**Neurophysiology scripts**

**Slide 2:**

Nervous tissue is composed of two main classes of cells: **neurons** and **neuroglia**. Neurons are cells that carry out the communicative role of the nervous system, while neuroglia play varying supportive roles to help the neurons function effectively.

**Slide 3:**

**Neurons** require three fundamental properties that enable them to communicate with other cells:

1. Excitability: This refers to a cell’s ability to respond to stimulation (develop electrical excitement). All cells are excitable to some degree, but neurons exhibit this property to the highest degree.

2. Conductivity: This refers to a cell’s ability to transmit its excitement along its entire length toward other cells.

3. Secretion: In order to communicate and stimulate the next cell, neurons must produce and secrete a neurotransmitter. This is a chemical used to cross the cleft between the neuron’s end and the beginning of the next cell to effectively transfer its electrical signals.

**Slide 4:**

There are three major classes of neurons:

1. Sensory neurons detect stimuli (pressure, temperature, light, sound, chemicals) in and around the body and transmit information about them to the central nervous system (CNS).

2. Interneurons are found exclusively in the CNS and receive and integrate signals from other neurons. They process, store, and retrieve information. About 90% of all neurons in the body are interneurons!

3. Motor neurons send signals from the CNS out to various target cells in the body (muscle cells and gland cells).

**Slide 5:**

You can follow the path of the neural signal in this illustration. The sensory neurons detect a stimulus in your finger and send that information to the CNS. The interneurons determine that your finger needs to move and send an appropriate response to the motor neuron. The motor neuron then sends the message to the muscle that will move your finger.

This illustration can be found on page 438 in the Saladin textbook.

**Slide 6:**

The motor neuron is used to learn about the structures commonly found within any neuron. Motor neurons have three major areas: the soma, the dendrites, and the axon.

The soma is the control center for the cell. It frequently is stellate in appearance (star-shaped) and contains the nucleus and other organelles we typically find in any cell. In terms of communication, the soma’s role is to receive information from its dendrites, integrate that information, and potentially transmit a response down the axon to its target cells.

The dendrites are a series of widespread, branched extensions off of the soma that receive signals (in the form of neurotransmitters) from other neurons. These signals are then conducted along the dendrites toward the soma in the form of electrical signals.

The axon is a long, thicker extension off of the soma that approaches the motor neuron’s target cells (which can be anywhere from a few millimeters away to over a meter away). It’s role is to conduct a strong electrical signal (called an action potential) from the soma to the target cells to elicit a response from them.

This slide has an illustration showing these three main regions of a motor neuron.

It is a form of the illustration found on page 439 in the Saladin textbook.

**Slide 7:**

The axon of a neuron has a few specific areas and components to it that are significant.

The axon hillock is the region where the soma narrows to become the axon. It is within this area that the neuron generates an electrical signal to transmit down its axon to its target cells; it also is referred to as the trigger zone.

Because neurons typically have several target cells with which they communicate, the end of the axon splits as it nears its target cells, allowing it to share its electrical signals with its targets. This area of the axon is referred to as the terminal arborization.

At the end of each branch of the terminal arborization is a widened end to the branch called a synaptic knob. As mentioned in the muscle chapter, these knobs contain neurotransmitters that are released from synaptic vesicles across the synaptic cleft to transmit the electrical signals to the target cells.

This slide has an illustration of a motor neuron, showing these specific regions along the axon. It is a form of the illustration found on page 439 in the Saladin textbook.

**Slide 8:**

Motor neurons also have a few significant structures associated with them that arise from their interaction with another type of nervous tissue cell called a Schwann cell. Schwann cells are a type of neuroglial cell that play a supportive role in the transmission of electrical signals down the axons of motor (and sensory) neurons. During development, Schwann cells approach the axons of PNS neurons and wrap themselves repeatedly around them. As they enwrap the axon, they leave behind an inner layer called the myelin sheath, composed of a lipid-protein called myelin. This layer helps to insulate the electrical signal, and as the signals pass through the myelinated areas, they actually speed up. When a Schwann cell finishes its myelin sheath, it creates one last outer layer called the neurilemma. This layer acts as a guide to help a damaged axon heal and follow its original path back to its target cells.

