CRANIAL NERVES AND BRAIN STEM

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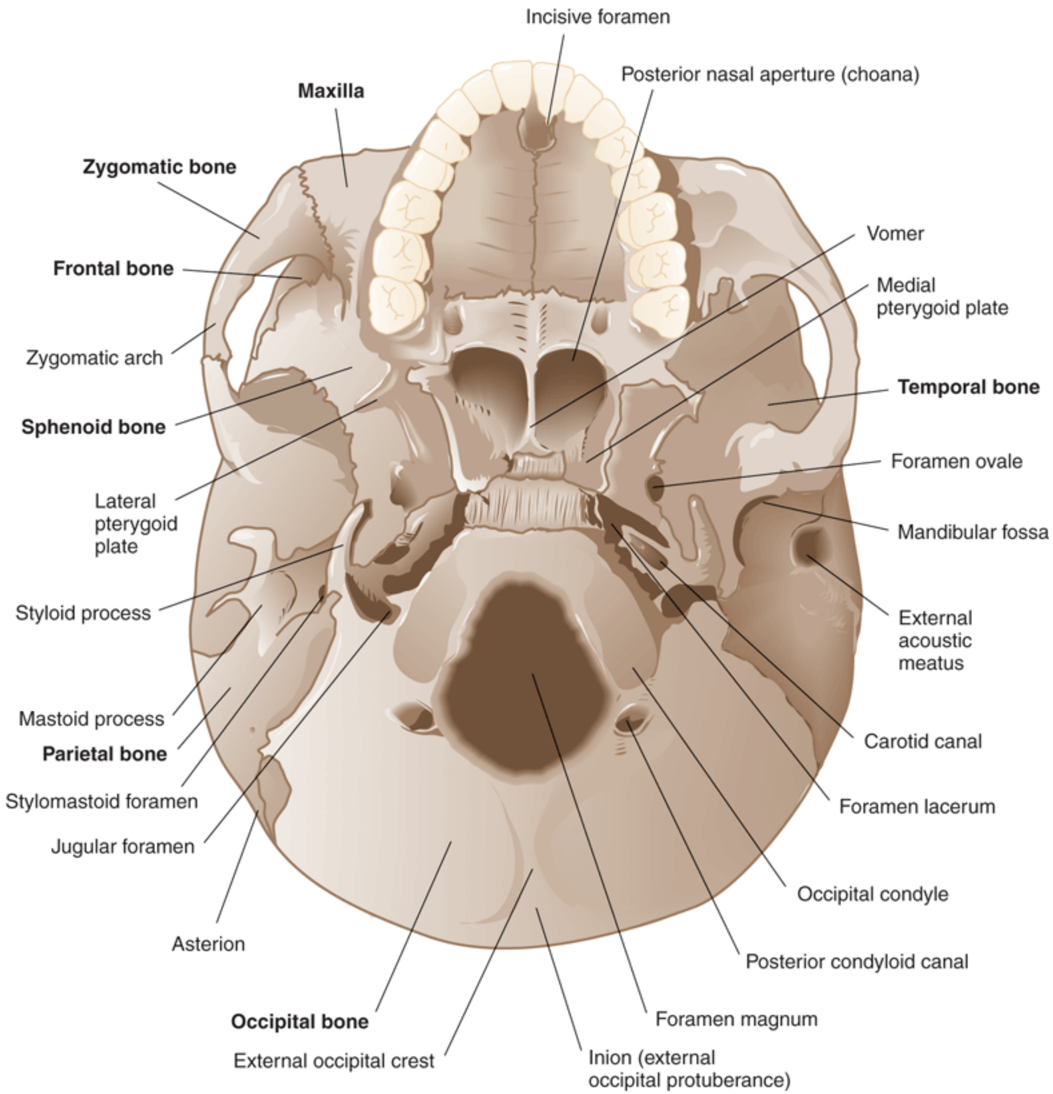
Skull base



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 11-18
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Skull base

Foramina	Structures
Cribriform plate of ethmoid	Olfactory nerves
Optic foramen	Optic nerve, ophthalmic artery, meninges
Superior orbital fissure	Oculomotor, trochlear, and abducens nerves; ophthalmic division of trigeminal nerve; superior ophthalmic vein
Foramen rotundum	Maxillary division of trigeminal nerve, small artery and vein
Foramen ovale	Mandibular division of trigeminal nerve, vein
Foramen lacerum	Internal carotid artery, sympathetic plexus
Foramen spinosum	Middle meningeal artery and vein
Internal acoustic meatus	Facial and vestibulocochlear nerves, internal auditory artery
Jugular foramen	Glossopharyngeal, vagus, and spinal accessory nerves; sigmoid sinus
Hypoglossal canal	Hypoglossal nerve
Foramen magnum	Medulla and meninges, spinal accessory nerve, vertebral arteries, anterior and posterior spinal arteries

Cranial nerves

- CN III (midbrain), IV, VI, and V_1 are gathered together in the cavernous sinus along the lateral margin of the sella turcica and exit the skull through the superior orbital fissure adjacent to the optic foramen through which CN II (diencephalon) passes.
- CN IV leaves midbrain from dorsal surface just behind the inferior colliculus, wraps around the lateral surface of the brain stem.
- CN VI (pons) has longest intracranial course.

Cranial nerves

- CN VII, VIII exit the pons at the cerebellopontine angle and enter the internal auditory canal.
- CN V emerges from the middle cerebellar peduncle (pons), near the cerebellopontine angle. V2 exits the round foramen of the sphenoid bone; V3, with the motor branch of CN V, exits the skull through the oval foramen of the sphenoid bone.
- CN IX, X, XI (medulla) exit through the jugular foramen.
- CN XII exits through the hypoglossal foramen.

Cranial nerves

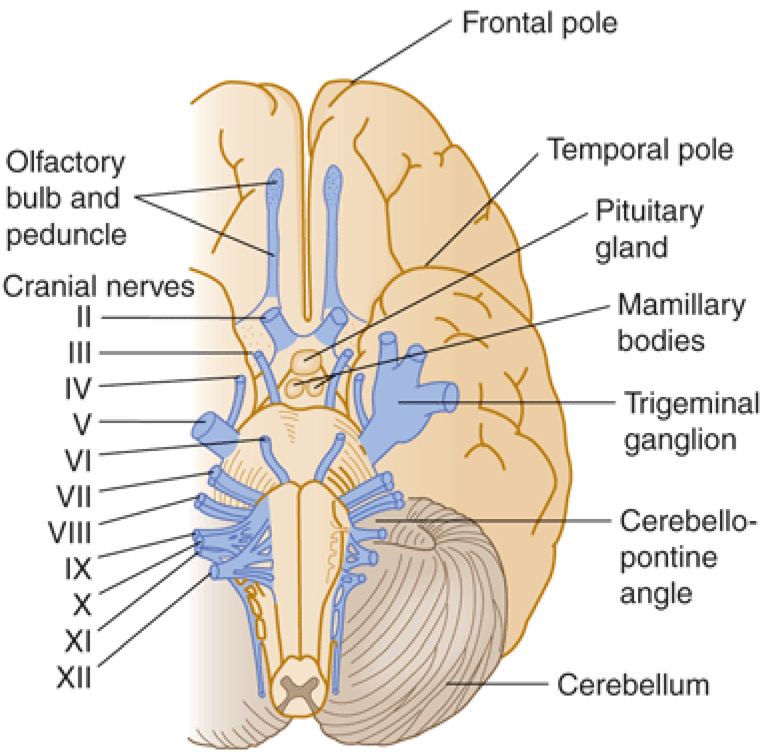

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Fig. 8-1 Accessed 02/01/2010

Cranial nerves

Functions	Cranial nerve	Type	Location	Major connections
Sense of smell	I	Special sensory	Within olfactory mucosa	Projects to olfactory bulb
Visual Input from eye	II	Special sensory	Within ganglion cells in retina	Projects to lateral geniculate; superior colliculus
Auditory and vestibular input from inner ear	VIII	Special sensory	Within cochlear ganglion Within vestibular ganglion	Projects to cochlear nucleus, then inferior colliculus, then medial geniculate Projects to vestibular nucleus

Functions	Cranial nerve	Type	Location	Major connections
Motor for ocular system	III	Sensory efferent	Innervates medial rectus, superior rectus, inferior rectus, inferior oblique muscles	Within oculomotor nucleus; Receives input from lateral gaze center (paramedial pontine recticular formation) via median longitudinal fasciculus
Pupil constriction		Visceral efferent	Edinger-Westphal nucleus (parasympathetic)	Projects to ciliary ganglion, then to pupil
	IV	Sensory efferent	Innervates superior oblique muscle	Within trochlear nucleus
	VI	Sensory efferent	Innervates lateral rectus muscle	Within abducens nucleus; Receives input from lateral gaze center (paramedial pontine recticular formation) via median longitudinal fasciculus

Functions	Cranial nerve	Type	Location	Major connections
Motor	XI	Branchial efferent	Innervates sternocleiodmastoid, trapezius muscles	Within ventral horns at C2-5
	XII	Sensory efferent	Innervates muscles of tongue and hyoid bone	Within hypoglossal nucleus
Sensation from face, cornea, teeth, gum, palate, anterior 2/3 of tongue	V Mixed	Sensory afferent	Within semilunar (gasserian, trigeminal) ganglion	Projects to sensory nuclei and spinal tract of V, then to thalamus (Ventral posterior medial)
		Branchial efferent	Innervates masticatory muscles	Within motor nucleus of V

Functions	Cranial nerve	Type	Location	Major connections
Facial expression	VII Mixed	Branchial efferent	Innervates muscles of facial expression, platysma, stapedius	Within facial nucleus
Taste		Visceral afferent	Anterior 2/3 of tongue (via chorda tympani)	Within geniculate ganglion; Projects to solitary tract and nucleus, then to thalamus (Ventral posterior medial)
		Visceral efferent	Submandibular, sublingual, lacrimal glands via nervus intermedius (parasympathetic)	Within superior salivatory nucleus

Functions	Cranial nerve	Type	Location	Major connections
	IX Mixed	Visceral efferent Visceral afferent	Parotid gland (parasympathetic) General sensation from posterior 1/3 of tongue, soft palate, auditory tube. Sensory input from carotid bodies and sinus. Taste from posterior 1/3 of tongue	Within inferior salivatory nucleus Within inferior (petrosal) and superior glossopharyngeal ganglia; Projects to solitary tract and nucleus
		Branchial efferent	Innervates stylopharyngeus muscle	Within nucleus ambiguus

Functions	Cranial nerve	Type	Location	Major connections
	X Mixed	Branchial efferent	Innervates soft palate and pharynx	Within nucleus ambiguus
Autonomic control of thoracic and abdominal viscera		Visceral efferent	Viscera (parasympathetic)	Within dorsal motor nucleus
		Sensory afferent	External auditory meatus	Within superior (jugular) ganglion; projects to thalamus (ventral posterior medial)
Sensation from abdominal and thoracic viscera		Visceral afferent	Viscera	Within inferior vagal (nodose) and superior ganglia; projects to solitary tract and nucleus

Cranial nerves and their ganglia

Ganglion	Cranial nerve	Functional type (synapse)
Ciliary	III	Visceral efferent (parasympathetic)
Pterygopalatine	VII	Visceral efferent (parasympathetic)
Submandibular	VII	Visceral efferent (parasympathetic)
Otic	IX	Visceral efferent (parasympathetic)
Intramural (in viscus)	X	Visceral efferent (parasympathetic)
Semilunar	V	Sensory afferent
Geniculate	VII	Visceral afferent (taste)
Inferior and superior	IX	Sensory afferent, Visceral afferent (taste)
Inferior and superior	X	Sensory afferent, Visceral afferent (taste)
Spiral	VIII (cochlear)	Special Sensory

Brain stem organization

- General somatic afferent column occupies most lateral portion of the alar plate.
- Spinal trigeminal nucleus is a continuation of the superficial laminae of the spinal dorsal horn into the medulla. The tract is a direct continuation of Lissauer's tract of the spinal cord; also receives sensory axons from all the cranial nerves concerned with sensation in the head; permits sensory information to be integrated to form a map of the body surface.

Brain stem organization

- Principal sensory trigeminal nucleus is at midpons and just lateral to the motor nucleus; receives same type of sensory information from the face as that carried by the dorsal columns from the body. Join dorsal column axons in medial lemniscus and ascend to ventroposterior medial thalamus.
- Mesencephalic trigeminal nucleus is in the midbrain lateral to the periacqueductal gray matter. Trigeminal ganglion cells here provide feedback to motor neurons in the trigeminal motor nucleus, control jaw movement.

Brain stem organization

- The special somatic afferent column develops from the intermediate portion of the alar plate. The cochlear nuclei are at the lateral margin of the pontomedullary junction
- The visceral afferent column derives from the most medial portion of the alar plate. Fibers terminate in the solitary nucleus; single visceral sensory map of the body. Projects directly to parasympathetic and sympathetic preganglionic neurons in the medulla and spinal cord as well as to that part of the reticulum system that coordinate autonomic responses.

Brain stem organization

- Most ascending visceral outputs to the forebrain are relayed via the parabrachial nucleus in the pons, although some proceed directly from the solitary nuclues.
- The general somatic motor column consists of nuclei that develop at the base of the central canal and remain near the midline at the floor of the ventricular system. CN III and IV are ventral to the cerebral acqueduct; CN VI lies beneath the floor of the 4^{th} ventricle at midpons; CN XII is near the midline beneath the floor of the 4^{th} ventricle and central canal in the medulla.

Brain stem organization

- The special visceral motor column includes motor nuclei that innervate muscles derived from the branchial arches. Originate dorsal to the somatic motor nuclei and migrate ventrolateterally into the tegmentum.
- CN V lies ventrolaterally at midpons.
- CN VII lies caudal to the trigeminal motor nucleus at caudal pons.
- CN IX, X lie in the longitudinal cluster, nucleus ambiguus, that runs the length of the ventral medulla. The nucleus ambiguus also contains preganglionic parasympathetic neurons that innervate the thoracic organs. Topographic.

Brain stem organization

- The general visceral motor column begins as the most dorsal part of the basal plate just below the sulcus limitans. The neurons of the Edinger-Westphal nuclues and the dorsal motor vagal and inferior salivatory nuclei remain in this position; preganglionic parasympathetic neurons in the nucleus ambiguus and superior salivatory nucleus follow those of the branchial motor nuclei and migrate into the tegmentum.
- The Edinger-Westphal nuclues is in the midbrain along the dorsomedial margin of the oculomotor complex just below the floor of the cerebral acqueduct.

Brain stem organization

- The superior salivatory nucleus lies at the level of the pons near CN VII. These axons exit with CN VII.
- Preganglionic neurons associated with the gastrointestinal tract form a column at the level of the medulla just dorsal to the hypoglossal nucleus and ventral to the nucleus of the solitary tract. At the rostral end is the inferior salivatory nucleus whose preganglionic neurons run through CN IX to innervate the parotid. The rest of the column is the dorsal motor vagal nucleus whose preganglionic neurons largely innervate the gastrointestinal tract.

