 6.1: The Resting Membrane Potential (RMP) of a Neuron

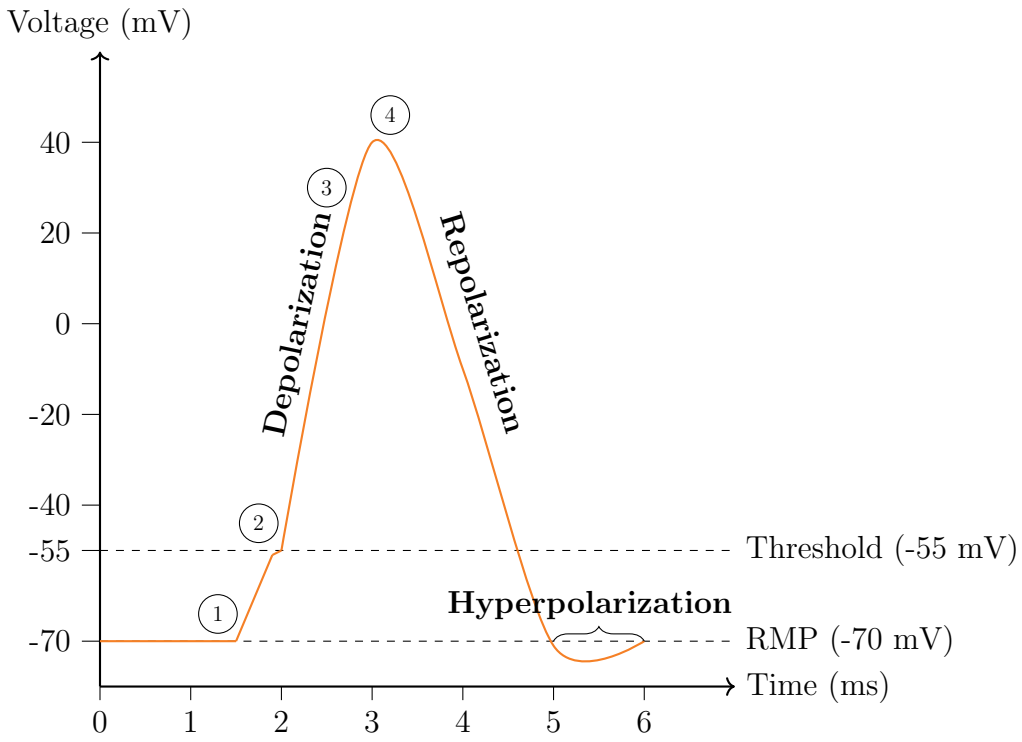

Figure 6.2: Action Potential Waveform