Nervous System Notes

The nervous system consists of a network of nerve cells or **neurons**.

I. A nervous system is an important part of a cell's (or an organism's) ability to respond to the environment.
   A. It also provides multicellular organisms with a mechanism for communication between cells of the body.
   B. In vertebrates, including humans, the brain and spinal cord form the **central nervous system (CNS)**.
   C. Nerves that connect the CNS with the rest of the animal's body make up the **peripheral nervous system (PNS).** The PNS is divided into two parts:
      1. The **somatic nervous system** carries signals to and from skeletal muscle, mainly in response to *external* stimuli and is subject to conscious control.
      2. The **autonomic nervous system** regulates the *internal* environment by controlling smooth and cardiac muscles and the organs of the digestive, cardiovascular, excretory, and endocrine systems.
         a. Three divisions make up the autonomic nervous system:
            (1) Activation of the **sympathetic division** correlates with arousal and energy generation - the "flight or fight" response.
            (2) Activation of the **parasympathetic division** generally promotes calming and a return to self-maintenance functions—"rest and digest."
            (3) The **enteric division** consists of complex networks of neurons in the digestive tract, pancreas, and gallbladder.
               (a) The enteric networks control the secretions of these organs as well as activity in the smooth muscles that produce peristalsis.
               (b) The sympathetic and parasympathetic divisions normally regulate the enteric division.
   D. The nervous system processes information in three stages:
      1. **Sensory neurons** transmit information from sensors that detect external stimuli (light, heat, touch) and internal conditions (blood pressure, muscle tension).
      2. Sensory input is conveyed to the CNS, where **interneurons** integrate the sensory input.
      3. Motor output leaves the CNS via **motor neurons,** which communicate with **effector cells** (muscle or endocrine cells).
         a. Effector cells carry out the body's response to a stimulus.

II. Individual neurons are the functional units of the nervous system
   A. The neuron's nucleus is located in the **cell body.**
   B. Arising from the cell body are two types of extensions: numerous dendrites and a single axon.
      1. **Dendrites** are highly branched extensions that *receive* signals from other neurons.
      2. An **axon** is a longer extension that *transmits* signals to neurons or effector cells.
         a. Many axons are enclosed in a **myelin sheath** which:
            (1) insulates the neuron.
            (2) is a fatty covering formed by Schwann cells.
            (3) nerve impulses jump from one node to the next which is faster than

non-myelinated neurons.

(4) In multiple sclerosis, the myelin sheath is destroyed, leading to double vision, slurred speech, decrease of motor control, and sometimes partial paralysis.

b. Near its end, axons divide into several branches, each of which ends in a **synaptic terminal.**

3. The site of communication between a synaptic terminal and another cell is called a **synapse.**

a. At most synapses, information is passed from the transmitting neuron (the **presynaptic cell**) to the receiving cell (the **postsynaptic cell**) by means of chemical messengers called **neurotransmitters.**

C. A reflex arc provides a fast response to certain stimuli.

1. Some stimuli are too dangerous to wait for brain to interpret and respond.
2. A sensory receptor perceives a stimulus and sends a signal to an interneuron.
3. From the interneuron, the signal is sent to a motor neuron.
4. An effector (usually a muscle) causes an appropriate response
5. The sensation is felt fractions of a second later as the signal reaches the brain.
6. It would take too much time for the brain to judge the intensity of pain, weigh alternatives, choose a course of action, and effect a response.
7. Common reflexes include blinking, sneezing, coughing, laughing when tickled, curling the toes when a pebble is stepped on.

III. Nerve signals are electrochemical impulses

A. All cells have an electrical potential difference (voltage) across their plasma membrane

1. This voltage is called the **membrane potential.**
2. In neurons, the membrane potential is typically around -70 mV when the cell is not transmitting signals.

a. This is called the **resting potential**.

3. The resting potential is caused by ion concentrations differences that exists across the cell membrane.

a. The extracellular fluid has a high [Na^+] concentration and a low [K^+].

b. In the cytosol there is a high [K^+] concentration and a low [Na^+].

