The PNS is separated into 2 divisions:

1. the afferent division, which carries sensory information from sensory receptors of the PNS to the CNS. Receptors include neurons or specialized cells that detect changes or respond to stimuli, and complex sensory organs such as the eyes and ears.

2. the efferent division, which carries motor commands from the CNS to muscles and glands of the PNS. The cells or organs that respond to efferent signals by doing something are called effectors

The efferent division is divided into 2 parts:
1. the somatic nervous system (SNS), which controls skeletal muscle contractions
a. voluntary muscle contractions
b. involuntary muscle contractions (reflexes)

2. the autonomic nervous system (ANS), which controls subconscious actions such as contractions of smooth muscle and cardiac muscle, and glandular secretions.

The ANS is separated into 2 divisions:
1. the sympathetic division, which has a stimulating effect
2. the parasympathetic division, which has a relaxing effect

Peripheral Nervous System (PNS)

- PNS – all neural structures outside the brain and spinal cord
- Includes sensory receptors, peripheral nerves, associated ganglia, and motor endings
- Provides links to and from the external environment

PNS in the Nervous System

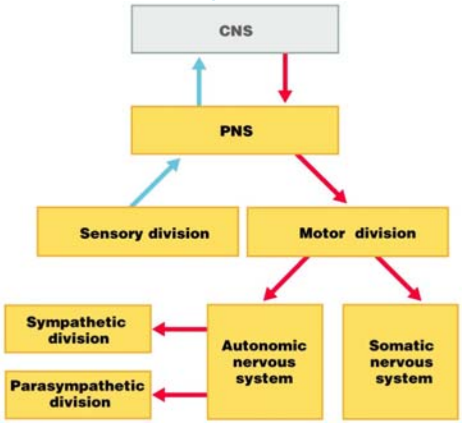


Figure 13.1

Peripheral Nervous System (PNS)

- PNS – all neural structures outside the brain and spinal cord
- Includes sensory receptors, peripheral nerves, associated ganglia, and motor endings
- Provides links to and from the external environment

Sensory Receptors

- Structures specialized to respond to stimuli
- Activation of sensory receptors results in depolarizations that trigger impulses to the CNS
- The realization of these stimuli, sensation and perception, occur in the brain

Receptor Classification by Stimulus Type

- Mechanoreceptors – respond to touch, pressure, vibration, stretch, and itch
- 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

Receptor Class by Location: Exteroceptors

- Respond to stimuli arising outside the body
- Found near the body surface
- Sensitive to touch, pressure, pain, and temperature
- Include the special sense organs

Receptor Class by Location: Interoceptors

- Respond to stimuli arising within the body
- Found in internal viscera and blood vessels
- Sensitive to chemical changes, stretch, and temperature changes

Receptor Class by Location: Proprioceptors

- Respond to degree of stretch of the organs they occupy
- Found in skeletal muscles, tendons, joints, ligaments, and connective tissue coverings of bones and muscles
- Constantly “advise” the brain of one’s movements

Receptor Classification by Structural Complexity

- Receptors are structurally classified as either simple or complex
- Most receptors are simple and include encapsulated and unencapsulated varieties
- Complex receptors are special sense organs

Simple Receptors: Unencapsulated

- Free dendritic nerve endings
  - Respond chiefly to temperature and pain
- Merkel (tactile) discs
- Hair follicle receptors

Simple Receptors: Encapsulated

- Meissner's corpuscles (tactile corpuscles)
- Pacinian corpuscles (lamellated corpuscles)
- Muscle spindles, Golgi tendon organs, and Ruffini's corpuscles
- Joint kinesthetic receptors

Simple Receptors: Unencapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function

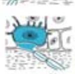
STRUCTURAL CLASS	ILLUSTRATION	FUNCTIONAL CLASSES ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
UNENCAPSULATED			
Free nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Thermoreceptors (warm and cool), chemoreceptors (itch, pH, etc.), mechanoreceptors (pressure), nociceptors (pain, hot, cold, pinch, and chemicals)	Most body tissues; most dense in connective tissues (ligaments, tendons, dermis, joint capsules, periostea) and epithelia (epidermis, cornea, mucosae, and glands)
Modified free nerve endings: Merkel discs (tactile discs)		L: Exteroceptors S: Mechanoreceptors (light pressure); slowly adapting	Basal layer of epidermis of skin
Hair follicle receptors		L: Exteroceptors S: Mechanoreceptors (hair deflection); rapidly adapting	In and surrounding hair follicles

Table 13.1.1

Simple Receptors: Encapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function (continued)

STRUCTURAL CLASS	ILLUSTRATION	FUNCTIONAL CLASSES ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
ENCAPSULATED			
Meissner's corpuscles (tactile corpuscles)		L: Exteroceptors S: Mechanoreceptors (light pressure, discriminative touch, vibration of low frequency); rapidly adapting	Dermal papillae of hairless skin, particularly nipples, external genitalia, fingertips, soles of feet, eyelids
Pacinian corpuscles (lamellated corpuscles)		L: Exteroceptors, interoceptors, and some proprioceptors S: Mechanoreceptors (deep pressure, stretch, vibration of high frequency); rapidly adapting	Dermis and hypodermis; periostea, mesentery, tendons, ligaments, joint capsules; most abundant on fingers, soles of feet, external genitalia, nipples
Ruffini endings		L: Exteroceptors and proprioceptors S: Mechanoreceptors (deep pressure and stretch); slowly or nonadapting	Deep in dermis, hypodermis, and joint capsules
Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch, length)	Skeletal muscles, particularly those of the extremities
Golgi tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch, tension)	Tendons
Joint kinesthetic receptors		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

Table 13.1.2

From Sensation to Perception

- Survival depends upon sensation and perception
- Sensation is the awareness of changes in the internal and external environment
- Perception is the conscious interpretation of those stimuli

Organization of the Somatosensory System

- Input comes from exteroceptors, proprioceptors, and interoceptors
- The three main levels of neural integration in the somatosensory system are:
  - Receptor level – the sensor receptors
  - Circuit level – ascending pathways
  - Perceptual level – neuronal circuits in the cerebral cortex

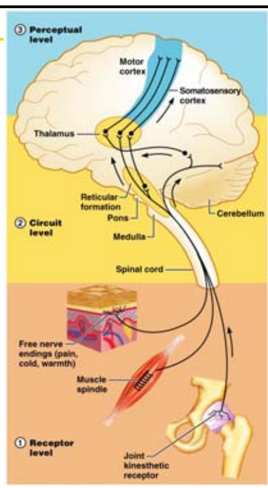


Figure 13.2

Processing at the Receptor Lever

- The receptor must have specificity for the stimulus energy
- The receptor's receptive field must be stimulated
- Stimulus energy must be converted into a graded potential
- A generator potential in the associated sensory neuron must reach threshold

Adaptation of Sensory Receptors

- Adaptation occurs when sensory receptors are subjected to an unchanging stimulus
  - Receptor membranes become less responsive
  - Receptor potentials decline in frequency or stop

Adaptation of Sensory Receptors

- Receptors responding to pressure, touch, and smell adapt quickly
- Receptors responding slowly include Merkel's discs, Ruffini's corpuscles, and interoceptors that respond to chemical levels in the blood
- Pain receptors and proprioceptors do not exhibit adaptation

Processing at the Circuit Level

- Chains of three neurons conduct sensory impulses upward to the brain
- First-order neurons – soma reside in dorsal root or cranial ganglia, and conduct impulses from the skin to the spinal cord or brain stem
- Second-order neurons – soma reside in the dorsal horn of the spinal cord or medullary nuclei and transmit impulses to the thalamus or cerebellum
- Third-order neurons – located in the thalamus and conduct impulses to the somatosensory cortex of the cerebrum

Processing at the Perceptual Level

- The thalamus projects fibers to:
  - The somatosensory cortex
  - Sensory association areas
- First one modality is sent, then those considering more than one
- The result is an internal, conscious image of the stimulus

Main Aspects of Sensory Perception

- Perceptual detection – detecting that a stimulus has occurred and requires summation
- Magnitude estimation – how much of a stimulus is acting
- Spatial discrimination – identifying the site or pattern of the stimulus

Main Aspects of Sensory Perception

- Feature abstraction – used to identify a substance that has specific texture or shape
- Quality discrimination – the ability to identify submodalities of a sensation (e.g., sweet or sour tastes)
- Pattern recognition – ability to recognize patterns in stimuli (e.g., melody, familiar face)

Structure of a Nerve

- Nerve – cordlike organ of the PNS consisting of peripheral axons enclosed by connective tissue
- Connective tissue coverings include:
  - Endoneurium – loose connective tissue that surrounds axons
  - Perineurium – coarse connective tissue that bundles fibers into fascicles
  - Epineurium – tough fibrous sheath around a nerve

Structure of a Nerve

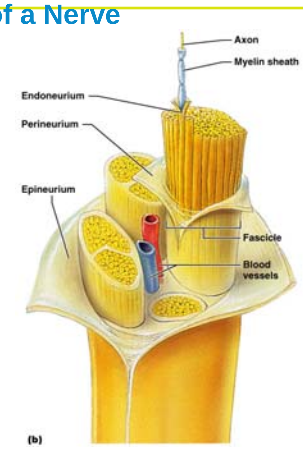


Figure 13.3b

Classification of Nerves

- Sensory and motor divisions
- Sensory (afferent) – carry impulse to the CNS
- Motor (efferent) – carry impulses from CNS
- Mixed – sensory and motor fibers carry impulses to and from CNS; most common type of nerve

Peripheral Nerves

- Mixed nerves – carry somatic and autonomic (visceral) impulses
- The four types of mixed nerves are:
  - Somatic afferent and somatic efferent
  - Visceral afferent and visceral efferent
- Peripheral nerves originate from the brain or spinal column

Regeneration of Nerve Fibers

- Damage to nerve tissue is serious because mature neurons are amitotic
- If the soma of a damaged nerve remains intact, damage can be repaired
- Regeneration involves coordinated activity among:
  - Macrophages – remove debris
  - Schwann cells – form regeneration tube and secrete growth factors
  - Axons – regenerate damaged part

Regeneration of Nerve Fibers

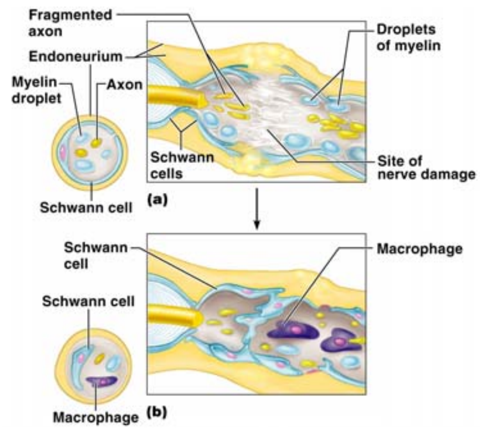


Figure 13.4

Regeneration of Nerve Fibers

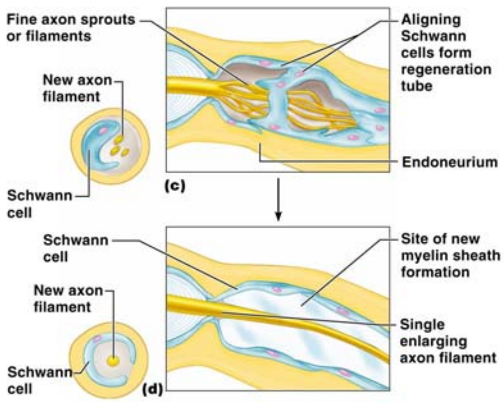


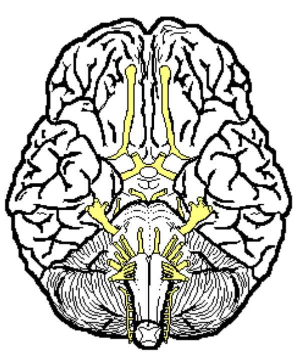
Figure 13.4

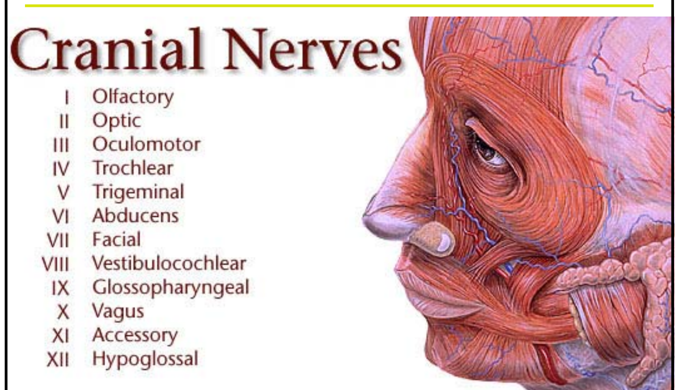
Cranial Nerves

- Twelve pairs of cranial nerves arise from the brain
- They have sensory, motor, or both sensory and motor functions
- Each nerve is identified by a number (I through XII) and a name
- Four cranial nerves carry parasympathetic fibers that serve muscles and glands

