Nervous system (chapters 12, 13, 15, and 16)

The two regions of the nervous system:

- Central nervous system (CNS) = The brain and spinal cord

- Peripheral nervous system (PNS) = All nervous tissue outside the CNS

Fig 12.2

Nervous system

Organs made of nervous tissue. The nervous system carries out these three functions:

1) Senses stimuli (such as sight, touch, taste, etc.)

2) Formulates a response to the stimuli

√ This function is our perceptions, thoughts, and reflexes

√ This function occurs in the CNS

3) Transmits signals rapidly between body parts

√ Ex: Signals from sense organs to the CNS

√ Ex: Response signals from the CNS to the muscles

Figs 12.2, 12.6, and 12.14

Nervous tissue consists of neuron cells and neuroglial cells

Neuron

The nervous tissue cell type that performs all the functions of the nervous system (senses stimuli, formulate responses, carries electrical signals between body parts)

- Cell body = The round region of the neuron that contains the nucleus and most other major organelles
- Processes = Extensions from the cell body
  - √ Dendrites = Detect stimuli and start the electrical signal
  - √ Axon = Conducts the electrical signal toward the target cell (the cell that will receive the signal)
  - √ Axon terminals = Bulbs at end of the axon where signals pass to the target cell
    - – Colaterals = Branchings of the axon near an axon's end
- Myelin sheath = A wrapping of myelin (white fatty material) around the axon that speeds the signal

Figs 4.19 and 12.8

Neuroglia cells

Cells that support and assist neurons, but that do not carry out any sensing, responding, or signaling

There are several types of neuroglia cells, each with a specialized structure and function

- Schwann cells = Neuroglia cells in the PNS that wrap themselves around axons to form the myelin sheath

- Oligodendrocytes = Star-shaped neuroglia cells in the CNS that wrap branches around several axons to form many myelin sheaths

- Astrocytes = Star-shaped neuroglia cells in the CNS that form a bridge between neurons and blood vessels to transfer nutrients from the blood to the neurons in the CNS

    √ Blood-brain barrier = Capillaries in the brain (unlike capillaries in other parts of the body) do **not** allow most nutrients and other molecules in the blood to exit by uncontrolled leaking out of the capillary

Figs 4.20, 12.11, 12.12, and 12.13a; Table 12.2

Functionally, there are three neuron types:

1) Sensory neurons (afferent neurons)

PNS neurons that detect sense stimuli and carry sense signals into the CNS

- They have a unipolar shape (axon and dendrites connect to the same side of the cell body)

- They are stimulated by sense stimuli (light, sound, touch, etc.)

- They pass their signal to neurons in the CNS

2) Interneurons (association neurons)

All neurons inside the CNS. Interneurons can receive sensory neuron signals, communicate with other interneurons, and generate response motor signals (signals to motor neurons to activate muscles)

- The communications between interneurons are our perceptions, feelings, emotions, and thoughts

3) Motor neurons (efferent neurons)

PNS neurons that conduct response motor signals out from the CNS

- They are stimulated by interneurons

- They pass their signal to muscles or glands

Figs 12.6 and 12.14

Nerves

Bundles of neurons (wrapped in connective tissue) in the PNS

- Most nerves are mixed nerves (they contain sensory and motor neurons)
- Cranial nerves = Nerves that connect to the CNS in the head
- Spinal nerves = Nerves that connect to the CNS in the spine

(• Inside the CNS, bundles of neurons are called tracts)

Figs 12.2, 13.21, 13.23, and 13.24; Table 12.1

Ganglion

A cluster of neuron cell bodies in the PNS (within a nerve)

- Ganglia are visible as a bulge in a nerve's connective tissue
- They can be clusters of sensory neuron cell bodies or motor neuron synapses within the nerve

(• Inside the CNS, clusters of cell bodies are called nuclei)

Fig 12.2; Table 12.1

Synapse

The location where a neuron passes its signal to its target cell (the cell that will receive the signal)

