**Introducing the Neuron**

Neurons are specialized cells that transmit chemical and electrical signals to facilitate communication between the brain and the body.

**Key Points**

* Neurons are specialized cells that transmit chemical and electrical signals in the brain; they are the basic building blocks of the central nervous system.
* The primary components of the neuron are the soma (cell body), the axon (a long slender projection that conducts electrical impulses away from the cell body), dendrites (tree-like structures that receive messages from other neurons), and synapses (specialized junctions between neurons).
* Some axons are covered with myelin, a fatty material that acts as an insulator and conductor to speed up the process of communication.
* Sensory neurons are neurons responsible for converting external stimuli from the environment into corresponding internal stimuli.
* Motor neurons are neurons located in the central nervous system (CNS); they project their axons outside of the CNS to directly or indirectly control muscles.
* Interneurons act as the “middle men” between sensory and motor neurons, which convert external stimuli to internal stimuli and control muscle movement, respectively.

**Key Terms**

* **glial cell**: Non-neuronal cells that provide structure and support to neurons.
* **synapse**: The junction between the terminal of a neuron and either another neuron or a muscle or gland cell, over which nerve impulses pass.
* **myelin**: A white, fatty material composed of lipids and lipoproteins that surrounds the axons of nerves and facilitates swift communication.
* **nodes of Ranvier**: Periodic gaps in the myelin sheath where the signal is recharged as it moves along the axon.

The neuron is the basic building block of the brain and central nervous system. Neurons are specialized cells that transmit chemical and electrical signals. The brain is made up entirely of neurons and glial cells, which are non-neuronal cells that provide structure and support for the neurons. Nearly 86 billion neurons work together within the nervous system to communicate with the rest of the body. They are responsible for everything from consciousness and thought to pain and hunger. There are three primary types of neuron: sensory neurons, motor neurons, and interneurons.

**Structures of a Neuron**

In addition to having all the normal components of a cell (nucleus, organelles, etc.) neurons also contain unique structures for receiving and sending the electrical signals that make neuronal communication possible.



**The structure of a neuron**: The above image shows the basic structural components of an average neuron, including the dendrite, cell body, nucleus, Node of Ranvier, myelin sheath, Schwann cell, and axon terminal.

**Dendrite**

Dendrites are branch-like structures extending away from the cell body, and their job is to receive messages from other neurons and allow those messages to travel to the cell body. Although some neurons do not have any dendrites, other types of neurons have multiple dendrites. Dendrites can have small protrusions called dendritic spines, which further increase surface area for possible connections with other neurons.

**Cell Body**

Like other cells, each neuron has a cell body (or soma) that contains a nucleus, smooth and rough endoplasmic reticulum, Golgi apparatus, mitochondria, and other cellular components.

**Axon**

An axon, at its most basic, is a tube-like structure that carries an electrical impulse from the cell body (or from another cell’s dendrites) to the structures at opposite end of the neuron—axon terminals, which can then pass the impulse to another neuron. The cell body contains a specialized structure, the axon hillock, which serves as a junction between the cell body and the axon.

**Synapse**

The synapse is the chemical junction between the axon terminals of one neuron and the dendrites of the next. It is a gap where specialized chemical interactions can occur, rather than an actual structure.

**Function of a Neuron**

The specialized structure and organization of neurons allows them to transmit signals in the form of electric impulses from the brain to the body and back. Individually, neurons can pass a signal all the way from their own dendrites to their own axon terminals; but at a higher level neurons are organized in long chains, allowing them to pass signals very quickly from one to the other. One neuron’s axon will connect chemically to another neuron’s dendrite at the synapse between them. Electrically charged chemicals flow from the first neuron’s axon to the second neuron’s dendrite, and that signal will then flow from the second neuron’s dendrite, down its axon, across a synapse,  into a third neuron’s dendrites, and so on.

