Peripheral Nervous System (PNS)

The PNS includes all neural structures outside the brain and spinal cord – sensory receptors, peripheral nerves and associated ganglia and efferent motor endings.

**Sensory Division**

*Sensory receptors* are specialized to respond to changes in environment (stimuli). Activation results in graded potentials that trigger nerve impulses. Sensation (awareness of stimulus) and perception (interpretation of meaning of stimulus) occur in brain. There are three ways to classify sensory receptors – (1) type of stimulus they detect, (2) by their body location and (3) by their structural complexity.

**Classification by Stimulus Type:**
- **Mechanoreceptors**—respond to touch, pressure, vibration, and stretch
- **Thermoreceptors**—sensitive to changes in temperature
- **Photoreceptors**—respond to light energy (e.g., retina)
- **Chemoreceptors**—respond to chemicals (e.g., smell, taste, changes in blood chemistry)
- **Nociceptors**—sensitive to pain-causing stimuli (e.g. extreme heat or cold, excessive pressure, inflammatory chemicals)

**Classification by Location:**
- **Exteroceptors** - respond to stimuli arising outside body; includes receptors in skin for touch, pressure, pain, and temperature and most receptors of special sense organs
- **Interceptors** (visceroceptors) - respond to stimuli arising in internal viscera and blood vessels. Receptors are sensitive to chemical changes, tissue stretch, and temperature changes. Sometimes their activity causes us to feel pain, discomfort, hunger or thirst --- we are usually unaware of their workings.
- **Proprioceptors** - respond to stretch in skeletal muscles, tendons, joints, ligaments, and connective tissue coverings of bones and muscles; informs the brain of one's movements

**Classification by Receptor Structure:**
1. Receptors for **special senses** - vision, hearing, equilibrium, smell, and taste
2. Simple receptors for **general senses** - tactile sensations (touch, pressure, stretch, vibration), temperature, pain, and muscle sense; modified dendritic endings of sensory neurons; either nonencapsulated or encapsulated

**Nonencapsulated (free) nerve endings** - abundant in epithelia and connective tissues; most nonmyelinated, small-diameter group C fibers; distal endings have knoblike swellings; respond mostly to temperature and pain; some to pressure-induced tissue movement; itch
- Thermoreceptors - cold receptors (10–40°C); in superficial dermis; heat receptors (32–48°C); in deeper dermis; outside those temperature ranges → nociceptors activated → pain
- Nociceptors – respond to pinch and chemicals released from damaged tissue
- Light touch receptors – tactile discs (Merkel) and hair follicle receptors


**Encapsulated dendritic endings** – All endings consist of one or more fiber terminals of sensory neurons enclosed in a connective tissue capsule. ~ All mechanoreceptors in connective tissue capsule.

- Tactile (Meissner’s) corpuscles—discriminative touch
- Lamellar (Pacinian) corpuscles—deep pressure and vibration
- Bulbous corpuscles (Ruffini endings)—deep continuous pressure
- Muscle spindles—muscle stretch
- Tendon organs—stretch in tendons
- Joint kinesthetic receptors—joint position and motion

**From Sensation to Perception**

Our survival depends upon sensation (awareness of changes in the internal and external environment) and perception (the conscious interpretation of those stimuli).

**Sensory Integration** – The somatosensory system or part of the sensory system serving body wall and limbs, receives input from exteroceptors, proprioceptors, and interoceptors. Input is relayed toward the head, but processed along the way. Levels of neural integration in sensory systems: (1) receptor level (sensory receptors), (2) circuit level (processing in ascending pathways, and (3) perceptual level (processing in cortical sensory areas).

**Processing at the receptor level** –

- To produce a sensation - receptors have specificity for stimulus energy; stimulus must be applied in receptive field. Transduction occurs - stimulus changed to graded potential and graded potentials must reach threshold → AP.
- In general sense receptors: Stimulus → Generator potential (graded potential) in afferent neuron → Action potential
- In special sense organs: Stimulus→ Graded potential in receptor cell called receptor potential → Affects amount of neurotransmitter released → Neurotransmitters generate graded potentials in sensory neuron
- Adaptations of sensory receptors: Adaptation is change in sensitivity in the presence of constant stimulus. Receptor membranes become less responsive -- receptor potentials decline in frequency or stop.