Central autonomic network

- Nucleus of the solitary tract receives visceral input from CN VII, IX, X. Relayed to forebrain via parabrachial nucleus (surrounds superior cerebellar peduncle in upper pons and provides input to hypothalamus, periacqueductal gray matter, amygdala, ventroposterior parvocellular nucleus of the thalamus, anterior insula and inralimbic area of the anterior cingulate cortex).
- The periacqueductal gray receives inputs from hypothalamus, nucleus of the solitary tract, and parabrachial nucleus; projects to medullary reticular formation.

Central autonomic network

- Hypothalamus integrates autonomic and endocrine functions with behavior. Compares sensory information with set points. Medial forebrain bundle.
- Periventricular fiber system links hypothalamus to periacqueductal gray (sterotyped behavioral patterns). Axons from parvocelluar neurons (releasing hormones) as well as paraventricular and arcuate nuclei conveyed to median eminence for control of anterior pituitary; axons from the magnocellular neurons (oxytocin, vasopressin) which continue down the pituitary stalk also meet in the median eminence.

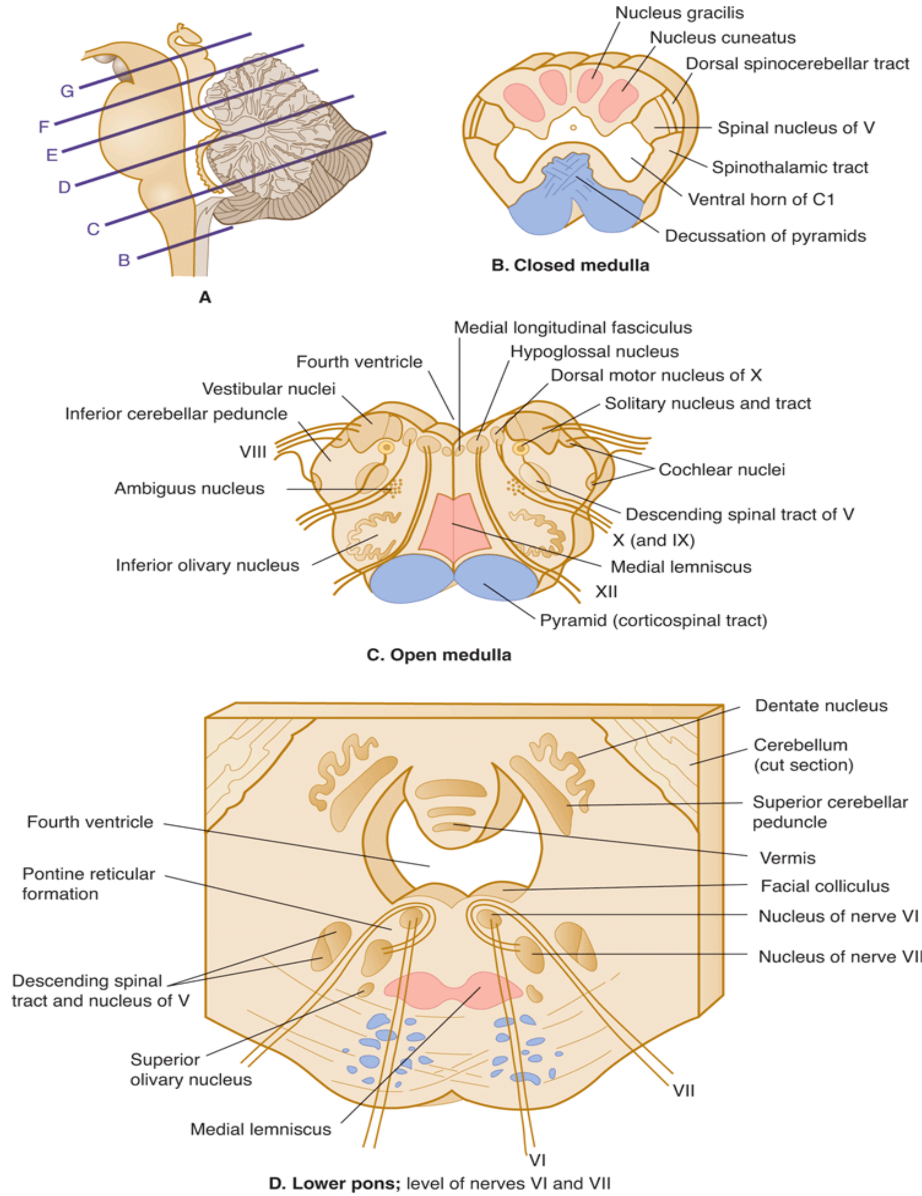
Reticular formation

- Groups of interneurons close to the motor nuclei of the cranial nerves coordinate reflexes and simple stereotyped behaviors mediated by the cranial nerves. Parvocellular neurons in the lateral reticular formation.
- Ventromedial medullary: swallowing, vomiting, respiratory rhythm, coughing, hiccupping, sneezing, barocepter reflexes, hypoxic responses.
- Lateral medulary and pontine reticular formation: extends from region lateral to the hypoglossal and ambiguus nuclei coordinate oro-facial responses.

Reticular formation

- Paramedian reticular formation of the pons adjacent to CN VI and in the midbrain adjacent to the oculomotor nucleus coordinates horizontal eye movements; neurons lateral to the oculomotor nucleus coordinate vertical eye movments as well as convergence.
- Medial reticular formation interneurons (magnocelllular neurons) have long ascending and descending axons that modulate actions of neurons involved in movement, posture, pain, arousal, autonomic functions. Defined by their neurotransmitters.

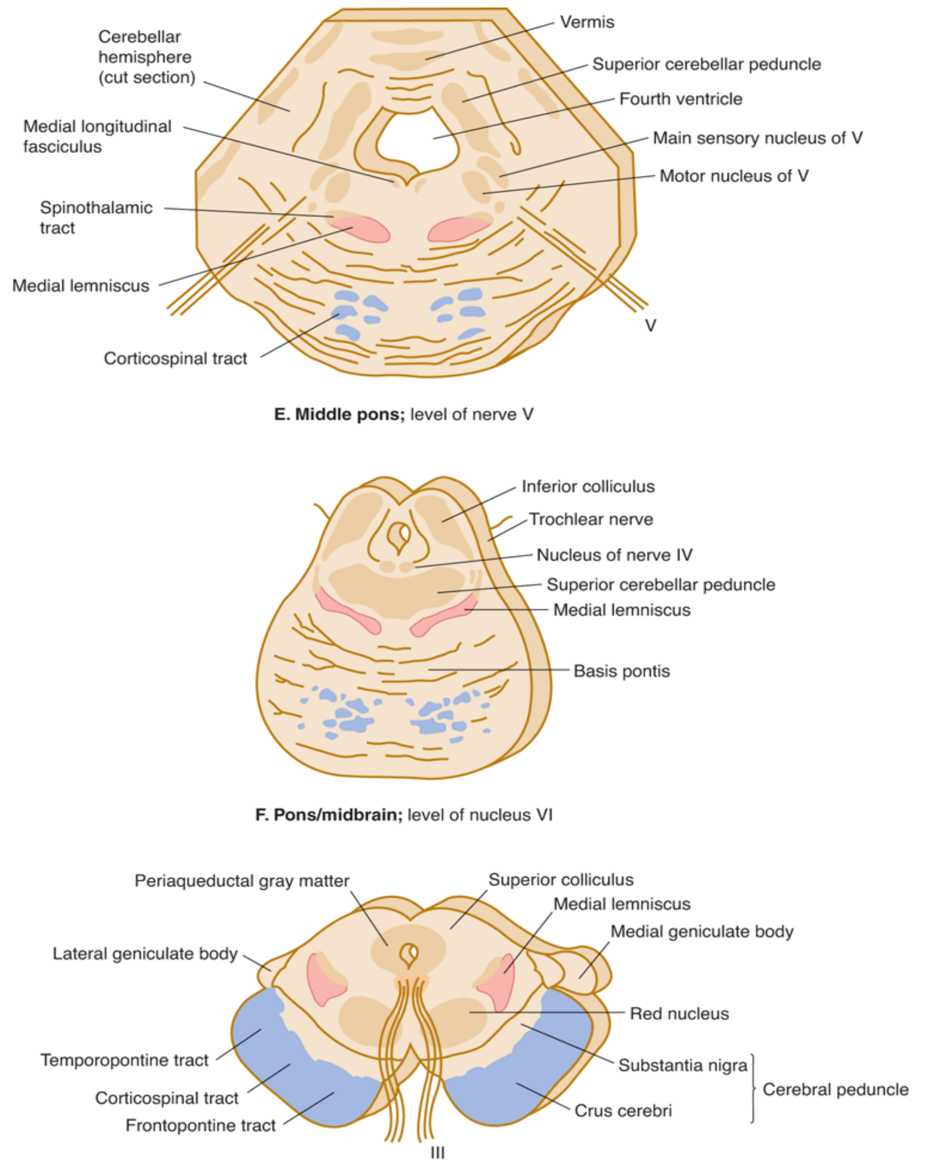
Slices through the brain stem relating nuclei to cranial nerves and major tracts



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 7-7 Accessed 02/01/2010

Slices through the brain stem relating nuclei to cranial nerves and major tracts



E. Middle pons; level of nerve V

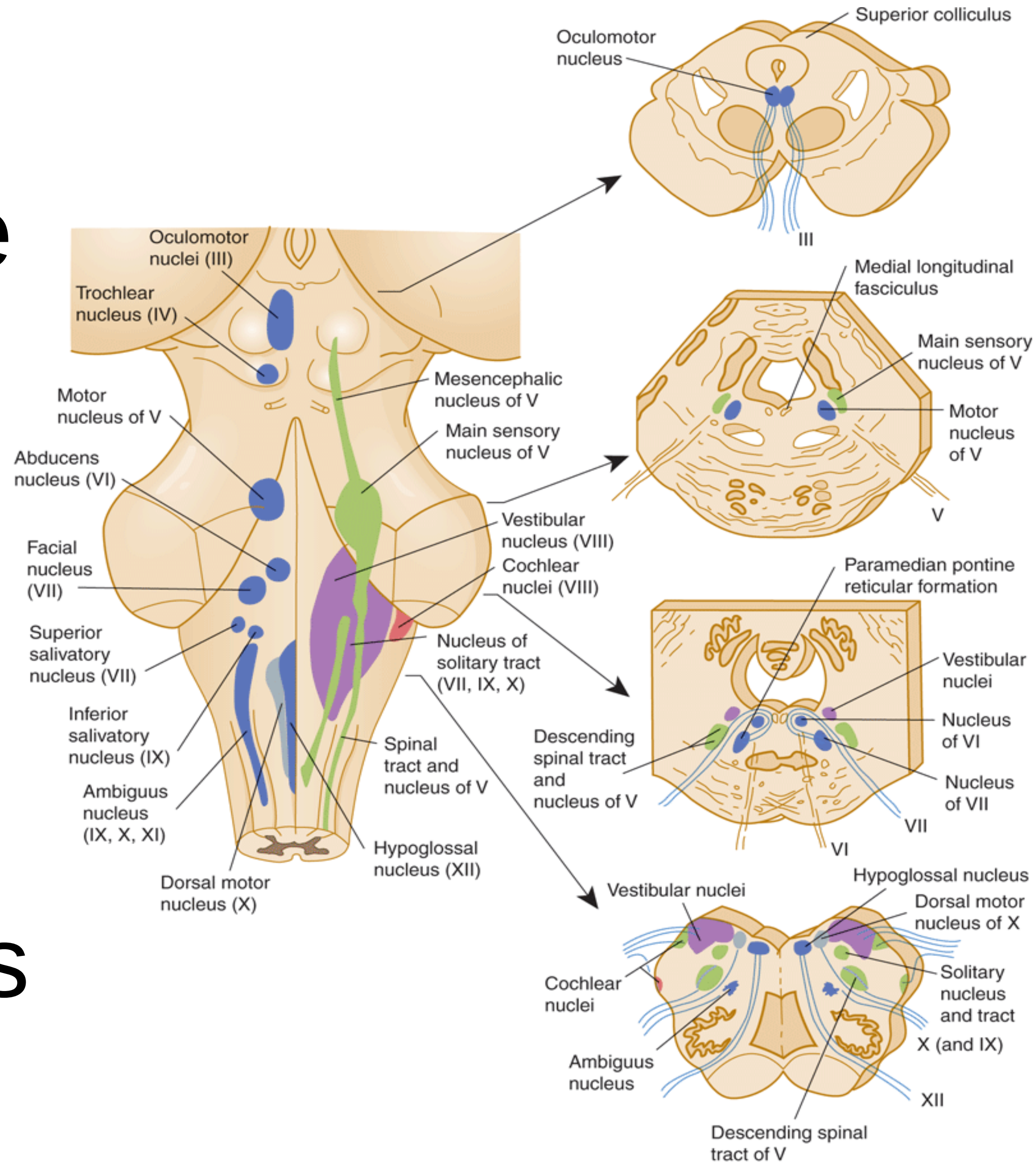
F. Pons/midbrain; level of nucleus VI

G. Upper midbrain; level of nerve III

Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 7-7 Accessed 02/01/2010

Slices through the brain stem relating nuclei to cranial nerves and major tracts



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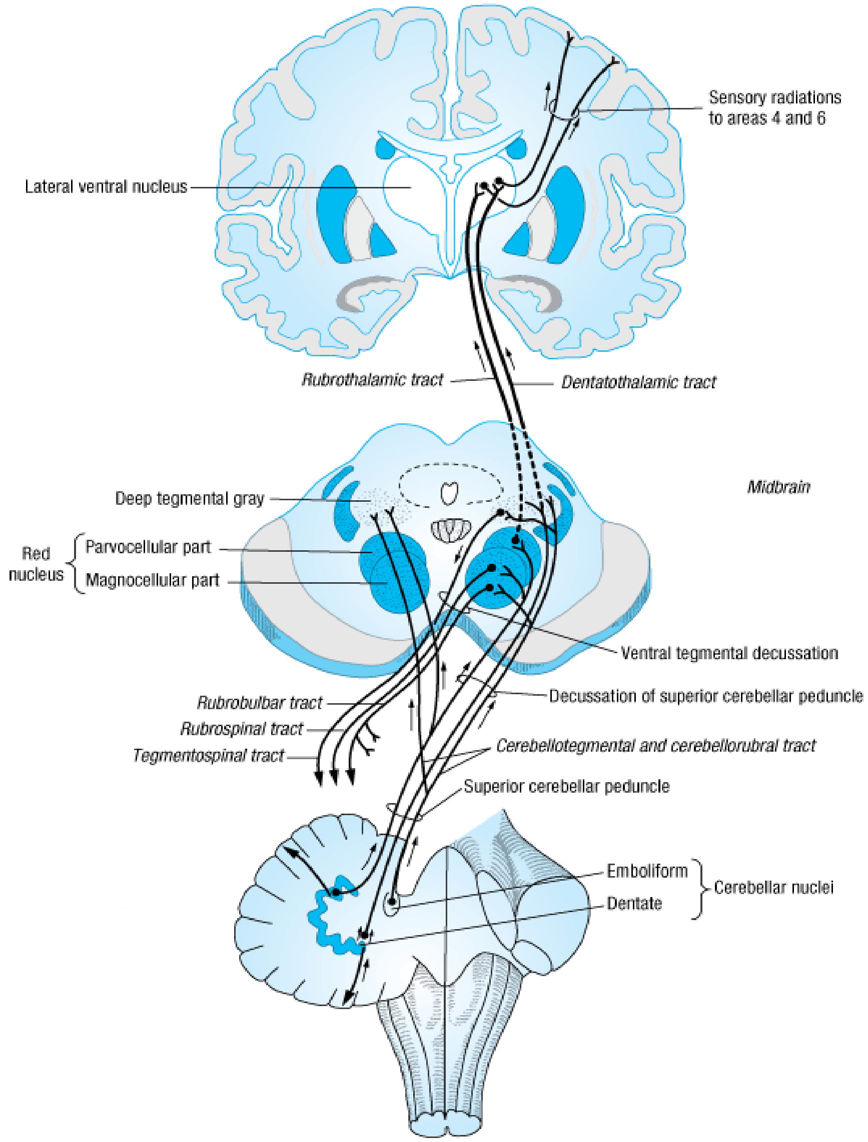
Cerebellar projections



Source: Ropper AH, Samuels MA: *Adams & Victor's Principles of Neurology 9th Edition*: http://www.accessmedicine.com

(Adapted by permission from House EL et al: *A Systematic Approach to Neuroscience*, 3rd ed. New York, McGraw-Hill, 1979.)

