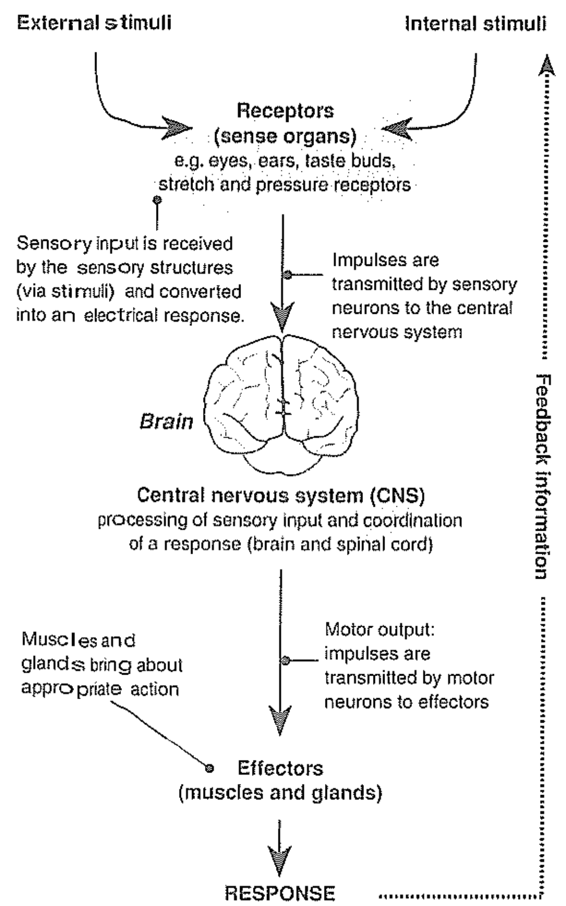
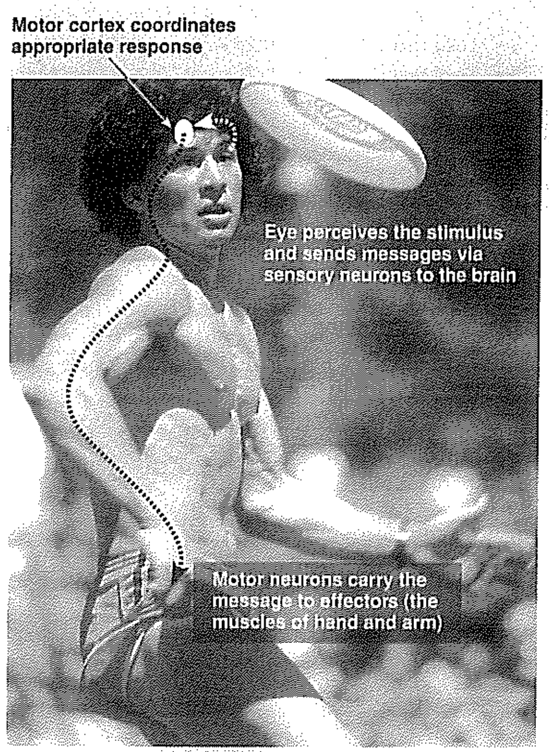
Nervous Regulatory Systems

An essential feature of living organisms is their ability to coordinate their activities. In mammals, such as humans, detecting and responding to environmental change, and regulating the internal environment (**homeostasis**) are brought about by two coordinating systems: the nervous and endocrine systems. Although these two systems are quite different structurally, they frequently interact to coordinate behavior and physiology. The nervous system contains cells called **neurons** (or nerve cells). Neurons are specialized to transmit information in the form of electrochemical impulses (action potentials). The nervous system is a signaling network with branches carrying information directly to and from specific target tissues. Impulses can be transmitted over considerable distances and the response is very precise and rapid. Whilst it is extraordinarily complex, comprising millions of neural connections, its basic plan (below, left) is quite simple, structured around reception of sensory input, integration or processing of the information, and formulation of a response.

Coordination by the Nervous System

The vertebrate nervous system consists of the central nervous system (brain and spinal cord), and the nerves and receptors outside it (peripheral nervous system). Sensory input to receptors comes via stimuli. Information about the effect of a response is provided by feedback mechanisms so that the system can be readjusted. The basic organization of the nervous system can be simplified into a few key components: the sensory receptors, a central nervous system processing point, and the effectors which bring about the response (below):





In the example above, the approach of the frisbee is perceived by the eye. The motor cortex of the brain integrates the sensory message. Coordination of hand and body orientation is brought about through motor neurons to the muscles.

Comparison of nervous and hormonal control

	Nervous control	Hormonal control
Communication	Impulses across synapses	Hormones in the blood
Speed	Very rapid (within a few milliseconds)	Relatively slow (over minutes, hours, or longer)
Duration	Short term and reversible	Longer lasting effects
Target pathway	Specific (through nerves) to specific cells	Hormones broadcast to target cells everywhere
Action	Causes glands to secrete or muscles to contract	Causes changes in metabolic activity

1. Identify the three basic components of a nervous system and explain how they function to maintain homeostasis:

   (a) ______

   (b) ______

   (c) ______

2. Describe two differences between nervous control and endocrine (hormonal) control of body systems:

   (a) ______

   (b) ______

Related activities: The Nervous System, Hormonal Regulatory Systems
Web links: Nervous System Animation

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The Nervous System

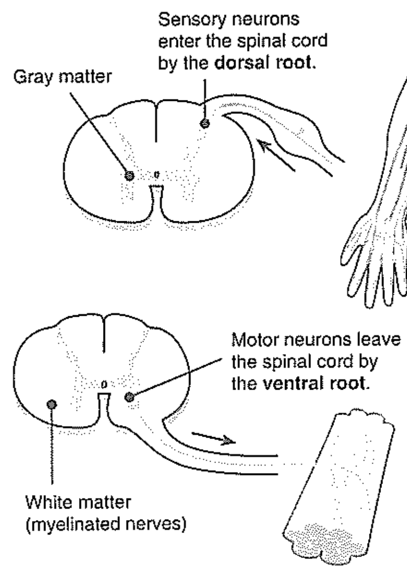
The **nervous system** is the body's control and communication center. It has three broad functions: detecting stimuli, interpreting them, and initiating appropriate responses. Its basic structure is outlined below. Further detail is provided in the following pages.

The Human Nervous System

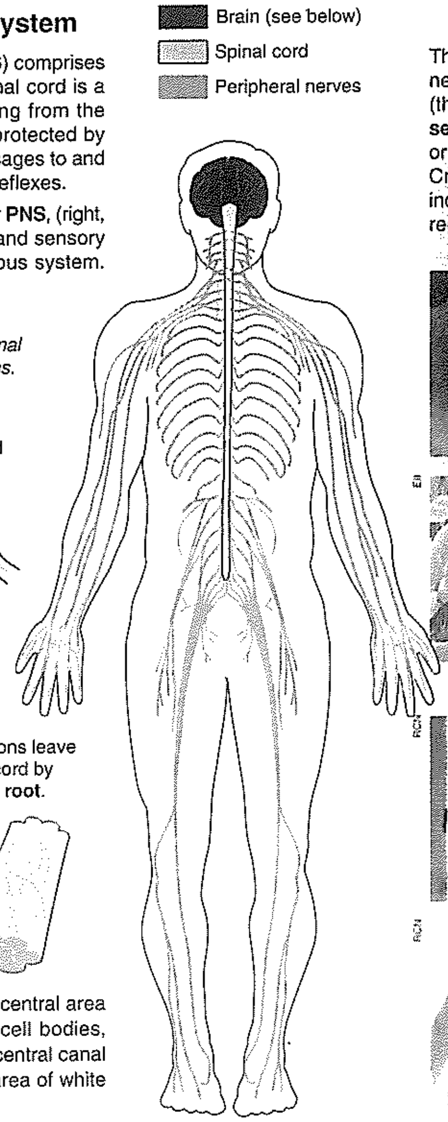
The **central nervous system (CNS)** comprises the brain and spinal cord. The spinal cord is a cylinder of nervous tissue extending from the base of the brain down the back, protected by the spinal column. It transmits messages to and from the brain, and controls spinal reflexes.

The **peripheral nervous system**, or **PNS**, (right, far right) comprises all the nerves and sensory receptors outside the central nervous system.

Below: cross sections through the spinal cord to show entry and exit of neurons.

