The Nervous System

Overview

- The nervous system is the master controlling and communicating system of the body. Every thought, action and emotion reflects its activity. Its cells communicate by electrical and chemical signals usually causing an almost immediate response.
- Neurons = nerve cells
- Functions of the Nervous System
    - Sensory Input—monitoring changes both inside and outside the body
    - Integration—processing and interpreting sensory input and deciding on course of action
    - Motor Output—a response based on the integration of sensory input; activating effector organs (i.e., muscles and glands).
- Divisions of Nervous System
    - Central Nervous System (CNS)
        - Consists of brain and spinal cord
        - Integration and command center of the nervous system
        - It interprets sensory input and dictates motor response based on reflexes, current conditions, and past experience.
    - Peripheral Nervous System (PNS)
        - A part of the nervous system outside the CNS
        - Consists mostly of nerves (bundles of axons) extending from brain and spinal cord
        - Spinal nerves carry impulses to and from the spinal cord
        - Cranial nerves carry impulses to and from the brain
        - It links all parts of the body to the brain.
            - Subdivisions of the PNS
                - Sensory or Afferent Division (afferent = “carrying toward”)
                    - Consists of nerve fibers (axons) that convey impulses to the central nervous system from sensory receptors located throughout the body.
                - Motor or Efferent Division (efferent = “carrying away”)
                    - Transmit impulses from the CNS to effector organs; activating muscles to contract and glands to secrete.
                    - They EFFECT (bring about) a motor response.
                        - Two Main Parts of the Motor Division
                            - Somatic Nervous System
                                - aka, Voluntary Nervous System
                                - Allows us to consciously control our skeletal muscles.
                            - Autonomic Nervous System (ANS)
                                - aka, Involuntary Nervous System
                                - Regulates the activity of smooth muscles, cardiac muscles and glands
                            - Two Functional Subdivisions of ANS:
                                - Sympathetic Division—stimulates
                                - Parasympathetic Division—inhibits

Histology of Nervous Tissue

- Nervous system consists mostly of nervous tissue, which is highly cellular.
- Less than 20% of the CNS is extracellular space which means that the cells are densely packed and tightly intertwined.
- Nervous tissue is made up of just two principal types of cells
    - Neuroglia (glial cells) = supporting cells
        - Provide a supporting scaffolding for neurons
        - Some produce chemicals that guide young neurons to the proper connections
        - Promote neuron health and growth
        - Some wrap around and insulate neuronal processes to speed up action potential conduction (i.e., Schwann cells which form myelin sheaths).
    - Neurons = excitable nerve cells that transmit electrical signals
        - aka, Nerve cells
        - Structural units of the nervous system
        - Characteristics of Nerve Cells
            - Extreme longevity—given good nutrition, neurons can function optimally for a lifetime
            - Amitotic—they lose their ability to divide
            - High metabolic rate—require continuous and abundant supplies of oxygen and glucose.
        - Structure of Neurons
            - Cell body = major biosynthetic center and receptive region of the neuron containing the usual organelles
            - Processes = armlike projections extending from the cell body of all neurons
                - Dendrites
                    - Main receptive or input regions
                    - Provide a large surface area for receiving signals from other neurons.
                    - Convey messages toward the cell body; these electrical signals are usually not action potentials (nerve impulses) but are short-distance signals (graded potentials).
                    - Dendrites are always unmyelinated
                - Axon
                    - Each neuron has one axon
                    - Any long axon is called a nerve fiber
                    - Terminal branches = ends of axon which may number 10,000+;
                    - Functionally, axon is the conducting region of the neuron
                        - It generates nerve impulses and transmits them typically away from the cell body along the plasma membrane.
                    - Axons may be either myelinated or unmyelinated
                        - Myelinated fibers conduct nerve impulses rapidly
                        - Nodes of Ranvier (myelin sheath gaps) = gaps at regular intervals along the myelinated axons