This is the basic chain of neural signal transmission, which is how the brain sends signals to the muscles to make them move, and how sensory organs send signals to the brain. It is important that these signals can happen quickly, and they do. Think of how fast you drop a hot potato—before you even realize it is hot. This is because the sense organ (in this case, the skin) sends the signal “This is hot!” to neurons with very long axons that travel up the spine to the brain. If this didn’t happen quickly, people would burn themselves.

**Other Structures**

Dendrites, cell bodies, axons, and synapses are the basic parts of a neuron, but other important structures and materials surround neurons to make them more efficient.

**Myelin Sheath**

Some axons are covered with myelin, a fatty material that wraps around the axon to form the myelin sheath. This external coating functions as insulation to minimize dissipation of the electrical signal as it travels down the axon. Myelin’s presence on the axon greatly increases the speed of conduction of the electrical signal, because the fat prevents any electricity from leaking out. This insulation is important, as the axon from a human motor neuron can be as long as a meter—from the base of the spine to the toes. Periodic gaps in the myelin sheath are called nodes of Ranvier. At these nodes, the signal is “recharged” as it travels along the axon.

**Glial Cells**

The myelin sheath is not actually part of the neuron. Myelin is produced by glial cells (or simply glia, or “glue” in Greek), which are non-neuronal cells that provide support for the nervous system. Glia function to hold neurons in place (hence their Greek name), supply them with nutrients, provide insulation, and remove pathogens and dead neurons. In the central nervous system, the glial cells that form the myelin sheath are called oligodendrocytes; in the peripheral nervous system, they are called Schwann cells.



**Neuron in the central nervous system**: This neuron diagram also shows the oligodendrocyte, myelin sheath, and nodes of Ranvier.

**Types of Neurons**

There are three major types of neurons: sensory neurons, motor neurons, and interneurons. All three have different functions, but the brain needs all of them to communicate effectively with the rest of the body (and vice versa).

**Sensory Neurons**

Sensory neurons are neurons responsible for converting external stimuli from the environment into corresponding internal stimuli. They are activated by sensory input, and send projections to other elements of the nervous system, ultimately conveying sensory information to the brain or spinal cord. Unlike the motor neurons of the central nervous system (CNS), whose inputs come from other neurons, sensory neurons are activated by physical modalities (such as visible light, sound, heat, physical contact, etc.) or by chemical signals (such as smell and taste).

Most sensory neurons are *pseudounipolar*, meaning they have an axon that branches into two extensions—one connected to dendrites that receive sensory information and another that transmits this information to the spinal cord.

**Multipolar and pseudounipolar neurons**: This diagram shows the difference between: 1) a unipolar neuron; 2) a bipolar neuron; 3) a multipolar neuron; 4) a pseudounipolar neuron.

**Motor Neurons**

Motor neurons are neurons located in the central nervous system, and they project their axons outside of the CNS to directly or indirectly control muscles. The interface between a motor neuron and muscle fiber is a specialized synapse called the neuromuscular junction. The structure of motor neurons is *multipolar*, meaning each cell contains a single axon and multiple dendrites. This is the most common type of neuron.

**Interneurons**

Interneurons are neither sensory nor motor; rather, they act as the “middle men” that form connections between the other two types. Located in the CNS, they operate locally, meaning their axons connect only with nearby sensory or motor neurons. Interneurons can save time and therefore prevent injury by sending messages to the spinal cord and back instead of all the way to the brain. Like motor neurons, they are multipolar in structure.

**Stages of the Action Potential**

Neural impulses occur when a stimulus depolarizes a cell membrane, prompting an action potential which sends an “all or nothing” signal.

**LEARNING OBJECTIVES**

Outline the steps of the process of communication among neurons

**KEY TAKEAWAYS**

**Key Points**

* The neurons (or excitable nerve cells) of the nervous system conduct electrical impulses, or signals, that serve as communication between sensory receptors, muscles and glands, and the brain and spinal cord.
* An action potential occurs when an electrical signal disrupts the original balance of Na+ and K+ within a cell membrane, briefly depolarizing the concentrations of each.
* An electrical impulse travels along the axon via depolarized voltage-gated ion channels in the membrane, and can either “jump” along a myelinated area or travel continuously along an unmyelinated area.
* While an action potential is being generated by a cell, no other action potential may be generated until the cell’s channels return to their resting state.
* Action potentials generated by neural impulses are “all or nothing,” meaning the signal reaches the threshold for communication or it doesn’t. No signal is stronger or weaker than another.