- Pre-synaptic cell = The neuron that brings the signal to the synapse
- Post-synaptic cell/Target cell = The cell that receives the signal
  - The target cell is usually a neuron or a muscle cell
  - The post-synaptic cell generates its own electrical signal in response to receiving the signal from the pre-synaptic neuron
- The synapse includes…
  a) The axon terminals of the pre-synaptic cell
  b) The dendrites of the post-synaptic cell
  c) The synaptic cleft (the gap between pre-synaptic cell and the post-synaptic cell)

Fig 12.27

Nerve signals crossing the synaptic cleft:

- Electrical nerve signals cannot cross the synaptic cleft
- The pre-synaptic neuron uses neurotransmitters to send the signal across the synaptic cleft

Fig 12.27

Neurotransmitters

Molecules released by axon terminals to carry the signal across the synapse to the target cell

- Neurotransmitters are stored in vesicles in the pre-synaptic cell's axon terminals

- When the electrical signal reaches the axon terminals, the vesicles release the neurotransmitters into the synaptic cleft

- The neurotransmitters diffuse across the cleft to the dendrites of the post-synaptic cell

  √ They bind receptor proteins on the dendrites

  √ The binding of neurotransmitter to receptor is what causes the post-synaptic cell to generate its own electrical nerve signal

    – Some neurotransmitters (called inhibitory neurotransmitters) do the opposite: They decrease the neuron's ability to generate its own electrical signal

- The neurotransmitters are rapidly removed from the synaptic cleft

  √ Enzymes in the pre-synaptic and postsynaptic cells destroy the neurotransmitters

  √ The pre-synaptic neuron can also reuptake unused neurotransmitters from the synaptic cleft

Figs 12.18, 12.27; Table 12.3

There are many types of neurotransmitters, but each individual neuron releases only one of the types

Neurotransmitter:	Usual location	Actions:
Acetylcholine	PNS & CNS	Contracts voluntary muscles Can relax or stimulate involuntary muscles and organs
Norepinephrine	PNS & CNS	Can relax or stimulate involuntary muscles and organs
Dopamine	CNS	Generation of motor signals Reward/pleasure feelings
Serotonin	CNS	Boosts mood, reduces appetite
Glutamic acid	CNS	General excitatory brain neurotransmitter
GABA and Glycine	CNS	General inhibitory brain neurotransmitters
Endorphin	CNS	Feelings of euphoria Pain reduction

Table 12.3

Action potential

The electrical nerve signal that travels through the axon

- Resting neurons (neurons that are not carrying a signal) have an electrical potential (voltage) of –70 millivolts (mV)

  √ This is due to removal of Na^+ ions from inside the neuron

  √ There are more K^+ ions inside the neuron than outside, and more Na^+ ions outside the neuron than inside (due to the sodium-potassium pump)

  √ The neuron is said to be "polarized" when it is at –70 mV

- The action potential is a change in the axon voltage from –70 mV to +30 mV

  √ The change in voltage is caused by voltage-gated sodium channels along the axon, which let Na^+ ions into the neuron

  √ The neuron is said to be "depolarized" when it reaches +30 mV

- After an action potential has passed through a region of the axon, that region returns to -70 mV

  √ The change in voltage is caused by opening of voltage-gated potassium channels along the axon

  √ The neuron is said to be "repolarized" when it returns to -70 mV

- When a region of the axon has started to depolarize, it must fully complete its entire depolarization and repolarization sequence before a new action potential can begin

  √ This is called the refractory period

Figs 3.9, 12.20. 12.21, 12.22, 12.23, and 12.24

Voltage-gated sodium channels

Channel proteins in the axon membrane that, when open, allow sodium ions to flow into the axon

• When a voltage-gated ion channel opens, it always allows enough sodium ions to enter so as to make its region of the axon +30 mV

• The voltage around the channel determines whether it is open or closed

√ Channels open when the voltage around them is -55 mV or more positive, but close when the voltage is more negative than –55 mV

- 55 mV is called the threshold voltage of the channel

• Voltage-gated sodium channels are found all along the axon

√ They are spaced closely enough together so that when one Na^+ channel opens it creates enough positive charge to open The next Na^+ channel, which creates enough positive charge to open the next Na^+ channel, etc.