**Processing at the circuit level** –

Pathways of three neurons conduct sensory impulses upward to appropriate cortical regions – 1st order sensory neurons (conduct impulses from receptor level to spinal reflexes or second-order neurons in CNS), 2nd order sensory neurons (transmit impulses to third-order sensory neurons) and 3rd order sensory neurons (conduct impulses from thalamus to the somatosensory cortex (perceptual level).
Processing at the perceptual level –
Interpretation of sensory input depends on specific location of target neurons in sensory cortex. Aspects of sensory perception:
- Perceptual detection—ability to detect a stimulus (requires summation of impulses)
- Magnitude estimation—intensity coded in frequency of impulses
- Spatial discrimination—identifying site or pattern of stimulus
- Feature abstraction—identification of more complex aspects and several stimulus properties
- Quality discrimination—ability to identify submodalities of a sensation (e.g., sweet or sour tastes)
- Pattern recognition—recognition of familiar or significant patterns in stimuli (e.g., melody in piece of music)

Perception of Pain - warns of actual or impending tissue damage → protective action. Stimuli include extreme pressure and temperature, histamine, K+, ATP, acids, and bradykinin -- impulses travel on fibers that release neurotransmitters glutamate and substance P. Some pain impulses are blocked by inhibitory endogenous opioids (e.g., endorphins).

Visceral and Referred pain – stimulation of visceral organ receptors; activated by tissue stretching, ischemia, chemicals, muscle spasms. Referred pain - pain from one body region perceived from different region. Visceral and somatic pain fibers travel in same nerves; brain assumes stimulus from common (somatic) region – (ex. left arm pain during heart attack).

Structure and Classification of a Nerve –
A nerve is a cordlike organ consisting of a bundle of myelinated and nonmyelinated peripheral axons enclosed by connective tissue. Connective tissue coverings include: Endoneurium—loose connective tissue that encloses axons and their myelin sheaths, Perineurium—coarse connective tissue that bundles fibers into fascicles and Epineurium—tough fibrous sheath around a nerve.

Most nerves are mixtures of afferent and efferent fibers and somatic and autonomic (visceral) fibers. Classified according to direction transmit impulses
1. Mixed nerves – both sensory and motor fibers; impulses both to and from CNS
2. Sensory (afferent) nerves – impulses only toward CNS
3. Motor (efferent) nerves – impulses only away from CNS
Pure sensory (afferent) or motor (efferent) nerves are rare; most mixed. Types of fibers in mixed nerves: Somatic afferent, Somatic efferent, Visceral afferent, Visceral efferent.

Peripheral nerves classified as cranial or spinal nerves.

Ganglia - contain neuron cell bodies associated with nerves in PNS. Ganglia associated with afferent nerve fibers contain cell bodies of sensory neurons. Dorsal root ganglia (sensory, somatic) -- Ganglia associated with efferent nerve fibers contain autonomic motor neurons -- Autonomic ganglia (motor, visceral).

**Regeneration of nerve fibers** –
Mature neurons are amitotic but if soma of damaged nerve is intact, peripheral axon may regenerate. If peripheral axon damaged: axon fragments (Wallerian degeneration); spreads distally from injury; macrophages clean dead axon; myelin sheath intact; axon filaments grow through regeneration tube; axon regenerates; new myelin sheath forms.

- Greater distance between severed ends-less chance of regeneration
- Most CNS fibers never regenerate -- CNS oligodendrocytes bear growth-inhibiting proteins that prevent CNS fiber regeneration. Astrocytes at injury site form scar tissue containing chondroitin sulfate that blocks axonal regrowth. Treatment: neutralizing growth inhibitors, blocking receptors for inhibitory proteins, destroying chondroitin sulfate promising

**Cranial Nerves**
Twelve pairs of nerves associated with brain -- two attach to forebrain; rest with brain stem; most mixed nerves; two pairs purely sensory. Each numbered (I through XII) and named from rostral to caudal.