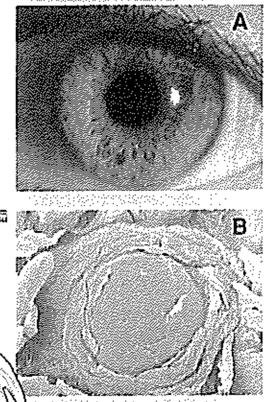


The **spinal cord** has an H shaped central area of gray matter, comprising nerve cell bodies, dendrites, and synapses around a central canal filled with cerebrospinal fluid. The area of white matter contains the nerve fibers.



The Peripheral Nervous System (PNS)

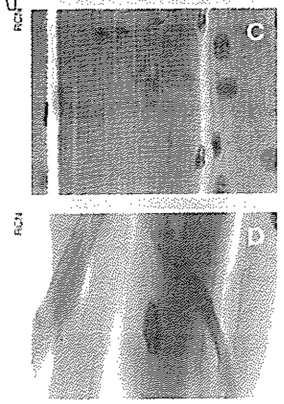
The PNS comprises **sensory** and **motor divisions**. Peripheral nerves all enter or leave the CNS, either from the spinal cord (the spinal nerves) or the brain (cranial nerves). They can be **sensory** (from sensory receptors), **motor** (running to a muscle or gland), or **mixed** (containing sensory and motor neurons). Cranial nerves are numbered in roman numerals, I-XII. They include the vagus (X), a mixed nerve with an important role in regulating bodily functions, including heart rate and digestion.



Sensory Division

Sensory nerves arise from **sensory receptors** (left) and carry messages to the central nervous system for processing.

The sensory system keeps the central nervous system aware of the external and internal environments. This division includes the familiar sense organs such as ears, eyes (A), and taste buds (B) as well as internal receptors that monitor internal state (e.g. thirst, hunger, body position, movement, pain).



Motor Division

Motor nerves carry impulses from the CNS to **effectors**: muscles (left) and glands. The motor division comprises two parts:

Somatic nervous system: the neurons that carry impulses to voluntary (skeletal) muscles (C).

Autonomic nervous system: regulates visceral functions over which there is generally no conscious control, e.g. heart rate, gut peristalsis involving smooth muscle (D), pupil reflex, and sweating.

1. Identify and briefly describe the three main functions of the nervous system:

   (a) ______

   (b) ______

   (c) ______

2. In the human nervous system, briefly explain the structure and role of each of the following:

   (a) The central nervous system: ______

   (b) The peripheral nervous system: ______

3. Explain the significance of the separation of the motor division of the PNS into somatic and autonomic divisions:

   ______

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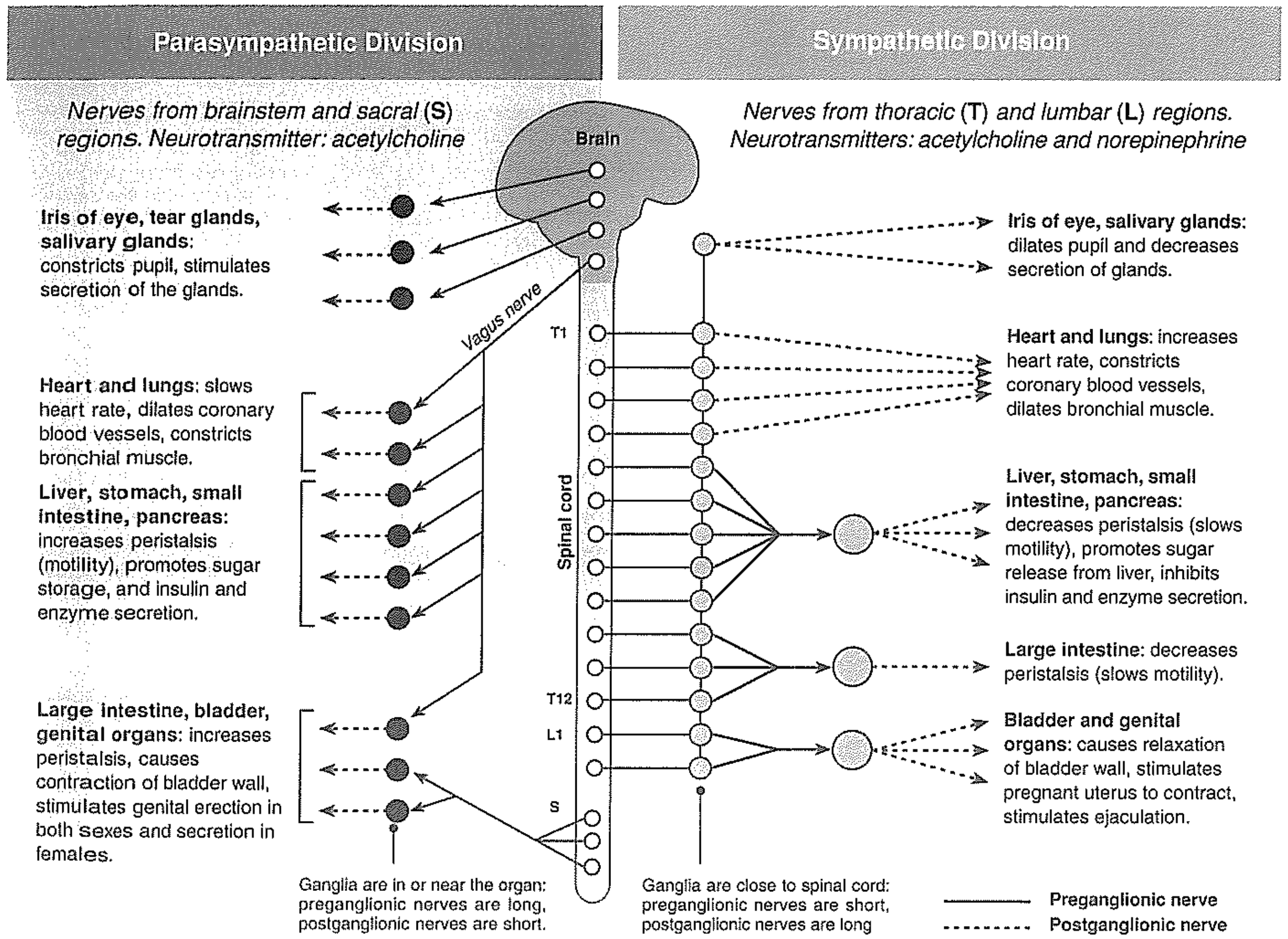
Related activities: Nervous Regulatory Systems, The Autonomic Nervous System

The Autonomic Nervous System

The **autonomic nervous system** (ANS) regulates involuntary visceral functions through **reflexes**. Although most autonomic nervous system activity is beyond our conscious control, voluntary control over some basic reflexes (such as bladder emptying) can be learned. Most visceral effectors have dual innervation, receiving fibers from both branches of the ANS. These two branches, the **parasympathetic** and **sympathetic** divisions, have broadly opposing actions on the organs they control (excitatory or inhibitory). Nerves in the parasympathetic division release acetylcholine. This neurotransmitter is rapidly deactivated at the synapse and its effects are short lived and localized. Most sympathetic postganglionic nerves release norepinephrine (noradrenaline), which enters the bloodstream and is deactivated slowly. Hence, sympathetic stimulation tends to have more widespread and long lasting effects than parasympathetic stimulation. Aspects of ANS structure and function are illustrated below. The arrows indicate nerves to organs or ganglia (concentrations of nerve cell bodies).