Fig. 5-2 Accessed 02/01/2010

Ascending tracts

System	Function	Origin	Ending	Location in Cord
Dorsal column system	Fine touch, proprioception, two-point discrimination	Skin, joints, tendons	Dorsal column nuclei. Second-order neurons project to contralateral thalamus (cross in medulla at lemniscal decussation)	Dorsal column
Spinothalamic tracts	Sharp pain, temperature, crude touch	Skin	Dorsal horn. Second-order neurons project to contralateral thalamus (cross in spinal cord close to level of entry)	Ventro-lateral column

Ascending tracts

System	Function	Origin	Ending	Location in Cord
Dorsal spinocerebellar tract	Movement and position mechanisms	Muscle spindles, Golgi tendon organs, touch and pressure receptors via nucleus dorsalis (Clarke's column)	Cerebellar paleocortex (via ipsilateral inferior cerebellar peduncle)	Lateral column
Ventral spinocerebellar	Movement and position mechanisms	Muscle spindles, Golgi tendon organs, touch and pressure receptors	Cerebellar paleocortex (via contralateral and ipsilateral superior cerebellar peduncle)	Lateral column

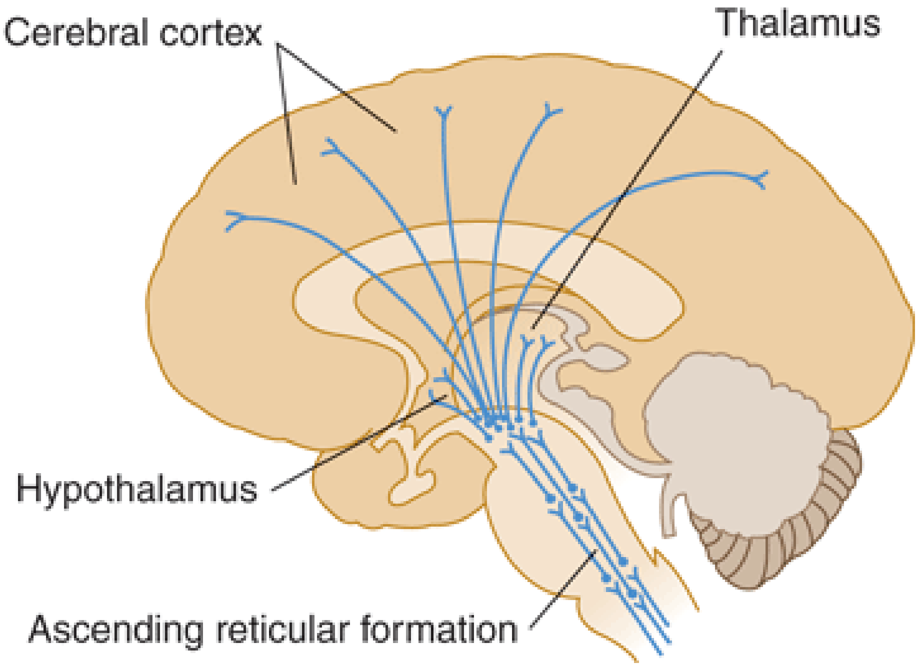
Descending tracts

System	Function	Origin	Ending	Location in Cord
Lateral corticospinal (pyramidal) tract	Fine motor function (controls distal musculature) Modulation of sensory functions	Motor and premotor cortex	Anterior horn cells (interneurons and lower motor neurons)	Lateral column (crosses in medulla at pyramidal decussation)
Anterior corticospinal tract	Gross and postural motor function (proximal and axial musculature)	Motor and premotor cortex	Anterior horn neurons (interneurons and lower motor neurons)	Anterior column (uncrossed until after descending, when some fibers decussate)
Rubrospinal	Motor function	Red nucleus	Ventral horn interneurons	Lateral column

Descending tracts

System	Function	Origin	Ending	Location in Cord
Reticulospinal	Modulation of sensory transmission (especially pain) Modulation of spinal reflexes	Brain stem reticular formation	Dorsal and ventral horn	Anterior column
Descending autonomic	Modulation of autonomic functions	Hypothalamus, brain stem nuclei	Preganglionic autonomic neurons	Lateral columns
Tectospinal	Reflex head turning	Midbrain	Ventral horn inter-neurons	Ventral column
Medial longitudinal fasciculus	Co-ordination of head and eye movements	Vestibular nuclei	Cervical gray	Ventral column

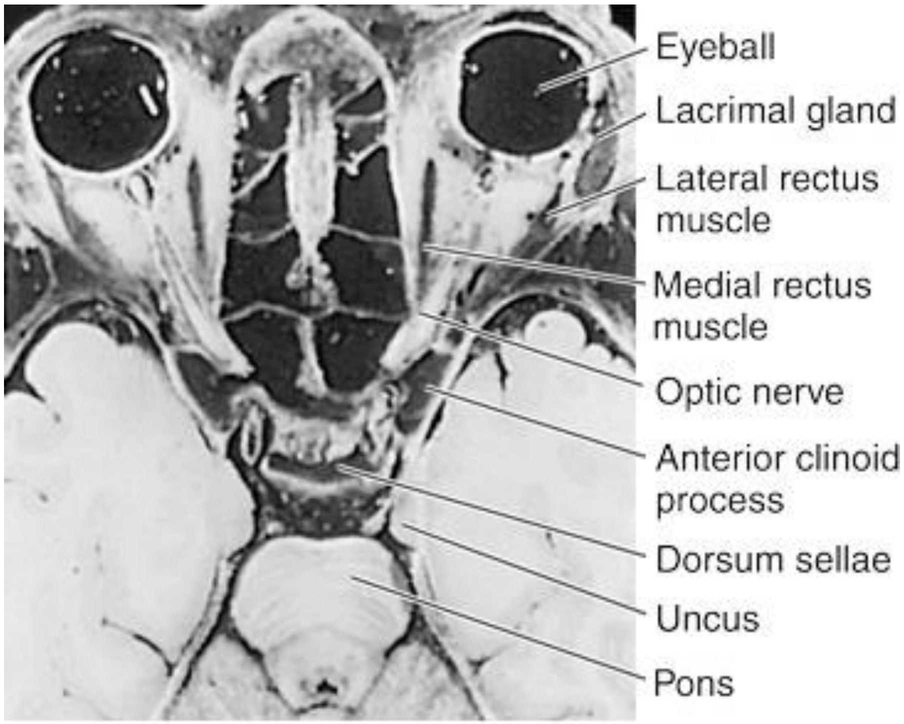
Reticular formation



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

The spino-reticular tract ascends in the ventro-lateral column of the spinal cord. It has its origin in deep somatic structures. The pathway is polysynaptic. Deep and chronic pain is modulated through this path. Diffuse.

Fig. 18-1 Accessed 07/01/2010

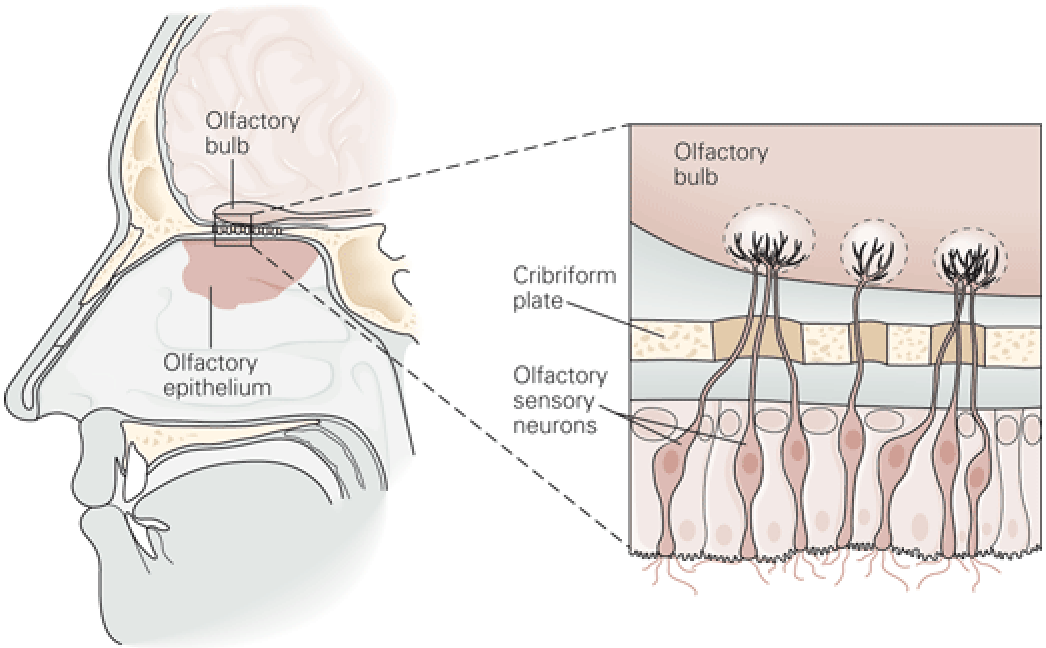


Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Horizontal section through the head at the level of the orbits.

Fig. 8-3 Accessed 02/01/2010

Olfactory apparatus



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

Olfactory sensory neurons embedded within the olfactory epithelium in the dorsal posterior recess of the nasal cavity. These neurons project axons to the olfactory bulb of the brain, a small ovoid structure that rests on the cribriform plate of the ethmoid bone.

(From Kandel ER, Schwartz JH, Jessell TM [editors]: *Principles of Neural Science,* 4th ed. McGraw-Hill, 2000.)

Fig. 14-1
Accessed 03/01/2010

Olfactory bulb

- Olfactory receptors are G-coupled proteins. Respond to single odor. Neurons bipolar; on surface epithelium.
- The olfactory receptor cells synapse in the glomerulus onto mitral and tufted cells.
- The synapses are excitatory; use glutamate and carnosine. However, periglomerular and granule cells use GABA (inhibitory).
- Only changes in concentration of odorant molecules are detected.

Olfactory system

- Axons of the primary afferents enter the cerebral cortex directly. No secondary afferents. Undergo continuous turnover, being replaced by basal stem cells.
- Olfactory tract divides into medial and lateral striae.
- Medial striae both cross the midline in the anterior commissure (contralateral inhibition).
- Centrifugal fibers bring information from the locus ceruleus and raphe and from the contralateral olfactory bulb via the anterior commissure.

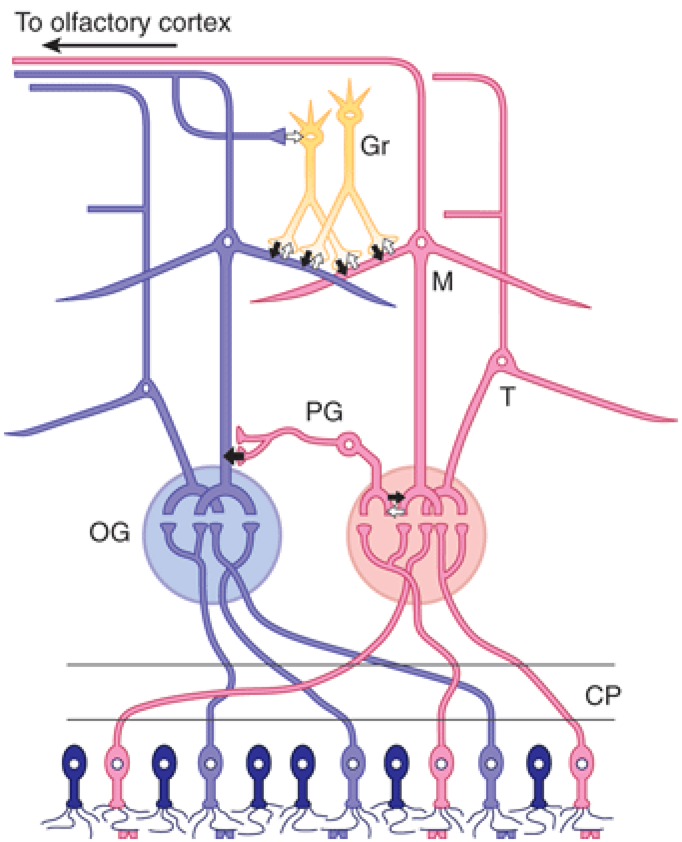
Olfactory system

- Lateral striae terminate in the piriform lobe of the anterior temporal cortex (amygdala, uncus, anterior end of parahippocampal gyrus).
- Highest center for olfactory discrimination is the posterior part of the orbitofrontal cortex. Recieves connections from the piriform lobe via the mediodorsal nucleus of the thalamus.
- The medial forebrain bundle links the olfactory cortical areas with the hypothalamus and brainstem; trigger autonomic responses. Ascend ipsilaterally to septal area via diagonal band.

Smell

- Odorant molecules bind receptor. G-protein is activated. Adenylate cyclase activated; cAMP as second messenger.
- Ca^{2+} channels opened.
- Ca^{2+} influx opens outward Cl^{-} channels.
- Cell depolarizes.