Peripheral Nervous System

- 31 spinal nerves
  - We've already discussed their structure
- 12 cranial nerves
  - How do they differ from spinal nerves?
  - We need to learn their:
    - Names
    - Locations
    - Functions





Cranial Nerves

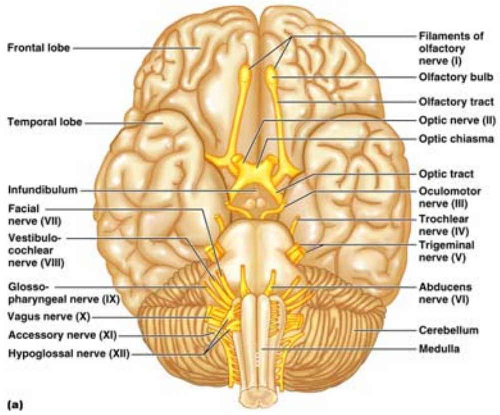


Figure 13.5a

Summary of Function of Cranial Nerves

Cranial nerves I – VI	Sensory function	Motor function	PS* fibers
I Olfactory	Yes (smell)	No	No
II Optic	Yes (vision)	No	No
III Oculomotor	No	Yes	Yes
IV Trochlear	No	Yes	No
V Trigeminal	Yes (general sensation)	Yes	No
VI Abducens	No	Yes	No

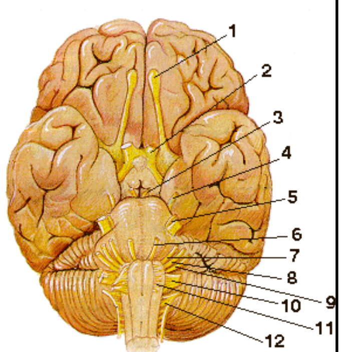
Cranial nerves VII – XII	Sensory function	Motor function	PS* fibers
VII Facial	Yes (taste)	Yes	Yes
VIII Vestibulocochlear	Yes (hearing and balance)	Some	No
IX Glossopharyngeal	Yes (taste)	Yes	Yes
X Vagus	Yes (taste)	Yes	Yes
XI Accessory	No	Yes	No
XII Hypoglossal	No	Yes	No

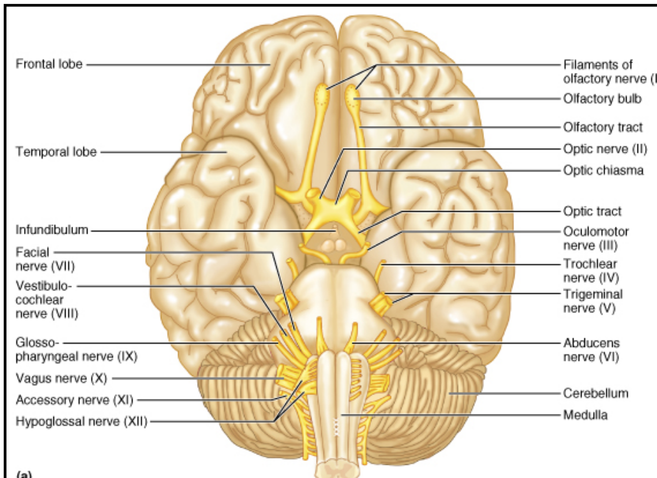
(b) *PS = parasympathetic

Figure 13.5b

12 Cranial Nerves

- How do you remember which nerve is which number?
  - Here is a G-rated mnemonic devices:
    - Old Opie occasionally tries trigonometry and feels very gloomy, vague, and hypoactive.
  - There are also several R-rated ones
- Some cranial nerves are sensory, some motor, and some are both (mixed)?
  - Some say marry money but my brother says big butts matter more.





Cranial Nerve I: Olfactory

- Arises from the olfactory epithelium
- Passes through the cribriform plate of the ethmoid bone
- Fibers run through the olfactory bulb and terminate in the primary olfactory cortex
- Functions solely by carrying afferent impulses for the sense of smell

Cranial Nerve I: Olfactory

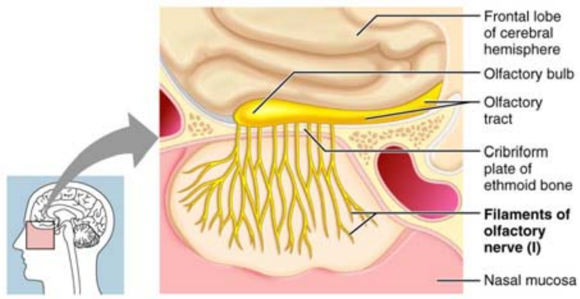
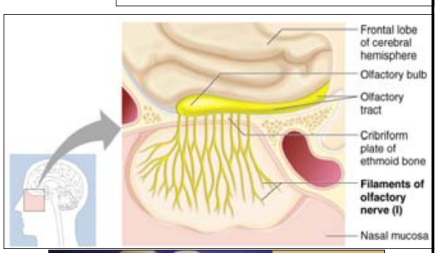
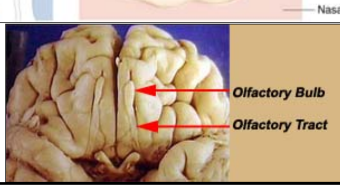


Figure I from Table 13.2

CN1 Olfactory nerves

- How many noses do you have?
- Sensory, motor, or mixed?
- Run from the nasal mucosa to the olfactory bulb.
- Extend thru the cribriform plate.
- Lesion to these nerves or cribriform plate fracture may yield anosmia – loss of smell.





Cranial Nerve II: Optic

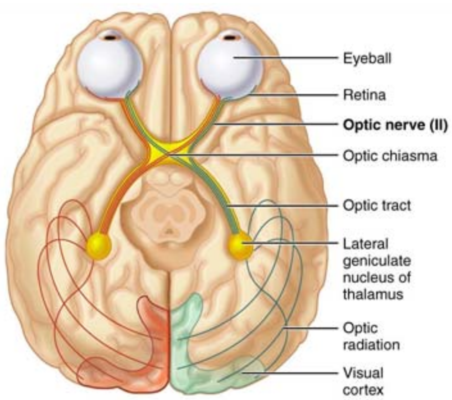
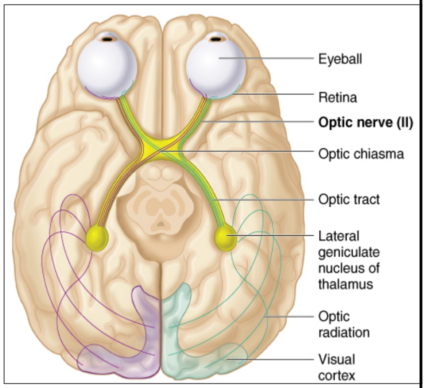
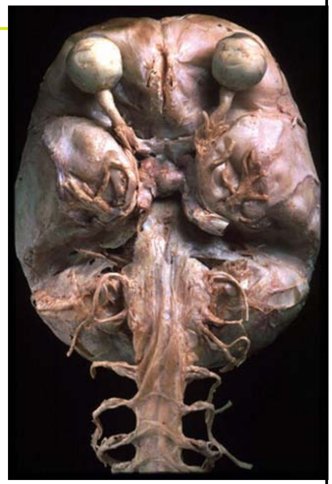


Figure II from Table 13.2

CN2
Optic Nerves

- How many eyes do you have?
- Sensory, motor, or mixed?
- Begin at the retina, run to the optic chiasm, cross over, continue as the optic tract and synapse in the thalamus.
- Optic nerve damage yields blindness in the eye served by the nerve. Optic tract damage yields partial visual loss.
- Visual defects = anopsias





Cranial Nerve III: Oculomotor

- Fibers extend from the ventral midbrain, pass through the superior orbital fissure, and go to the extrinsic eye muscles
- Functions in raising the eyelid, directing the eyeball, constricting the iris, and controlling lens shape
- Parasympathetic cell bodies are in the ciliary ganglia

Cranial Nerve III: Oculomotor

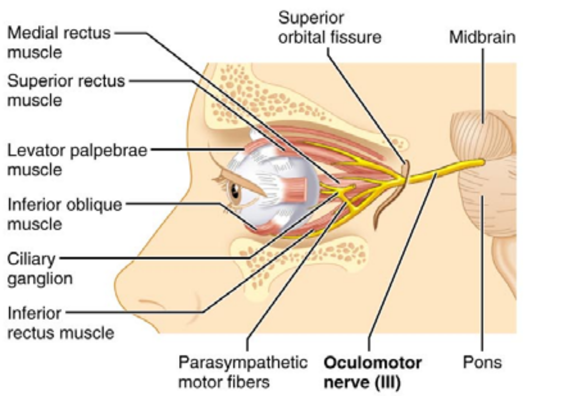
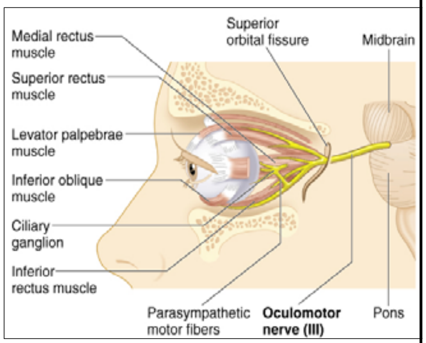


Figure III from Table 13.2

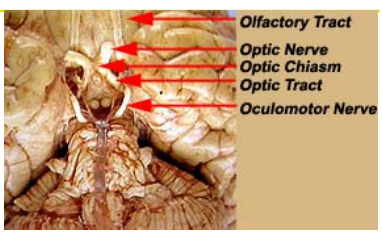
CN3
Oculomotor Nerves

- "Eye mover"
- Sensory, motor, or mixed?
- Originate at the ventral midbrain.
- Synapse on:
  - Extraocular muscles
    - Inferior oblique; Inferior, medial, and superior rectus
  - Iris constrictor muscle
  - Ciliary muscle
- Disorders can result in eye paralysis, diplopia or ptosis.



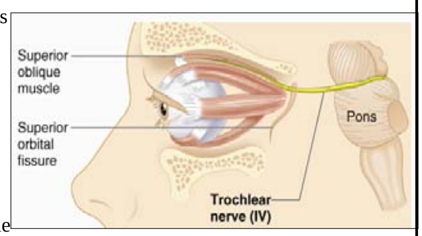
Cranial Nerve IV: Trochlear

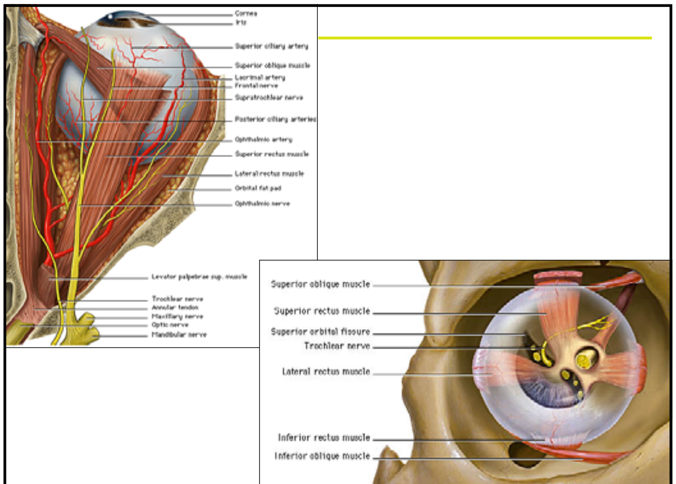
- Fibers emerge from the dorsal midbrain and enter the orbits via the superior orbital fissures; innervate the superior oblique muscle
- Primarily a motor nerve that directs the eyeball



CN4
Trochlear Nerves

- Controls the superior oblique muscle which depresses the eye via pulling on the superior oblique tendon which loops over a ligamentous pulley known as the trochlea.
- Originates on the dorsal midbrain and synapses on the superior oblique
- Sensory, motor, or mixed?
- Trauma can result in double vision. Why?