1. Explain the structure and role of each of the following divisions of the autonomic nervous system:

   (a) The sympathetic nervous system: ______________________

   (b) The parasympathetic nervous system: ______________________

2. Using an example (e.g. pupil reflex or control of heart rate), describe the role of reflexes in the functioning of the autonomic nervous system:

   ____

3. With reference to the emptying of the bladder, explain how a reflex activity can be modified by learning:

   ____

Related activities: The Nervous System, Reflexes

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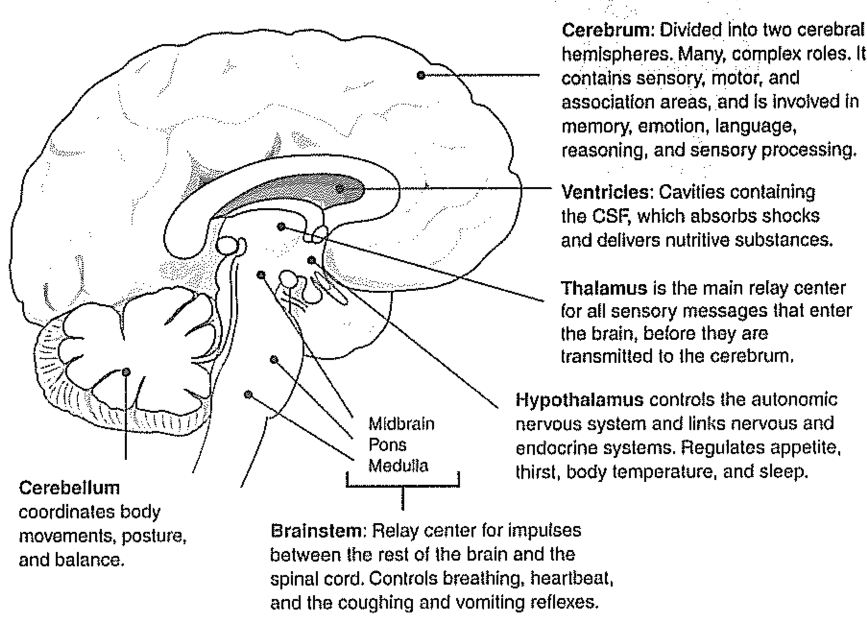
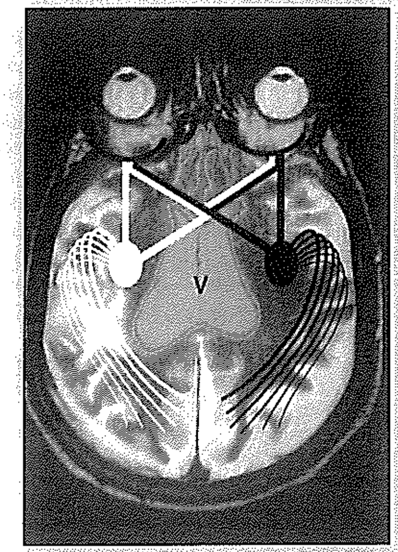
The Human Brain

The brain is one the largest organs in the body. It is protected by the skull, the **meninges**, and the **cerebrospinal fluid** (CSF). The brain is the body's control center. It receives a constant flow of sensory information, but responds only to what is important at the time. Some responses are very simple (e.g. cranial reflexes), whilst others require many levels of processing. The human brain is noted for its large, well developed cerebral region, with its prominent folds (**gyri**) and grooves (**sulci**). Each cerebral hemisphere has an outer region of gray matter and an inner region of white matter, and is divided into four lobes by deep sulci or fissures. These lobes: temporal, frontal, occipital, and parietal, correspond to the bones of the skull under which they lie.

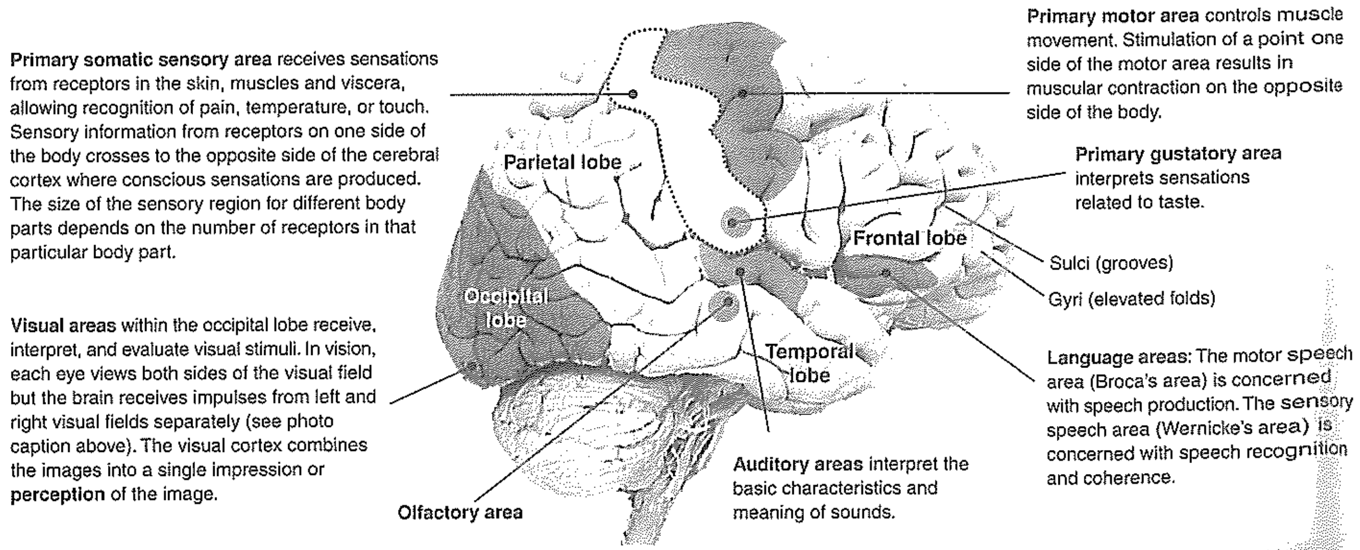
Primary Structural Regions of the Brain

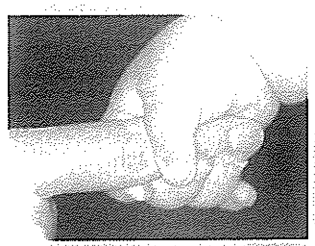




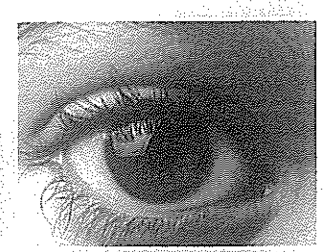
MRI scan of the brain viewed from above. The visual pathway has been superimposed on the image. Note the crossing of some sensory neurons to the opposite hemisphere and the fluid filled ventricles (V) in the center.

Sensory and Motor Regions in the Cerebrum

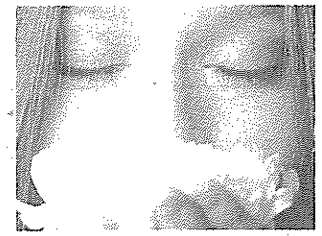




Touch is interpreted in the primary somatic sensory area. The fingertips and the lips have a relatively large amount of area devoted to them.



Humans rely heavily on vision. The importance of this special sense in humans is indicated by the large occipital region of the brain.



The olfactory tract connects the olfactory bulb with the cerebral hemispheres where olfactory information is interpreted.

The endothelial tight junctions of the capillaries supplying the brain form a protective **blood-brain barrier** against toxins and infection.

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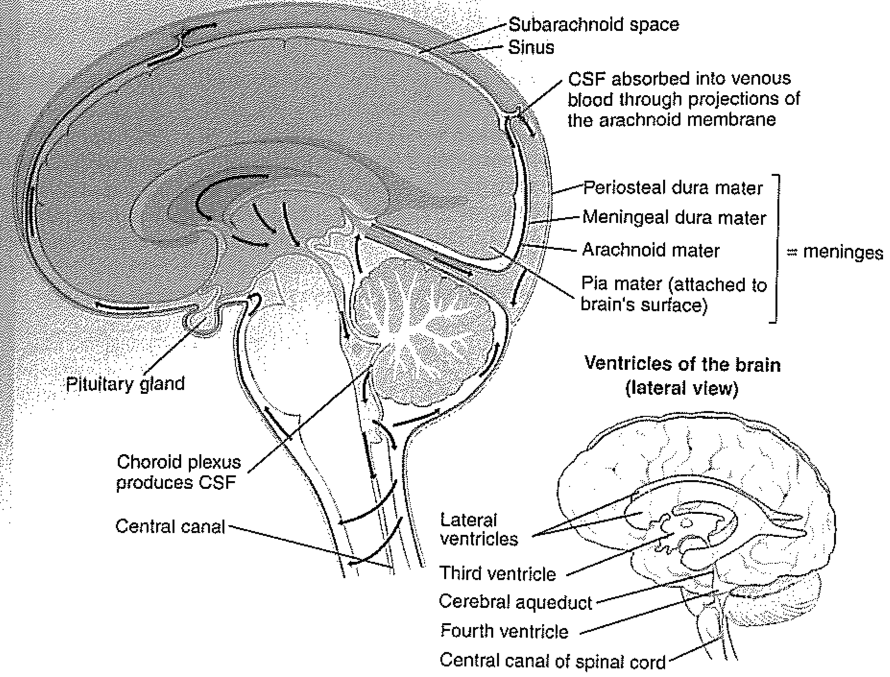
Related activities: The Nervous System, Aging and the Brain
Web links: Inside the Brain: An Interactive Tour, Brain Anatomy

The Ventricles and CSF

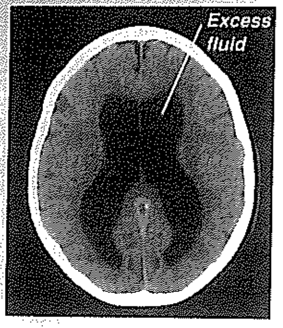
The delicate nervous tissue of the brain and spinal cord is protected against damage by the **bone** of the skull and vertebral column, the membranes overlying the brain (the **meninges**), and the watery but nutritive **cerebrospinal fluid** (CSF), which lies between the inner two of the meningeal layers.