Neural circuit



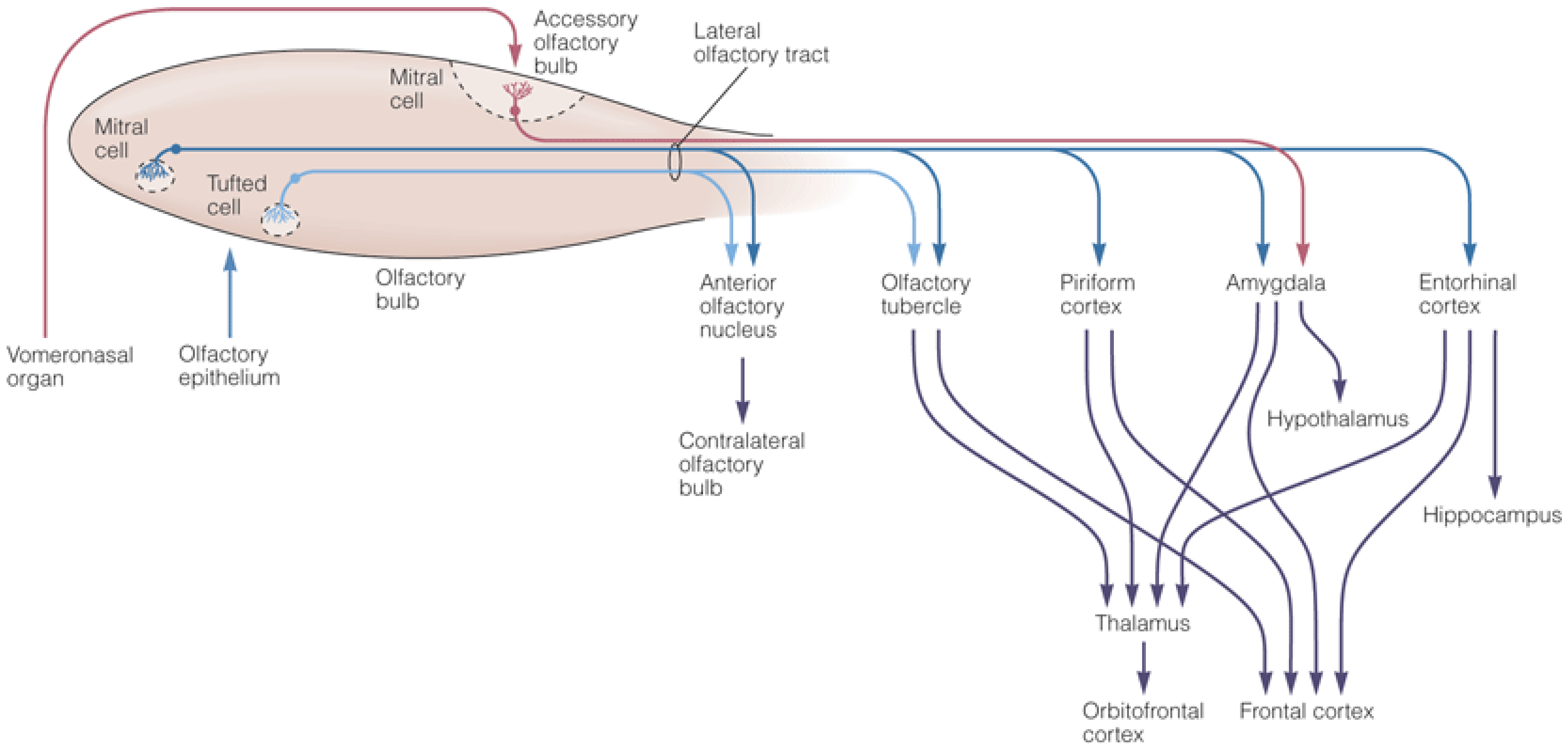
Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology*, 23rd *Edition*: http://www.accessmedicine.com

Note that olfactory receptor cells with one type of odorant receptor project to one olfactory glomerulus (OG) and olfactory receptor cells with another type of receptor project to a different olfactory glomerulus. CP, cribriform plate; PG, periglomerular cell; M, mitral cell; T, tufted cell; Gr, granule cell.

(Modified from Mori K, Nagao H, Yoshihara Y: The olfactory bulb: Coding and processing of odor molecular information. Science 1999;286:711.)

Fig. 14-3
Accessed 03/01/2010

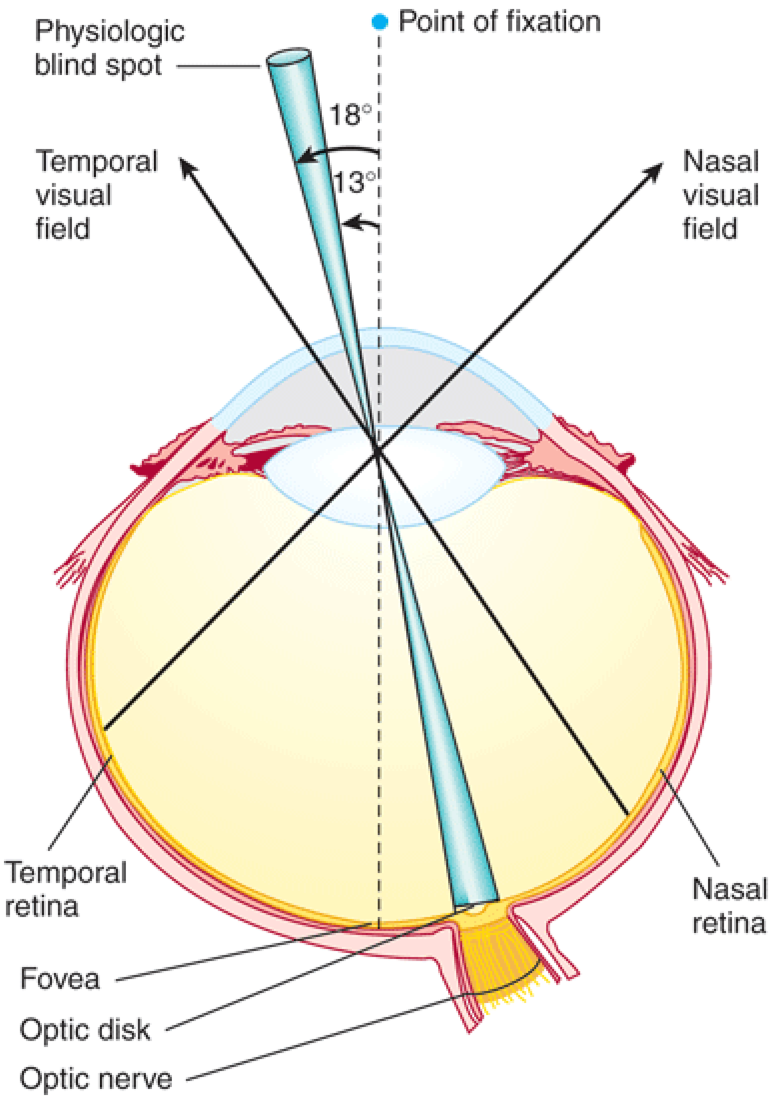
Olfactory circuit



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

(From Kandel ER, Schwartz JH, Jessell TM [editors]: *Principles of Neural Science,* 4th ed. McGraw-Hill, 2000.) Fig. 14-4 Accessed 03/01/2010

Field of vision



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

(Reproduced, with permission, from Simon RP, Aminoff MJ, Greenberg DA: *Clinical Neurology*, 4th ed. Appleton & Lange, 1999.)

Fig. 15-1 Accessed 02/01/2010

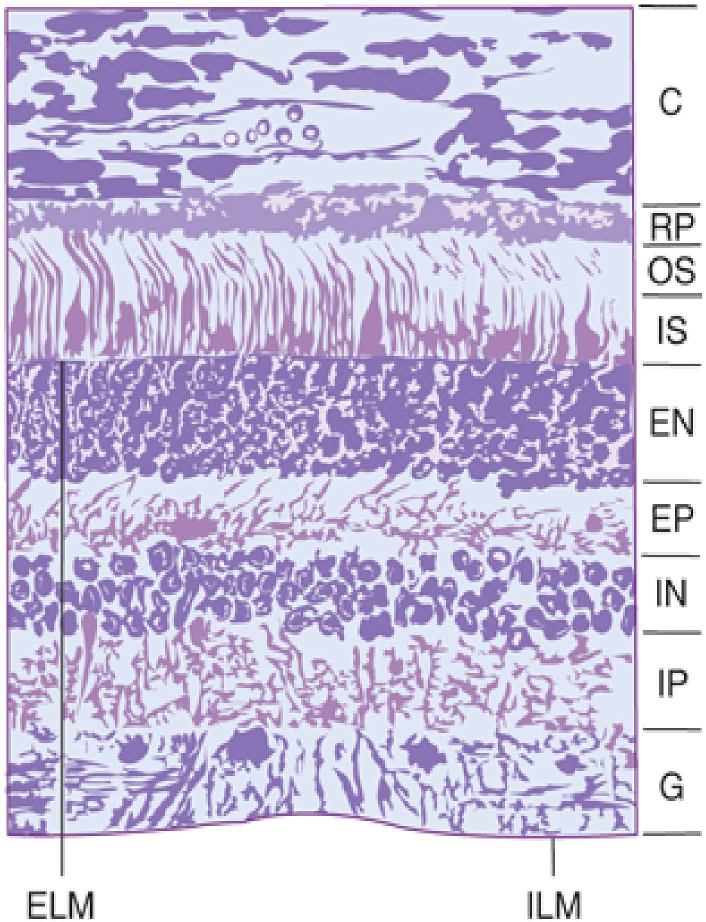
Retinal processing

- Light rays excite photoreceptors.
- Photoreceptors excite bipolar cells and horizontal cells. Horizontal cells provide lateral communication.
- Bipolar cells excite ganglion cells and amacrine cells.
- Only ganglion cells (tonically active) generate action potentials. All others generate receptor potentials.

Retina

- Pigmented epithelium is a single layer of polygonal cells. Absorbs light and prevents reflection that would distort vision.
- Store and release vitamin A (rhodopsin precursor, under control of thyroid hormone).
- Phagocytize membrane remnants from the photoreceptor lamellae. Failure to do so is thought to be the cause of retinitis pigmentosa.
- Rods embedded in pigmented epithelium. Contain rhodopsin. Cylindrical outer segment contains membrane bound discs (lamellae). Outer segment connected to mitochondrion rich inner segment by a thin neck.

Retina and choroid



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Light enters from the bottom and traverses the following layers: internal limiting membrane (ILM), ganglion cell layer (G), internal plexiform layer (IP), internal nuclear layer (IN) (bipolar neurons), external plexiform layer (EP), external nuclear layer (EN) (nuclei of rods and cones), external limiting membrane (ELM), inner segments of rods (IS) (narrow lines) and cones (triangular dark structures), outer segments of rods and cones (OS), retinal pigment epithelium (RP), and choroid (C). x655.

Fig. 15-2 Accessed 02/01/2010

Retina

- Inverted. Light must pass through optic nerve fibers, ganglion cells, and bipolar neurons to reach photoreceptors. Pigmented epithelium blocks light reflection.
- At the fovea, light strikes the photoreceptors directly. (Cones are bunched and principally located in the fovea; outer segment is tapered. Lamellae are infoldings of plasma membrane. Rods, periphery. One cone, one bipolar cell; many rods, one bipolar cell.)
- Rods function in dim light and not to color. Cones respond to bright light, color, shape.

Retinal processing

- Darkness causes Na^+ channels to open.
- Light activates rhodopsin (associated with G-Protein in the disk membrane). 11-cis-retinal isomerizes to all trans-retinal. Opsin is released. Phosphodiesterase activated.
- Phosphodiesterase breaks down cGMP.
- Without cGMP, the cell polarizes; Na^+-Ca^{2+} ion channel closes. Glutamine not released from cell.
- In the dark, trans-retinal is converted to 11-cis-retinal through retinal isomerase. Requires ATP.
- cGMP produced, opens ion channels. Rod cell depolarizes and releases glutamine.

Retina

- Ganglion cells are either ON or OFF.
- ON and OFF midget and parasol ganglion cells sample complete population of cones sensitive to red and green light.
- Midget ganglion cells do not sample in a random fashion.
- OFF midget ganglion cells are sensitive to blue light input.
- Photoreceptors are clustered. Bulk of retinal receptors respond to dark. Sight is not presented in pixel form but as light and dark contrast.

Retina

- Circadian and arousal neurons (OFF midget ganglion cells) react to blue light, regulate slow biochemical processes; may also induce rapid phototransduction.
- Cryptochromes enable animals and humans to synchronize their circadian clocks by absorbing blue light and transferring the light signal through the optic nerve to a different part of the brain from the center for vision.
- They are linked to Vitamin B2 and are found in a different part of the retina than is rhodopsin.

Sleep cycle

- One of the domains of the CLOCK protein is also shared with PER protein. PER and TIM gene products shuttle between cytoplasm and nucleus, regulating target gene expression.
- PER and TIM are transcribed in the morning; their mRNAs accumulate. TIM protein degraded by light. PER cannot accumulate until sufficient TIM is present to bind PER. With dusk, TIM degradation decreases and TIM-PER complexes form, become functional, and enter the nucleus to repress gene transcription.

Retina

- The characteristic response of ganglion cells (green, red, blue) is one of color opponency.
- Axons leave the retinal ganglion cells leave the retina via the optic papilla and are myelinated proximal to the lamina cribosa.
- Axons from the nasal half of the retina cross in the optic chiasm. Those from the temporal half are uncrossed.
- Some optic fibers enter the supra-chiasmatic nucleus of the hypothalamus and connect with the pineal gland.

Retina

- The right visual field projects to the left half of the brain; the left visual field, to the right half.
- During passage through the lens, the image is reversed.
- Vision is a crossed sensation.
- Upper visual field projects to the lower retina.
- Retinal representation is posterior-anterior.

Retina

- The axons synapse in the lateral geniculate nucleus.
- The lateral geniculate body is binocular. There is no feedback to retinal ganglion cells.
- Axons then project to Area 17 (the primary visual cortex, V1) which occupies the wall of the calcarine sulcus. Heavily myelinated. Retinotopic.

Receptive fields

- Ganglion cells, lateral geniculate cells, and cells in layer IV of cortical area 17 have circular fields with an excitatory center and an inhibitory surround or an inhibitory center and an excitatory surround. There is no preferred orientation of a linear stimulus.
- Simple cells respond best to a linear stimulus with a particular orientation in a specific part of the cell's receptive field.
- Complex cells respond to linear stimuli with a particular orientation. They are less selective in terms of location in the receptive field. They often respond maximally when the stimulus is moved laterally.

Loop of Meyer

- The neurons of the lateral part of the lateral geniculate body which receive input from the lower retina, project via the loop of Meyer to the lower lip of the calcarine sulcus.
- The loop forms as optic radiations from the lateral part of the lateral geniculate are pulled forward by the growth of the temporal horn. The loop of Meyer loops around from the inferior horn of the lateral ventricle. (Dorsal and ventral streams.)
- Damage to the temporal lobe (and loop of Meyer) may cause a contrateral loss of the upper quadrant of the visual vield.

Vision

- From the primary visual area, there is a dorsal stream to the mid temporal (V5) and mid-superior temporal cortex where motion, position, and stereovision are determined.
- From the primary visual area, there is a ventral stream (in a feed-forward direction) to association areas 18-19 (V2-V3) to the inferior temporal cortex where color, orientation, shape, texture, and direction are determined.
- The pre-frontal cortex is involved in the moment-to-moment control of the visual system.

Saccades

- Saccadic eye movements shift the fovea rapidly to a moving target in the periphery.
- Frontal eye field tonically active bilaterally. Activity on side causes contralateral saccade.
- Parietal eye field involved in reflexive saccades.
- Supplementary eye field involved in motor planning. Describes saccades to a part of the target.
- Dorsolateral lateral prefrontal cortex describes saccade to a remembered target.
- Area 22 saccades to sound source.