Membrane Potentials

- Basic Principles of Electricity
  - Voltage = measure of potential energy generated by separated charge
  - Potential or potential difference = measurement of voltage between two points; the greater the difference in charge between two points, the higher the voltage
  - Current = flow of electrical charge between two points
  - Resistance = hindrance to charge flow provided by substances through which the current must pass.
    - Insulators = high electrical resistance
    - Conductors = low electrical resistance
  - Ohm's law describes the relationship between voltage, current and resistance:
    - Current (I) = voltage (V)/Resistance (R)
      - Greater Voltage = Greater Current
      - Greater Resistance = Lower Current
      - No Current if voltage and resistance are the same (i.e., have same potential)
- In the body, electrical charges are provided by ions; cellular plasma membranes provide resistance to ion flow.
  - Membranes contain leakage channels (nongated, always open) and gated channels.
  - Ions move along **chemical concentration gradients** when they diffuse passively from an area of their higher concentration to an area of lower concentration
  - Ions move along **electrical gradients** when they move toward an area of opposite electrical charge.
- Resting Membrane Potential
  - At rest, a voltage across the plasma membrane is -70 mV; the inside (cytoplasmic side) of the membrane is negatively charged relative to the outside.
  - Resting potential exists only across the membrane; bulk solutions inside and outside the cell are electrically neutral.
  - Resting membrane potential is generated by differences in the ionic makeup of the intracellular and extracellular fluids and by the differential permeability of the plasma membrane to those ions.
  - Sodium-Potassium Pump = a primary active transport system that simultaneously drives sodium ions (Na+) out of the cell against a steep gradient and pumps potassium ions (K+) back in.
    - A cell at rest is like a leaky boat that is constantly leaking K+ out and Na+ in through open channels. The "bailing pump" for this boat counteracts the leaks by transporting Na+ out and K+ in.
    - It ejects 3 Na+ and transports 2 K+ in.
- Membrane Potentials Act as Signals
  - Neurons use changes in their membrane potential as communication signals for receiving, integrating and sending information.
  - A change in membrane potential can be caused by:
    - Anything that alters ion concentrations on the two sides of the membrane
    - Anything that changes membrane permeability to any ion
  - Action Potentials
    - The principle way neurons send signals over long distances is by generating and propagating action potentials (AP)
    - Only cells with excitable membranes (neurons and muscle cells) can generate action potentials.

        - An action potential is a brief reversal of membrane potential with total amplitude (change in voltage) of about 100 mV (from -70mV to +30mV).
        - The whole event is over in a few milliseconds.
        - Unlike graded potentials, action potentials do not decrease in strength with distance.

The Synapse

- Synapse = from Greek syn, "to clasp or join"; a junction that mediates information transfer from one neuron to the next or from a neuron to an effector cell
- Two varieties of synapses: electrical and chemical; electrical is less common
    - Chemical Synapses
        - Specialized for release and reception of chemical neurotransmitters.
        - Made up of two parts:
            1. Axon terminal: contains many tiny, membrane-bounded sacs (synaptic vesicles) containing thousands of neurotransmitter molecules
            2. A neurotransmitter receptor region on the membrane of a dendrite or the cell body of the postsynaptic neuron.
        - Synaptic cleft = a fluid-filled space approximately 30-50 nm wide which separates the presynaptic and postsynaptic membranes.
        - Chemical synapses convert electrical signals to chemical signals (neurotransmitters) that travel across the synapse to the postsynaptic cells, where they are converted back into electrical signals.
        - Information Transfer Across Chemical Synapses
            1. Action potential arrives at axon terminal.
            2. Voltage-gated Ca^{2+} channels open and Ca^{2+} enters the axon terminal.
            3. Ca^{2+} entry causes neurotransmitter-containing vesicles to release their contents by exocytosis.
            4. Neurotransmitter diffuses across the synaptic cleft and binds to specific receptors on the postsynaptic membrane.
            5. Binding of neurotransmitter opens ion channels, resulting in graded potentials.
            6. Neurotransmitter effects are terminated.