The meninges are collectively three membranes: a tough double-layered outer **dura mater**, a web-like middle **arachnoid mater**, and an inner delicate **pia mater** that adheres to the surface of the brain. The CSF is formed from the blood by clusters of capillaries on the roof of each of the brain's ventricles (choroid plexuses). The CSF is constantly circulated through the ventricles of the brain (and into the spinal cord), returning to the blood via specialized projections of the middle meningeal layer (the arachnoid).

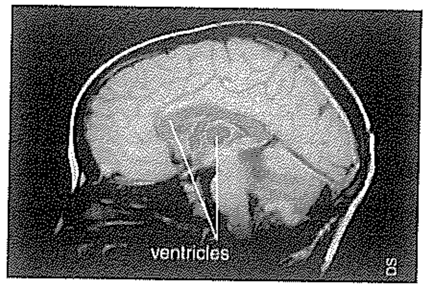


If the passages that normally allow the CSF to exit the brain become blocked, the CSF accumulates within the brain's ventricles causing a condition called hydrocephalus

The accumulated fluid can be seen in this MRI scan.



MRI scanning is a powerful technique to visualize the structure and function of the body. It provides much greater contrast between the different soft tissues than computerized tomography (CT) does, making it especially useful in neurological (brain) imaging, especially for indicating the presence of tumors or fluid, and showing up abnormalities in blood supply. In the scan pictured right, the fluid within the lateral and third ventricles is clearly visible.



1. For each of the following bodily functions, identify the region(s) of the brain involved in its control:
   (a) Breathing and heartbeat: ______
   (b) Memory and emotion: ______
   (c) Posture and balance: ______
   (d) Autonomic functions: ______
   (e) Visual processing: ______
   (f) Body temperature: ______
   (g) Language: ______
   (h) Muscular movement: ______

2. Explain how the brain is protected against physical damage and infection: ______

3. (a) Describe where CSF is produced and how the CSF returns to the blood: ______

   (b) Explain the consequences of blocking this return flow of CSF: ______

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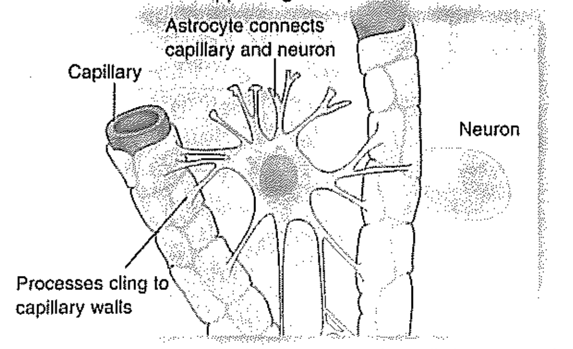
The Cells of Nervous Tissue

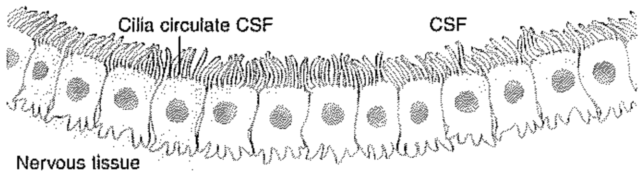
Nervous tissue is made up of two main cell types: **neurons**, which are specialized to transmit nerve impulses, and supporting cells, which are collectively called **neuroglia**. Neurons (right panel) have a recognizable structure with a cell body and armlike **processes** (**dendrites** and **axons**). Most long neurons in the PNS are also supported by a fatty insulating sheath of myelin. Supporting cells are more variable and are specialized to perform different roles. Some, such as astrocytes, help to form the **blood-brain barrier**, while others line the cavities of the brain and spinal cord. Although they appear similar in structure to neurons, glial cells are unable to transmit nerve impulses. The features of some of these cell types are described below.

Supporting Glial Cells

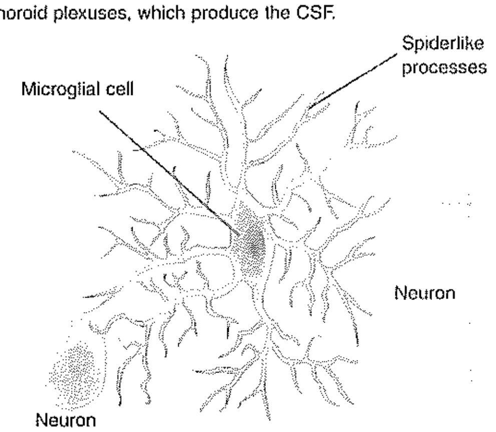
Glial cells are of four basic types, each with a particular function in supporting the neurons of the CNS.



Astrocytes are the most abundant supportive cells in nervous tissue. They anchor neurons to capillaries and support the blood-brain barrier by restricting the passage of certain substances. They are also important in the repair of the brain and spinal cord following injury.



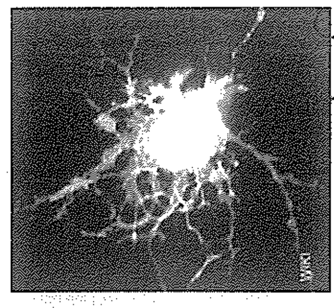
Ependymal cells are the epithelial cells lining the ventricles in the brain and the central canal of the spinal cord. The surfaces of these cuboidal cells are covered in cilia and microvilli, which circulate and absorb CSF. Specialized ependymal cells and capillaries together form the choroid plexuses, which produce the CSF.



Microglia are the defense cells of nervous tissue. Antibodies are too large to cross the blood-brain barrier, so the phagocytic microglia must be able to recognize and dispose of foreign material and debris.

Oligodendrocytes produce insulating myelin sheaths around the axons of neurons in the CNS. A single oligodendrocyte can extend to wrap around up to 50 axons.

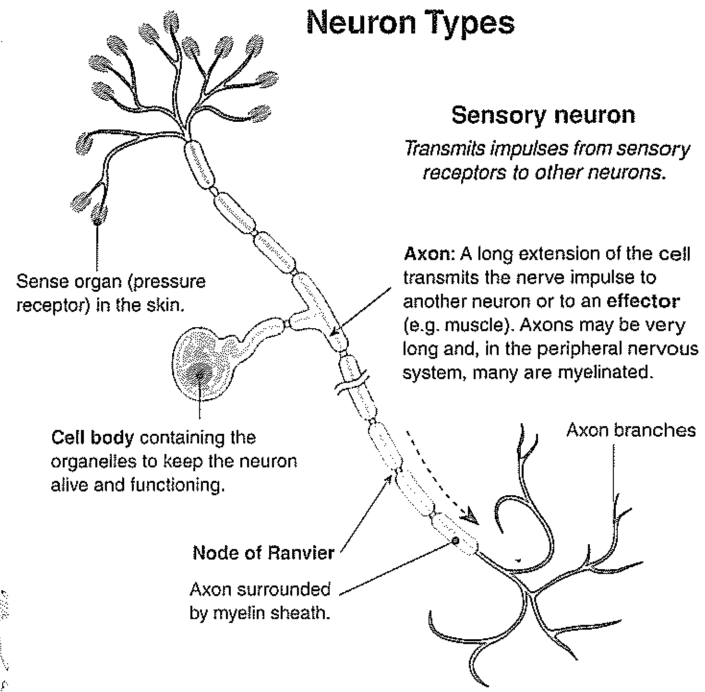
This image shows an oligodendrocyte genetically altered to fluoresce.