Saccades

- Pulse component of motor signal arise from burst cells within the paramedian pontine reticular formation. Fire just before horizontal saccade. Omnipause cells fire continuously except around the time of a saccade. Located in dorsal raphe nucleus on the midline immediately caudal to the abducens nucleus.
- Cerebellar flocculus as well as the medial vestibular nucleus and the nucleus prepositus hypoglossi required for neural integration of the velocity signal. Tonic firing.

Saccades

- Lateral rectus motor neurons are driven directly by burst neurons; vestibular and prepositus nuclei neurons supply the tonic signal.
- Medial rectus motor neurons are not directly effected by burst and tonic neurons. Their signal is first sent to interneurons in the abducens nucleus which in turn project to motor neurons in the contralateral oculomotor nucleus through a tract that crosses the midline and ascends with the medial longitudinal fasciculus.

Saccades

- Vertical saccades are organized in the rotstral interstitial nucleus of the medial longitudinal fasciculus in the mesencephalic reticular formation. Burst and tonic neurons are controlled by pontine omnipause cells.
- Superior colliculus integrates visual and motor information into oculomotor signals to the brain stem. Rostral superior colliculus facilitates visual fixation.
- Superior colliculus inhibited by GABAnergic projection from the substantia nigra pars reticulata (neurons function as do omnipause cells).

Saccades

- Lateral intraparietal area of the posterio parietal cortex (Brodmann 7) modulates visual attention; frontal eye field (Brodmann 8) provides motor commands.
- Vergence movements move the eyes in opposite directions so that the image is positioned on both foveae. It is organized in the midbrain (oculomotor nuclei).

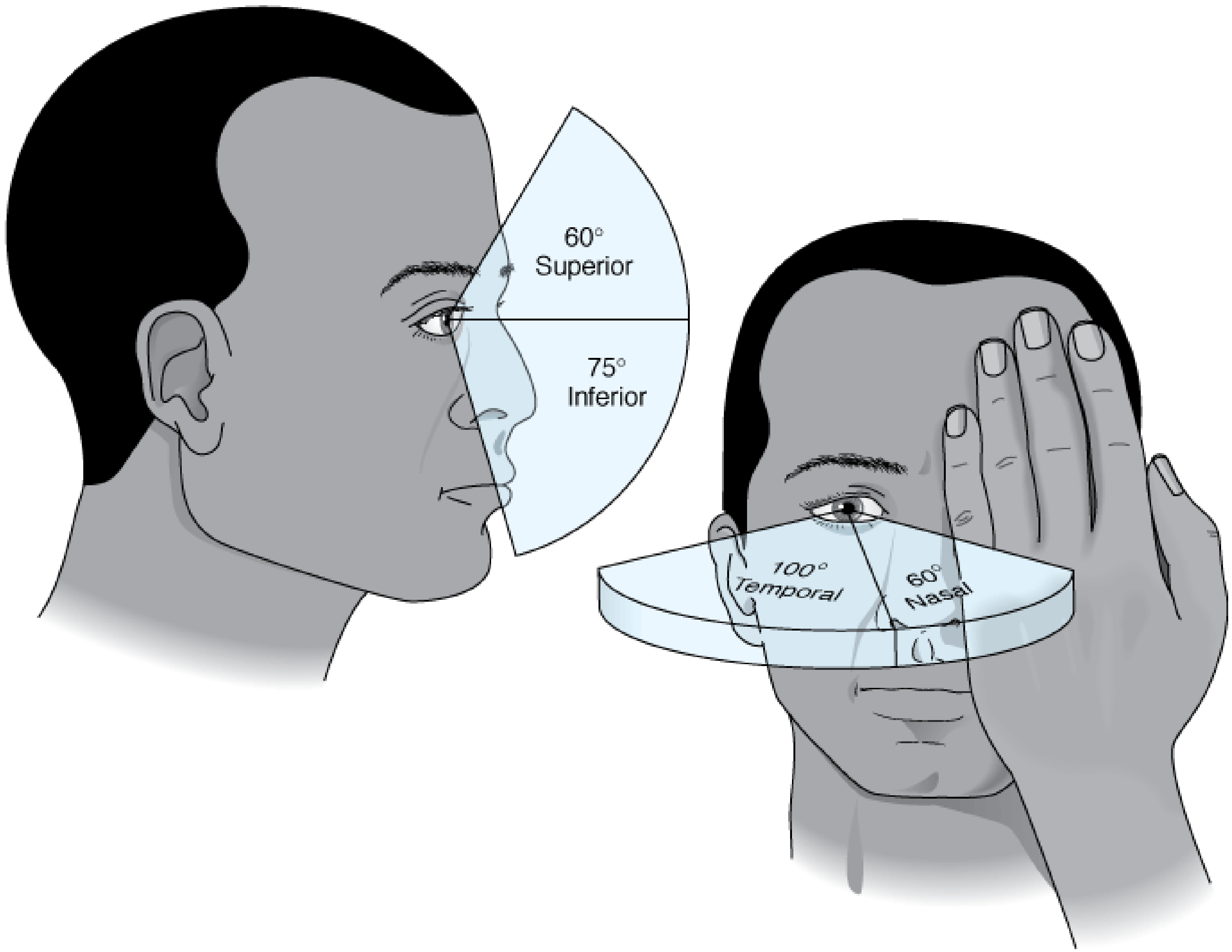
Saccades

- Smooth pursuit movements keep the image of a moving target on the fovea. Cerebellar flocculus as well as the medial vestibular nucleus and the nucleus prepositus hypoglossi required for neural integration of the velocity signal. Project to abducens as well as the ocular motor nuclei. Neurons in the paramedian pontine reticular formation also carry smooth pursuit signals and receive signals from the cerebellar vermis. Both the flocculus and vermis receive signals from cortex relayed by the dorsolateral pontine nucleus.

Saccades

- Vestibulo-ocular movements hold images still on the retina during brief head movements (vestibular system signals). Vestibular nerve signals head velocity to the vestibular nuclei. Nuclei project to the ventral posterior and ventral lateral nucleus of the thalaus and then to the primary somatosensory cortex where integrated to generate a subjective measure of self-movment and the external world.
- Adaptive learning under cerebellar control.
- Optokinetic movements hold images during sustained head rotation (visual stimuli signal).

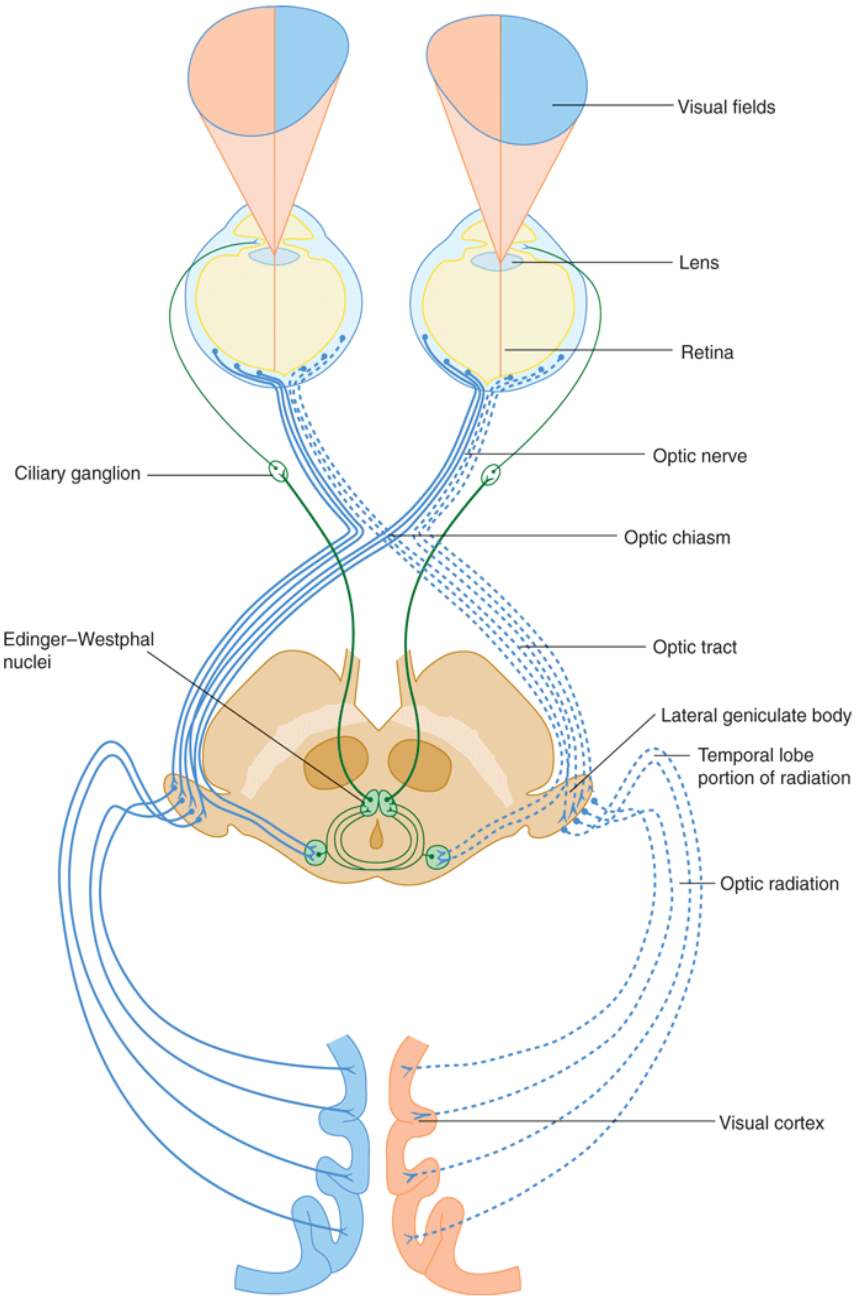
Visual Field



Source: Simon RP, Greenberg DA, Aminoff MJ:
Clinical Neurology, 7th Edition: http://www.accessmedicine.com