This slide has an illustration showing the creation of the myelin sheath and neurilemma by a Schwann cell around an axon. In the top left, the Schwann cell approaches and attaches to the axon. In the next two illustrations, the Schwann cell wraps itself repeatedly around the axon, leaving behind more and more of itself. In the final, lower right illustration, the Schwann cell has completed its wrapping, having created an inner myelin sheath and an outer neurilemma around the axon.

This illustration can be found on page 445 in the Saladin textbook.

**Slide 9:**

The Schwann cells have to make sure that they leave a small amount of axon unmyelinated between each other; this gap of exposed, uninsulated axon is referred to as a Node of Ranvier. Here you can see how several Schwann cells have enwrapped the axon down its length and have left gaps of unmyelinated axon (nodes of Ranvier) between themselves.

A form of this illustration can be found on page 439 in the Saladin textbook.

**Slide 10:**

As mentioned earlier, there are two types of cells in the nervous system: neurons and neuroglial cells. Neuroglial cells don’t transmit electrical signals like the neurons do, but they provide various supportive roles to the neurons and the nervous system overall. There are 6 major types of neuroglial cells:

1. Oligodendrocytes are found in the CNS and provide the myelin sheaths for the axons of neurons within the CNS. Rather than wrapping themselves entirely around the axon as the Schwann cells do in the PNS, oligodendrocytes position themselves near several neurons and reach out with extensions of themselves to wrap small regions of the axons with myelin. Unlike the Schwann cells, oligodendrocytes do NOT create a neurilemma layer; therefore, CNS axons that become damaged and need to regrow do not have the benefit of a guiding neurilemma layer to reestablish their previous connections to each other.

2. Ependymal cells are also found in the CNS. They reside along the internal cavities of the brain and spinal cord, where they produce cerebrospinal fluid (CSF) and use their cilia to help circulate it.

3. Microglia are macrophages that wander throughout the CNS, phagocytizing dead tissues, microorganisms, and other foreign material.

4. Astrocytes, also found only in the CNS, are the most abundant neuroglia in the body. They perform several functions, including supporting the framework of the interconnecting neurons, stimulating the capillaries of the brain to form a prohibitive, protective blood/brain barrier, and monitoring and maintaining the overall health of the neurons in the CNS.

5. Schwann cells provide myelin and the neurilemma for PNS axons.

6. Satellite cells are found around the somas of neurons in the PNS and provide a supportive role still being explored.

**Slide 11:**

Here is a diagram of the neuroglial cells in relation to neurons. The ones shown here are the four found in the CNS: ependymal cells are shown to the left in a tight line, producing CSF; astrocytes are shown sitting between a capillary and neuron, using numerous extensions of itself to limit the interactions between them; oligodendrocytes sitting between neighboring neurons, using extensions of themselves to provide regions of myelin around their axons; and microglia patrolling the spaces between the neurons.

This illustration can be found on page 443 in the Saladin textbook.

**Slide 12:**

How do neurons generate and transmit electrical signals? The answers to this question are related to the electrophysiology of the neuron. First, we have to understand what an **electrical potential** is and what a **current** is.

An **electrical potential** is a difference between the concentration of charged particles between one point and another. If there is no difference in charged particles between two points, then there is no electrical potential.

**Slide 13:**

In this slide, you can see the space has been sectioned into a left and right chamber. In the first example, the left chamber contains 5 cations, and the right chamber contains 1 cation. This means that there is a difference in charge between the two chambers, so an electrical potential exists along that dividing wall. In the second example, the left chamber contains 3 cations, and the right chamber contains 3 cations. Since there is no difference in charge between the two chambers, the dividing wall between them experiences no electrical potential.