Neuron Types

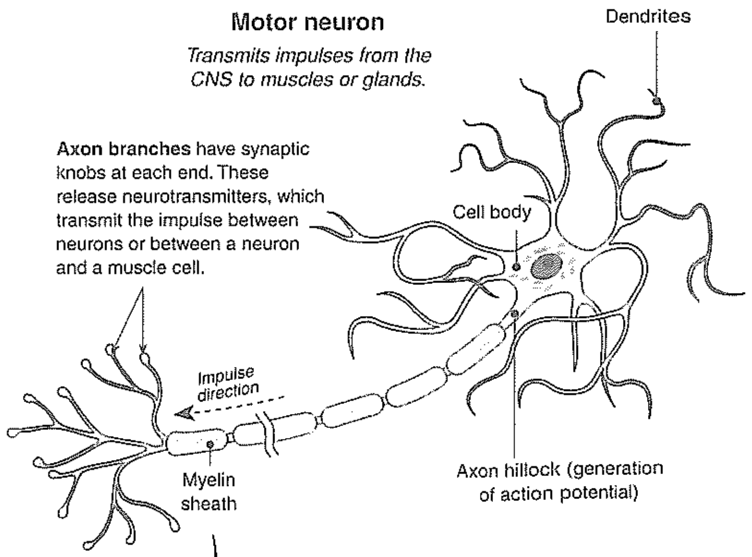
Sensory neuron

Transmits impulses from sensory receptors to other neurons.



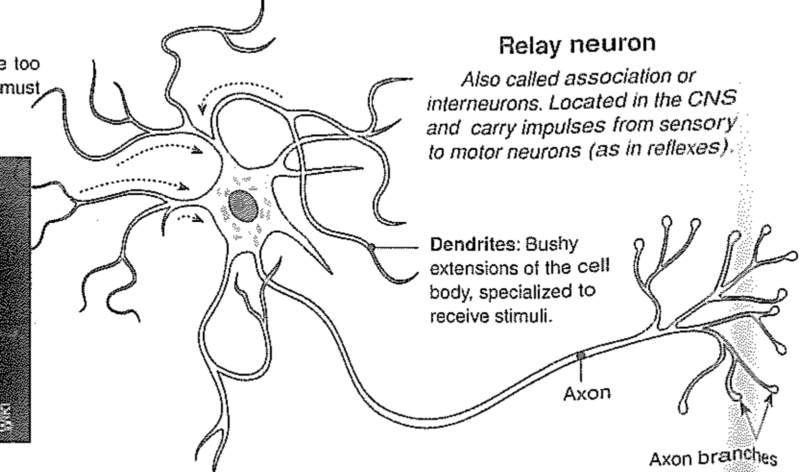
Motor neuron

Transmits impulses from the CNS to muscles or glands.



Relay neuron

Also called association or interneurons. Located in the CNS and carry impulses from sensory to motor neurons (as in reflexes).



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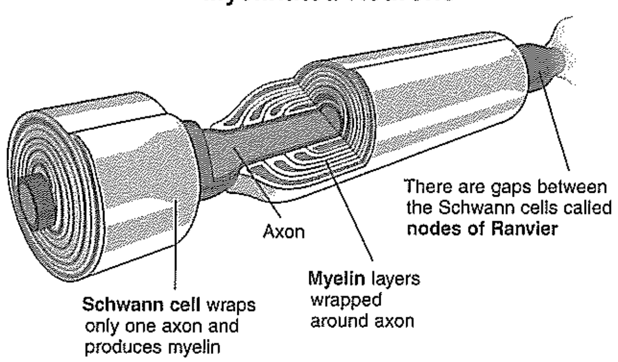
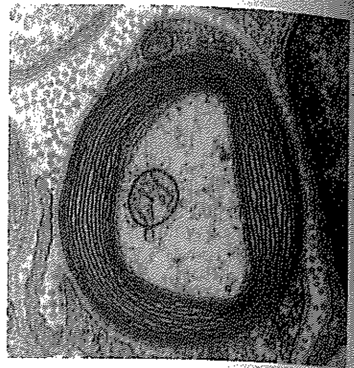
Related activities: The Nervous System, Nervous Regulatory Systems, Autoimmune Diseases **Web links:** Unipolar and Multipolar Neurons

Where conduction speed is important, the axons of neurons are sheathed within a lipid and protein rich substance called **myelin**. Myelin is produced by **oligodendrocytes** in the central nervous system (CNS) and by **Schwann cells** in the peripheral nervous system (PNS). Myelin acts as an insulator, increasing the speed at which nerve impulses travel because it prevents ion flow across the neuron membrane and forces the current to "jump" along the axon.

Myelinated Neurons

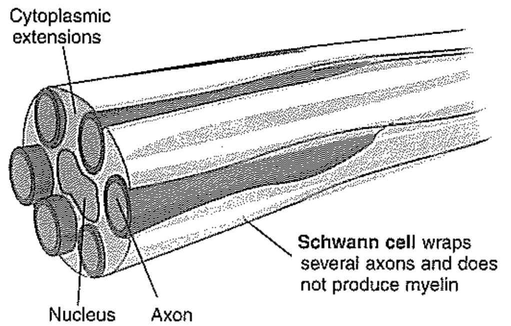


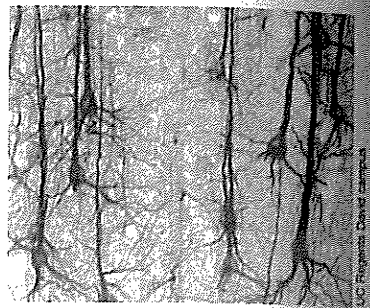


TEM cross section through a myelinated axon

Non-myelinated axons are relatively more common in the central nervous system where the distances travelled are less than in the PNS. Here, the axons are encased within the cytoplasmic extensions of oligodendrocytes or Schwann cells, rather than within a myelin sheath. The speed of impulse conduction is slower than in myelinated neurons because the nerve impulse is propagated along the entire axon membrane, rather than jumping from node to node as occurs in myelinated neurons.

Non-myelinated Neurons





Unmyelinated pyramidal neurons of the cerebral cortex

1. (a) Describe a structural difference between a motor and a sensory neuron: ______

   (b) Describe a functional difference between a motor and a relay or interneuron: ______

2. Describe the functional role of each of the following glial cells, with reference to the features associated with that role:

   (a) Oligodendrocytes: ______

   (b) Ependymal cells: ______

   (c) Microglia: ______

   (d) Astrocytes: ______

3. (a) Explain the function of myelination in neurons: ______

   (b) Name the cell type responsible for myelination in the CNS: ______

   (c) Name the cell type responsible for myelination in the PNS: ______

   (d) Explain why myelination is a typically a feature of neurons in the peripheral nervous system: ______

4. Multiple sclerosis (MS) is a disease involving progressive destruction of the myelin sheaths around axons (see *Autoimmune Diseases*). Explain why MS impairs nervous system function even though axons are undamaged:

______

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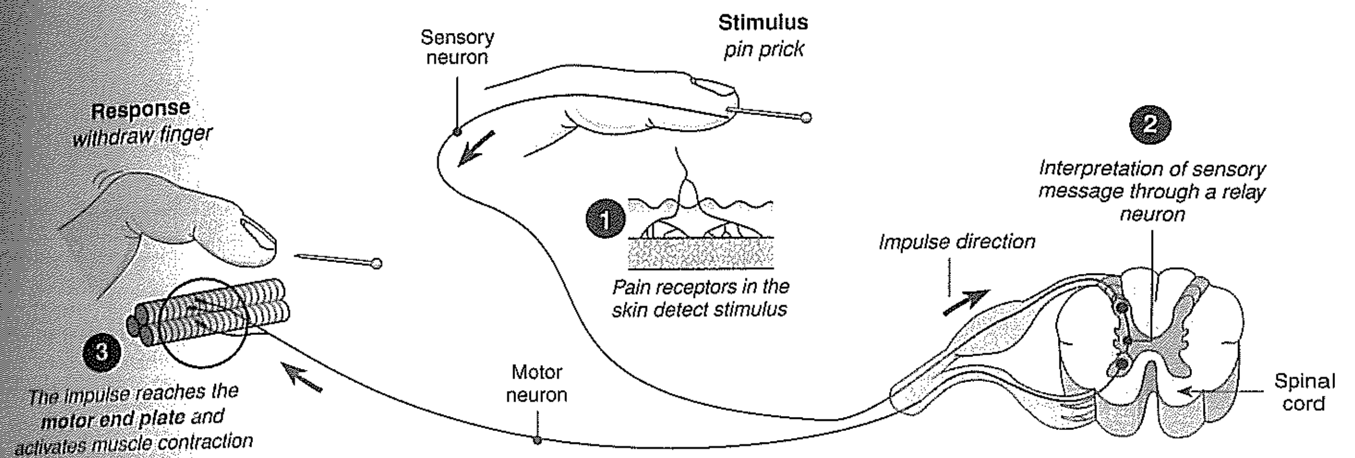
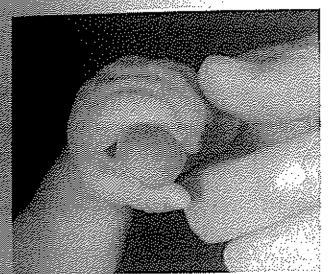
Reflexes