**Key Terms**

* **polarity**: The spatial differences in the shape, structure, and function of cells. Almost all cell types exhibit some sort of polarity, which enables them to carry out specialized functions.
* **action potential**: A short-term change in the electrical potential that travels along a cell, such as a nerve or muscle fiber, and allows nerves to communicate.
* **neural impulse**: The signal transmitted along a nerve fiber, either in response to a stimulus (such as touch, pain, or heat), or as an instruction from the brain (such as causing a muscle to contract).
* **resting potential**: The nearly latent membrane potential of inactive cells.

**Neural Impulses in the Nervous System**

The central nervous system (CNS) goes through a three-step process when it functions: sensory input, neural processing, and motor output. The sensory input stage is when the neurons (or excitable nerve cells) of the sensory organs are excited electrically. Neural impulses from sensory receptors are sent to the brain and spinal cord for processing. After the brain has processed the information, neural impulses are then conducted from the brain and spinal cord to muscles and glands, which is the resulting motor output.

A neuron affects other neurons by releasing a neurotransmitter that binds to chemical receptors. The effect upon the postsynaptic (receiving) neuron is determined not by the presynaptic (sending) neuron or by the neurotransmitter itself, but by the *type of receptor*that is activated. A neurotransmitter can be thought of as a key, and a receptor as a lock: the key unlocks a certain response in the postsynaptic neuron, communicating a particular signal. However, in order for a presynaptic neuron to release a neurotransmitter to the next neuron in the chain, it must go through a series of changes in electric potential.

**Stages of Neural Impulses**

” Resting potential ” is the name for the electrical state when a neuron is not actively being signaled. A neuron at resting potential has a membrane with established amounts of sodium (Na+) and potassium (K+) ions on either side, leaving the inside of the neuron negatively charged relative to the outside.

The action potential is a rapid change in polarity that moves along the nerve fiber from neuron to neuron. In order for a neuron to move from resting potential to action potential—a short-term electrical change that allows an electrical signal to be passed from one neuron to another—the neuron must be stimulated by pressure, electricity, chemicals, or another form of stimuli. The level of stimulation that a neuron must receive to reach action potential is known as the threshold of excitation, and until it reaches that threshold, nothing will happen. Different neurons are sensitive to different stimuli, although most can register pain.

The action potential has several stages.

1. Depolarization: A stimulus starts the depolarization of the membrane. Depolarization, also referred to as the “upswing,” is caused when positively charged sodium ions rush into a nerve cell. As these positive ions rush in, the membrane of the stimulated cell reverses its polarity so that the outside of the membrane is negative relative to the inside.
2. Repolarization. Once the electric gradient has reached the threshold of excitement, the “downswing” of repolarization begins. The channels that let the positive sodium ion channels through close up, while channels that allow positive potassium ions open, resulting in the release of positively charged potassium ions from the neuron. This expulsion acts to restore the localized negative membrane potential of the cell, bringing it back to its normal voltage.
3. Refractory Phase. The refractory phase takes place over a short period of time after the depolarization stage. Shortly after the sodium gates open, they close and go into an inactive conformation. The sodium gates cannot be opened again until the membrane is repolarized to its normal resting potential. The sodium-potassium pump returns sodium ions to the outside and potassium ions to the inside. During the refractory phase this particular area of the nerve cell membrane cannot be depolarized. Therefore, the neuron cannot reach action potential during this “rest period.”



**Action potentials**: A neuron must reach a certain threshold in order to begin the depolarization step of reaching the action potential.