Cranial Nerve V: Trigeminal

- Three divisions: ophthalmic (V_1), maxillary (V_2), and mandibular (V_3)
- Fibers run from the face to the pons via the superior orbital fissure (V_1), the foramen rotundum (V_2), and the foramen ovale (V_3)
- Conveys sensory impulses from various areas of the face (V_1) and (V_2), and supplies motor fibers (V_3) for mastication

Cranial Nerve V: Trigeminal

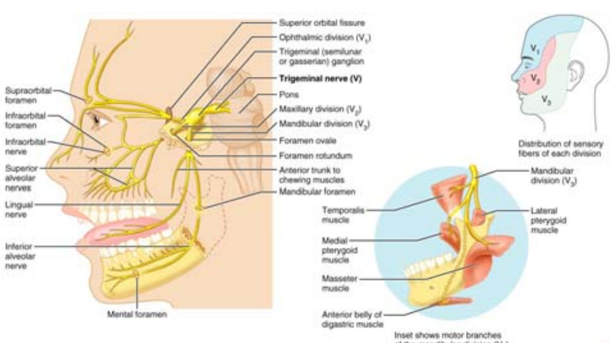
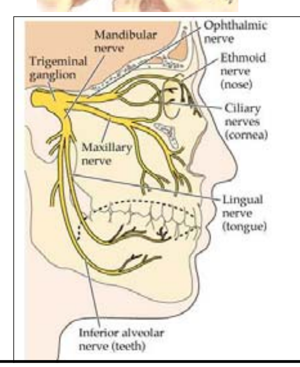


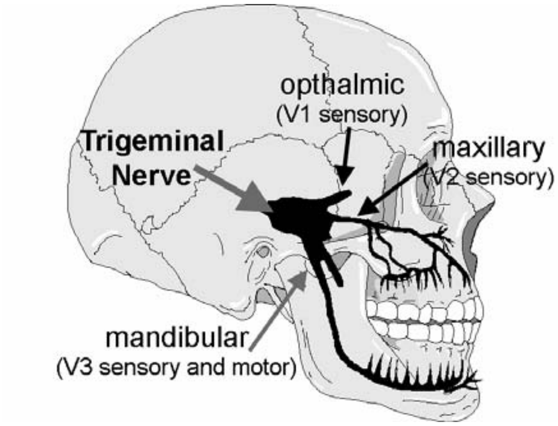
Figure V from Table 13.2

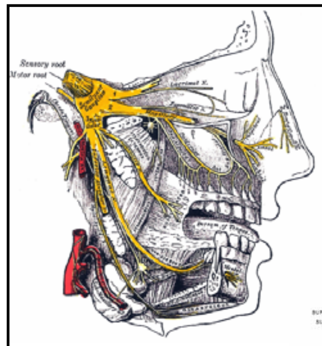
CN5
Trigeminal Nerves

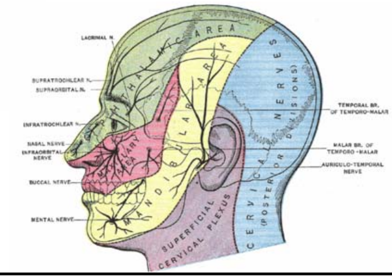
- Biggest cranial nerve
- Originates in the pons and eventually splits into 3 divisions:
  - Ophthalmic (V1), Maxillary (V2), &

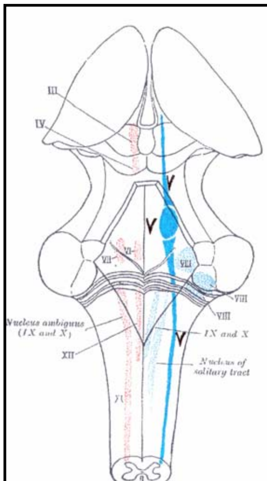
    Mandibular (V3).
- Sensory info (touch, temp., and pain) from face.
- Motor info to muscles of mastication
- Damage?











The **spinal trigeminal nucleus** represents **pain/temperature** sensation from the face. Pain/temperature fibers from peripheral nociceptors are carried in cranial nerves V, VII, IX and X. On entering the brainstem, sensory fibers are grouped together and sent to the spinal trigeminal nucleus. This bundle of incoming fibers can be identified in cross sections of the pons and medulla as the **spinal tract of the trigeminal nucleus**, which parallels the spinal trigeminal nucleus itself. The spinal tract of V is analogous to, and continuous with, **Lissauer's tract** in the spinal cord.

Cranial Nerve VI: Abdcuens

- Fibers leave the inferior pons and enter the orbit via the superior orbital fissure
- Primarily a motor nerve innervating the lateral rectus muscle

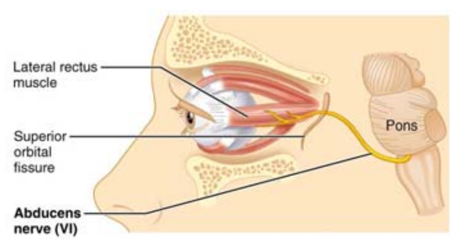
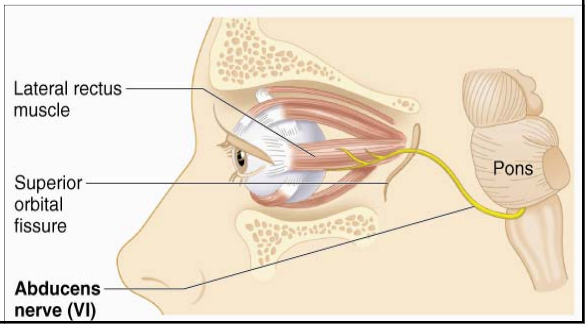
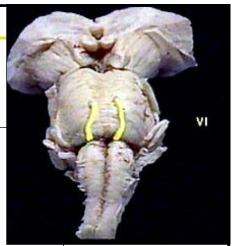


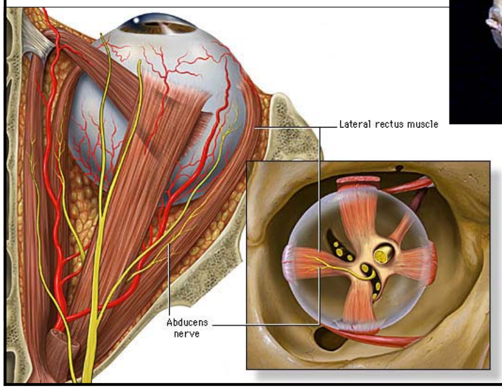
Figure VI from Table 13.2

- Sensory, motor, or mixed?
- Runs between inferior pons and lateral rectus.

CN6
Abducens Nerves



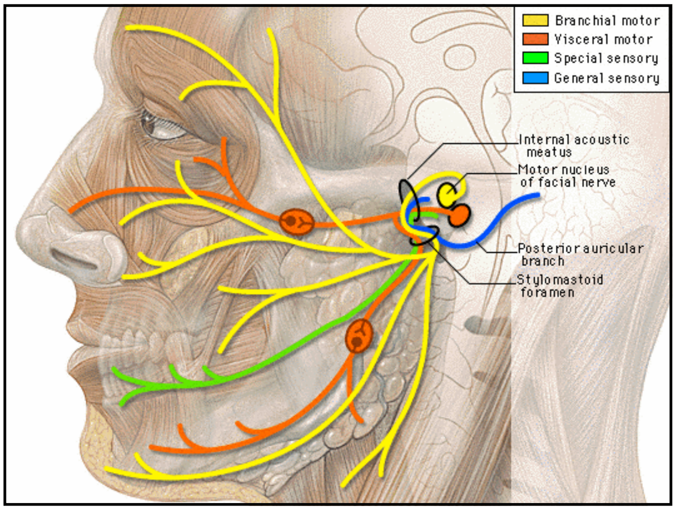


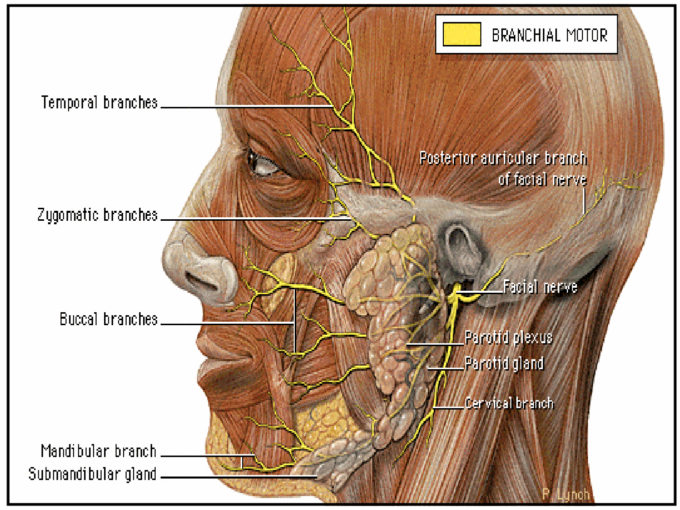


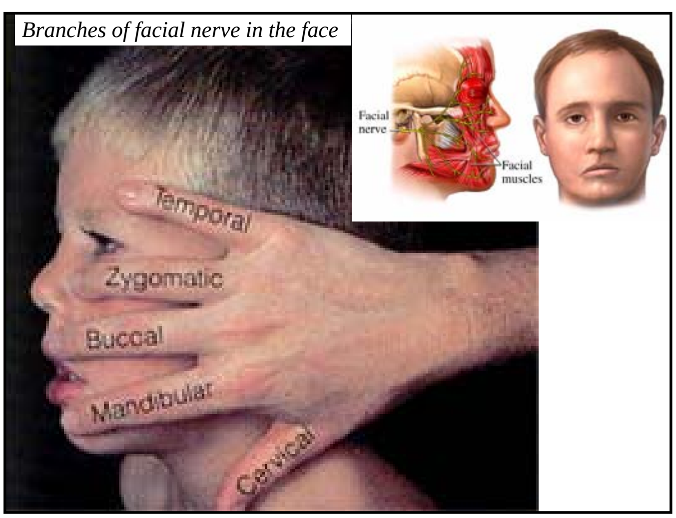
Cranial Nerve VII: Facial

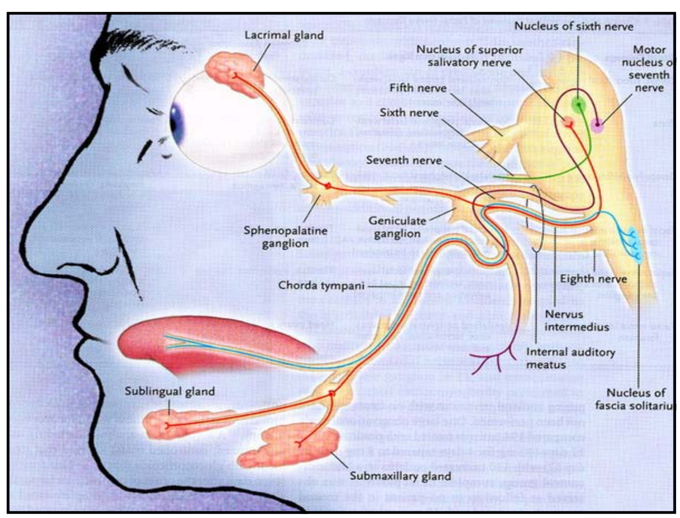
- Fibers leave the pons, travel through the internal acoustic meatus, and emerge through the stylomastoid foramen to the lateral aspect of the face
- Mixed nerve with five major branches
- Motor functions include facial expression, and the transmittal of autonomic impulses to lacrimal and salivary glands
- Sensory function is taste from the anterior two-thirds of the tongue

The facial nerve has four components with distinct functions:	Brancial motor (special visceral efferent)	Supplies the muscles of facial expression; posterior belly of digastric muscle; stylohyoid, and stapedius.
	Visceral motor (general visceral efferent)	Parasympathetic innervation of the lcrimal, submandibular, and sublingual glands, as well as mucous membranes of nasopharynx, hard and soft palate.
	Special sensory (special afferent)	Taste sensation from the anterior 2/3 of tongue; hard and soft palates.
	General sensory (general somatic afferent)	General sensation from the skin of the concha of the auricle and from a small area behind the ear.