**Slide 14:**

An electrical current is a flow, or movement, of charged particles from one point to another. In the first example above, we again see the area with two divided chambers; on the left, there are 5 cations, and on the right there is 1 cation. In this state, the dividing wall between them is experiencing an electrical potential but no current. In the second example above, arrows imply that some of the cations in the left chamber are able to cross through the dividing wall to the right chamber. This movement means that an electrical current now exists at the wall.

**Slide 15:**

In the case of neurons, the concept of electrical potentials and currents plays out at the neuron’s plasma membrane. The question of whether a difference in the concentration of charged particles exists between two points is in reference to the extracellular fluid (ECF) and the intracellular fluid (ICF). In other words, is there a difference in the concentration of charged particles between the fluid outside of the neuron and the fluid inside of the neuron? If so, then the dividing wall (the neuron’s plasma membrane in this case) experiences an electrical potential. The role of charged particles is played by sodium ions (+), potassium ions (+), and cellular proteins (-).

This slide has an illustration showing the relative concentrations of the ions in the ECF and ICF. The way this picture is set up, the **ECF** chamber has an abundance of **sodium ions**, which have a **positive charge**. The **ICF** has an abundance of **potassium ions**, which also have a **positive charge**, but the additional presence of **negatively-charged** **proteins** in the ICF cancels a significant amount of the potassium ions’ positive charges. In addition, the plasma membrane is more permeable to potassium ions, and they tend to diffuse through the membrane from the ICF to the ECF to some degree on a regular basis. Therefore, a difference exists at the plasma membrane: **the fluid on its ECF side has a significant positive charge to it, and the fluid on its ICF side has a negative charge to it**. As we learned earlier, this difference between the two fluids means an electrical potential exists at the plasma membrane.

This illustration is found on page 449 in the Saladin textbook.

**Slide 16:**

As we saw, the electrical potential of the plasma membrane occurs because of the difference between the positive charge of the ECF (due to sodium ions) and the negative charge of the ICF (due to proteins that cancel much of the potassium ions’ charge). But how do the ions come to be in this state in the first place? Within the plasma membrane of a neuron are sodium/potassium pumps, proteins that use ATP to actively transport sodium ions out of the neuron at the same time as they actively transport potassium ions into the neuron. These pumps run non-stop, and it is their action that causes the cations to be in the concentrations that they are on either side of the plasma membrane. As mentioned in the previous slide, the cation distribution is also somewhat affected by the diffusion of potassium ions through their gates from the ICF to the ECF. Technically, there are potassium ions out in the ECF and sodium ions in the ICF, but for the sake of understanding electrical potentials and currents, it is easier to consider them according to where they are most concentrated.

This slide has an illustration at the bottom, showing a plasma membrane with a sodium/potassium pump. It shows the pump using ATP to actively-transport sodium ions out of the ICF and potassium ions into the ICF.

**Slide 17:**

The actual value of the ICF’s charge can be measured. When a neuron is “at rest” and is capable of and ready to send a signal down its length, the ICF has a measured value of **-70 mV**. This value is referred to as the **resting membrane potential**.

**Slide 18:**

Summary:

1. A neuron uses sodium/potassium pumps to continually make sure that sodium ions exist in a higher concentration in the ECF and that potassium ions exist in a higher concentration in the ICF.
2. While these ions are both positive, the potassium ions in the ICF contend with negatively-charged proteins, which means that the ECF has a positive nature to it, and the ICF has a negative nature to it. . In addition, the ECF is more positive due to the diffusion of potassium ions to some degree through the plasma membrane.
3. This difference on the two sides on the plasma membrane means an electrical potential exists at the membrane, called the resting membrane potential, which leads to a -70 mV value for the ICF while the neuron is in this ready/at rest state.

This slide has an illustration at the bottom, showing a plasma membrane with a sodium/potassium pump. It shows the pump using ATP to actively-transport sodium ions out of the ICF and potassium ions into the ICF to help set up the resting membrane potential of -70 mV in the ICF.

**Slide 19:**

One last description about a neuron at rest has to do with how to describe the state of the plasma membrane. The fact that there is a charge difference between the ECF and ICF establishes that there is an electrical potential at the plasma membrane, and the fact that the ICF has a value of -70 mV tells us the membrane has specifically achieved its resting membrane potential. In this state ( sodium ions outside, potassium ions inside, ICF = -70 mV), the membrane is said to be in a **polarized** state.