This process of depolarization, repolarization, and recovery moves along a nerve fiber from neuron to neuron like a very fast wave. While an action potential is in progress, another cannot be generated under the same conditions. In unmyelinated axons (axons that are not covered by a myelin sheath), this happens in a continuous fashion because there are voltage-gated channels throughout the membrane. In myelinated axons (axons covered by a myelin sheath), this process is described as saltatory because voltage-gated channels are only found at the nodes of Ranvier, and the electrical events seem to “jump” from one node to the next. Saltatory conduction is faster than continuous conduction. The diameter of the axon also makes a difference, as ions diffusing within the cell have less resistance in a wider space. Damage to the myelin sheath from disease can cause severe impairment of nerve-cell function. In addition, some poisons and drugs interfere with nerve impulses by blocking sodium channels in nerves.

**All-or-none Signals**

The amplitude of an action potential is independent of the amount of current that produced it. In other words, larger currents do not create larger action potentials. Therefore, action potentials are said to be all-or-none signals, since either they occur fully or they do not occur at all. The frequency of action potentials is correlated with the intensity of a stimulus. This is in contrast to receptor potentials, whose amplitudes are dependent on the intensity of a stimulus.

**Reuptake**

Reuptake refers to the reabsorption of a neurotransmitter by a presynaptic (sending) neuron after it has performed its function of transmitting a neural impulse. Reuptake is necessary for normal synaptic physiology because it allows for the recycling of neurotransmitters and regulates the neurotransmitter level in the synapse, thereby controlling how long a signal resulting from neurotransmitter release lasts.

**Mechanics of the Action Potential**

The synapse is the site at which a chemical or electrical exchange occurs between the presynaptic and postsynaptic cells.

**LEARNING OBJECTIVES**

Summarize the importance of the synapse to neurotransmitter communication

**KEY TAKEAWAYS**

**Key Points**

* Receptors are pores that admit chemical or electrical signals into the postsynaptic cell. There are two main types of receptor: ligand-gated ion channels, which receive neurostransmitters, and g-protein coupled receptors, which do not.
* There are two types of possible reactions at the synapse: a chemical reaction or an electrical reaction.
* During a chemical reaction, neurotransmitters trigger the opening of ligand-gated ion channels on the membrane of the postsynaptic cell, resulting in a modification of the cell’s interior chemical composition and, in some cases, physical structure.
* In an electrical reaction, the electrical charge of one cell is influenced by another.
* Although electrical synapses yield faster reactions, chemical synapses result in stronger, more complex changes to the postsynaptic cell.

**Key Terms**

* **vesicle**: A membrane-bound compartment found in a cell.
* **action potential**: A short-term change in the electrical potential that travels along a cell, such as a nerve or muscle fiber, and allows nerves to communicate.
* **depolarization**: The act of depriving of polarity, or the result of such action; reduction to an unpolarized condition.
* **membrane potential**: The voltage across the cell membrane, with the inside relative to the outside.

**Synapses**

The synapse is the junction where neurons trade information. It is not a physical component of a cell but rather a name for the gap between two cells: the presynaptic cell (giving the signal) and the postsynaptic cell (receiving the signal). There are two types of possible reactions at the synapse—chemical or electrical. During a chemical reaction, a chemical called a neurotransmitter is released from one cell into another. In an electrical reaction, the electrical charge of one cell is influenced by the charge an adjacent cell.



**The electrical response of a neuron to multiple synaptic inputs**: Synaptic responses summate in order to bring the postsynaptic neuron to the threshold of excitation, so it can fire an action potential (represented by the peak on the chart).

All synapses have a few common characteristics:

* Presynaptic cell: a specialized area within the axon of the giving cell that transmits information to the dendrite of the receiving cell.
* Synaptic cleft: the small space at the synapse that receives neurotransmitters.
* G-protein coupled receptors: receptors that sense molecules outside the cell and thereby activate signals within it.
* Ligand-gated ion channels: receptors that are opened or closed in response to the binding of a chemical messenger.
* Postsynaptic cell: a specialized area within the dendrite of the receiving cell that contains receptors designed to process neurotransmitters.