- In other words, each Na^+ channel that opens causes the next Na^+ channel to pass its threshold of -55 mV

√ Therefore, whenever the first Na^+ channel opens it starts a chain reaction that opens all the Na^+ channel down the axon, one after another

Figs 12.20, 12.23, and 12.24

Voltage-gated potassium channels

Channel proteins in the axon membrane that, when open, allow potassium ions to flow out of the axon

- Potassium channels are found near each voltage-gated sodium channel

- The potassium channel opens just after the nearby sodium channel has made the region of the axon +30 mV

- The exiting of K+ ions from the axon return the voltage to –70 mV

Figs 12.21, 12.23, and 12.24

Excitatory and inhibitory neurotransmitters

- Excitatory neurotransmitters promote an action potential in the post-synaptic neuron

- Inhibitory neurotransmitters inhibit an action potential in the post-synaptic neuron

Receptors for excitatory neurotransmitters are chemical-gated Na^+ ion channels

- When they bind to their neurotransmitter, they open their Na^+ channel, which allows Na^+ to enter the cell

    √ This causes the postsynaptic cell to have a region of positive charge inside

    √ Excitatory Postsynaptic Potential (EPSP) = The region of positive charge inside the neuron from one binding of excitatory neurotransmitter

    √ The more excitatory neurotransmitters in the synapse, the more EPSPs will occur in the postsynaptic neuron

        – The total amount of positive voltage in the neuron is the sum of all EPSPs together

    √ If the sum of all EPSPs is enough to make the first voltage-gated sodium channel in the axon -55 mV or more positive, then the in the post-synaptic neuron will have an action potential

Figs 12.18 and 12.28a

Receptors for inhibitory neurotransmitters are chemical-gated Cl^- ion channels

- When they bind to their neurotransmitter, they open their Cl^- channel, which allows Cl^- to enter the cell

  √ This causes the postsynaptic cell to have a region of negative charge inside

  √ Inhibitory Postsynaptic Potential (IPSP) = The region of negative charge inside the neuron from one exposure to inhibitory neurotransmitter

  √ The more inhibitory neurotransmitters in the synapse, the more IPSPs will occur in the postsynaptic neuron

  – The total amount of negative voltage in the neuron is the sum of all IPSPs together

  √ If the sum of all IPSPs is enough to keep the first voltage-gated sodium channel in the axon more negative than -55 mV then no action potential will occur

The sum total of all EPSPs and IPSPs is what determines whether the postsynaptic neuron will have an action potential

√ If the sum of all EPSPs and IPSPs together makes the first voltage-gated sodium channel in the axon -55 mV or more positive, then the action potential occurs

√ If the sum of all EPSPs and IPSPs together keeps the first voltage-gated sodium channel in the axon more negative than -55 mV then no action potential occurs

Central nervous system (CNS)

The brain and the spinal cord

- The brain and spinal cord are surrounded by cerebrospinal fluid (CSF)

  √ Ventricles = Hollow areas in the brain filled with CSF

Figs 12.2, 12.6, and 13.18; Table 13.2

Regions of the CNS:

- White matter = Areas containing mylenated axons

  √ Tract = A bundle of axons in the CNS

- Gray matter = Areas of CNS containing cell bodies and dendrites

  √ Nuclei = A cluster of cell bodies in the CNS

- The brain has four major regions: The cerebrum, the diencephalon, the brain stem, and the cerebellum

Table 12.1

Cerebrum

The largest and most superior brain region

- The cerebrum has many functions, including sense perception, muscle movements, emotion, memories and "higher functions" such as language, social behavior, logic, and mental images

Fig 13.6

Regions of the cerebrum:

- The cerebrum is gray matter on its cortex (surface) but is mostly white matter below the surface

    √ Basal nuclei = Small regions of gray matter deep within the white matter

- Cerebral hemispheres = The left and right halves of the cerebrum

    √ The hemispheres are mirror images of each other; most structures and functions in one hemisphere are found in the matching location in the other hemisphere

        - Cerebral lateralization: Structures and functions that are only in one hemisphere

    √ Corpus callosum = A large tract that connects the two hemispheres, allowing them to communicate with each other

- Cerebral lobes = Areas of the cerebrum named after the cranial bones that cover them.