**Slide 20:**

Now let’s consider the generation of electrical signals in this system. The signals that travel along the plasma membrane of a neuron are actually currents, or movements of sodium and potassium ions into and out of the ICF. These currents are disruptions to the membrane’s polarized state and the resting membrane potential, and they can be stimulated via various methods: chemicals, light, changes in temperature, pressure, etc.

**Slide 21:**

The sodium/potassium pumps are constantly using ATP to maintain the resting membrane potential and polarized state of the plasma membrane. However, to send electrical signals, the ions need to be allowed to diffuse across the membrane to generate a current that can be repeated down the length of the membrane. The presence of sodium gates and potassium gates in the plasma membrane provides a way for ions to move when a signal is desired. **Gates** are membrane proteins that are specific to certain substances and can be in a closed state (in which the substance can NOT diffuse through the gate) or open state (in which the substance CAN diffuse through the gate). While at rest, the neuron’s sodium gates and potassium gates are closed, which means that the pumps are transporting sodium ions out and potassium ions in and they are largely staying where they have been pumped. From the sodium ions’ perspective, they find themselves in a crowded, positively-charged fluid. Because of this, the sodium ions have a strong attraction for the ICF: there are fewer sodium ions there, and it is negatively-charged. But the pumps and the closed state of the sodium gates means that the sodium ions can’t diffuse into the ICF . . . yet!

This slide has an illustration of a plasma membrane with a closed sodium gate and a closed potassium gate, as well as an ECF rich with sodium ions and an ICF rich with potassium ions.

This illustration can be found at the top left on page 452 in the Saladin textbook.

**Slide 22:**

What happens when the neuron’s plasma membrane is stimulated depends on where the stimulation occurs. When a dendrite is stimulated, its sodium gates will open, and sodium ions will diffuse into the ICF. This influx of cations disrupts the -70 mV resting membrane potential, causing it to become more positive; any shift in the membrane potential in a positive direction is called **depolarization**. The opening of the sodium gates and the diffusion of the sodium ions into the ICF at the site of the stimulation causes neighboring sodium gates to open as well. If strong enough, this current can progress through the plasma membrane of the soma and possibly to the axon hillock region. This kind of signal is called a local potential. Local potentials have the following characteristics:

1. They are **graded**, meaning they vary in magnitude depending on the strength of the stimulus. The more stimulation that occurs, the more sodium channels will open, and the more sodium ions will enter the ICF, depolarizing the membrane to a greater and greater degree.
2. They are **decremental**, meaning that the current gets weaker the farther away from the site of stimulation it gets.
3. They are **reversible**, meaning that if the stimulation stops, the membrane will return to its resting membrane potential. This is due to the fact that the sodium gates will close again without stimulation and the pumps can return the sodium ions to the ECF.

The bottom of the slide has an illustration showing a zoomed-in view of a dendrite. We see a plasma membrane and an ECF with an abundance of sodium ions. There is a sodium gate that has received a chemical stimulus, and the gate is now shown in an open conformation and sodium ions are diffusing through it to the ICF.

This illustration can be found on page 449 in the Saladin textbook.

**Slide 23:**

What happens when a local potential from the dendrites is strong enough to pass along the soma’s plasma membrane and reach the axon hillock? The axon hillock and the axon beyond have seven to ten times the number of sodium and potassium gates as the dendrites and soma do, and if a local potential is still strong enough when it reaches the hillock, it can trigger a much more dramatic change in the polarity and membrane potential. This stronger, more rapid disturbance is called an action potential. If a neuron is said to be sending electrical signals down its axon toward its target cells, then it is actually these action potentials that are being transmitted down the axon.