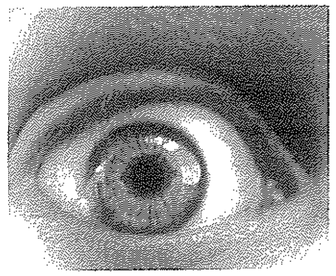
A reflex is an automatic response to a stimulus involving a small number of neurons and a central nervous system (CNS) processing point (usually the spinal cord, but sometimes the brain stem). This type of circuit is called a **reflex arc**. Reflexes permit rapid responses to stimuli. They are classified according to the number of CNS synapses involved; **monosynaptic reflexes** involve only one CNS synapse (e.g. knee jerk reflex), **polysynaptic reflexes** involve two or more (e.g. pain withdrawal reflex). Both are spinal reflexes. The pupil reflex (opening and closure of the pupil) is an example of a cranial reflex.

Pain Withdrawal: A Polysynaptic Reflex Arc

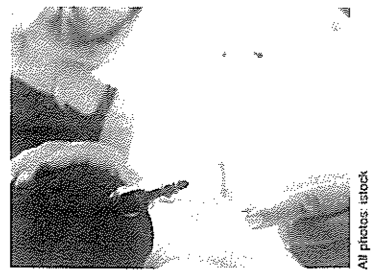




Normal newborns exhibit a number of primitive reflexes in response to particular stimuli. These reflexes disappear within a few months of birth as the child develops. Primitive reflexes include the grasp reflex (above left) and the startle or Moro reflex (right) in which a sudden noise will cause the infant to throw out its arms, extend the legs and head, and cry. The rooting and sucking reflexes are other examples of primitive reflexes.



The pupillary light reflex refers to the rapid expansion or contraction of the pupils in response to the intensity of light falling on the retina. It is a polysynaptic cranial reflex and can be used to test for brain death.



The patella (knee jerk) reflex is a simple deep tendon reflex that is used to test the function of the femoral nerve and spinal cord segments L2-L4. It helps to maintain posture and balance when walking.

All photos: istock

1. Explain why higher reasoning or conscious thought are not necessary or desirable features of reflex behaviors:

______

2. Distinguish between a spinal reflex and a cranial reflex and give an example of each: ______

3. Distinguish between a monosynaptic and a polysynaptic reflex arc and give an example of each: ______

4. (a) With reference to specific examples, describe the adaptive value of primitive reflexes in newborns:

   ______

   (b) Explain why newborns are tested for the presence of these reflexes: ______

5. Describe the adaptive value of cranial reflexes such as the pupillary light reflex and the blink reflex:

______

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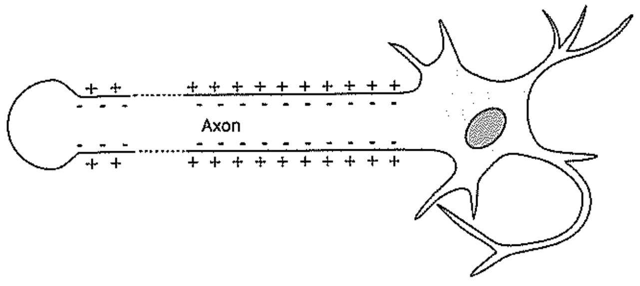
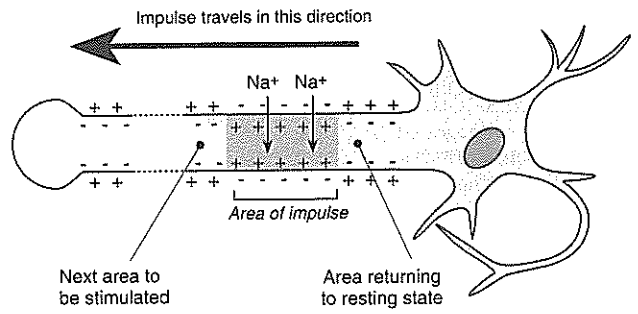
Related activities: The Nervous System, Chemical Synapses
Web links: Parasympathetic Eye Response, Knee Jerk Reflex

Transmission of Nerve Impulses

Neurons, like all cells, contain ions or charged atoms. Those of special importance include sodium (Na^+), potassium (K^+), and negatively charged proteins. Neurons are **electrically excitable** cells: a property that results from the separation of ion charge either side of the neuron membrane. They may exist in either a resting or stimulated state. When stimulated, neurons produce electrical impulses that are transmitted along the axon. These impulses are transmitted between neurons across junctions called **synapses**. Synapses enable the transmission of impulses rapidly all around the body.





The Resting Neuron

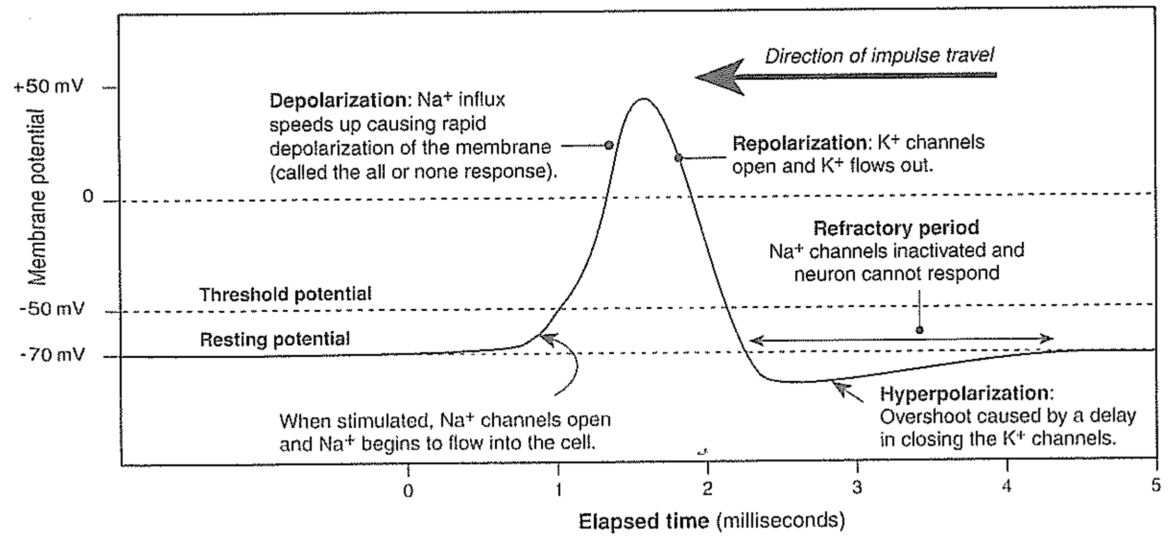
When a neuron is not transmitting an impulse, the inside of the cell is negatively charged compared with the outside of the cell. The cell is said to be electrically polarized, because the inside and the outside of the cell are oppositely charged. The potential difference (voltage) across the membrane is called the resting potential and for most nerve cells is about -70 mV. Nerve transmission is possible because this membrane potential exists.

The Nerve Impulse

When a neuron is stimulated, the distribution of charges on each side of the membrane changes. For a millisecond, the charges reverse. This process, called **depolarization**, causes a burst of electrical activity to pass along the axon of the neuron. As the charge reversal reaches one region, local currents depolarize the next region. In this way the impulse spreads along the axon. An impulse that spreads this way is called an **action potential**.

The Action Potential

The depolarization described above can be illustrated as a change in membrane potential (in millivolts). In order for an action potential to be generated, the stimulation must be strong enough to reach the **threshold** potential; this is the potential (voltage) at which the depolarization of the membrane becomes "unstoppable" and the action potential is generated. The action potential is **all or none** in its generation. Either the **threshold** is reached and the action potential is generated or the nerve does not fire. The resting potential is restored by the movement of potassium ions (K^+) out of the cell. During this **refractory period**, the nerve cannot respond.