    √ The frontal lobe, the parietal lobe, the temporal lobe, and the occipital lobe

Figs 12.3, 13.6, and 13.7

Sense areas of the cerebrum

Areas that receive nerve signals from sensory neurons and allow us to experience the sense

- There are separate sense areas for vision, gustatory (taste), olfactory (smell), hearing, and touch (the “primary sensory area”)

Figs 13.8, 14.23, and 16.5

The primary motor area

The area of the cerebrum where voluntary motor signals (signals that control voluntary muscle movements) are generated

• The movements generated by the primary motor area are not smooth and coordinated. Its motor signals are refined by other brain areas (the substancia nigra and the cerebellum) for normal smooth movement to occur

Figs 13.8 and 16.5

The limbic system

A group of cerebral areas that cause feelings of emotion (such as anger, fear, sadness, and happiness, and pleasure) as well as sex drive and hunger

√ The thalamus (in the diencephalons brain region) works with the limbic system to generate many of these feelings

• Two important regions of the limbic system are the hippocampus and the amygdala

√ The amygdala specializes in fear

√ The hippocampus specializes in several emotions, and also converts short term memories into long term memories

Other areas of the cerebrum

- Areas of the frontal lobe allow us to control impulses, act socially, and provide motivation for actions

- The left hemisphere has areas that specialize in language, math, and using logic to solve problems

    √ Examples: Broca's Area = Area that controls movement of vocal organs to speak words

    Wernicke's area = Area that matches meaning to each word

- The right hemisphere has areas that specialize in spatial visualization ("mental images") and facial recognition

Figs 13.8 and 16.5

Diencephalon

The brain region located between the cerebral hemispheres and the brain stem. It is composed of the thalamus and the hypothalamus regions

- The thalamus = A region that routes incoming sense signals to the proper sense areas in the cerebrum

- The hypothalamus = A region that controls thirst, temperature, and sleep/wake cycles

    √ Working in conjunction with the limbic system, the hypothalamus also regulates emotions, hunger, and sex drive

    √ The hypothalamus controls the pituitary gland, a major source of hormones

Fig 13.11

Brain stem

A tubular region between the diencephalon and the spinal cord that controls many basic body functions

- Its three regions (from top to bottom) are the midbrain, the pons, and the medulla oblongata

- The midbrain contains the substancia nigra area, which (working with the cerebellum) adds smoothness and coordination to motor signals

- The pons and the medulla oblongata contain respiratory control centers that control breathing, and control centers for heart rate and blood pressure

    √ The inferior end of the medulla oblongata is continuous with the spinal cord

Fig 13.12

Cerebellum

A round region of the brain located posterior to the brain stem

- The cerebellum gives us the ability to stand with balance, and is also involved in motor learning (learning movements “by heart”)

- Working with the substancia nigra, the cerebellum adds smoothness and coordination to motor signals

Fig 13.13

The spinal cord

A downward extension of nervous tissue from the brain stem

- The spinal cord conducts most of the signals between the brain and the rest of the body

  √ The spine conducts motor signals downward from the brain and touch sense signals upward to the brain

  √ The signals enter and exit the spinal cord through spinal nerves, located in pairs at various distances from the brain

- The center of the spinal cord is gray matter (in transverse section, it has a butterfly shape) and white (myelinated) matter along the edges

  √ The white matter is ascending tracts (for touch sense signals) and descending tracts (for motor signals)

  √ The gray matter contains (a) cell bodies of motor neurons, (b) axon terminals of sensory neurons, and (c) interneurons that synapse with the motor and sensory neurons

Figs 12.2 and 13.14

Spinal nerves

Nerves that connect to the spinal cord

• There are 31 pairs of spinal nerves

• Spinal nerves are bundles of sensory and motor neurons

• Where each nerve connects to the spine, it splits into a dorsal root (on the posterior side) and a ventral root (on the anterior side)

√ The dorsal root contains the sensory neurons

- Dorsal root ganglion = The cluster of sensory neuron cell bodies in the dorsal root