Action potentials differ from local potentials in the following ways:

1. They follow the all-or-none law: if the local potential that reaches the hillock is strong enough to trigger an action potential, the action potential will occur at full strength. If not, no action potential occurs. So action potentials are NOT graded.
2. They are nondecremental; action potentials maintain their full strength down the entire length of the axon, regardless of distance.
3. They are irreversible; once an action potential starts, it cannot be stopped.

**Slide 24:**

To understand the process of an action potential, we will consider the state of the gates, the corresponding movement of the cations, the measured value of the membrane potential, and the state of the membrane.

1. When a local potential from the soma reaches the axon hillock, it will begin to depolarize the hillock’s resting membrane potential (-70 mV). The local potential has to be strong enough to cause enough sodium gates in the hillock to open, and the membrane potential to reach the **threshold** for creating an action potential **(-55 mV**).
2. Once threshold is reached, the abundant sodium gates in the membrane of the hillock open rapidly, and sodium ions from the ECF diffuse into the ICF. This causes the membrane potential to undergo a rapid depolarization that will see the value of the ICF go from -55 mV, through 0 mV, and up to +35 mV.
3. At **+35 mV** (**peak value of the action potential**), the sodium gates close, and the potassium gates open. Now the potassium ions in the ICF diffuse out to the ECF. This causes the membrane potential to undergo a rapid **repolarization** (a shift of the voltage back to the negative values).
4. When a value of -70 mV is again achieved, the potassium gates close. With both gates closed, the sodium/potassium pumps are able to return the cations to their original locations, allowing the membrane to recover and be ready to do it again.

**Slide 25:**

This slide shows all of the changes that happen during the action potential process, in four stages. In the top left illustration, the plasma membrane is polarized and at rest; the sodium and potassium gates are in their closed positions. In the top right illustration, the action potential event begins; the sodium gate is open, and we see sodium ions diffuse through it from the ECF to the ICF. A graph below the illustration shows the value of the current in the ICF beginning to ascend from -70 mV toward +35 mV as the membrane depolarizes. In the lower left illustration, the sodium gate is closed, the potassium gate is fully open, and we see that potassium ions in the ICF diffuse through the gate to the ECF. The graph shows the ICF current descending back into the negative values toward -70 mV as the membrane repolarizes. In the lower right illustration, the potassium gate closes; the membrane has achieved a polarized state again, and the resting membrane potential has been reestablished.

This illustration can be found on page 452 in the Saladin textbook.

**Slide 26:**

This slide shows a graph of the membrane potential before, during, and after the action potential event. The vertical axis of the slide represents millivolts (strength of the current), and the horizontal axis represents time. As the graph line begins, it represents an axon at rest (-70 mV). In a short amount of time, the graph depicts a local potential reaching the axon, and we see the graph line begin to ascend at about a 45 degree angle as the local potential causes the resting membrane potential to shift in a positive direction. When the graph line reaches the value on the graph of -55 mV (threshold potential), an action potential occurs: the graph line rapidly ascends over a short amount of time (depolarizes) until it peaks at +35 mV (peak action potential), then rapidly descends (repolarizes) until unsteadily reaching -70 mV again, and taking a small amount of time (recovery) to settle steadily at -70 mV again.

This graph can be found on page 453 of the Saladin textbook.

**Slide 27:**

This slide has an illustration that shows the relative charges of the ECF and ICF during the propagation of an action potential. It shows three sequential moments of an axon during an action potential. In the first example, a region of the axon is colored in red and shows the ECF is negative and the ICF is positive, indicating that this region is undergoing the depolarization event of the action potential. Behind that, the previous region of the axon is colored in yellow and is showing the charges of the two fluids to be in the state in which they began while at rest; however, the yellow color indicates that this region is still undergoing repolarization and is recovering. Behind this is a region at the beginning of the axon that is green in color and is currently in a state of being polarized and at rest; the action potential event passed through this region long enough ago that it has recovered and is ready to send another action potential. Similarly, the region out ahead of the red action potential is green and ‘ready’, as it has not yet undergone the action potential event. The second and third illustrations show this patch of depolarization and repolarization moving down the axon as time goes on, while the previous areas fully recover and return to the ready, polarized state.