1. Explain how an action potential is able to pass along a nerve: ______________________________

____

2. Explain how the refractory period influences the direction in which an impulse will travel: ______________________________

____

3. Action potentials themselves are indistinguishable from each other. Explain how the nervous system is able to interpret the impulses correctly and bring about an appropriate response:

____

____

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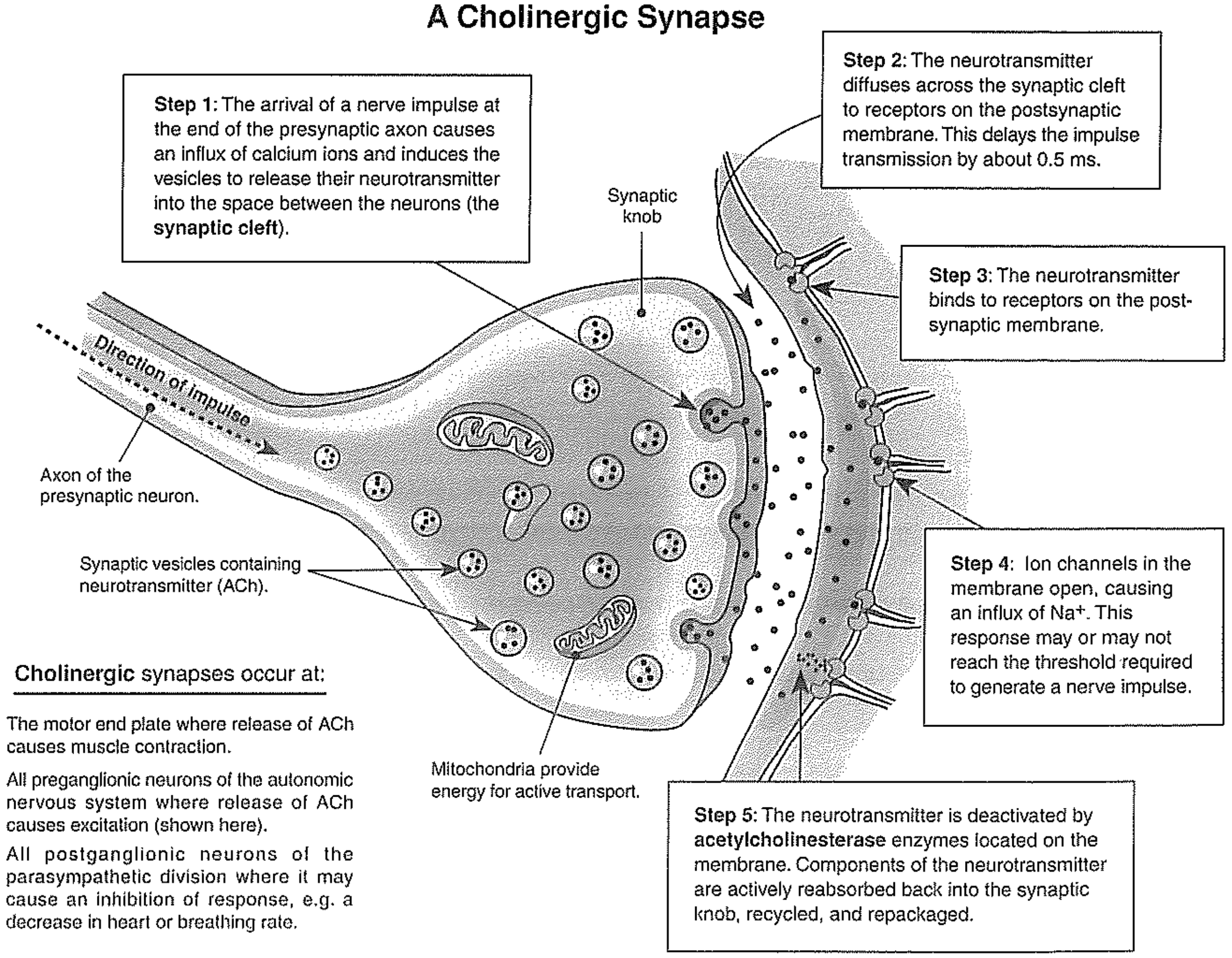
Chemical Synapses

Action potentials are transmitted between neurons across **synapses**: junctions between the end of one axon and the dendrite or cell body of a receiving neuron. Electrical synapses, where cells are electrically coupled through gap junctions between cells, occur in heart muscle and in the cerebral cortex, but they are relatively uncommon elsewhere. Most synapses in the nervous system are **chemical synapses**. In these, the axon terminal is a swollen knob, and a small gap, the **synaptic cleft**, separates it from the receiving neuron. The synaptic knobs are filled with tiny packets of chemicals called **neurotransmitters**.

Nerve transmission involves the diffusion of the neurotransmitter across the cleft, where it interacts with the receiving membrane and causes an electrical response. The response of a receiving (post-synaptic) cell to the arrival of a neurotransmitter depends on the nature of the cell itself, on its location in the nervous system, and on the neurotransmitter involved. Synapses that release acetylcholine (ACh) are termed **cholinergic**. In the example below, ACh results in membrane depolarization and an action potential (an excitatory response). Unlike electrical synapses, transmission at chemical synapses is always unidirectional.

A Cholinergic Synapse



Cholinergic synapses occur at:

- The motor end plate where release of ACh causes muscle contraction.
- All preganglionic neurons of the autonomic nervous system where release of ACh causes excitation (shown here).
- All postganglionic neurons of the parasympathetic division where it may cause an inhibition of response, e.g. a decrease in heart or breathing rate.

1. Explain what is meant by a **synapse**: ______________________________

2. Explain what causes the release of neurotransmitter into the synaptic cleft: ______________________________

____

3. State why there is a brief delay in transmission of an impulse across the synapse: ______________________________

____

4. (a) Explain how the neurotransmitter is deactivated: ______________________________

(b) Explain why it is important for the neurotransmitter substance to be deactivated soon after its release:

____

(c) Explain why transmission at chemical synapses is unidirectional and comment on the significance of this:

____

5. Describe one factor that might influence the strength of the response in the receiving cell: ______________________________

____

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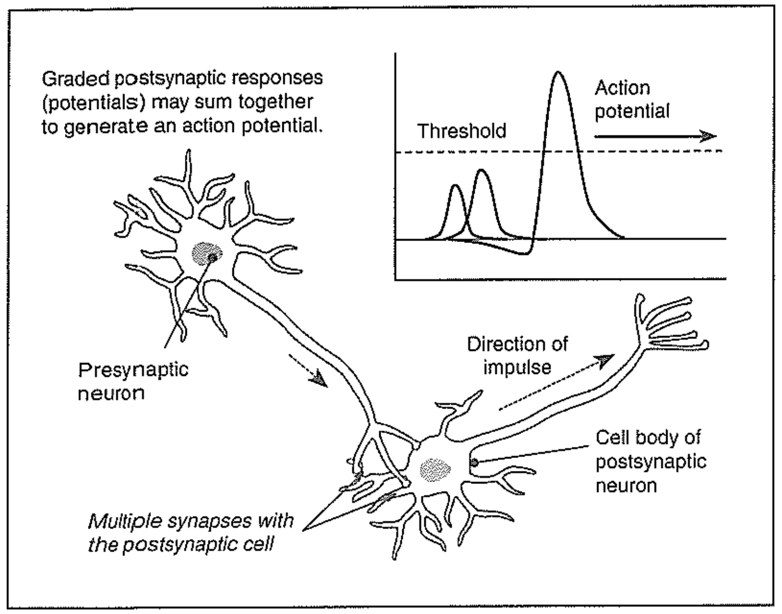
Integration at Synapses

Synapses play a pivotal role in the ability of the nervous system to respond appropriately to stimulation and to adapt to change. The nature of synaptic transmission allows the **integration** (interpretation and coordination) of inputs from many sources. These inputs need not be just excitatory (causing depolarization). Inhibition results when the neurotransmitter released causes negative chloride ions (rather than sodium ions) to enter the postsynaptic neuron. The postsynaptic neuron then becomes more negative inside (hyperpolarized) and an action potential is less likely to be generated. At synapses, it is the sum of **all** inputs (excitatory and inhibitory) that leads to the final response in a postsynaptic cell. Integration at synapses makes possible the various responses we have to stimuli. It is also the most probable mechanism by which learning and memory are achieved.