Fig. 4-8 Accessed 02/01/2010

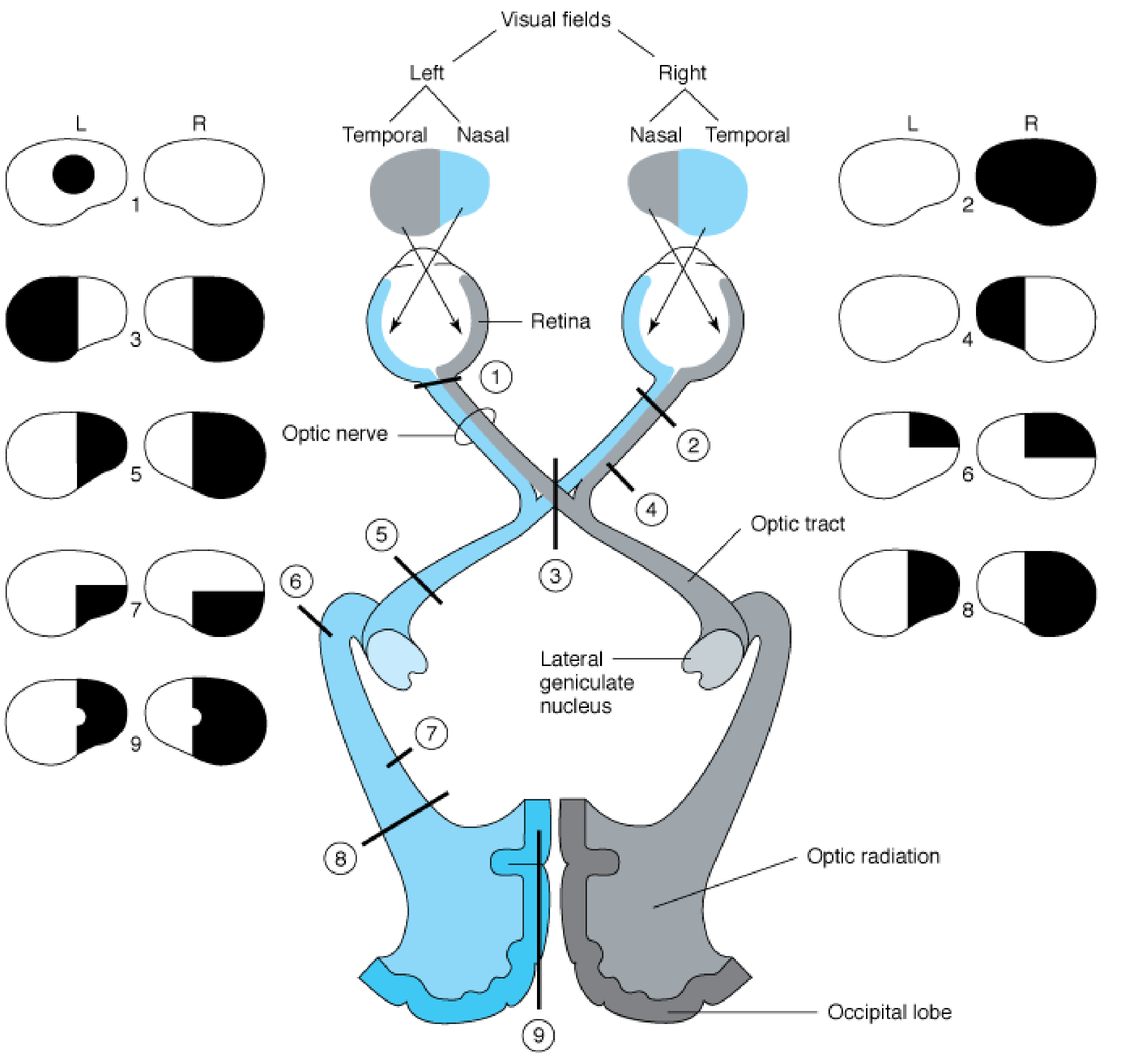
Visual Field



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 15-14 Accessed 02/01/2010

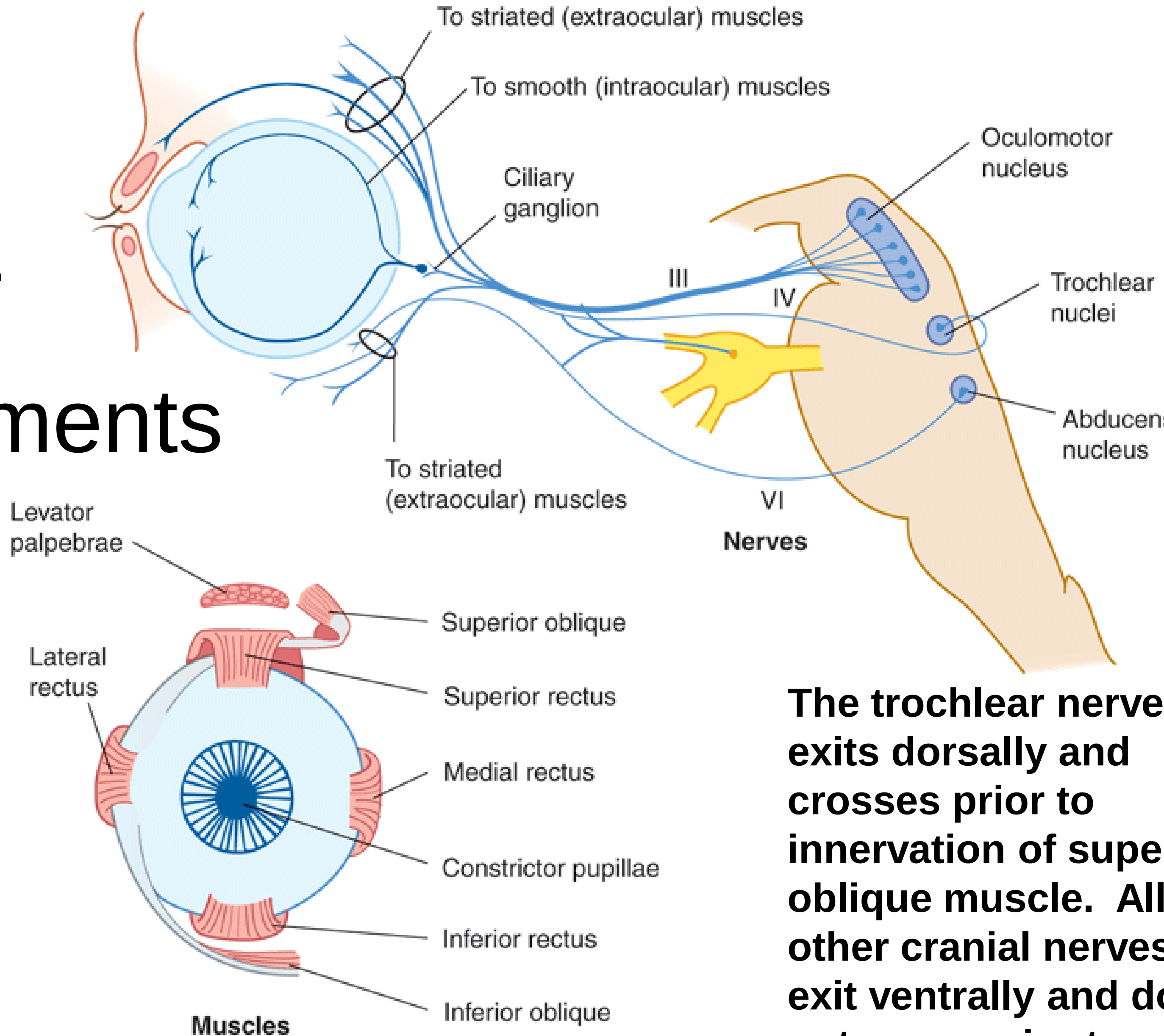
Visual field defects



Source: Simon RP, Greenberg DA, Aminoff MJ:
Clinical Neurology, 7th Edition: http://www.accessmedicine.com

Fig. 4-7 Accessed 02/01/2010

Extra-ocular movements

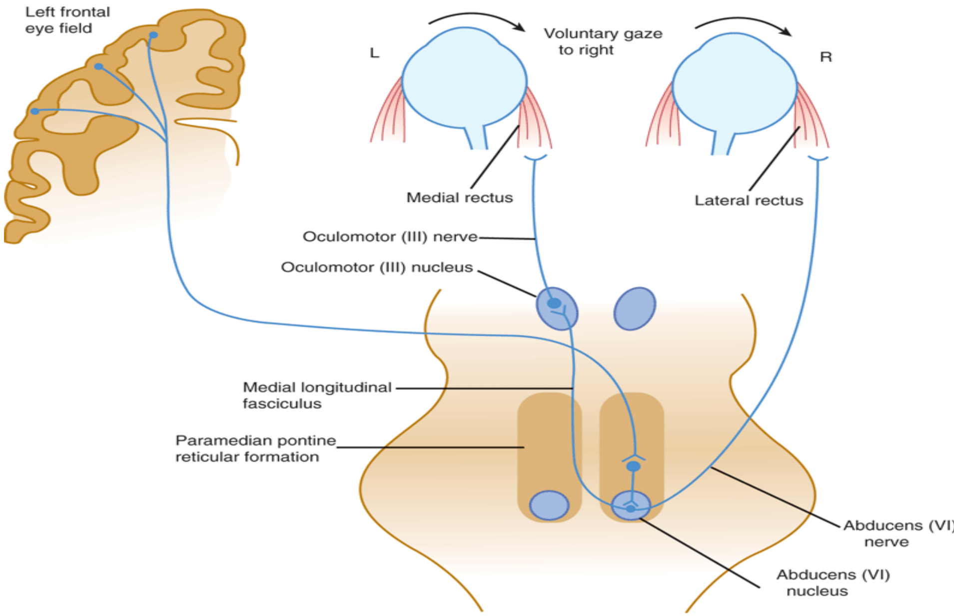


Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 8-4 Accessed 02/01/2010

The trochlear nerve exits dorsally and crosses prior to innervation of superior oblique muscle. All other cranial nerves exit ventrally and do not cross prior to innervation of their muscles.

Co-ordination of eye movement



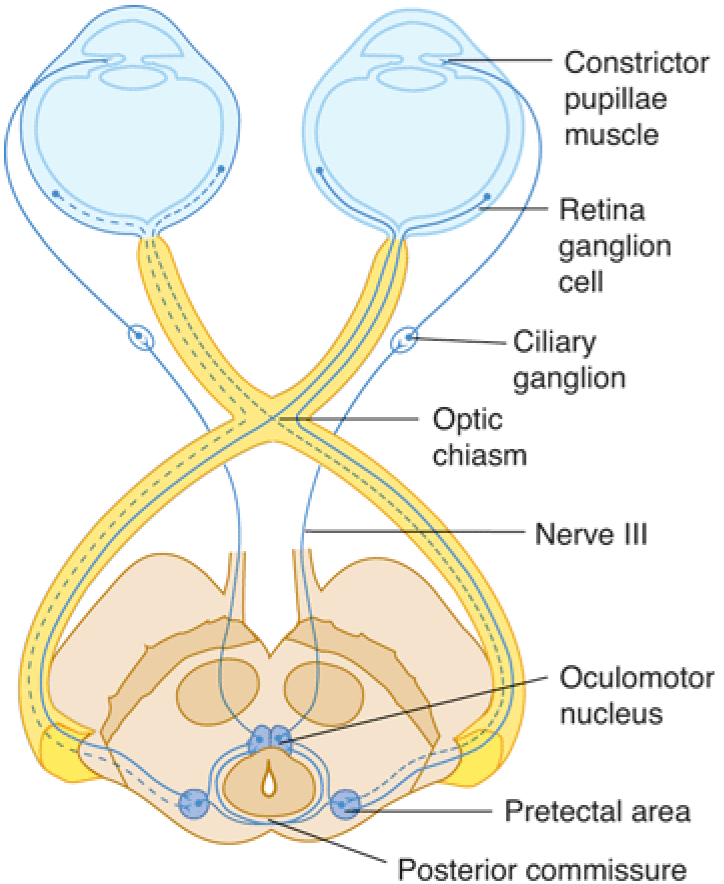
Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*:
http://www.accessmedicine.com

Reproduced, with permission, from Aminoff ML, Greenberg DA, Simon RP: *Clinical Neurology*, 6th ed. McGraw-Hill, 2005.)

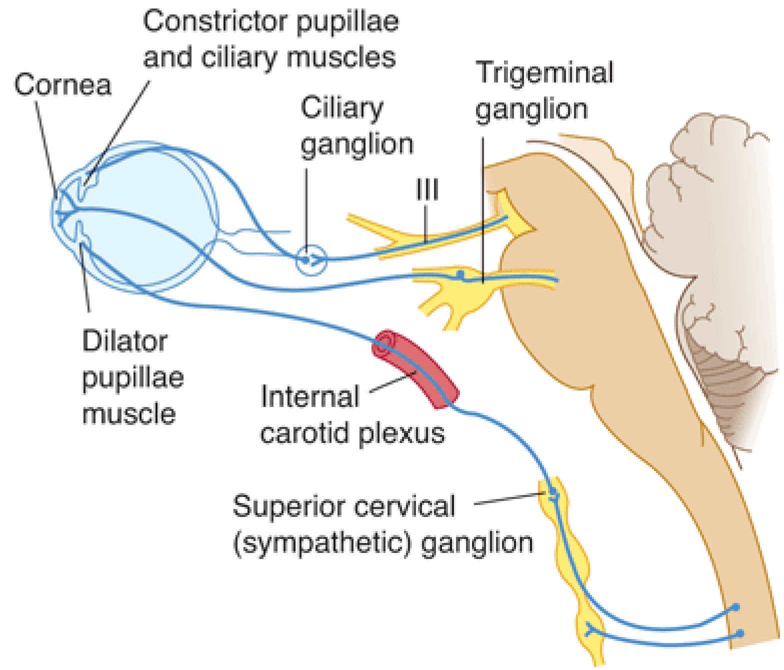
Fig. 8-7   Accessed 02/01/2010

The command for voluntary conjugate movements in right lateral gaze originates in the frontal eye fields in the left frontal lobe. This command excites a lateral gaze control center, adjacent to the abducens nucleus, within the paramedian pontine reticular formation on the right side. This, in turn, activates the abducens nucleus on the right, turning the right eye to the right, and projects via the median longitudinal fasciculus to the oculomotor nucleus on the left, which turns the left eye to the right.

Pupillary activity



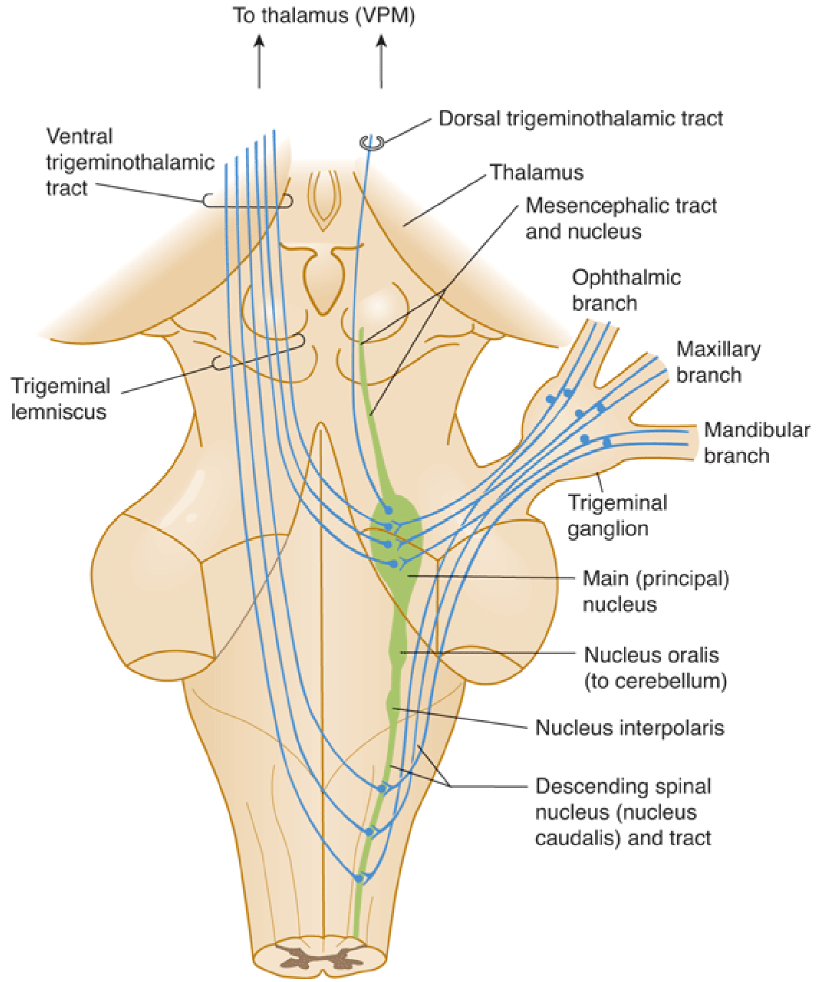
Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Figs. 8-9 and 8-8 Accessed 02/01/2010

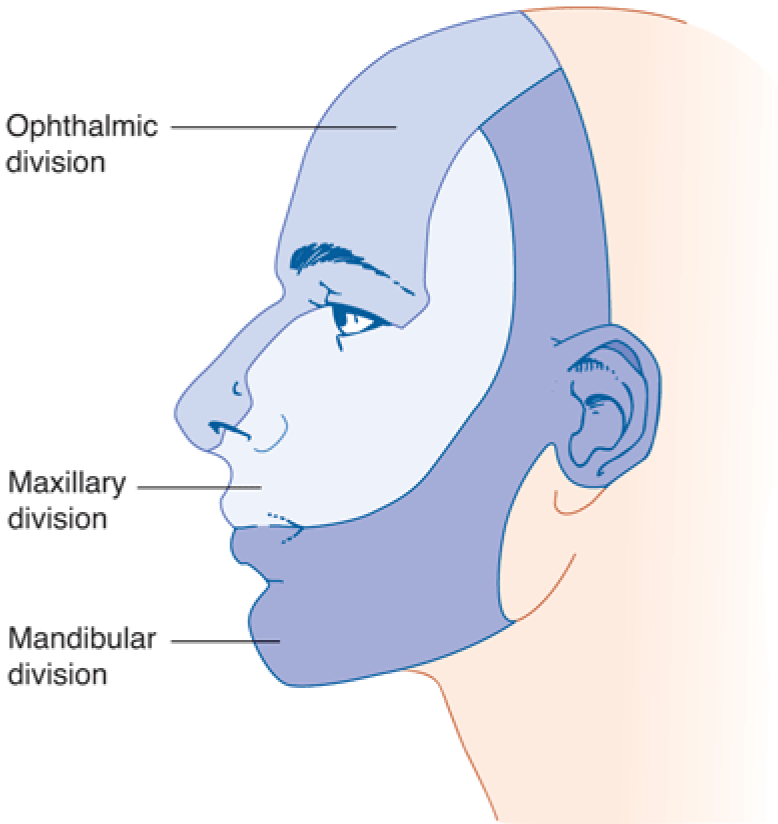
Cranial nerve V



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 7-8 Accessed 02/01/2010

Sensory distribution of trigeminal nerve



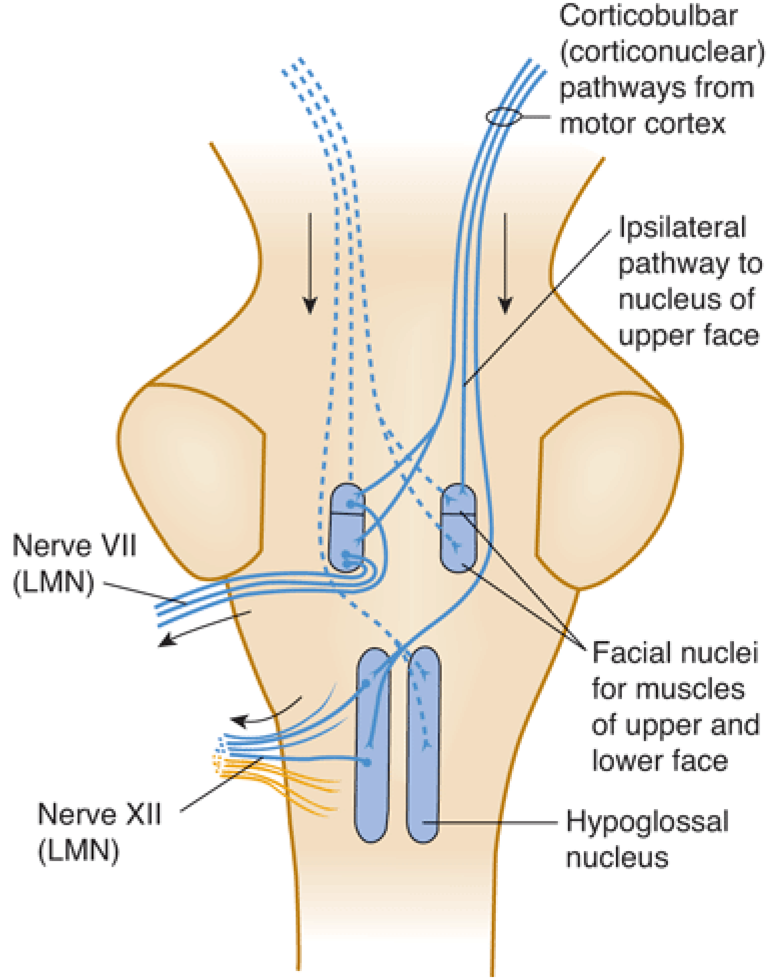
Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

- Motor function of the trigeminal nerve is tested by tensing the temporalis muscles, tensing the masseter muscles, moving the jaw from side-to-side.