√ The ventral root contains the motor neurons

Figs 13.14, 13.20, and 13.24

Reflex

A response to stimulation that is rapid, involuntary, and predictable

• Reflex arc = The neural pathway of a reflex

√ All reflex arcs have sensory and motor neurons

√ Some, but not all, reflex arcs have interneurons between the sensory and motor neurons

Fig 15.8

Peripheral nervous system (PNS)

All the nervous tissue outside the CNS

- The subdivisions of the PNS:

PNS
/ \
Sensory neurons   Motor neurons
/ \
ANS   SNS
/ \
Sympathetic Division   Parasympathetic Division

Fig 12.2

Somatic nervous system (SNS)

Motor neurons that control voluntary muscles

- Each SNS signal travels by a single motor neuron to its target cell

- All SNS neurons release acetylcholine as their neurotransmitter

Fig 15.6

Autonomic nervous system (ANS)

Motor neurons that control involuntary muscles and glands

- The ANS mostly controls hollow internal organs

  √ Examples: The heart, digestive system organs, blood vessels, passages in the respiratory system

- Each ANS signal travels through two consecutive motor neurons to its target cell

  √ Preganglionic neuron = The first of the two neurons

  √ Postganglionic neuron = The second of the two neurons

Figs 15.2, 15.4, and 15.6

Divisions of ANS:

The sympathetic and parasympathetic divisions

• They have mutually antagonistic effects on most organs:

Organ:	Stimulation by Sympathetic	Stimulation by Parasympathetic
Heart	Stronger, faster beats	Softer, slower beats
Airway Passages	Dilate/relax (more airflow)	Contract (less airflow)
Digestive Organs	Less activity/relax	More activity/contract
Blood Vessels	Vessels in skin and digestive organs contract (less blood flow) Vessels in skeletal muscle heart, lungs dilate/relax (more blood flow)	*Blood vessels have no parasympathetic innervation*

Figs 15.4 and 19.32

Sympathetic division

Puts organs in mode appropriate for threatening or harmful situations

- Ganglion usually near spine, distant from target organ

- Postganglionic neurons secrete norepinephrine as their neurotransmitter

- The preganglionic neurons secrete acetylcholine as their neurotransmitter

Figs 15.2 and 15.4; Table 15.1

Parasympathetic division

Puts organs in mode appropriate for relaxed peaceful situations

- Ganglion in or near target organ

- Postganglionic neurons release acetylcholine as their neurotransmitter

- The preganglionic neurons release acetylcholine as their neurotransmitter

Figs 15.2 and 15.4; Table 15.1

Adrenergic receptors

Receptor proteins that bind the neurotransmitter norepinephrine and the hormone epinephrine

- There are several types of adrenergic receptors

  β_1 = Found only in cardiac muscle cells. It causes stronger and faster heart contractions

  β_2 = Found in some smooth muscle cells. It causes the cells to relax (no contractions)

  α_1 and α_2 = Found in some smooth muscle cells. It causes the cells to contact

Fig 15.2; Table 15.1

Nervous system disorders:

Newborns

- Mental retardation = Failure of cerebrum to develop to its full potential
  - √ Usually caused by chromosomal abnormalities or through alcohol/drug abuse by mother during pregnancy

- Cerebral palsy = A neuromuscular disability; poorly controlled voluntary muscles

Any age:

- Spinal cord injury = Leads to paralysis of all limbs controlled by nerves below the point of damage

- Injuries to brain = Symptoms vary with site of damage
  - √ Deterioration of mental function often begins several minutes after the injury (due to swelling inside cranium)

- Alcohol/drugs = Kill brain cells; decreases brain mass

Older adults:

- Slow loss of neurons throughout life is normal; causes mild senility (forgetfulness or confusion) in some seniors

- Stroke (cerebrovascular accident) = Lack of blood to a region of brain due to a clogged or broken blood vessel

  - √ Effects vary with part of brain affected

- Alzheimers disease = Brain neurons become engulfed and damaged by protein fibers

  - √ Causes severe senility and dementia

  - √ Cause not known

Fig 16.3