"On occasion, our trusty truck acts funny—very good vehicle anyhow"
"Oh once one takes the anatomy final, very good vacations are heavenly"
<table>
<thead>
<tr>
<th>Cranial Nerve</th>
<th>Functions</th>
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<tbody>
<tr>
<td>I. Olfactory nerves</td>
<td>Purely sensory – carry afferent impulses for sense of smell</td>
</tr>
<tr>
<td>II. Optic nerves</td>
<td>Purely sensory – carry afferent impulses for vision</td>
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<tr>
<td>III. Oculomotor</td>
<td>Motor - Supplies 4 of the 6 extrinsic eye muscles that move the eye</td>
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<tr>
<td>IV. Trochlear</td>
<td>Motor - Innervates an extrinsic eye muscle – superior oblique. Primary motor nerve that directs eyeball.</td>
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<tr>
<td>V. Trigeminal</td>
<td>Motor - Supplies sensory fibers to the face and motor fibers to the chewing muscle.</td>
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<tr>
<td>VI. Abducens</td>
<td>Motor - Controls the extrinsic eye muscle that abducts the eye – turns it laterally</td>
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<tr>
<td>VII. Facial</td>
<td>Motor function -- Innervates muscles of facial expression. Sensory function (taste) from anterior two-thirds of tongue</td>
</tr>
<tr>
<td>VIII. Vestibulocochlear</td>
<td>Mostly sensory - nerve for hearing and balance. Small motor component for adjustment of sensitivity of receptors</td>
</tr>
<tr>
<td>IX. Glossopharyngeal</td>
<td>Motor functions - innervate part of tongue and pharynx for swallowing, and provide parasympathetic fibers to parotid salivary glands Sensory functions - fibers conduct taste and general sensory impulses from pharynx and posterior tongue, and impulses from carotid chemoreceptors and baroreceptors</td>
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<tr>
<td>X. Vagus</td>
<td>Only cranial nerve to extend beyond head/neck to thorax/abdomen -- Most motor fibers are parasympathetic fibers that help regulate activities of heart, lungs, and abdominal viscera. Sensory fibers carry impulses from thoracic and abdominal viscera, baroreceptors, chemoreceptors, and taste buds of posterior tongue and pharynx.</td>
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<tr>
<td>XI. Accessory</td>
<td>Motor - Innervates the trapezius and sternocleidomastoid muscles</td>
</tr>
<tr>
<td>XII. Hypoglossal</td>
<td>Motor - Innervate extrinsic and intrinsic muscles of tongue that contribute to swallowing and speech</td>
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**SPINAL NERVES**

Thirty-one pairs of mixed nerves named for point of issue from spinal cord -- supply all body parts but head and part of neck.

- 8 cervical (C₁–C₈), 12 thoracic (T₁–T₁₂), 5 Lumbar (L₁–L₅), 5 Sacral (S₁–S₅), 1 Coccygeal (C₀)
- Only 7 cervical vertebrae, yet 8 pairs of cervical spinal nerves -- 7 exit vertebral canal superior to vertebrae for which named and 1 exits canal inferior to C₇.
**Spinal Nerves - Roots**
Each spinal nerve connects to spinal cord via two roots: **Ventral roots** - contain motor (efferent) fibers from ventral horn motor neurons; fibers innervate skeletal muscles. **Dorsal roots** - contain sensory (afferent) fibers from sensory neurons in dorsal root ganglia and conduct impulses from peripheral receptors; Dorsal and ventral roots unite to form **spinal nerves**, which emerge from vertebral column via *intervertebral foramina*.

**Spinal Nerves – Rami**
Spinal nerves are quite short (~1-2 cm) – each spinal nerve branches into dorsal ramus, ventral ramus and meningeal branch (tiny, reenters vertebral canal, innervates meninges and blood vessels). At the base of the ventral ramus of the thoracic spinal nerves are rami communicantes which contain autonomic nerve fibers.
- All ventral rami except T₂–T₁₂ form interlacing nerve networks called **nerve plexuses** (cervical, brachial, lumbar, and sacral). Back innervated by dorsal rami via several branches. Ventral rami of T₂–T₁₂ form intercostal nerves supply muscles of ribs, anterolateral thorax, and abdominal wall.
- Spinal roots longer as move inferiorly in cord -- Lumbar and sacral roots extend as **cauda equina**.

**Spinal Nerves – Plexus**
Within plexus fibers crisscross, each branch contains fibers from several spinal nerves. Fibers from ventral ramus go to body periphery via several routes -- each limb muscle innervated by more than one spinal nerve. Damage to one does not → paralysis.