Fig. 8-12 Accessed 02/01/2010

Cranial nerve VII

- The facial nucleus for muscles of the upper face (forehead) receives descending input from the motor cortex on both sides, whereas the facial nucleus for lower facial muscles (eyelids, cheek, mouth) receives input from only the contralateral cortex.



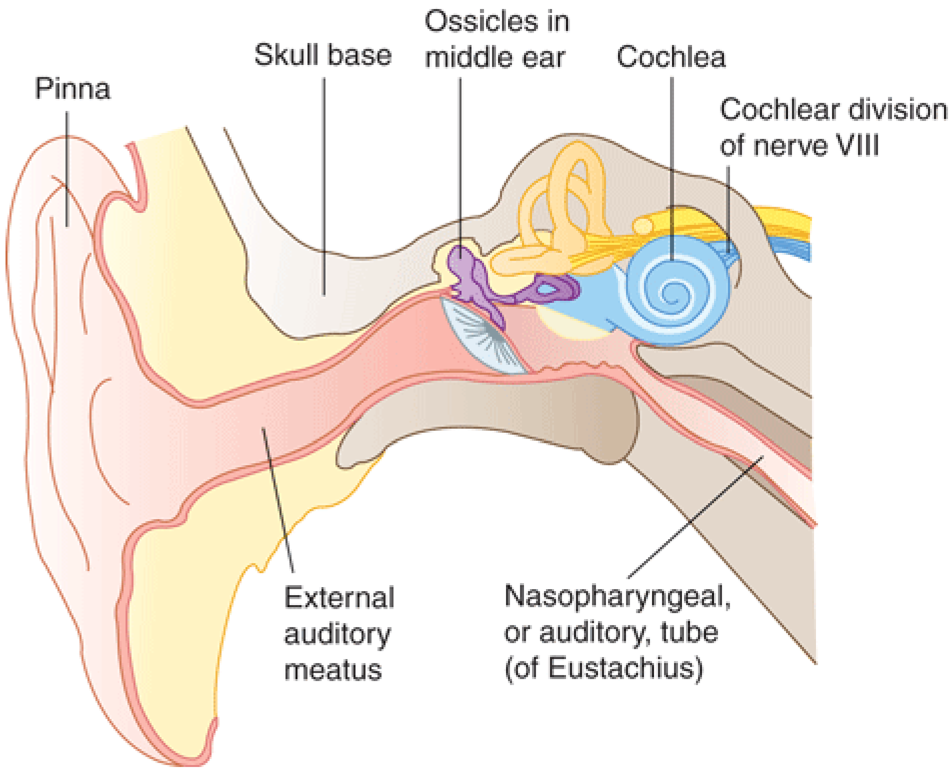
Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 7-9 Accessed 02/01/2010

Brainstem reflexes involving the facial nerve

	Corneal	Sucking	Blink (light)	Blink (sound)	Sound
Receptor	Cornea	Lips	Retina	Cochlea	Cochlea
Afferent	CN II	Mandibular nerve	CN III	Coclear nucleus	Cochlear nucleus
First synapse	Spinal nucleus CN V	Pontine nucleus CN V	Superior colliculus	Inferior colliculus	Superior olivary nucleus
Second synapse	CN VII nucleus	CN VII nucleus	CN VII nucleus	CN VII nucleus	CN VII nucleus
Muscle	Orbicularis oculi	Orbicularis oris	Orbicularis oculi	Orbicularis oculi	Stapedius

Cranial nerve VIII



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 16-1 Accessed 02/01/2010

Impedance matching

- The malleus and the incus act together as a single lever; when the malleus moves, the footplate of the stapes applies pressure at the oval window.
- The handle of the malleus is pulled inward by the tensor tympani and leads to better transmission at the tympanic membrane.
- Attenuation reflex is the result of contraction of stapedius muscle.
- Impedance matching between sound waves in air and sound vibrations in cochlear fluid (perilymph) works extremely well for frequencies between 30 and 3000Hz.

Audition

- Tonotopic deflection of basilar membrane causes it to move relative to the tectorial membrane.
- High frequency pressure waves (high pitch) produce resonance in the basal turn of the cochlea. Low frequency, in the apical turn.
- The Organ of Corti sits on the basilar membrane and contains the principal sensory epithelium, hair cells bathed in perilymph.

Audition

- Tympanic membrane vibrations in response to sound waves are transmitted along the ossicular chain. Stapedic vibrations are converted into pressure waves in the scala vestibuli and are transmitted through the vestibular membrane to reach the basilar membrane (impedance matching).
- 40-80 msec following exposure to loud sound, the stapedius and tensor tympanus muscles contract, increasing ossicle rigidity in the middle ear. Masks loud, low sensitivity sounds as well as decreases sensitivity to one's own voice.

Audition

- Pilar cells are stiff. High content of microtubules. Act as fulcrum for the movement of the tectorial membrane.
- Stereocilia of the outer and inner hair cells (embedded in the tectorial membrane) undergo sheer stress (and depolarize).
- Hair cells in humans do not regenerate.

Audition

- Peripheral processes of bipolar neurons in the spiral ganglion contact hair cells. Central processes travel via the cochlear nerve to the anterior (ventral) and posterior (dorsal) cochlear nuclei.
- Postsynaptic neurons in the cochlear nucleus send their axons to centers in the brain via
- (1) dorsal acoustic stria;
- and bilaterally, (2) intermediate acoustic stria (posteroventral nucleus);

Audition

- (3) anteroventral nucleus to the trapezoid body (ventral acoustic stria) to the superior olivary complex in the pons (medial and lateral divisions involved with localizing sound in space with the former based on time delay and the latter on sound intensity),
- and (along with axons from the posteroventral nucleus) rostrally via the lateral lemniscus to the inferior colliculus and then to the medial geniculate nucleus of the thalamus with termination in the auditory cortex.

Audition

- Neurons from the nucleus of the trapezoid body that receive ipsilateral input from the cochlear nuclei project axons rostrally in the contralateral lateral lemniscus.
- The dorsal stria cross and run with the others in the lateral lemniscus.
- Unilateral neural hearing loss reflects a lesion proximal to the cochlear ganglion.

Audition

- The superior olive contains binaural neurons. Ipsilateral, excitatory; contralateral, inhibitory, and mediated by the internuncials in the nucleus of the trapezoid body. Interaural timing disparities indicate spatial direction.
- Fibers ascend via the lateral lemniscus to the central nucleus of the inferior colliculus. Spatial information (superior olive), intensity (ventral cochlear nucleus), and pitch (dorsal cochlear nucleus) are integrated. Fibers are projected to the medial geniculate body.
- Through the collicular commisure, the inferior colliculus inhibits its opposite number.

Audition

- Bilateral projections serve to localize sound in space by comparing input to the two ears.
- Neurons of the inferior colliculus project to the medial geniculate nucleus via the brachium of the inferior colliculus.
- Bilateral connections exist between the inferior colliculi.
- The medial geniculate nucleus projects to the transverse temporal gyrus (Herschel’s gyrus, Area 41).

Audition

- The medial geniculate body of the thalamus and the primary auditory cortex (Herschel's gyrus) are tonotopic (frequency coded).
- The cortex responds to auditory stimuli within the contralateral found field.
- Fibers entering motor nuclei of CN V and VII link with motor neurons supplying tensor tympani and stapedius, respectively. Damp ossicles.
- Olivocochlear bundle (descending tract) is involved in enhancement of faint sounds.

Basilar membrane

- Frequency sensitivity of the basilar membrane varies by location.
- As fluid is non-compressible, action of the footplate of the stapes at the oval window creates a traveling wave that runs along the basilar membrane.
- The frequency of the wave corresponds to the frequency components of the stimulus.
- The basilar membrane vibrates according to the frequency of the traveling wave.

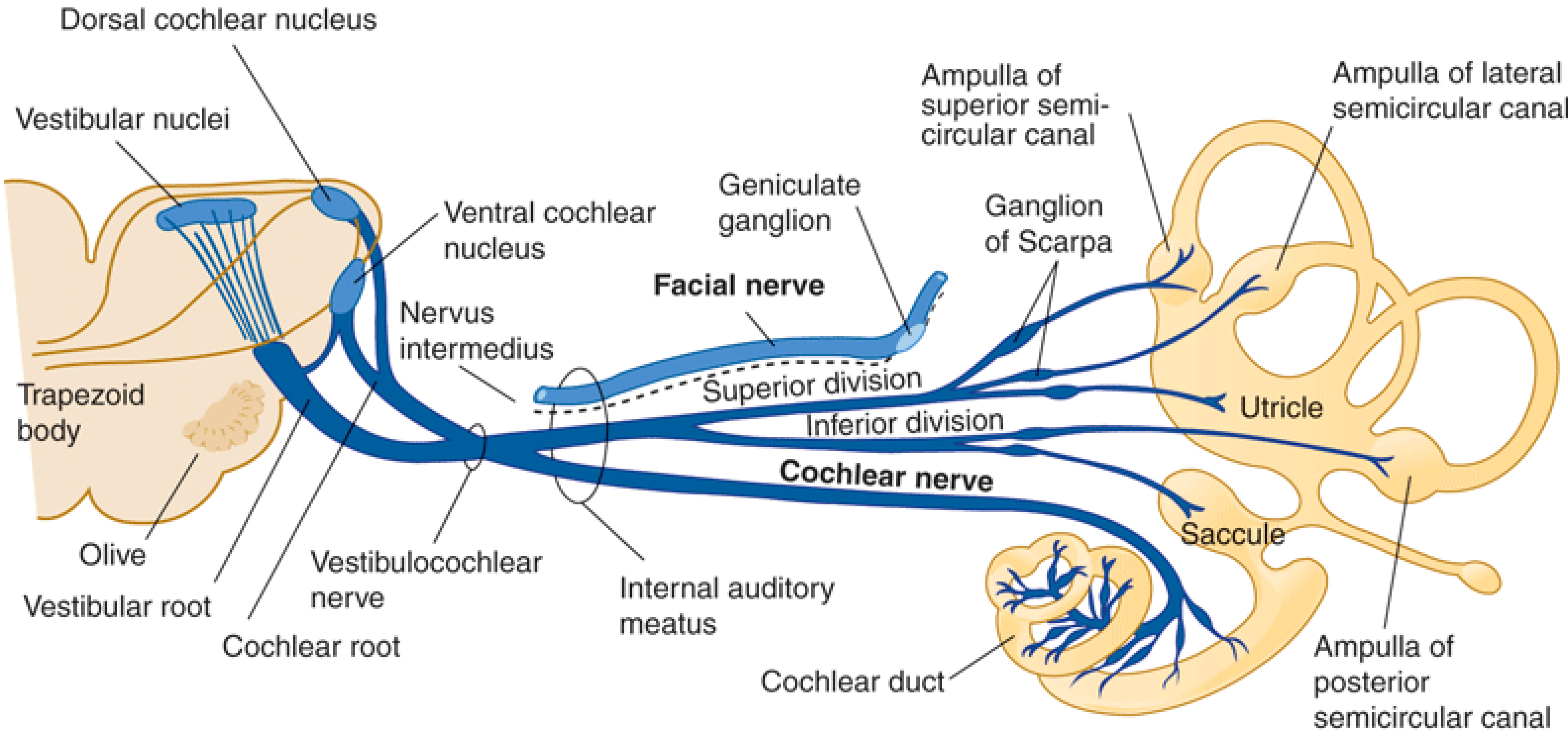
Cochlea

- Cochlea is a spiral. 2.5 turns over 35mm length.
- The central core is the modulus, a bony structure that contains the spiral ganglion and the acoustic portion of CN VIII.
- Suspended within the bony cochlea is the membranous cochlear duct (scala media). Contains endolymph.
- Scala vestibuli is above the cochlear duct.
- Scala media is the level of the cochlear duct.
- Scala tympani is below the dochlear duct.
- Scala vestibuli and tympani contain perilymph and are part of the bony labyrinth.

Cochlea

- Hair cells have vertical stereocilia projecting from their apical surface.
- The tips of adjacent stereocilia are connected by tip links.
- Deflection of the stereocilia towards the tallest member results in the opening of cation channels and depolarization.
- Spiral ganglion spirals about modiolus.
- Cells myelinated in both directions.
- Rinné test of little diagnostic value.