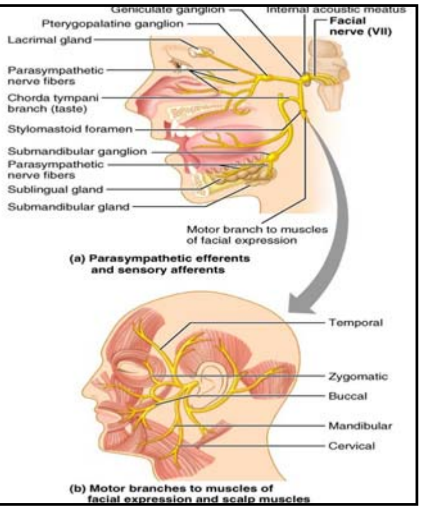

Branchial motor
Visceral motor
Special sensory
General sensory
Internal acoustic meatus
Motor nucleus of facial nerve
Posterior auricular branch
Stylomastoid foramen


BRANCHIAL MOTOR
Temporal branches
Posterior auricular branch of facial nerve
Zygomatic branches
Facial nerve
Buccal branches
Parotid plexus
Parotid gland
Cervical branch
Mandibular branch
Submandibular gland
P. Lynch


Branches of facial nerve in the face
Facial nerve
Facial muscles
Temporal
Zygomatic
Buccal
Mandibular
Cervical


Nucleus of sixth nerve
Lacrimal gland
Nucleus of superior salivatory nerve
Motor nucleus of seventh nerve
Fifth nerve
Sixth nerve
Seventh nerve
Sphenopalatine ganglion
Geniculate ganglion
Chorda tympani
Eighth nerve
Nervus intermedius
Internal auditory meatus
Sublingual gland
Nucleus of fascia solitariu
Submaxillary gland

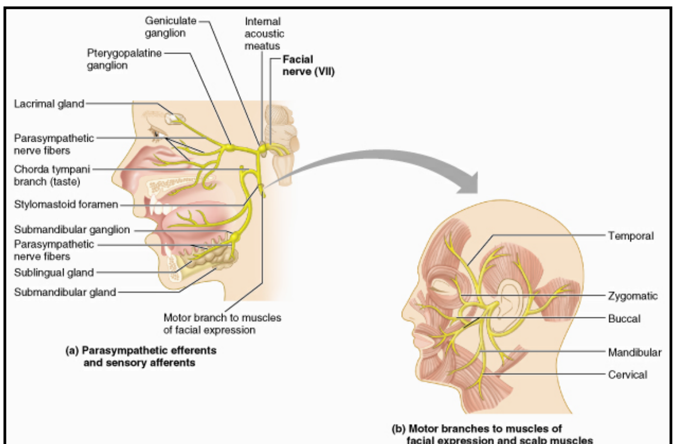
Cranial Nerve VII: Facial



CN7 Facial Nerves

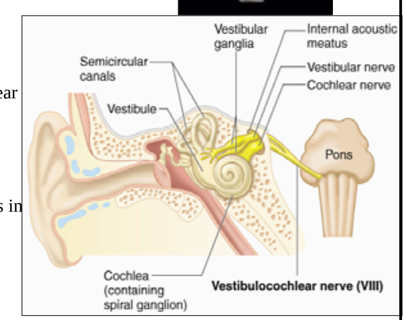
- Sensory, motor, or mixed?
- Originates at the pons
- Convey motor impulses to facial skeletal muscles – except for chewing muscles.
- Convey parasympathetic motor impulses to tear, nasal, and some salivary glands.
- Convey sensory info from taste buds on anterior

  2/3 of the tongue.
- Facial nerve damage may yield Bell's palsy, total ipsilateral hemifacial paralysis



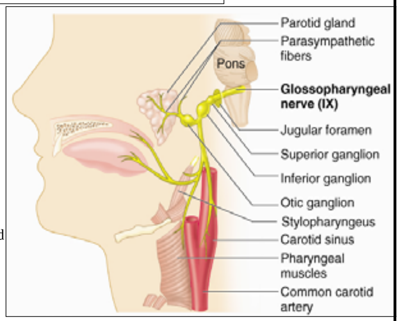
CN8 Auditory/Vestibulocochlear Nerves

- Sensory, motor, or mixed?
- Originates at the pons
- 2 divisions:
  - Cochlear
    - Afferent fibers from cochlea in the inner ear
    - HEARING
  - Vestibular
    - Afferent fibers from equilibrium receptors in inner ear
    - BALANCE
- Functional impairment?



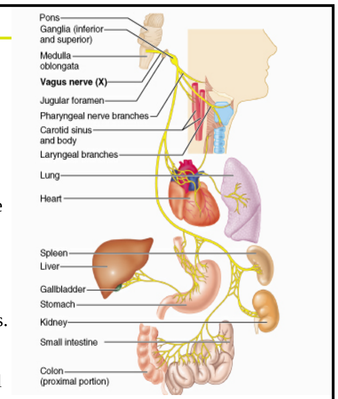
CN9
Glossopharyngeal Nerves

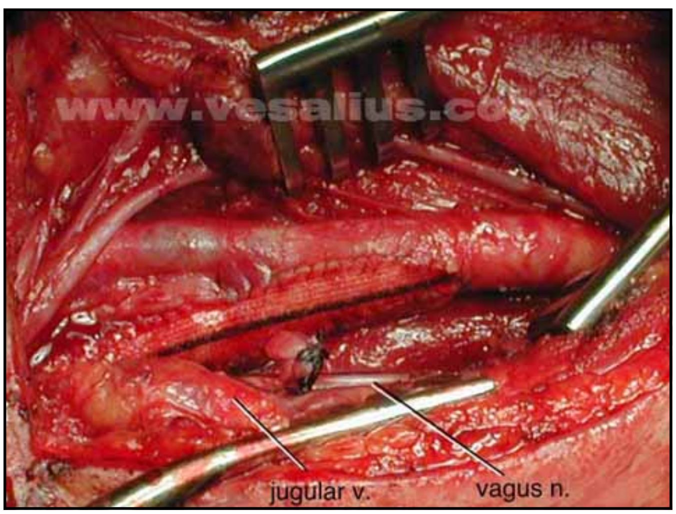
- Sensory, motor, or mixed?
- Fibers run emerge from medulla and run to the throat.
- Motor Functions:
  - Motor fibers to some swallowing muscles
  - Parasympathetic fibers to some salivary glands
- Sensory Functions:
  - Taste, touch, heat from pharynx and posterior tongue.
  - Info from chemoreceptors on the level of O_2 and CO_2 in the blood. Info from baroreceptors on BP.
    - Chemoreceptors and baroreceptors are located in the carotid sinus – a dilation in the internal carotid artery.



CN10
Vagus Nerves

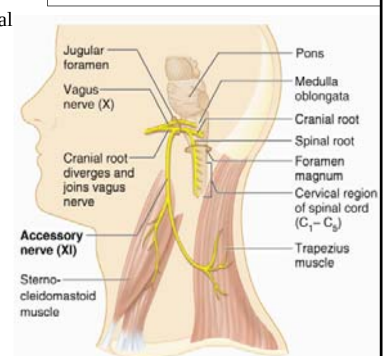
- Sensory, motor, or mixed?
- Only cranial nerves to extend beyond head and neck.
  - Fibers emerge from medulla, leave the skull, and course downwards into the thorax and abdomen.
- Motor Functions:
  - Parasympathetic efferents to the heart, lungs, and abdominal organs.
- Sensory Functions:
  - Input from thoracic and abdominal viscera; from baro- and chemoreceptors in the carotid sinus; from taste buds in posterior tongue and pharynx

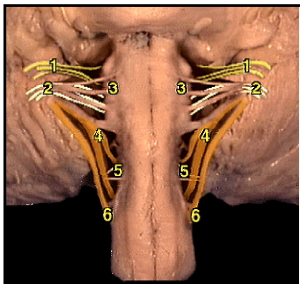


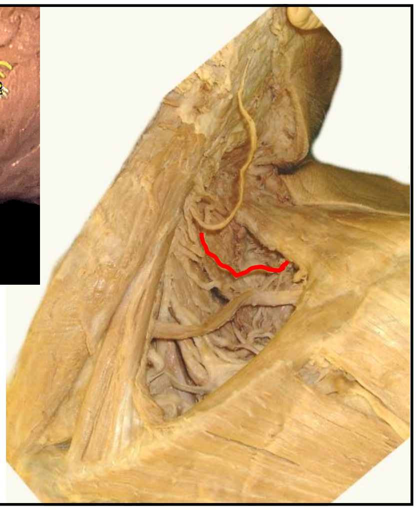


CN11
Accessory Nerves

- Sensory, motor, or mixed?
- Formed by the union of a cranial root and a spinal root.
  - CR arises from medulla while SR arises from superior spinal cord. SR passes thru the FM and joins with CR to form the accessory nerve. They then leave the skull via the jugular foramen.
  - Cranial division then joins vagus and innervates larynx, pharynx, and soft palate.
  - Spinal division innervates sternocleidomastoids and trapezius.

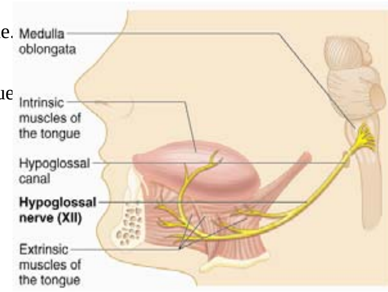






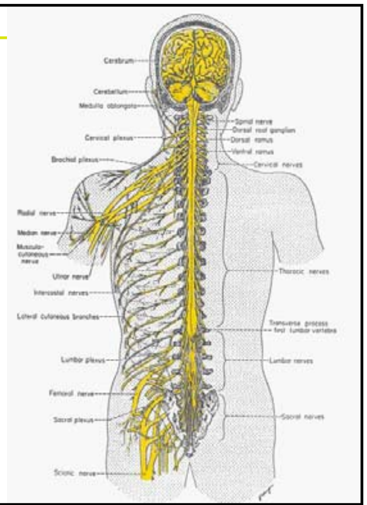
CN12
Hypoglossal Nerves

- Sensory, motor, or mixed?
- Arise from the medulla and exit the skull via the hypoglossal canal and innervate the tongue.
- Innervate the intrinsic & extrinsic muscles of the tongue
  - Swallowing, speech, food manipulation.
- Damage?



Peripheral Nervous System

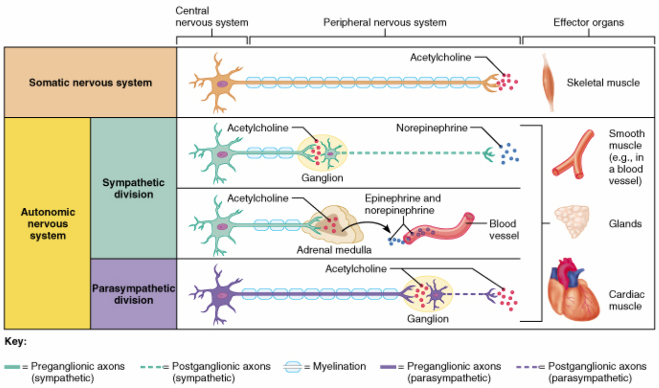
- Now that we've looked at spinal and cranial nerves, we can examine the divisions of the PNS.
- The PNS is broken down into a sensory and a motor division.
- We'll concentrate on the motor division which contains the somatic nervous system and the autonomic nervous system.



Somatic vs. Autonomic

- Voluntary
- Skeletal muscle
- Single efferent neuron
- Axon terminals release acetylcholine
- Always excitatory
- Controlled by the cerebrum

- Involuntary
- Smooth, cardiac muscle; glands
- Multiple efferent neurons
- Axon terminals release acetylcholine or norepinephrine
- Can be excitatory or inhibitory
- Controlled by the homeostatic centers in the brain – pons, hypothalamus, medulla oblongata

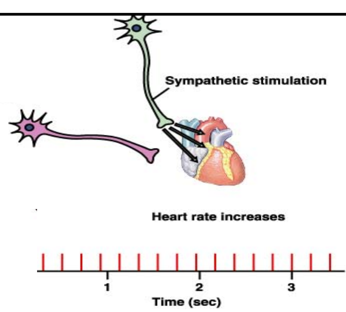


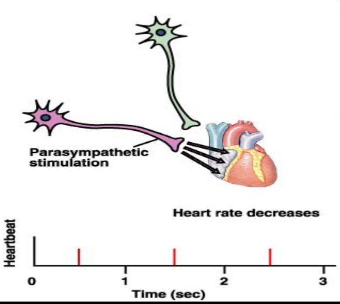
Autonomic Nervous System

- 2 divisions:
  - Sympathetic
    - "Fight or flight"
    - "E" division
      - Exercise, excitement, emergency, and embarrassment
  - Parasympathetic
    - "Rest and digest"
    - "D" division
      - Digestion, defecation, and diuresis

Antagonistic Control

- Most internal organs are innervated by both branches of the ANS which exhibit antagonistic control





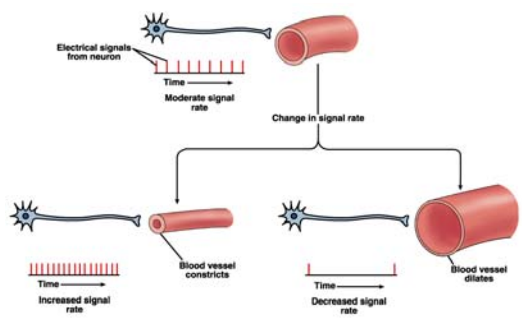
A great example is heart rate. An increase in sympathetic stimulation causes HR to increase whereas an increase in parasympathetic stimulation causes HR to decrease

<u>**Exception to the dual innervation rule:**</u>

Sweat glands and blood vessel smooth muscle are only innervated by symp and rely strictly on up-down control.