4. The sodium-potassium pump maintains this concentration gradient.

B. The action potential is the signal carried by an axon.

1. Neurons have **voltage-gated ion channels,** which open or close in response to changes in membrane potential (voltage).
2. Some stimuli cause gated Na^+ channels open.

a. Na^+ diffuses into the cell.

b. The inside of the membrane becomes less negative.

c. As Na^+ diffuses into the cell, the potential increases further and opens more gates, allowing more Na^+ to enter. This opens even more gates, and so on.

3. If the stimulus is strong enough for the membrane potential to reach threshold, an action potential is triggered.
4. Each voltage-gated Na^+ channel has two gates, an activation gate and an inactivation gate, and both must be open for Na^+ to diffuse through the channel.

a. At the resting potential, the activation gate is closed and the inactivation gate is open.

b. Depolarization of the membrane *rapidly opens* the activation gate and *slowly closes* the inactivation gate.

5. Each voltage-gated K^+ channel has just one gate, an activation gate.
   a. At the resting potential, the activation gate on K^+ channels is closed.
   b. Depolarization of the membrane *slowly opens* the K^+ channel's activation gate.
6. The inactivation gates on most Na^+ channels close, preventing more Na^+ from entering.
   a. The inactivation gates of the Na^+ channels take some time to be able to open again, resulting in the **refractory period**.
   b. During this time, a nerve impulse cannot be conducted.
7. The activation gates on most K^+ channels open, allowing K^+ to exit the cell.
8. The K^+ channels' activation gates eventually close, and the membrane potential returns to the resting potential.
   a. Although the original polarity is now restored, the ions are on the wrong side of membrane.
   b. The sodium-potassium pumps restore the ions to the correct side of the membrane.
9. In the myelinated neurons of vertebrates, voltage-gated channels are concentrated at gaps in the myelin sheath called nodes of Ranvier.
   a. Extracellular fluid is in contact with the axon only at the nodes.
   b. This is why the impulse "jumps" from node to node.
10. The action potential is all-or-nothing.
    a. This means that the neuron either fires or it does not.
    b. Stimuli below threshold do not cause a signal.
    c. The response is independent of the strength of the stimulus.
    d. Different thresholds and summation allow us to perceive a range of stimuli.
       (1) When a neuron fires twice in rapid succession, the effects are added in what is called **temporal summation**.
       (2) When two or more neurons fire simultaneously, there effects are added in what is called **spatial summation**.
       (3) The intensity of the stimulus is interpreted by where these impulses are processed in the brain.

C. The action potential travels along the axon.
   1. An action potential achieved at one region of the membrane is sufficient to depolarize a neighboring region above the threshold level, thus triggering a new action potential.
   2. Immediately behind the area of depolarization is an area of repolarization.
      a. In the repolarized zone, the activation gates of Na^+ channels are still closed.
      b. Consequently, the inward current that depolarizes the axon membrane *ahead* of the action potential cannot produce another action potential *behind* it.
      c. Once an action potential starts, it moves in only one direction - toward the synaptic terminals.

IV. When an action potential reaches the axon terminal, it generally stops there, although information is transmitted from a neuron to another cell at a synapse.

A. Synapses are small spaces between neurons, between neurons and effectors, or between neurons and sensory receptors.

B. The presynaptic neuron synthesizes the neurotransmitter and packages it in **synaptic vesicles,** which are stored in the neuron's synaptic terminals.

C. When an action potential reaches a terminal, it depolarizes the terminal membrane, opening voltage-gated calcium channels in the membrane.

1. Calcium ions (Ca^{2+}) then diffuse into the terminal, and the rise in Ca^{2+} concentration in the terminal causes some of the synaptic vesicles to fuse with the terminal membrane, releasing the neurotransmitter.
2. The neurotransmitter diffuses across the narrow gap, called the **synaptic cleft,** which separates the presynaptic neuron from the postsynaptic cell.

D. **Neurotransmitters** are chemicals that bind to receptors on the post-synaptic membrane and trigger the opening of gates. There are over 100 currently known.