Neurotransmitters and their receptors

- Neurotransmitters along with electrical signals are the language of the nervous system—the means by which each neuron communicates with others to process and send messages to the rest of the body.
- More than 50 neurotransmitters or neurotransmitter candidates have been identified.
- In most cases, different neurotransmitters are released at different stimulation frequencies.
- Neurotransmitters are classified chemically and functionally.
    - Based on Chemical Structure
        - Acetylcholine
        - Biogenic amines
        - Amino acids
        - Peptides
        - Purines
        - Dissolved gases
        - Lipids

    - Functionally Classified
        - Inhibitory or excitatory (either one or both)

- Direct or indirect action
    - Direct-acting neurotransmitters bind to and open ion channels
    - Indirect-acting neurotransmitters act through second messengers.

The Central Nervous System

- Brain and spinal cord division of the nervous system
    - Brain
        - Cerebral Cortex
            - "Executive Suite" of the nervous system where our conscious mind is found.
            - It enables us to be aware of ourselves and our sensations, to communicate, remember, and understand and to initiate voluntary movements.
        - Diencephalon
            - Forming the central core of the forebrain and surrounded by the cerebral hemispheres
            - Consists largely of three paired structures:
                - Thalamus
                    - The relay station for information coming into the cerebral cortex
                    - Plays a key role in mediating sensations, motor activities, cortical arousal, learning and memory.
                    - Gateway to the cerebral cortex
                - Hypothalamus
                    - The main visceral control center of the body (i.e., influences blood pressure, rate and force of heartbeat, digestive tract motility, eye pupil size, etc.).
                    - Important to overall body homeostasis (i.e., regulates body temperature, food intake, water balance and thirst, and sleep-wake cycle).
                    - Involved in the perception of pleasure, fear, rage and biological rhythms and drives (i.e., sex drive).
                    - Controls endocrine system functioning (will discuss this in lesson on endocrine system).
                - Epithalamus
                    - Contains the pineal gland which secretes hormone melatonin, a sleep inducing signal and antioxidant)
                    - Helps regulate sleep-wake cycle.
        - Brain Stem
            - Centers which produce the rigidly programmed, automatic behaviors necessary for survival.
            - Consists of three parts:
                - Midbrain
                    - Location between diencephalon and pons
                    - Conduction pathway between higher and lower brain centers
                - Pons
                    - Bulging brain stem region wedged between the midbrain and medulla oblongata

        - Consists of conduction tracts which act as relays for communication between motor cortex and cerebellum
    - Medulla Oblongata
        - Most inferior part of the brain stem
        - Serves as an autonomic reflex center involved in maintaining body homeostasis
- Cerebellum
    - Processes information from cerebral motor cortex and from proprioceptors and visual and equilibrium pathways, and provides "instructions" to cerebral motor cortex and subcortical motor centers that result in proper balance and posture and smooth, coordinated skeletal muscle movements.

Peripheral Nervous System

- Two divisions
    - Sensory (Afferent) Division
        - Receive information from environment and communicate back to the brain
        - Respond to changes in their environment
    - Motor (Efferent) Division
        - Take impulses from the brain to areas of the body where appropriate responses are acted upon due to sensory input.
        - Two subdivisions of Motor Division
            - Somatic Nervous System
                - Provides the motor innervations to skeletal muscles
            - Autonomic Nervous System (ANS)
                - The system of motor neurons that innervates smooth and cardiac muscle and glands.
                - Two aspects of the ANS
                    - Sympathetic Division
                        - Prepares the body for fight-or-flight
                        - Response includes pupil dilation, increased heart rate, increased blood glucose levels, and sweating.
                    - Parasympathetic Division
                        - Conserves body energy and maintains body activities at basal levels.
                        - Response includes pupil constriction, glandular secretion, increased digestive tract motility, and smooth muscle activity leading to elimination of feces and urine.