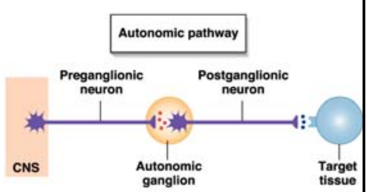
<u>**Exception to the antagonism rule:**</u>

Symp and parasymp work cooperatively to achieve male sexual function. Parasymp is responsible for erection while symp is responsible to ejaculation. There's similar ANS cooperation in the female sexual response.



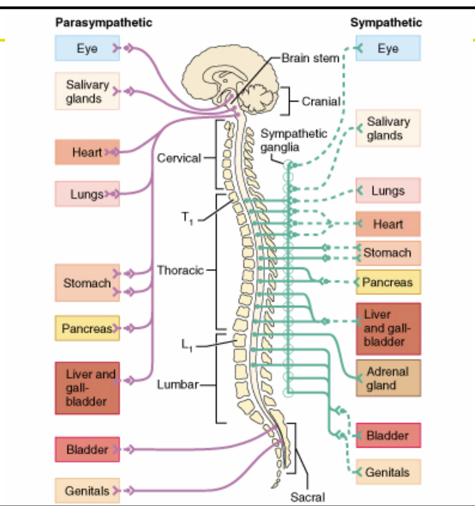
ANS Structure

- Both ANS divisions share the same general structure.
  - Autonomic pathways always consist of 2 neurons in series.
  - They synapse in an autonomic ganglion – would this be inside or outside the CNS?
  - The 1st neuron in the autonomic pathway is the preganglionic neuron,
    - Cell body in CNS, myelinated, and projects to the autonomic ganglion.
  - While the 2nd neuron is the postganglionic neuron.
    - Cell body in autonomic ganglion, unmyelinated, and projects to the effector.



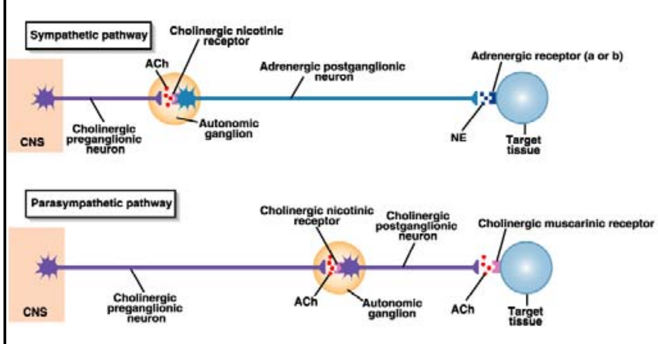
Sympathetic vs. Parasympathetic *Structural Differences:*

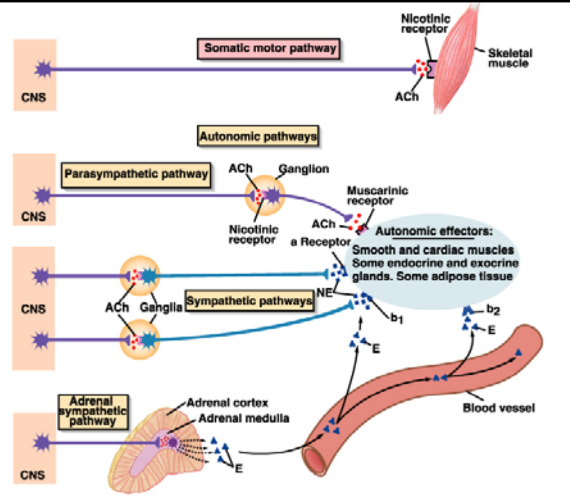
	Symp.	Parasymp.
Point of CNS Origin	T1 → L2 (thoracolumbar)	Brainstem, S2 → S4 (craniosacral)
Site of Peripheral Ganglia	Paravertebral – in sympathetic chain	On or near target tissue
Length of preganglionic fiber	Short	Long
Length of postganglionic fiber	Long	Short



Sympathetic vs. Parasympathetic *Receptor/NT Differences:*

	Symp.	Parasymp.
NT at Target Synapse	Norepinephrine (adrenergic neurons)	Acetylcholine (cholinergic neurons)
Type of NT Receptors at Target Synapse	Alpha and Beta (α and β)	Muscarinic
NT at Ganglion	Acetylcholine	Acetylcholine
Receptor at Ganglion	Nicotinic	Nicotinic





Sympathetic vs. Parasympathetic *Effects:*

- In the following tables, note the effects of the sympathetic and parasympathetic nervous systems on various body organs.
- Try to deduce why the divisions cause these particular actions. What's the point?

Target Organ	***Parasympathetic Effects***	***Sympathetic Effects***
Eye (Iris)	Stimulates constrictor muscles. Pupil constriction.	Stimulates dilator muscles. Pupil dilates.
Eye (Ciliary muscle)	Stimulates. Lens accommodates – allows for close vision.	No innervation.
Salivary Glands	Watery secretion.	Mucous secretion.
Sweat Glands	No innervation.	Stimulates sweating in large amounts. (Cholinergic)
Gallbladder	Stimulates smooth muscle to contract and expel bile.	Inhibits gallbladder smooth muscle.
Arrector Pili	No innervation	Stimulates contraction. Piloerection (Goosebumps)

Target Organ	Parasympathetic Effects	Sympathetic Effects
Cardiac Muscle	Decreases HR.	Increases HR and force of contraction.
Coronary Blood Vessels	Constricts.	Dilates
Urinary Bladder; Urethra	Contracts bladder smooth muscle; relaxes urethral sphincter.	Relaxes bladder smooth muscle; contracts urethral sphincter.
Lungs	Contracts bronchiole (small air passage) smooth muscle.	Dilates bronchioles.
Digestive Organs	Increases peristalsis and enzyme/mucus secretion.	Decreases glandular and muscular activity.
Liver	No innervation	No innervation (indirect effect).

Target Organ	Parasympathetic Effects	Sympathetic Effects
Kidney	No innervation.	Releases the enzyme renin which acts to increase BP.
Penis	Vasodilates penile arteries. Erection.	Smooth muscle contraction. Ejaculation.
Vagina; Clitoris	Vasodilation. Erection.	Vaginal reverse peristalsis.
Blood Coagulation	No effect.	Increases coagulation rate.
Cellular Metabolism	No effect.	Increases metabolic rate.
Adipose Tissue	No effect.	Stimulates fat breakdown.

Target Organ	Parasympathetic Effects	Sympathetic Effects
Mental Activity	No innervation.	Increases alertness.
Blood Vessels	Little effect.	Constricts most blood vessels and increases BP. Exception – dilates blood vessels serving skeletal muscle fibers (cholinergic).
Uterus	Depends on stage of the cycle.	Depends on stage of the cycle.
Endocrine Pancreas	Stimulates insulin secretion.	Inhibits insulin secretion.

Duration/Location of Parasympathetic Effects

- Parasympathetic preganglionic neurons synapse on only a few postganglionic neurons.

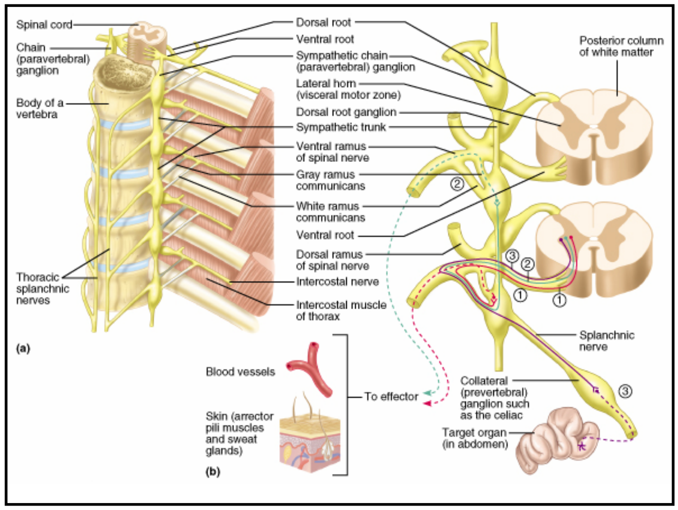
Would you expect parasympathetic activity to be widespread or local?

- All parasympathetic fibers release ACh.
  - ACh is quickly broken down by what enzyme?

What can you say about the duration of parasympathetic effects?

Why Is Sympathetic Activity Diffuse?

- Preganglionic fibers have their somata in the lateral horns of the thoracic and lumbar spinal cord.
- Preganglionic fibers leave the cord via the ventral root and enter a white ramus communicans to enter a chain ganglion – which is part of the sympathetic trunk.
- Let's look at a picture!

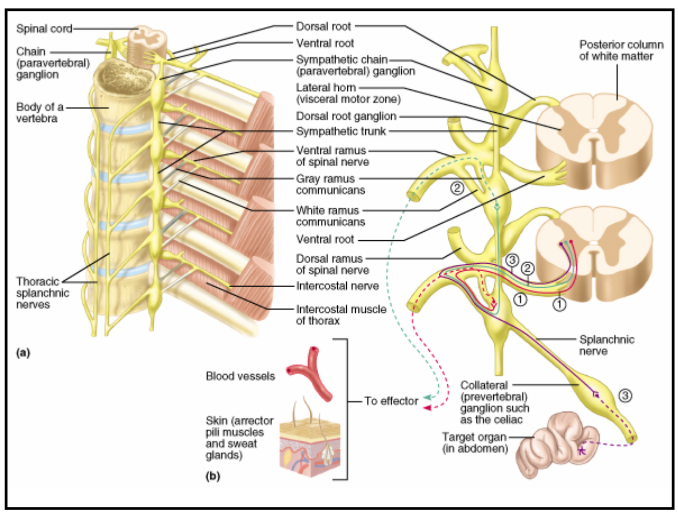


Once a preganglionic axon reaches the chain ganglion, it may:

1 …synapse with a ganglionic neuron w/i the same chain ganglion.

2 …ascend or descend in the trunk to synapse within another chain ganglion.

3 …pass thru the chain ganglion and emerge from the chain w/o synapsing.



If the preganglionic axon synapses in a chain ganglion (routes 1 and 2)…

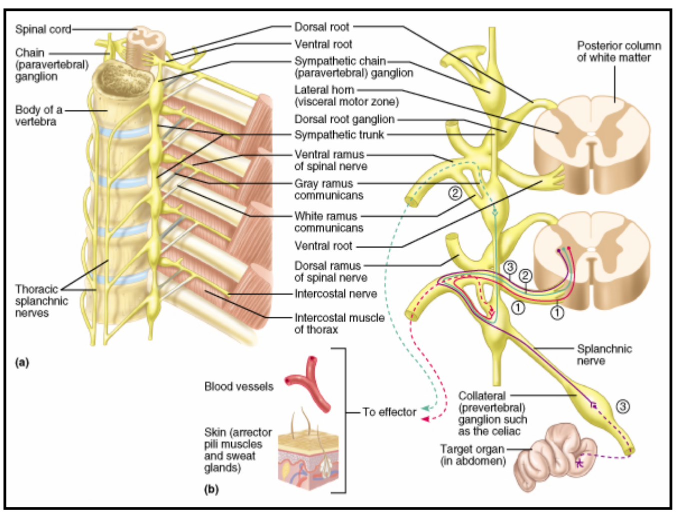
↓

It will enter the ventral or dorsal ramus of the adjoining spinal nerve via a gray ramus communicans.

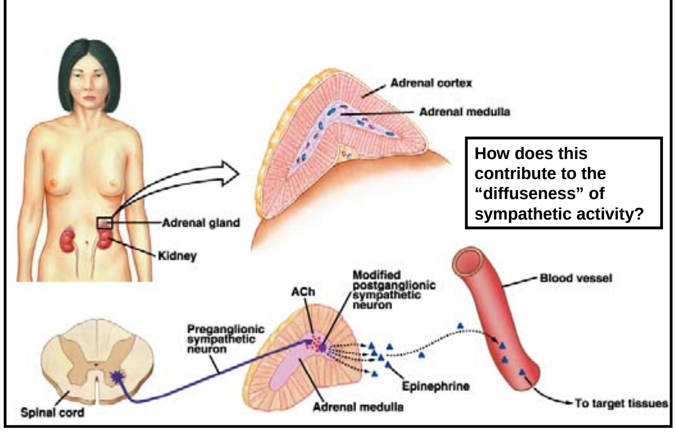
↓

From here it may give branches to sweat glands, arrector pili, and vascular smooth muscle – while it continues to its final destination which could be the iris muscles, the heart, or something else.

- **Preganglionic fibers that do not synapse in the trunk synapse with prevertebral ganglia located anterior to the vertebral column.**
- These are not arranged in a chain and occur only in the abdomen and the pelvis.
- These are the splanchnic nerves.
- Thoracic splanchnic nerves form a large plexus (abdominal aortic plexus) which yields multiple fibers that innervate visceral and vascular smooth muscle of the abdominal cavity.
- Pelvic splanchnic nerves innervate the lower digestive organs (inferior large intestine) as well as urinary and reproductive structures.