**The Electrical Synapse**

The stages of an electrical reaction at a synapse are as follows:

1. Resting potential. The membrane of a neuron is normally at rest with established concentrations of sodium ions (Na+) and potassium ions (K+) on either side. The membrane potential (or, voltage across the membrane) at this state is -70 mV, with the inside being negative relative to the outside.
2. Depolarization. A stimulus begins the depolarization of the membrane. Depolarization, also referred to as the “upswing,” occurs when positively charged sodium ions (Na+) suddenly rush through open sodium gates into a nerve cell. If the membrane potential reaches -55 mV, it has reached the threshold of excitation. Additional sodium rushes in, and the membrane of the stimulated cell actually reverses its polarity so that the outside of the membrane is negative relative to the inside. The change in voltage stimulates the opening of additional sodium channels (called a voltage-gated ion channel), providing what is known as a positive feedback loop. Eventually, the cell potential reaches +40 mV, or the action potential.
3. Repolarization. The “downswing” of repolarization is caused by the closing of sodium ion channels and the opening of potassium ion channels, resulting in the release of positively charged potassium ions (K+) from the nerve cell. This expulsion acts to restore the localized negative membrane potential of the cell.
4. Refractory Phase. The refractory phase is a short period of time after the repolarization stage. Shortly after the sodium gates open, they close and go into an inactive conformation where the cell’s membrane potential is actually even lower than its baseline -70 mV. The sodium gates cannot be opened again until the membrane has completely repolarized to its normal resting potential, -70 mV. The sodium-potassium pump returns sodium ions to the outside and potassium ions to the inside. During the refractory phase this particular area of the nerve cell membrane cannot be depolarized; the cell cannot be excited.

**The Chemical Synapse**

The process of a chemical reaction at the synapse has some important differences from an electrical reaction. Chemical synapses are much more complex than electrical synapses, which makes them slower, but also allows them to generate different results. Like electrical reactions, chemical reactions involve electrical modifications at the postsynaptic membrane, but chemical reactions also require chemical messengers, such as neurotransmitters, to operate.



**Neuron & chemical synapse**: This image shows electric impulses traveling between neurons; the inset shows a chemical reaction occurring at the synapse.

A basic chemical reaction at the synapse undergoes a few additional steps:

1. The action potential (which occurs as described above) travels along the membrane of the presynaptic cell until it reaches the synapse. The electrical depolarization of the membrane at the synapse causes channels to open that are selectively permeable, meaning they specifically only allow the entry of positive sodium ions (Na+).
2. The ions flow through the presynaptic membrane, rapidly increasing their concentration in the interior.
3. The high concentration activates a set of ion-sensitive proteins attached to vesicles, which are small membrane compartments that contain a neurotransmitter chemical.
4. These proteins change shape, causing the membranes of some “docked” vesicles to fuse with the membrane of the presynaptic cell. This opens the vesicles, which releases their neurotransmitter contents into the synaptic cleft, the narrow space between the membranes of the pre- and postsynaptic cells.
5. The neurotransmitter diffuses within the cleft. Some of it escapes, but the rest of it binds to chemical receptor molecules located on the membrane of the postsynaptic cell.
6. The binding of neurotransmitter causes the receptor molecule to be activated in some way. Several types of activation are possible, depending on what kind of neurotransmitter was released. In any case, this is the key step by which the synaptic process affects the behavior of the postsynaptic cell.
7. Due to thermal shaking, neurotransmitter molecules eventually break loose from the receptors and drift away.
8. The neurotransmitter is either reabsorbed by the presynaptic cell and repackaged for future release, or else it is broken down metabolically.