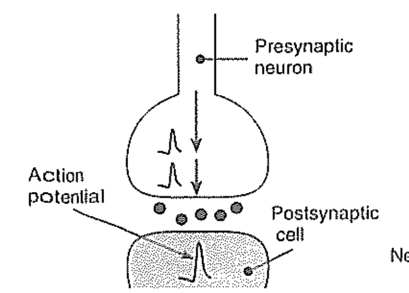


Synapses and Summation

Nerve transmission across chemical synapses has several advantages, despite the delay caused by neurotransmitter diffusion. Chemical synapses transmit impulses in one direction to a precise location and, because they rely on a limited supply of neurotransmitter, they are subject to fatigue (inability to respond to repeated stimulation). This protects the system against overstimulation.

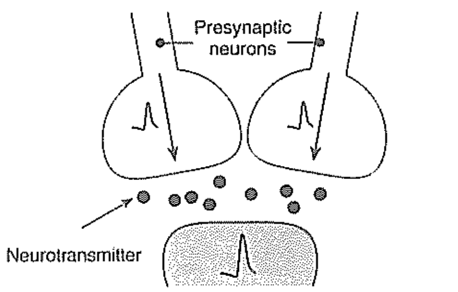
Synapses also act as centers for the **integration** of inputs from many sources. The response of a postsynaptic cell is often graded; it is not strong enough on its own to generate an action potential. However, because the strength of the response is related to the amount of neurotransmitter released, subthreshold responses can sum to produce a response in the post-synaptic cell. This additive effect is termed **summation**. Summation can be **temporal** or **spatial** (below). A neuromuscular junction (photo below) is a specialized form of synapse between a motor neuron and a skeletal muscle fiber. Functionally, it is similar to any excitatory cholinergic synapse.

1 Temporal summation



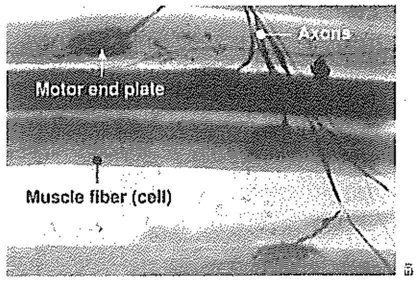
Several impulses may arrive at the synapse in quick succession from a single axon. The individual responses are so close together in time that they sum to reach threshold and produce an action potential in the postsynaptic neuron.

2 Spatial summation



Individual impulses from spatially separated axon terminals may arrive **simultaneously** at different regions of the same postsynaptic neuron. The responses from the different places sum to reach threshold and produce an action potential.

3 Neuromuscular junction



The arrival of an impulse at the neuromuscular junction causes the release of acetylcholine from the synaptic knobs. This causes the muscle cell membrane (sarcolemma) to depolarize, and an action potential is generated in the muscle cell.

1. Explain the purpose of nervous system integration: ______________________

2. (a) Explain what is meant by **summation**: ______________________

   (b) In simple terms, distinguish between temporal and spatial summation: ______________________

3. Describe two ways in which a neuromuscular junction is similar to any excitatory cholinergic synapse:

   (a) ______________________

   (b) ______________________

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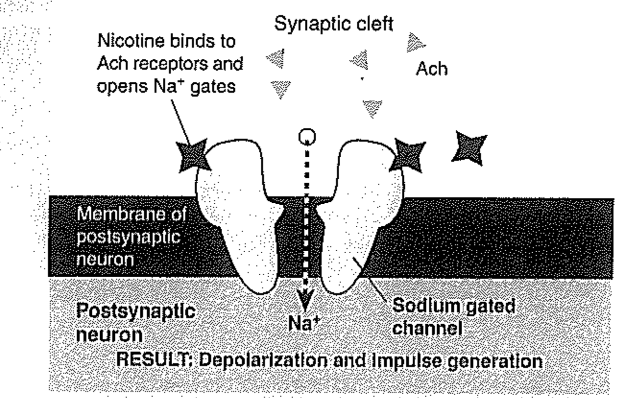
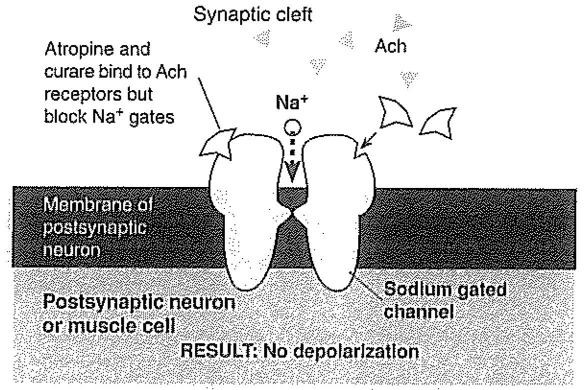
Drugs at Synapses

Synapses in the peripheral nervous system are classified according to the neurotransmitter they release; **cholinergic** synapses release **acetylcholine** (**Ach**) while **adrenergic** synapses release **epinephrine** (adrenaline) or **norepinephrine** (noradrenaline). The effect produced by these neurotransmitters depends, in turn, on the type of receptors present on the postsynaptic membrane. Ach receptors are classified as nicotinic or muscarinic according to their response to nicotine or muscarine (a fungal toxin). Adrenergic receptors are also of two types, alpha (α) or beta (β), classified according to their particular responses to specific chemicals. **Drugs** exert their effects on the nervous system by mimicking (**agonists**) or blocking (**antagonists**) the action of neurotransmitters at synapses. Because of the small amounts of chemicals involved in synaptic transmission, drugs that affect the activity of neurotransmitters, or their binding sites, can have powerful effects even in small doses.

Drugs at Cholinergic Synapses

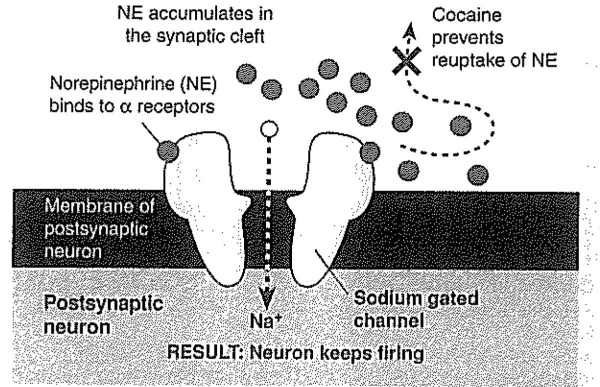


Nicotine acts as a **direct agonist** at nicotinic synapses. Nicotine binds to and activates acetylcholine (Ach) receptors on the postsynaptic membrane. This opens sodium gates, leading to a sodium influx and membrane depolarization. Some agonists work indirectly at the synapse by preventing Ach breakdown. Such drugs are used to treat elderly patients with Alzheimer's disease.

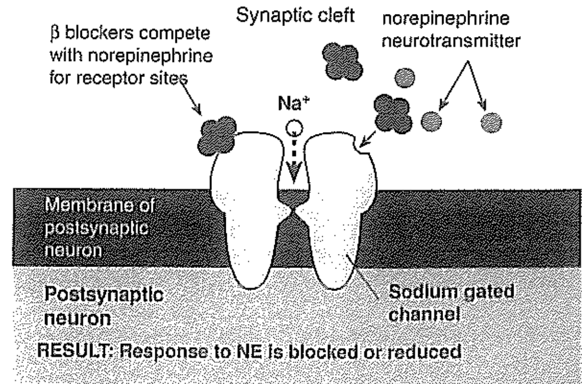


Atropine and **curare** act as antagonists at some cholinergic synapses. These molecules compete with Ach for binding sites on the postsynaptic membrane, and block sodium influx so that impulses are not generated. If the postsynaptic cell is a muscle cell, muscle contraction is prevented. In the case of curare, this causes death by flaccid paralysis.

Drugs at Adrenergic Synapses



Under normal circumstances, the continued activity of the neurotransmitter norepinephrine (NE) at the synapse is prevented by reuptake of NE by the presynaptic neuron. **Cocaine** and **amphetamine** drugs act indirectly as agonists by preventing this reuptake. This action allows NE to linger at the synapse and continue to exert its effects.



Therapeutic drugs called **beta (β) blockers** act as direct antagonists at adrenergic synapses (sympathetic nervous system). They compete for the adrenergic β receptors on the postsynaptic membrane and block impulse transmission. Beta blockers are prescribed primarily to treat hypertension and heart disorders because they slow heart rate and reduce the force of contraction.

1. Providing an example of each, outline two ways in which drugs can act at a cholinergic synapse:

   (a) ______________________

   (b) ______________________

2. Providing an example, outline one way in which drugs can operate at adrenergic synapses: ______________________

3. Explain why atropine and curare are described as direct antagonists: ______________________

4. Suggest why curare (carefully administered) is used during abdominal surgery: ______________________

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