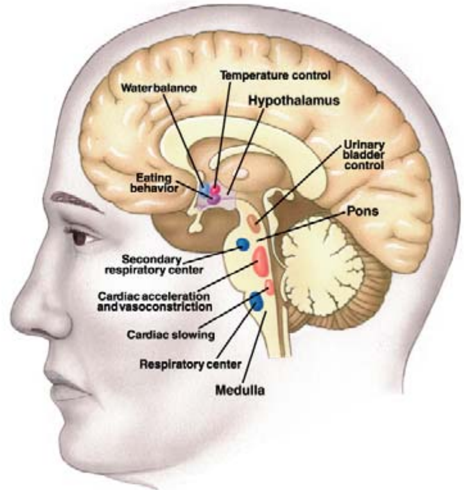
Certain splanchnic nerves synapse on hormone-producing cells of the adrenal medulla – the interior of the adrenal glands which sit upon the kidneys.



How does this contribute to the "diffuseness" of sympathetic activity?

How Does the Brain *Control* the ANS?

- The hypothalamus is the Boss:
  - Its anterior and medial regions direct parasympathetic function while its posterior and lateral regions direct sympathetic function
  - These centers exert control directly and via nuclei in the reticular formation (e.g., the cardiovascular centers in the MO, respiratory centers in MO and pons, etc.)
  - The connection of the limbic system to the hypothalamus mediates our "flight or flight" response to emotional situations.
  - The relationship btwn the hypothalamus and the amygdala and periaquaductal gray matter allow us to respond to fear.



Segmental Level

- The segmental level is the lowest level of motor hierarchy
- It consists of segmental circuits of the spinal cord
- Its circuits control locomotion and specific, oft-repeated motor activity
- These circuits are called central pattern generators (CPGs)

Projection Level

- The projection level consists of:
  - Cortical motor areas that produce the direct (pyramidal) system
  - Brain stem motor areas that oversee the indirect (multineuronal) system
- Helps control reflex and fixed-pattern activity and houses command neurons that modify the segmental apparatus

Precommand Level

- Cerebellar and basal nuclei systems that:
  - Regulate motor activity
  - Precisely start or stop movements
  - Coordinate movements with posture
  - Block unwanted movements
  - Monitor muscle tone

PNS in the Nervous System

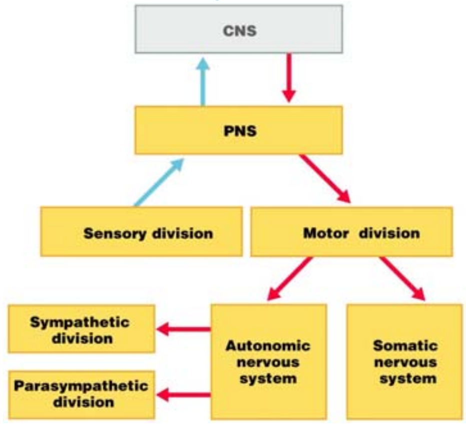


Figure 13.1

Sensory Receptors

- Structures specialized to respond to stimuli
- Activation of sensory receptors results in depolarizations that trigger impulses to the CNS
- The realization of these stimuli, sensation and perception, occur in the brain

Receptor Classification by Stimulus Type

- Mechanoreceptors – respond to touch, pressure, vibration, stretch, and itch
- 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

Receptor Class by Location: Exteroceptors

- Respond to stimuli arising outside the body
- Found near the body surface
- Sensitive to touch, pressure, pain, and temperature
- Include the special sense organs

Receptor Class by Location: Interoceptors

- Respond to stimuli arising within the body
- Found in internal viscera and blood vessels
- Sensitive to chemical changes, stretch, and temperature changes

Receptor Class by Location: Proprioceptors

- Respond to degree of stretch of the organs they occupy
- Found in skeletal muscles, tendons, joints, ligaments, and connective tissue coverings of bones and muscles
- Constantly "advise" the brain of one's movements

Receptor Classification by Structural Complexity

- Receptors are structurally classified as either simple or complex
- Most receptors are simple and include encapsulated and unencapsulated varieties
- Complex receptors are special sense organs

Simple Receptors: Unencapsulated

- Free dendritic nerve endings
  - Respond chiefly to temperature and pain
- Merkel (tactile) discs
- Hair follicle receptors

Simple Receptors: Encapsulated

- Meissner’s corpuscles (tactile corpuscles)
- Pacinian corpuscles (lamellated corpuscles)
- Muscle spindles, Golgi tendon organs, and Ruffini’s corpuscles
- Joint kinesthetic receptors

Simple Receptors: Unencapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function

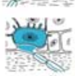
STRUCTURAL CLASS	ILLUSTRATION	FUNCTIONAL CLASSES ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
UNENCAPSULATED			
Free nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Thermoreceptors (warm and cool), chemoreceptors (itch, pH, etc.), mechanoreceptors (pressure), nociceptors (pain, hot, cold, pinch, and chemicals)	Most body tissues; most dense in connective tissues (ligaments, tendons, dermis, joint capsules, periostea) and epithelia (epidermis, cornea, mucosae, and glands)
Modified free nerve endings: Merkel discs (tactile discs)		L: Exteroceptors S: Mechanoreceptors (light pressure); slowly adapting	Basal layer of epidermis of skin
Hair follicle receptors		L: Exteroceptors S: Mechanoreceptors (hair deflection); rapidly adapting	In and surrounding hair follicles

Table 13.1.1

Simple Receptors: Encapsulated

TABLE 13.1 General Sensory Receptors Classified by Structure and Function (continued)

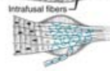
STRUCTURAL CLASS	ILLUSTRATION	FUNCTIONAL CLASSES ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
ENCAPSULATED			
Meissner's corpuscles (tactile corpuscles)		L: Exteroceptors S: Mechanoreceptors (light pressure, discriminative touch, vibration of low frequency); rapidly adapting	Dermal papillae of hairless skin, particularly nipples, external genitalia, fingertips, soles of feet, eyelids
Pacinian corpuscles (lamellated corpuscles)		L: Exteroceptors, interoceptors, and some proprioceptors S: Mechanoreceptors (deep pressure, stretch, vibration of high frequency); rapidly adapting	Dermis and hypodermis; periostea, mesentery, tendons, ligaments, joint capsules; most abundant on fingers, soles of feet, external genitalia, nipples
Ruffini endings		L: Exteroceptors and proprioceptors S: Mechanoreceptors (deep pressure and stretch); slowly or nonadapting	Deep in dermis, hypodermis, and joint capsules
Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch, length)	Skeletal muscles, particularly those of the extremities
Golgi tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch, tension)	Tendons
Joint kinesthetic receptors		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

Table 13.1.2

From Sensation to Perception

- Survival depends upon sensation and perception
- Sensation is the awareness of changes in the internal and external environment
- Perception is the conscious interpretation of those stimuli

Organization of the Somatosensory System

- Input comes from exteroceptors, proprioceptors, and interoceptors
- The three main levels of neural integration in the somatosensory system are:
  - Receptor level – the sensor receptors
  - Circuit level – ascending pathways
  - Perceptual level – neuronal circuits in the cerebral cortex

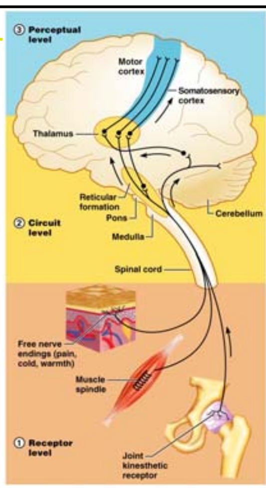


Figure 13.2

Processing at the Receptor Lever

- The receptor must have specificity for the stimulus energy
- The receptor's receptive field must be stimulated
- Stimulus energy must be converted into a graded potential
- A generator potential in the associated sensory neuron must reach threshold

Adaptation of Sensory Receptors

- Adaptation occurs when sensory receptors are subjected to an unchanging stimulus
  - Receptor membranes become less responsive
  - Receptor potentials decline in frequency or stop

Adaptation of Sensory Receptors

- Receptors responding to pressure, touch, and smell adapt quickly
- Receptors responding slowly include Merkel's discs, Ruffini's corpuscles, and interoceptors that respond to chemical levels in the blood
- Pain receptors and proprioceptors do not exhibit adaptation

Processing at the Circuit Level

- Chains of three neurons conduct sensory impulses upward to the brain
- First-order neurons – soma reside in dorsal root or cranial ganglia, and conduct impulses from the skin to the spinal cord or brain stem
- Second-order neurons – soma reside in the dorsal horn of the spinal cord or medullary nuclei and transmit impulses to the thalamus or cerebellum
- Third-order neurons – located in the thalamus and conduct impulses to the somatosensory cortex of the cerebrum

Processing at the Perceptual Level

- The thalamus projects fibers to:
  - The somatosensory cortex
  - Sensory association areas
- First one modality is sent, then those considering more than one
- The result is an internal, conscious image of the stimulus

Main Aspects of Sensory Perception

- Perceptual detection – detecting that a stimulus has occurred and requires summation
- Magnitude estimation – how much of a stimulus is acting
- Spatial discrimination – identifying the site or pattern of the stimulus

Main Aspects of Sensory Perception

- Feature abstraction – used to identify a substance that has specific texture or shape
- Quality discrimination – the ability to identify submodalities of a sensation (e.g., sweet or sour tastes)
- Pattern recognition – ability to recognize patterns in stimuli (e.g., melody, familiar face)

Structure of a Nerve

- Nerve – cordlike organ of the PNS consisting of peripheral axons enclosed by connective tissue
- Connective tissue coverings include:
  - Endoneurium – loose connective tissue that surrounds axons
  - Perineurium – coarse connective tissue that bundles fibers into fascicles
  - Epineurium – tough fibrous sheath around a nerve

Structure of a Nerve

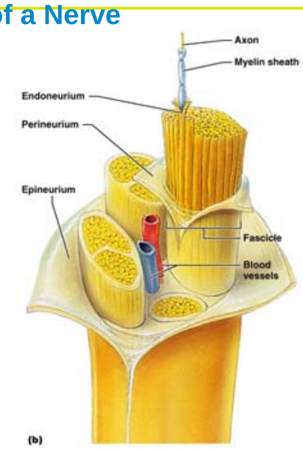


Figure 13.3b

Classification of Nerves

- Sensory and motor divisions
- Sensory (afferent) – carry impulse to the CNS
- Motor (efferent) – carry impulses from CNS
- Mixed – sensory and motor fibers carry impulses to and from CNS; most common type of nerve

Peripheral Nerves

- Mixed nerves – carry somatic and autonomic (visceral) impulses
- The four types of mixed nerves are:
  - Somatic afferent and somatic efferent
  - Visceral afferent and visceral efferent
- Peripheral nerves originate from the brain or spinal column

Regeneration of Nerve Fibers

- Damage to nerve tissue is serious because mature neurons are amitotic
- If the soma of a damaged nerve remains intact, damage can be repaired
- Regeneration involves coordinated activity among:
  - Macrophages – remove debris
  - Schwann cells – form regeneration tube and secrete growth factors
  - Axons – regenerate damaged part

Regeneration of Nerve Fibers

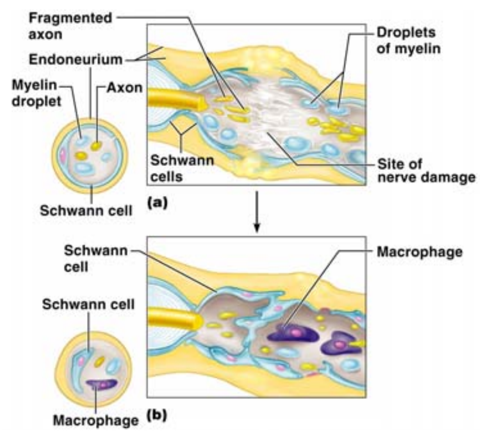


Figure 13.4

Regeneration of Nerve Fibers

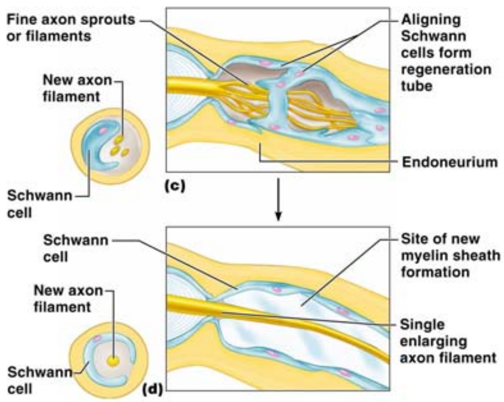


Figure 13.4

Cranial Nerves

- Twelve pairs of cranial nerves arise from the brain
- They have sensory, motor, or both sensory and motor functions
- Each nerve is identified by a number (I through XII) and a name
- Four cranial nerves carry parasympathetic fibers that serve muscles and glands