This illustration can be found on page 453 of Saladin textbook.

**Slide 28:**

How a signal is conducted down the length of an axon depends upon whether or not the axon is myelinated. In axons that are unmyelinated, the local potential from the soma triggers the initial action potential at the axon hillock, and this disturbance in the resting membrane potential and polarity is passed on to the next, neighboring stretch of the plasma membrane. Eventually, the action potential event travels continuously along the axon’s plasma membrane to the synaptic knobs at the end near the target cells.

The action potentials and signal conduction in unmyelinated neurons is like the process of a line of standing dominoes being pushed. Beginning with the first one, each domino (region of the plasma membrane) undergoes a single event: falling forward (action potential). The action of each domino triggers the same event to occur in the one in front of it. While no domino travels down to the end of the line, the disturbance (electrical signal) is conveyed down the length of the dominoes.

There is a graphic at the bottom of the slide showing a line of dominoes frozen in mid-fall.

**Slide 29:**

In axons that are myelinated, the local potential from the soma triggers the initial action potential at the axon hillock, but when the action potential reaches the first myelinated region, the signal can no longer travel in this form; the myelin around the axon prevents the movement of ions between the ECF and ICF. Instead, the signal travels as a current within the ICF. As the last incoming sodium ions enter the ICF adjacent to the myelin, they opt to diffuse rapidly downstream through the ICF. They do this for several reasons: 1) the pumps can’t transport them back out to the ECF due to the myelin, 2) there is a lower concentration of sodium ions in the ICF downstream (still resting), and 3) the downstream ICF still has a negative charge to it (resting), attracting the sodium cations.

While this means of travel does speed up the electrical signal being sent, the signal gets weaker and weaker as it passes internally through the myelinated areas. This is due to the negatively-charged proteins attracting the sodium ions as they pass by; the strength of the signal is directly related to the quantity of sodium ions. If the entire axon were to be myelinated, the signal would never make it. Prior to the signal weakening to the point of ending, the current reaches a node of Ranvier, where it triggers a new action potential event at the plasma membrane. In this way, the signal alternates its mode of conduction along a myelinated axon: it travels as an action potential at the plasma membrane at the nodes (unmyelinated) and as a more rapid, internal current in the myelinated areas.

Because the action potential phase of the signal appears to ‘jump’ from node to node as it travels, the term for this process is **saltatory conduction** (saltare=leap).

**Slide 30:**

This slide shows the process of **saltatory conduction**. The top portion shows an illustration of sodium ions entering the axon at a node of Ranvier and progressing rapidly down the axon’s ICF toward the next node. It also shows the strength of the signal (represented by a yellow arc) diminishing as it gets closer and closer to the next node. Just before the internal signal gets too weak to continue, it reaches the next node, causing a new influx of sodium ions to enter the axon’s ICF and continue the signal propagation.

In the lower portion of the slide, the illustration shows how the action potential phase of a signal in a myelinated axon (shown in red) seems to leap from one node to the next.

This illustration can be found on page 455 in the Saladin textbook.

**Slide 31:**

A synapse is a region where a neuron carries info toward its target cell (a muscle cell, a glandular cell, or the dendrites of another neuron). There are 3 components: the terminal end of the neuron’s axon (pre-synaptic structure), the synaptic cleft (the fluid-filled gap between the two cells), and the plasma membrane of the target cell (post-synaptic structure). Neurotransmitters are stored and released from vesicles in the pre-synaptic structure and travel across the cleft to the post-synaptic structure. This is how an impulse can be passed on from cell to cell.

**Slide 32:**

In this slide, the illustration shows the enlarged ending of the presynaptic neuron’s axon, called its synaptic knob, filled with synaptic vesicles. These vesicles contain a neurotransmitter. Just across from the synaptic knob is the plasma membrane of the postsynaptic target cell. Also shown is the presence of the neurotransmitter in the space between the two cells, called the synaptic cleft, as the presynaptic neuron attempts to chemically-communicate with the postsynaptic cell.

This illustration can be found on page 457 in the Saladin textbook.