**Differences Between Electrical and Chemical Synapses**

* Electrical synapses are faster than chemical synapses because the receptors do not need to recognize chemical messengers. The synaptic delay for a chemical synapse is typically about 2 milliseconds, while the synaptic delay for an electrical synapse may be about 0.2 milliseconds.
* Because electrical synapses do not involve neurotransmitters, electrical neurotransmission is less modifiable than chemical neurotransmission.
* The response is always the same sign as the source. For example, depolarization of the presynaptic membrane will always induce a depolarization in the postsynaptic membrane, and vice versa for hyperpolarization.
* The response in the postsynaptic neuron is generally smaller in amplitude than the source. The amount of attenuation of the signal is due to the membrane resistance of the presynaptic and postsynaptic neurons.
* Long-term changes can be seen in electrical synapses. For example, changes in electrical synapses in the retina are seen during light and dark adaptations of the retina.

**Neurotransmitters**

Neurotransmitters are chemicals that transmit signals from a neuron across a synapse to a target cell.

**LEARNING OBJECTIVES**

Explain the role of neurotransmitters in the communication process between neurons

**KEY TAKEAWAYS**

**Key Points**

* Neurotransmitters dictate communication between cells by binding to specific receptors and depolarizing or hyperpolarizing the cell.
* Inhibitory neurotransmitters cause hyperpolarization of the postsynaptic cell; excitatory neurotransmitters cause depolarization of the postsynaptic cell.
* Too little of a neurotransmitter may cause the overaccumulation of proteins, leading to disorders like Alzheimer’s; too much of a neurotransmitter may block receptors required for proper brain function, leading to disorders like schizophrenia.
* The three neurotransmitter systems in the brain are cholinergic, amino acids, and biogenic amines.

**Key Terms**

* **reuptake**: The reabsorption of a neurotransmitter by a neuron after the transmission of a neural impulse across a synapse.
* **vesicle**: A membrane-bound compartment found in a cell.
* **action potential**: A short-term change in the electrical potential that travels along a cell (such as a nerve or muscle fiber); the basis of neural communication.

Neurotransmitters are chemicals that transmit signals from a neuron to a target cell across a synapse. When called upon to deliver messages, they are released from their synaptic vesicles on the presynaptic (giving) side of the synapse, diffuse across the synaptic cleft, and bind to receptors in the membrane on the postsynaptic (receiving) side.

An action potential is necessary for neurotransmitters to be released, which means that neurons must reach a certain threshold of electric stimulation in order to complete the reaction. A neuron has a negative charge inside the cell membrane relative to the outside of the cell membrane; when stimulation occurs and the neuron reaches the threshold of excitement this polarity is reversed. This allows the signal to pass through the neuron. When the chemical message reaches the axon terminal, channels in the postsynaptic cell membrane open up to receive neurotransmitters from vesicles in the presynaptic cell.

Inhibitory neurotransmitters cause hyperpolarization of the postsynaptic cell (that is, decreasing the voltage gradient of the cell, thus bringing it further away from an action potential), while excitatory neurotransmitters cause depolarization (bringing it closer to an action potential). Neurotransmitters match up with receptors like a key in a lock. A neurotransmitter binds to its receptor and will not bind to receptors for other neurotransmitters, making the binding a specific chemical event.

There are several systems of neurotransmitters found at various synapses in the nervous system. The following groups refer to the specific chemicals, and within the groups are specific systems, some of which block other chemicals from entering the cell and some of which permit the entrance of chemicals that were blocked before.

**Cholinergic System**

The cholinergic system is a neurotransmitter system of its own, and is based on the neurotransmitter acetylcholine (ACh). This system is found in the autonomic nervous system, as well as distributed throughout the brain.

The cholinergic system has two types of receptors: the nicotinic receptor and the acetylcholine receptor, which is known as the muscarinic receptor. Both of these receptors are named for chemicals that interact with the receptor in addition to the neurotransmitter acetylcholine. Nicotine, the chemical in tobacco, binds to the nicotinic receptor and activates it similarly to acetylcholine. Muscarine, a chemical product of certain mushrooms, binds to the muscarinic receptor. However, they cannot bind to each others’ receptors.