Cranial Nerves

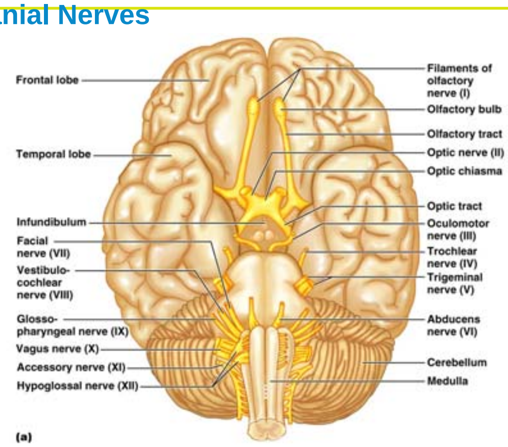


Figure 13.5a

Summary of Function of Cranial Nerves

Cranial nerves I – VI	Sensory function	Motor function	PS* fibers
I Olfactory	Yes (smell)	No	No
II Optic	Yes (vision)	No	No
III Oculomotor	No	Yes	Yes
IV Trochlear	No	Yes	No
V Trigeminal	Yes (general sensation)	Yes	No
VI Abducens	No	Yes	No

Cranial nerves VII – XII	Sensory function	Motor function	PS* fibers
VII Facial	Yes (taste)	Yes	Yes
VIII Vestibulocochlear	Yes (hearing and balance)	Some	No
IX Glossopharyngeal	Yes (taste)	Yes	Yes
X Vagus	Yes (taste)	Yes	Yes
XI Accessory	No	Yes	No
XII Hypoglossal	No	Yes	No

(b) *PS = parasympathetic

Figure 13.5b

Cranial Nerve I: Olfactory

- Arises from the olfactory epithelium
- Passes through the cribriform plate of the ethmoid bone
- Fibers run through the olfactory bulb and terminate in the primary olfactory cortex
- Functions solely by carrying afferent impulses for the sense of smell

Cranial Nerve I: Olfactory

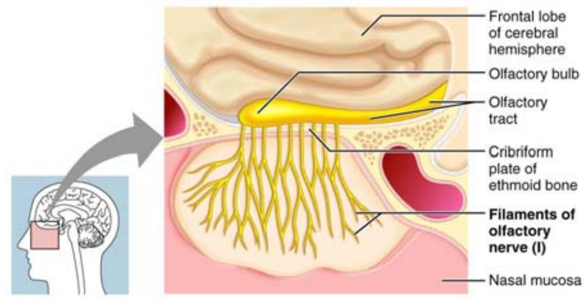


Figure I from Table 13.2

Cranial Nerve II: Optic

- Arises from the retina of the eye
- Optic nerves pass through the optic canals and converge at the optic chiasm
- They continue to the thalamus where they synapse
- From there, the optic radiation fibers run to the visual cortex
- Functions solely by carrying afferent impulses for vision

Cranial Nerve II: Optic

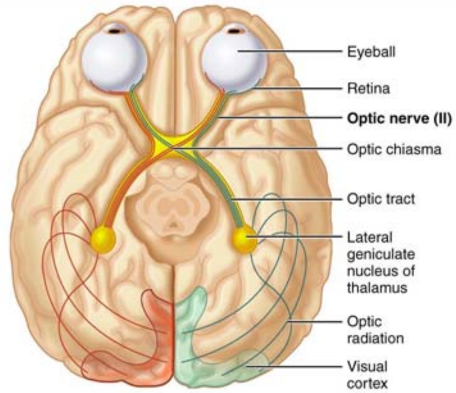


Figure II from Table 13.2

Cranial Nerve III: Oculomotor

- Fibers extend from the ventral midbrain, pass through the superior orbital fissure, and go to the extrinsic eye muscles
- Functions in raising the eyelid, directing the eyeball, constricting the iris, and controlling lens shape
- Parasympathetic cell bodies are in the ciliary ganglia

Cranial Nerve III: Oculomotor

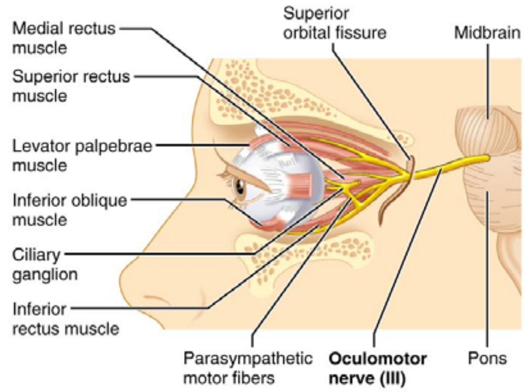


Figure III from Table 13.2

Cranial Nerve IV: Trochlear

- Fibers emerge from the dorsal midbrain and enter the orbits via the superior orbital fissures; innervate the superior oblique muscle
- Primarily a motor nerve that directs the eyeball

Cranial Nerve IV: Trochlear

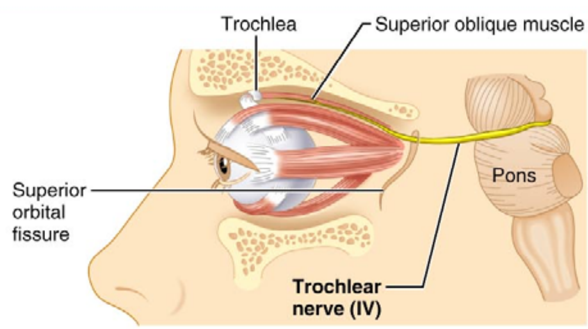


Figure IV from Table 13.2

Cranial Nerve V: Trigeminal

- Three divisions: ophthalmic (V_1), maxillary (V_2), and mandibular (V_3)
- Fibers run from the face to the pons via the superior orbital fissure (V_1), the foramen rotundum (V_2), and the foramen ovale (V_3)
- Conveys sensory impulses from various areas of the face (V_1) and (V_2), and supplies motor fibers (V_3) for mastication

Cranial Nerve V: Trigeminal

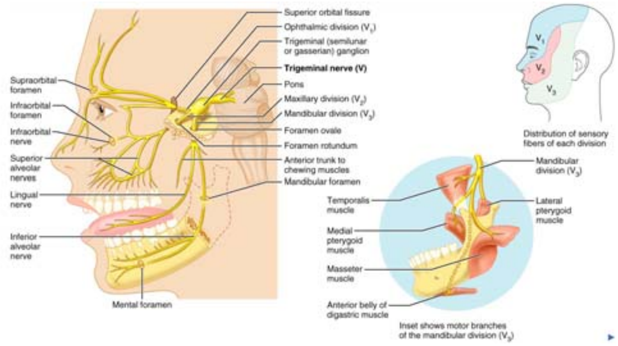


Figure V from Table 13.2

Cranial Nerve VI: Abdcuens

- Fibers leave the inferior pons and enter the orbit via the superior orbital fissure
- Primarily a motor nerve innervating the lateral rectus muscle

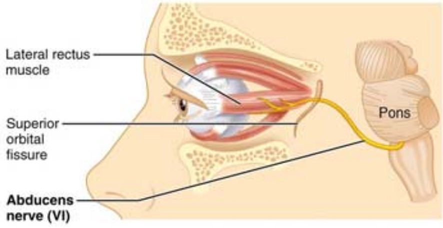


Figure VI from Table 13.2

Cranial Nerve VII: Facial

- Fibers leave the pons, travel through the internal acoustic meatus, and emerge through the stylomastoid foramen to the lateral aspect of the face
- Mixed nerve with five major branches
- Motor functions include facial expression, and the transmittal of autonomic impulses to lacrimal and salivary glands
- Sensory function is taste from the anterior two-thirds of the tongue

Cranial Nerve VII: Facial

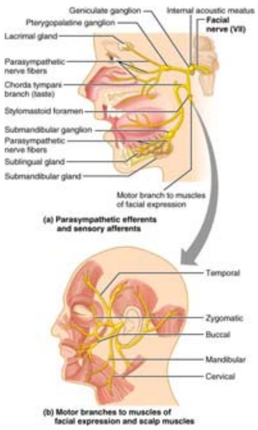


Figure VII from Table 13.2

Cranial Nerve VIII: Vestibulocochlear

- Fibers arise from the hearing and equilibrium apparatus of the inner ear, pass through the internal acoustic meatus, and enter the brainstem at the pons-medulla border
- Two divisions – cochlear (hearing) and vestibular (balance)
- Functions are solely sensory – equilibrium and hearing

Cranial Nerve VIII: Vestibulocochlear

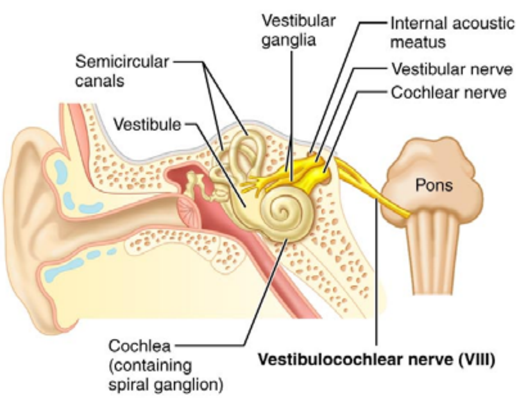


Figure VIII from Table 13.2

Cranial Nerve IX: Glossopharyngeal

- Fibers emerge from the medulla, leave the skull via the jugular foramen, and run to the throat
- Nerve IX is a mixed nerve with motor and sensory functions
- Motor – innervates part of the tongue and pharynx, and provides motor fibers to the parotid salivary gland
- Sensory – fibers conduct taste and general sensory impulses from the tongue and pharynx

Cranial Nerve IX: Glossopharyngeal

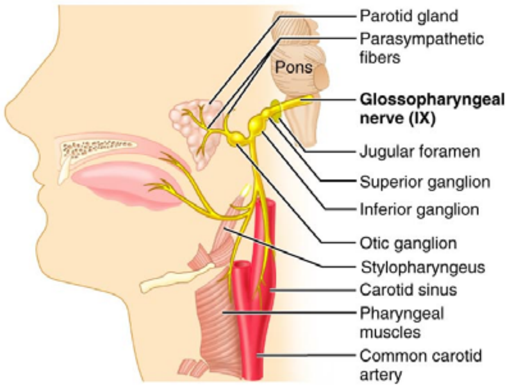


Figure IX from Table 13.2

Cranial Nerve X: Vagus

- The only cranial nerve that extends beyond the head and neck
- Fibers emerge from the medulla via the jugular foramen
- The vagus is a mixed nerve
- Most motor fibers are parasympathetic fibers to the heart, lungs, and visceral organs
- Its sensory function is in taste

Cranial Nerve X: Vagus

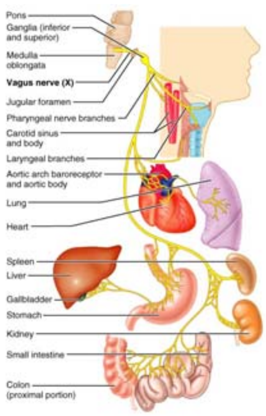


Figure X from Table 13.2

Cranial Nerve XI: Accessory

- Formed from a cranial root emerging from the medulla and a spinal root arising from the superior region of the spinal cord
- The spinal root passes upward into the cranium via the foramen magnum
- The accessory nerve leaves the cranium via the jugular foramen

Cranial Nerve XI: Accessory

- Primarily a motor nerve
  - Supplies fibers to the larynx, pharynx, and soft palate
  - Innervates the trapezius and sternocleidomastoid, which move the head and neck

Cranial Nerve XI: Accessory

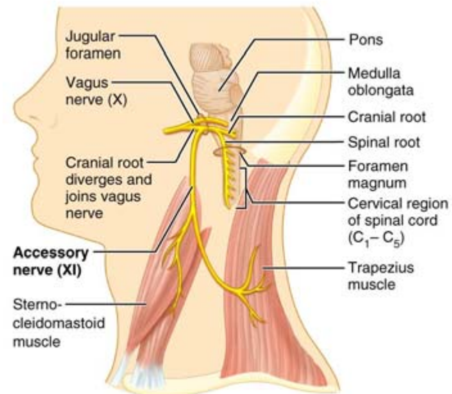


Figure XI from Table 13.2

Cranial Nerve XII: Hypoglossal

- Fibers arise from the medulla and exit the skull via the hypoglossal canal
- Innervates both extrinsic and intrinsic muscles of the tongue, which contribute to swallowing and speech