- **Cervical Plexus** - formed by ventral rami of C₁–C₄. Most branches form **cutaneous nerves** -- innervate skin of neck, ear, back of head, and shoulders. Other branches innervate neck muscles. **Phrenic nerve** -- major motor and sensory nerve of diaphragm (receives fibers from C₃–C₅).
- **Brachial Plexus** - formed by ventral rami of C₅–C₈ and T₁ (and often C₄ and/or T₂). Gives rise to nerves that innervate upper limb. Five important nerves –
  - **Axillary**—innervates deltoid, teres minor, and skin and joint capsule of shoulder
  - **Musculocutaneous**—innervates biceps brachii and brachialis, coracobrachialis, and skin of lateral forearm
- **Median**—innervates skin, most flexors, forearm pronators, wrist and finger flexors, thumb opposition muscles
- **Ulnar**—supplies flexor carpi ulnaris, part of flexor digitorum profundus, most intrinsic hand muscles, skin of medial aspect of hand, wrist/finger flexion
- **Radial**—innervates essentially all extensor muscles, supinators, and posterior skin of limb

* **Lumbar Plexus** - arises from L₁–L₄. Innervates thigh, abdominal wall, and psoas muscle.
  - **Femoral nerve**—innervates quadriceps and skin of anterior thigh and medial surface of leg
  - ** Obturator nerve**—passes through obturator foramen to innervate adductor muscles
* **Sacral Plexus** - arises from L₄–S₄. Serves the buttock, lower limb, pelvic structures, and perineum
  - **Sciatic nerve** - longest and thickest nerve of body; innervates hamstring muscles, adductor magnus, and most muscles in leg and foot. Composed of two nerves: **tibial** and **common fibular**

**Innervation of Skin**

Dermatome - area of skin innervated by cutaneous branches of single spinal nerve. All spinal nerves except C₁ participate in dermatomes. Extent of spinal cord injuries ascertained by affected dermatomes. Most dermatomes overlap, so destruction of a single spinal nerve will not cause complete numbness.

**Innervation of Joints**

To remember which nerves serve which synovial joint -- **Hilton's law**: Any nerve serving a muscle that produces movement at joint also innervates joint and skin over joint.

**Motor Division**

Motor endings are the PNS elements that activate effectors by releasing neurotransmitters. Cerebellum and basal nuclei are ultimate planners and coordinators of complex motor activities. Complex motor behavior depends on complex patterns of control -- segmental level, projection level and precommand level.

* **Segmental Level** – reflexes and automatic movements. CPGs activate network of ventral horn neurons to stimulate specific groups of muscles.
* **Projection Level** – produce voluntary skeletal muscle movements
* **Precommand Level** – neurons in cerebellum and basal nuclei regulate motor activity, precise timing and coordination and block unwanted movements
**REFLEXES**

Inborn (intrinsic) reflexes are rapid, involuntary, predictable motor responses to stimulus (e.g., maintain posture, control visceral activities). Intrinsic reflexes can be modified by learning and conscious effort. Learned (acquired) reflexes result from practice or repetition. Components of a reflex arc:

1. **Receptor**—site of stimulus action
2. **Sensory neuron**—transmits afferent impulses to CNS
3. **Integration center**—either monosynaptic or polysynaptic region within CNS
4. **Motor neuron**—conducts efferent impulses from integration center to effector organ
5. **Effector**—muscle fiber or gland cell that responds to efferent impulses by contracting or secreting

**Functional classification**

Somatic reflexes - activate skeletal muscle
Autonomic (visceral) reflexes - activate visceral effectors (smooth or cardiac muscle or glands)

- Spinal somatic reflexes - integration center in spinal cord; effectors are skeletal muscle. Testing of somatic reflexes important clinically to assess condition of nervous system. If exaggerated, distorted, or absent \(\rightarrow\) degeneration/pathology of specific nervous system regions.
- Stretch and Tendon reflexes - to smoothly coordinate skeletal muscle nervous system must receive proprioceptor input regarding length of muscle (from muscle spindles) and amount of tension in muscle (from tendon organs). Stretch reflex - maintains muscle tone in large postural muscles, and adjusts it reflexively; causes muscle contraction in response to increased muscle length (stretch). Tendon reflex - helps prevent damage due to excessive stretch; important for smooth onset and termination of muscle contraction.
- Superficial reflexes - elicited by gentle cutaneous stimulation; depend on upper motor pathways and cord-level reflex arcs. (best known – plantar reflex and abdominal reflex)

**Developmental Aspects of PNS**

Each spinal nerve provides the sensory and motor supply of an adjacent muscle mass and the cutaneous supply of a dermatome. With age, sensory receptors atrophy, muscle tone decreases in face and neck, reflexes slow -- decreased numbers of synapses per neuron, and slower central processing. Peripheral nerves viable throughout life unless subjected to trauma.