**Amino Acids**

Another group of neurotransmitters are amino acids, including glutamate (Glu), GABA (gamma-aminobutyric acid, a derivative of glutamate), and glycine (Gly). These amino acids have an amino group and a carboxyl group in their chemical structures. Glutamate is one of the 20 amino acids used to make proteins. Each amino acid neurotransmitter is its own system, namely the glutamatergic, GABAergic, and glycinergic systems. They each have their own receptors and do not interact with each other. Amino acid neurotransmitters are eliminated from the synapse by reuptake. A pump in the cell membrane of the presynaptic element, or sometimes a neighboring glial cell, clears the amino acid from the synaptic cleft so that it can be recycled, repackaged in vesicles, and released again.



**The reuptake process**: This illustration shows the process of reuptake, in which  leftover neurotransmitters are returned to vesicles in the presynaptic cell.

**Biogenic Amines**

Another class of neurotransmitter is the biogenic amine, a group of neurotransmitters made enzymatically from amino acids. They have amino groups in them, but do not have carboxyl groups and are therefore no longer classified as amino acids.

**Neuropeptides**

A neuropeptide is a neurotransmitter molecule made up of chains of amino acids connected by peptide bonds, similar to proteins. However, proteins are long molecules while some neuropeptides are quite short. Neuropeptides are often released at synapses in combination with another neurotransmitter.

**Dopamine**

Dopamine is the best-known neurotransmitter of the catecholamine group. The brain includes several distinct dopamine systems, one of which plays a major role in reward-motivated behavior. Most types of reward increase the level of dopamine in the brain, and a variety of addictive drugs increase dopamine neuronal activity. Other brain dopamine systems are involved in motor control and in controlling the release of several other important hormones.

**Effect on the Synapse**

The effect of a neurotransmitter on the postsynaptic element is entirely dependent on the receptor protein. If there is no receptor protein in the membrane of the postsynaptic element, then the neurotransmitter has no effect. The depolarizing (more likely to reach an action potential) or hyperpolarizing (less likely to reach an action potential) effect is also dependent on the receptor. When acetylcholine binds to the nicotinic receptor, the postsynaptic cell is depolarized. However, when acetylcholine binds to the muscarinic receptor, it might cause depolarization or hyperpolarization of the target cell.

The amino acid neurotransmitters (glutamate, glycine, and GABA) are almost exclusively associated with just one effect. Glutamate is considered an excitatory amino acid because Glu receptors in the adult cause depolarization of the postsynaptic cell. Glycine and GABA are considered inhibitory amino acids, again because their receptors cause hyperpolarization, making the receiving cell less likely to reach an action potential.

**The Right Dose**

Sometimes too little or too much of a neurotransmitter may affect an organism’s behavior or health. The underlying cause of some neurodegenerative diseases, such as Parkinson’s, appears to be related to overaccumulation of proteins, which under normal circumstances would be regulated by the presence of dopamine. On the other hand, when an excess of the neurotransmitter dopamine blocks glutamate receptors, disorders like schizophrenia can occur.

**Neural Networks**

Neural networks consist of a series of interconnected neurons, and serve as the interface for neurons to communicate with each other.

**LEARNING OBJECTIVES**

Explain the different theories of how neural networks operate in the body

**KEY TAKEAWAYS**

**Key Points**

* The connections between neurons form a highly complex network through which signals or impulses are communicated across the body.
* The basic kinds of connections between neurons are chemical synapses and electrical gap junctions, through which either chemical or electrical impulses are communicated between neurons.
* Neural networks are primarily made up of axons, which in some cases deliver information as far as two meters.
* Networks formed by interconnected groups of neurons are capable of a wide variety of functions; in fact the range of capabilities possible for even small groups of neurons are beyond our current understanding.
* Modern science views the function of the nervous system both in terms of stimulus -response chains and in terms of intrinsically generated activity patterns within neurons.
* Cell assembly, or Hebbian theory, asserts that “cells that fire together wire together,” meaning neural networks can be created through associative experience and learning.