1. Some neurotransmitters are excitatory.
   a. The binding of neurotransmitter to postsynaptic receptors opens gated channels that allow Na^{+} to diffuse into the cell, increasing the membrane potential toward threshold.
2. Some neurotransmitters are inhibitory.
   a. The binding of neurotransmitter to postsynaptic receptors open gated channels that allow K^{+} to exit the cell, decreases the membrane potential away from threshold.
3. **Acetylcholine** is one of the most common neurotransmitters in both invertebrates and vertebrates.
   a. In the vertebrate CNS, it can be inhibitory or excitatory, depending on the type of receptor. For instance, it has an excitatory effect on most muscle cells but is inhibitory to cardiac muscle cell contraction. Acetylcholine in the CNS it tends to help us filter out weak stimuli while amplifying stronger ones
4. **Dopamine** is associated with the reward system but is believed to be active mostly in the anticipation of reward and reward-seeking behavior. It might be involved in learning to associate new behavior with a reward. Dopamine is normally released when a need is filled, causing a feeling of pleasure or satisfaction.
5. **Serotonin** has several functions in the CNS, including the regulation of mood (feeling of happiness), appetite, sleep. Serotonin also has some cognitive functions, including memory and learning. Serotonin is synthesized from the amino acid tryptophan - likely where the myth about becoming sleepy after eating turkey originated.

E. Imbalances in neurotransmitters are associated with several disorders.

   a. Parkinson's disease is associated with a lack of dopamine in the brain while schizophrenia might be related to high dopamine.
   b. Depression has been linked to low serotonin and norepinephrine.

F. A **drug** is any substance, other than food, that changes the structure or function of the body. Some drugs produce the desired effect by interfering with the normal activity of neurotransmitters.

1. **Stimulants** (*e.g.*, amphetamines like meth and ecstasy, cocaine) increase the actions regulated by the nervous system by blocking the removal of dopamine from

the synaptic cleft. In the autonomic nervous system they increase the effect of norepinephrine (a neurotransmitter involved in the fight-or-flight response). Some of these are strong enough stimulants to increase the heart rate and blood pressure significantly enough to cause death.

a. Once the drug wears off, the supply of neurotransmitters is depleted and depression results.
b. Adenosine has a sedative effect because it inhibits the release of stimulating neurotransmitters. Caffeine occupies adenosine receptors, blocking its effect.

2. **Depressants** (barbiturates, tranquilizers), tend to enhance the neurotransmitters that inhibit neurons. Many mimic GABA, the main inhibitory neurotransmitter in the CNS. This calms the parts of the brain that sense fear and having a relaxing effect. Continued use creates a dependency in which the user cannot cope with normal anxiety without the drug.
   a. Heroine is a pain-relieving sedative.
   b. Blocking the breakdown of serotonin at synapses is the method of action of many antidepressants.
      (1) Prozac inhibits the uptake of serotonin after its release, increasing its effect.
   c. Alcohol is a depressant that slows down the function of the CNS. Ethanol binds to acetylcholine, GABA, serotonin, and NMDA receptors. Blocking NMDA receptors results in hallucinations, paranoid delusions, confusion, difficulty concentrating, agitation, alterations in mood, nightmares, catatonia, ataxia, anaesthesia, and learning and memory deficits.
3. **Nicotine** inhibits the enzymes that breakdown dopamine and serotonin, resulting in feelings of pleasure and relaxation. It binds to the same receptors as acetylcholine, resulting in the wide range of effects reported (alertness, relaxation, increased concentration and memory).
4. **LSD** binds to serotonin and dopamine receptors and blocks the inhibitory effect which causes hallucinations (acid trip). The complete mechanism of action is unknown.
5. **Opiates** (morphine, codeine) mimic the effects of endorphins. The body quickly adjusts to the higher level of endorphins so that withdrawal includes intense pain and sickness.
   a. **Endorphins** are natural analgesics (pain killers). They block the release of GABA and increase the release of dopamine. They also block pain signals.
6. THC in **marijuana** signals the presynaptic neurons that they have sent a message when in reality they have not. THC can thus exert both excitatory and inhibitory effects (by inhibiting the release of both the inhibitory neurotransmitter GABA and the excitatory neurotransmitter glutamate). This explains the sedation and euphoria that it causes.