Cranial Nerve XII: Hypoglossal

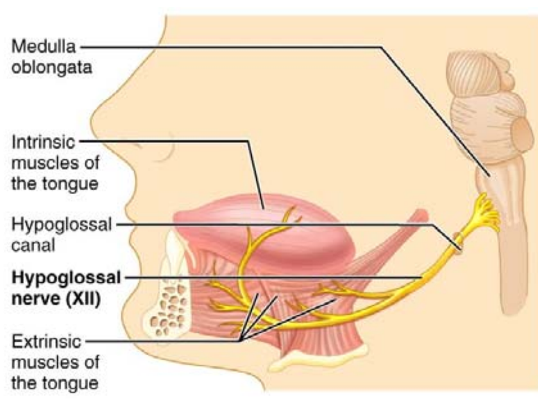


Figure XII from Table 13.2

Spinal Nerves

- Thirty-one pairs of mixed nerves arise from the spinal cord and supply all parts of the body except the head
- They are named according to their point of issue
  - 8 cervical (C_1-C_8)
  - 12 thoracic (T_1-T_{12})
  - 5 Lumbar (L_1-L_5)
  - 5 Sacral (S_1-S_5)
  - 1 Coccygeal (C_0)

Spinal Nerves

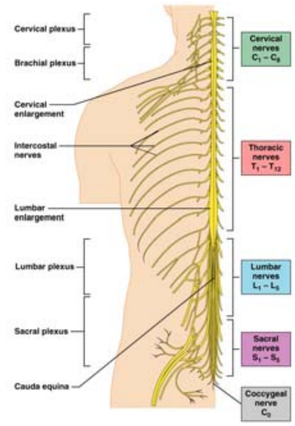


Figure 13.6

Spinal Nerves: Roots

- Each spinal nerve connects to the spinal cord via two medial roots
- Each root forms a series of rootlets that attach to the spinal cord
- Ventral roots arise from the anterior horn and contain motor (efferent) fibers
- Dorsal roots arise from sensory neurons in the dorsal root ganglion and contain sensory (afferent) fibers

Spinal Nerves: Roots

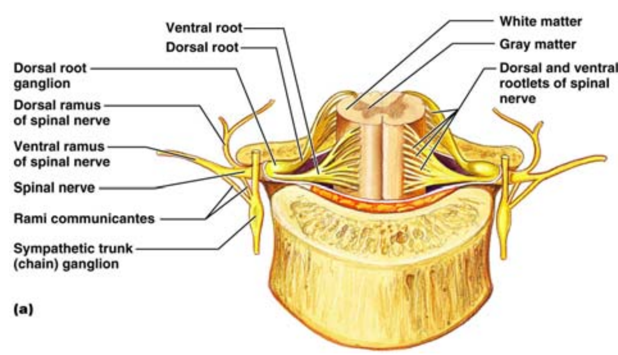


Figure 13.7a

Spinal Nerves: Rami

- The short spinal nerves branch into three or four mixed, distal rami
  - Small dorsal ramus
  - Larger ventral ramus
  - Tiny meningeal branch
  - Rami communicantes at the base of the ventral rami in the thoracic region

Nerve Plexuses

- All ventral rami except T_2-T_{12} form interlacing nerve networks called plexuses
- Plexuses are found in the cervical, brachial, lumbar, and sacral regions
- Each resulting branch of a plexus contains fibers from several spinal nerves

Nerve Plexuses

- Fibers travel to the periphery via several different routes
- Each muscle receives a nerve supply from more than one spinal nerve
- Damage to one spinal segment cannot completely paralyze a muscle

Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall

- The back is innervated by dorsal rami via several branches
- The thorax is innervated by ventral rami T_1-T_{12} as intercostal nerves
- Intercostal nerves supply muscles of the ribs, anterolateral thorax, and abdominal wall

Spinal Nerve Innervation: Back, Anterolateral Thorax, and Abdominal Wall

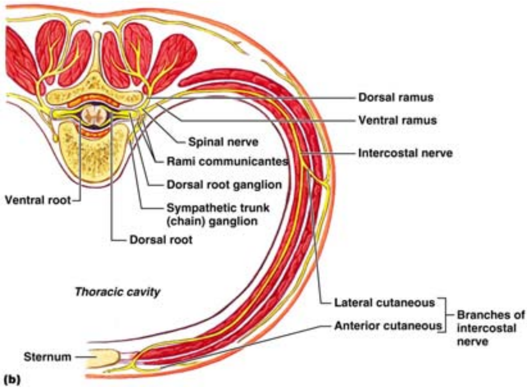


Figure 13.7b

Cervical Plexus

- The cervical plexus is formed by ventral rami of C_1-C_4
- Most branches are cutaneous nerves of the neck, ear, back of head, and shoulders
- The most important nerve of this plexus is the phrenic nerve
- The phrenic nerve is the major motor and sensory nerve of the diaphragm

Cervical Plexus

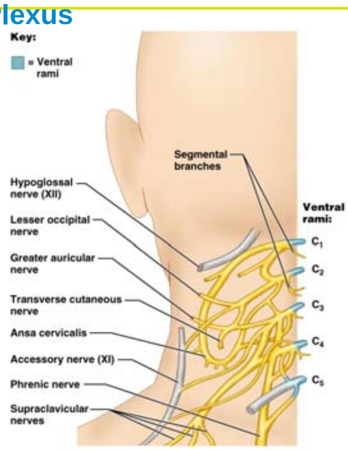


Figure 13.8

Brachial Plexus

- Formed by C_5-C_8 and T_1 (C_4 and T_2 may also contribute to this plexus)
- It gives rise to the nerves that innervate the upper limb

Brachial Plexus

- There are four major branches of this plexus
  - Roots – five ventral rami (C_5-T_1)
  - Trunks – upper, middle, and lower, which form divisions
  - Divisions – anterior and posterior serve the front and back of the limb
  - Cords – lateral, medial, and posterior fiber bundles

Brachial Plexus

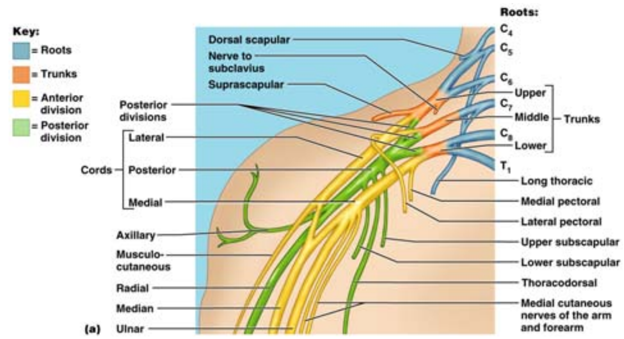


Figure 13.9a

Brachial Plexus: Nerves

- Axillary – innervates the deltoid and teres minor
- Musculocutaneous – sends fibers to the biceps brachii and brachialis
- Median – branches to most of the flexor muscles of arm
- Ulnar – supplies the flexor carpi ulnaris and part of the flexor digitorum profundus
- Radial – innervates essentially all extensor muscles

Brachial Plexus: Distribution of Nerves

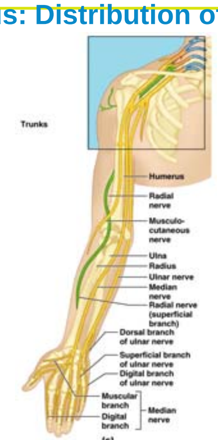


Figure 13.9c

Brachial Plexus: Nerves

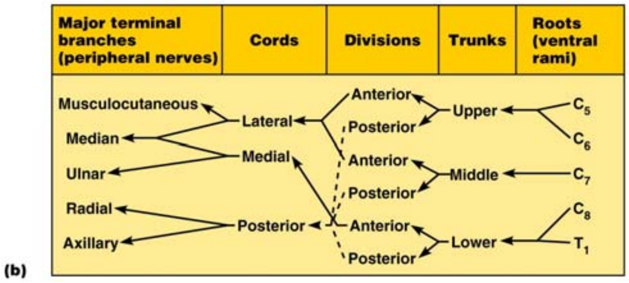


Figure 13.9b

Lumbar Plexus

- Arises from L_1-L_4 and innervates the thigh, abdominal wall, and psoas muscle
- The major nerves are the femoral and the obturator

Lumbar Plexus

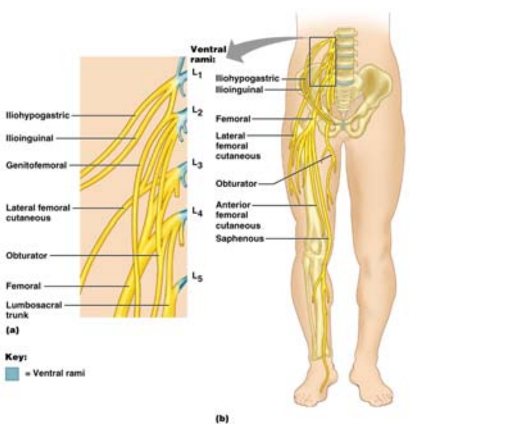


Figure 13.10

Sacral Plexus

- Arises from L_4-S_4 and serves the buttock, lower limb, pelvic structures, and the perineum
- The major nerve is the sciatic, the longest and thickest nerve of the body
- The sciatic is actually composed of two nerves: the tibial and the common fibular (peroneal) nerves

Sacral Plexus

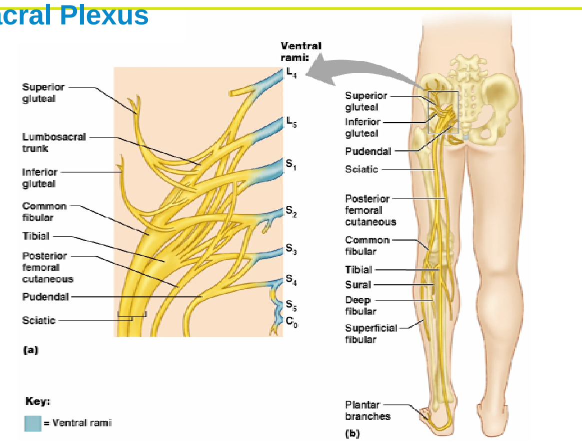


Figure 13.11

Dermatomes

- A dermatome is the area of skin innervated by the cutaneous branches of a single spinal nerve
- All spinal nerves except C_1 participate in dermatomes

Dermatomes

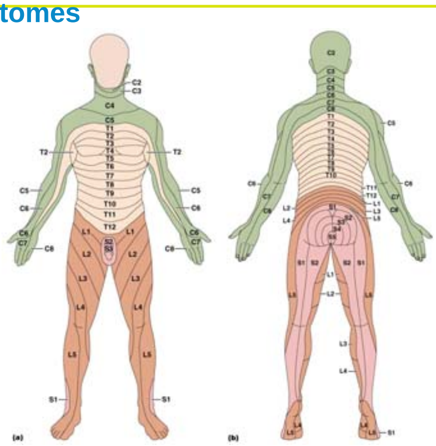


Figure 13.12

Innervation of Joints

- Hilton's law: any nerve serving a muscle that produces movement at a joint also innervates the joint itself and the skin over the joint

Motor Endings

- PNS elements that activate effectors by releasing neurotransmitters at:
  - Neuromuscular junctions
  - Varicosities at smooth muscle and glands

Innervation of Skeletal Muscle

- Takes place at a neuromusclular junction
- Acetylcholine is the neurotransmitter that diffuses across the synaptic cleft
- ACh binds to receptors resulting in:
  - Movement of Na^+ and K^+ across the membrane
  - Depolarization of the interior of the muscle cell
  - An end-plate potential that triggers an action potential

Innervation of Visceral Muscle and Glands

- Autonomic motor endings and visceral effectors are simpler than somatic junctions
- Branches form *synapses en passant* via varicosities
- Acetylcholine and norepinephrine are used as neurotransmitters
- Visceral responses are slower than somatic responses

Levels of Motor Control

- The three levels of motor control are
  - Segmental level
  - Projection level
  - Precommand level

Hierarchy of Motor Control

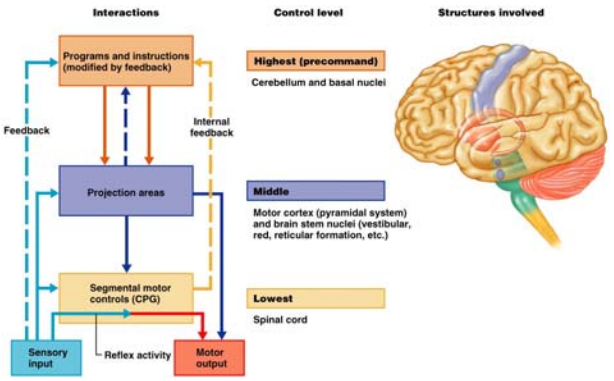


Figure 13.13