**Key Terms**

* **cell assembly**: Also referred to as Hebbian theory; the concept that “cells that fire together wire together,” meaning neural networks can be created through associative experience and learning.
* **action potential**: A short-term change in the electrical potential that travels along a cell such as a nerve or muscle fiber, and allows nerves to communicate.
* **plasticity**: The ability to change and adapt over time.

A neural network (or neural pathway) is the interface through which neurons communicate with one another. These networks consist of a series of interconnected neurons whose activation sends a signal or impulse across the body.



**Neural networks**: A neural network (or neural pathway) is the complex interface through which neurons communicate with one another.

**The Structure of Neural Networks**

The connections between neurons form a highly complex network. The basic kinds of connections between neurons are chemical synapses and electrical gap junctions, through which either chemical or electrical impulses are communicated between neurons. The method through which neurons interact with neighboring neurons usually consists of several axon terminals connecting through synapses to the dendrites on other neurons.

If a stimulus creates a strong enough input signal in a nerve cell, the neuron sends an action potential and transmits this signal along its axon. The axon of a nerve cell is responsible for transmitting information over a relatively long distance, and so most neural pathways are made up of axons. Some axons are encased in a lipid-coated myelin sheath, making them appear a bright white; others that lack myelin sheaths (i.e., are unmyelinated) appear a darker beige color, which is generally called gray.



**The process of synaptic transmission in neurons**: Neurons interact with other neurons by sending a signal, or impulse, along their axon and across a synapse to the dendrites of a neighboring neuron.

Some neurons are responsible for conveying information over long distances. For example, motor neurons, which travel from the spinal cord to the muscle, can have axons up to a meter in length in humans. The longest axon in the human body is almost two meters long in tall individuals and runs from the big toe to the medulla oblongata of the brain stem.

**The Capacity of Neural Networks**

The basic neuronal function of sending signals to other cells includes the capability for neurons to exchange signals with each other. Networks formed by interconnected groups of neurons are capable of a wide variety of functions, including feature detection, pattern generation, and timing. In fact, it is difficult to assign limits to the types of information processing that can be carried out by neural networks. Given that individual neurons can generate complex temporal patterns of activity independently, the range of capabilities possible for even small groups of neurons are beyond current understanding. However, we do know that we have neural networks to thank for much of our higher cognitive functioning.

**Behaviorist Approach**

Historically, the predominant view of the function of the nervous system was as a stimulus-response associator. In this conception, neural processing begins with stimuli that activate sensory neurons, producing signals that propagate through chains of connections in the spinal cord and brain, giving rise eventually to activation of motor neurons and thereby to muscle contraction or other overt responses. Charles Sherrington, in his influential 1906 book *The Integrative Action of the Nervous System,*developed the concept of stimulus-response mechanisms in much more detail, and behaviorism, the school of thought that dominated psychology through the middle of the 20th century, attempted to explain every aspect of human behavior in stimulus-response terms.

**Hybrid Approach**

However, experimental studies of electrophysiology, beginning in the early 20th century and reaching high productivity by the 1940s, showed that the nervous system contains many mechanisms for generating patterns of activity intrinsically—without requiring an external stimulus. Neurons were found to be capable of producing regular sequences of action potentials (“firing”) even in complete isolation. When intrinsically active neurons are connected to each other in complex circuits, the possibilities for generating intricate temporal patterns become far more extensive. A modern conception views the function of the nervous system partly in terms of stimulus-response chains, and partly in terms of intrinsically generated activity patterns; both types of activity interact with each other to generate the full repertoire of behavior.

**Hebbian Theory**

In 1949, neuroscientist Donald Hebb proposed that simultaneous activation of cells leads to pronounced increase in synaptic strength between those cells, a theory that is widely accepted today. Cell assembly, or Hebbian theory, asserts that “cells that fire together wire together,” meaning neural networks can be created through associative experience and learning. Since Hebb’s discovery, neuroscientists have continued to find evidence of plasticity and modification within neural networks.