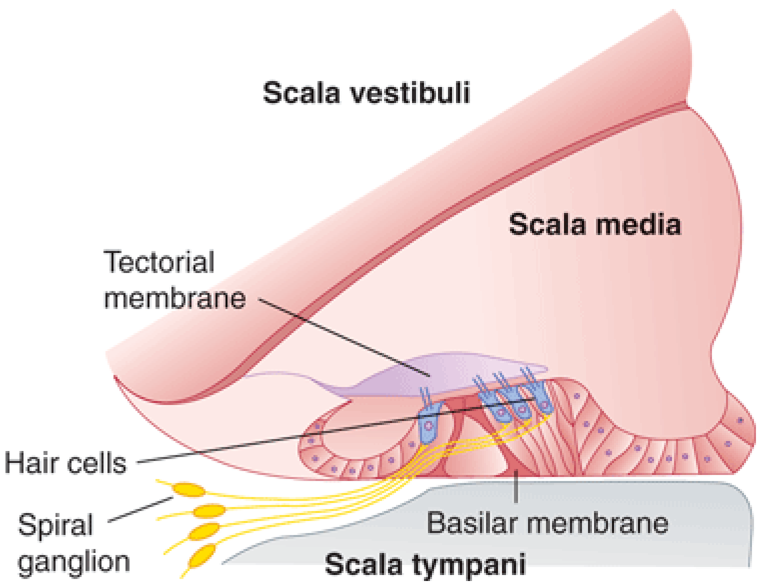
Cranial nerve VIII



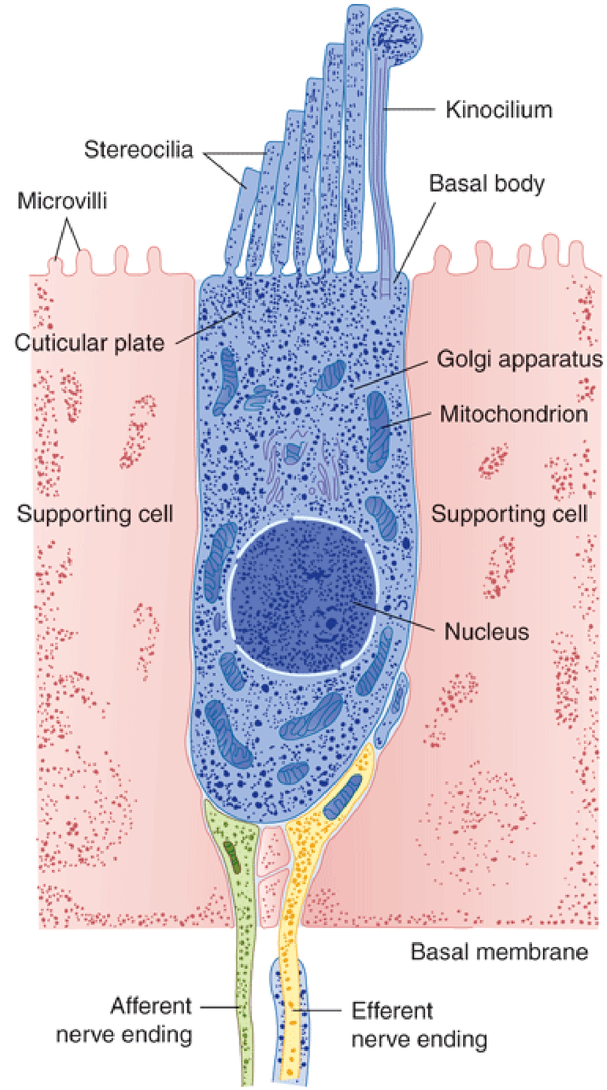
Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig.16-5
Accessed 02/01/2010

Inner ear



Figs. 16-3 and 16-4   Accessed 02/01/2010

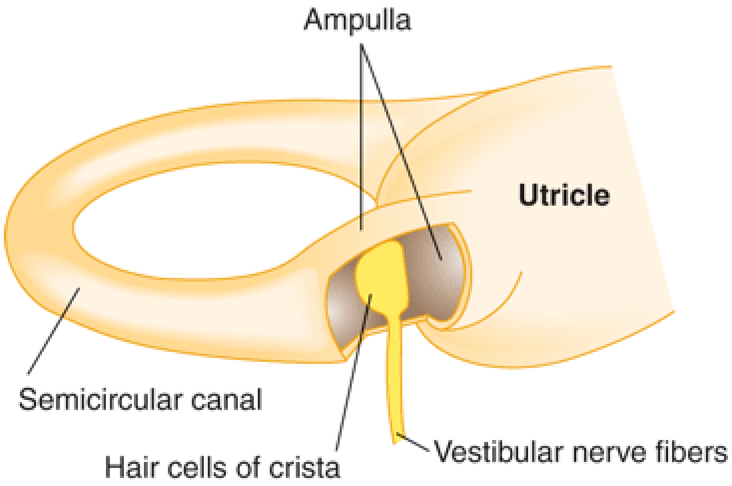


(Reproduced, with permission, from Hudspeth AJ:
The hair cells of the inner ear. *Sci Am* 1983;248:54.)

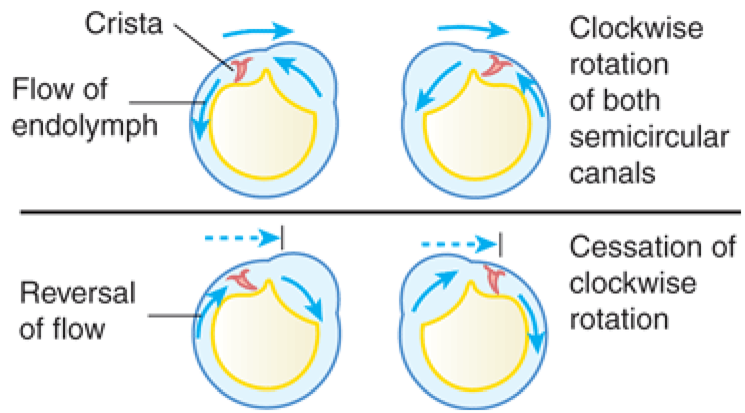
Organ of Corti

- The scala vestibuli and the scala tympani contain perilymph (similar in composition to CSF)
- The scala media contains endolymph (made by the stria vascularis); this solution is high in K^+ and low in Na^+.
- There is a great voltage difference between endolymph and hair cell.

Vestibular function



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Figs. 17-4 and 17-5 Accessed 02/01/2010

Labyrinth

- The bony labyrinth of the inner ear is a very dense shell containing perilymph (resembles extracellular fluid) that provides a liquid jacket for the membranous labyrinth that contains the sense organs of balance and hearing. The sense organs are bathed in endolymph (resembles intracellular fluid).
- The vestibular labyrinth comprises the utricle, saccule, and three semicircular canals or ducts.
- The utricle and saccule are found at the common chamber from which arise the semicircular canals.

Labyrinth

- Each utricle and saccule contains a macule: Vestibular nerve endings are applied to hair cells whose cilia are embedded in a gelatinous matrix containing calcium carbonate crystals (otoconia). The otoconia exert gravitational drag on the hair cells.
- Each semicircular canals contains a crista at its ampulla.
- In cristae, vestibular nerve endings are applied to hair cells. The kinocilia of the hair cells penetrate into a gelatinous projection, the cupula. The cristae are sensitive to angular rotation.
- Vestibular neurons are bipolar.

Labyrinth

- The utricular macula is relatively horizontal; the saccular macula, relatively vertical. Their primary function is to signal the position of the head relative to the trunk. Antigravity action is triggered mainly from the horizontal macula.
- In response to the signal, the vestibular nucleus initiates compensatory movements that maintain the center of gravity between the feet (standing) or just in front of the feet (locomotion) or of keeping the head horizontal (prone or recumbent).

Labyrinth

- Hair cells of the maculae have one cilium and 60 long sterocilia.
- The cilia are embedded in a gelatinous matrix. Within the surface of the matrix are calcium carbonate crystals (otoliths).
- Gravity causes the weight of the otoliths to distort the gelatinous matrix. This leads to firing of the receptor cells.

Labyrinth

- The lateral vestibular (Deiter's) nucleus is somatotopically organized. It has two way connections with the flocculondular lobe of the cerebellum.
- The lateral vestibulospinal tract descends from Deiter's nucleus via the ipsilateral anterior funiculus and synapse upon extensor (antigravity) neurons. Both α and γ neurons are excited. Muscle tone is maintained via the gamma loop.

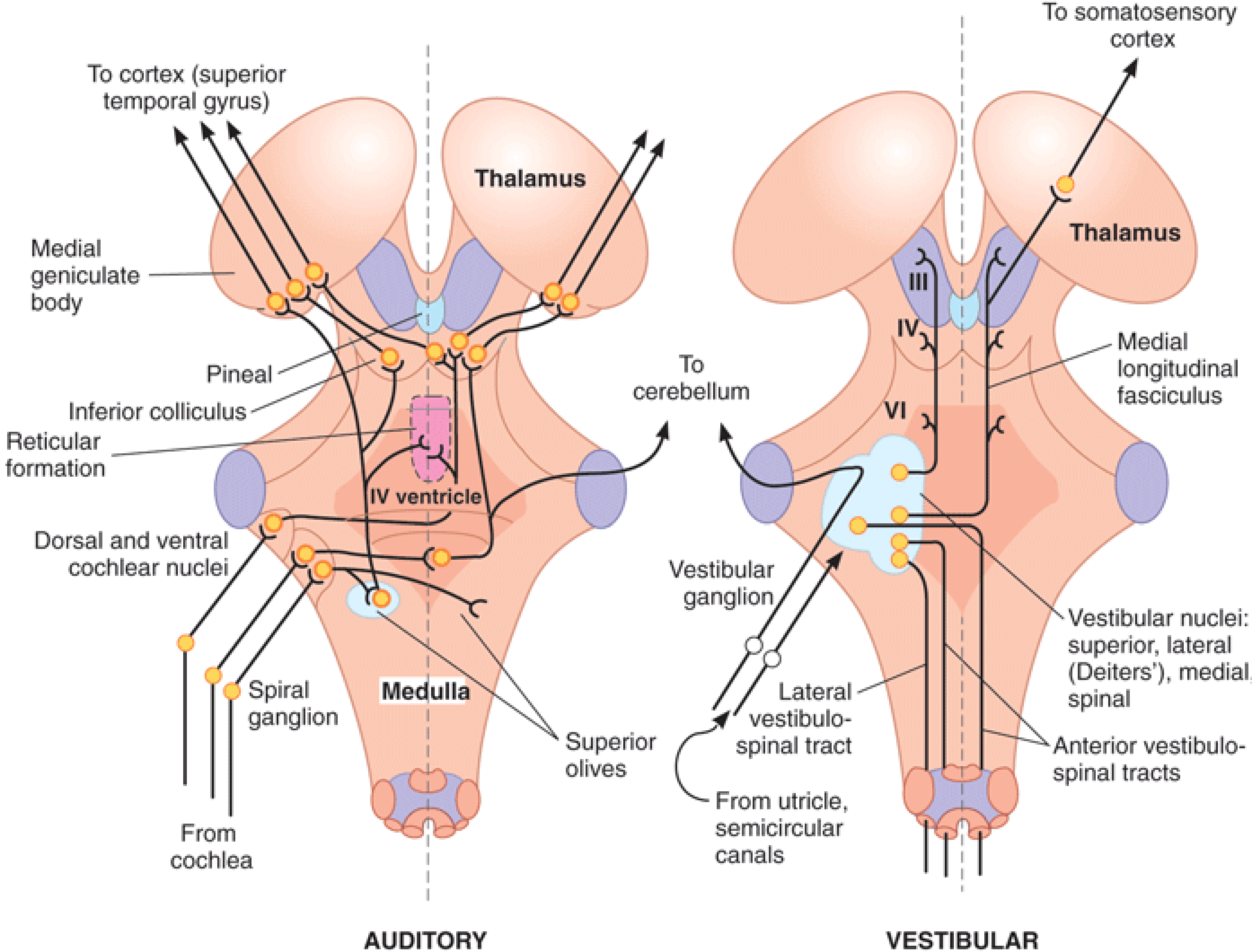
Labyrinth

- The medial vestibulospinal tract arises in the medial and inferior vestibular nucleus and descends bilaterally in the medial longitudinal fasciculus and terminates upon excitatory and inhibitory internuncials in the cervical cord.
- It operates head-righting reflexes.
- The tract is also active in maintaining gaze.
- Projections from the vestibular nuclei terminate with trigemino-thalamic fibers in the contralateral ventral posterior nucleus. Projection from the thalamus terminate immediately behind the face representation of the sensory cortex.

Labyrinth

- The lateral ampulla is activated by head turning (ipsilateral). Both superior ampullae are activated by head flexion; both posterior ampullae are activated by head extension.
- Afferents terminate in the medial and superior vestibular nuclei which maintain two way connections with the flocculonodular lobe of the cerebellum.
- Vestibulo-ocular reflexes operate to maintain the gaze on a selected target.

Cranial nerve VIII



Source: Barrett KE, Barman SM, Boitano S, Brooks H: *Ganong's Review of Medical Physiology, 23rd Edition*: http://www.accessmedicine.com

Fig. 13-12
Accessed 07/01/2010

Vestibular pathways

- There are four vestibular nuclei that receive inputs from the vestibular apparatus via neurons in the vestibular (Scarpa's) ganglion.
- **Superior nucleus**. Input from ampullary crest. Gives rise to vestibulo-ocular tract. Ascends rostrally in the medial longitudinal fasciculus. Permit eye fixation while head and body move (to CN III).
- **Lateral nucleus**. Receives input from the utricle, saccule, and macule. Descending branches give rise to the lateral vestibulospinal tract in the ipsilateral spinal cord. Integrates equilibratory reflexes.

Vestibular pathways

- Primary vestibular neurons in the Scarpa's ganglion project directly to the flocculonodular lobe of the cerebellum. Secondary neurons project from the superior and lateral vestibular nuclei to the cerebellum, where they end in the cerebellar cortex within the flocculonodular component.

Vestibular pathways

- **Medial nucleus**. Receives input from utricule, saccule. Ascending branches run to CN III, CN IV, CN VI via the medial longitudinal fasciculus whose origin is in the medial nucleus. Small contribution to CN III from medial nucleus. Gives rise to the medial vestibulospinal tract. Descends bilaterally to cervical cord. Facilitates anti-gravity response as it integrates vestibular and visual pathways.
- **Inferior (descending spinal) nucleus** fibers join medial vestibulospinal tract.

Vestibular pathways

- The medial vestibulospinal tract (the descending portion of the MLF) connects to the anterior horn of the cervical and upper thoracic cord; this tract is involved in the labyrinthine righting reflexes that adjust the position of the head in response to signals of vestibular origin.
- Some vestibular nuclei send fibers to the reticular formation. Some ascending fibers from the vestibular nuclei travel by way of the thalamus (ventral posterior nucleus) to the parietal cortex (area 40). This is thought to be involved in the righting reflex as well.

Vestibular pathways

- Cold calorics lower temperature of endolymph. Flows as though the head is moving in the opposite direction.
- Warm irrigation leads to flow as though the head is moving in the same direction.

Labyrinth and movement

- The right horizontal canal is excited by a right turn of the head. The eyes move left.
- The right anterior canal is excited when the neck is flexed. Right upward eye movement. If the head is tilted to the right, eyes move to the left (counterclockwise torsion).
- The right posterior canal is excited when the neck is extended. Left downward eye movement. If the head is tilted to the right, eyes move to the right (counterclockwise torsion).

Labyrinth and movement

- The left horizontal canal is excited by a left turn of the head. The eyes move right.
- The left anterior canal is excited when the neck is flexed. Left upward eye movement. If the head is tilted to the left, eyes move to the right (counterclockwise torsion).
- The left posterior canal is excited when the neck is extended. Right downward eye movement. If the head is tilted to the left, eyes move to the left (counterclockwise torsion).

Nystagmus

- Loss of tonic vestibular discharge on side leads to imbalance (nystagmus and vertigo).
- Peripheral lesions (nerve or receptor destruction) result in no brainstem input. Fast component beats away from diseased ear. (Compensatory mechanisms develop in a few weeks.)
- Central lesions produce vertical nystagmus.

Vertigo

- No hearing loss and episodic vertigo that lasts seconds; positional; recurrent: benign positional vertigo (positive likelihood ratio, LR+, 11; LR-, 0.1)
- 10% dizzy patients have benign positional vertigo
- No hearing loss and persistent vertigo: vestibular neuronitis
- Hearing loss and persistent vertigo: labyrinthitis
- Hearing loss and episodic vertigo that lasts minutes to hours; tinnitus or aural fullness: Ménière’s disease
- Panic attack common; lightheadedness as result of hyperventilation

Cranial nerve IX

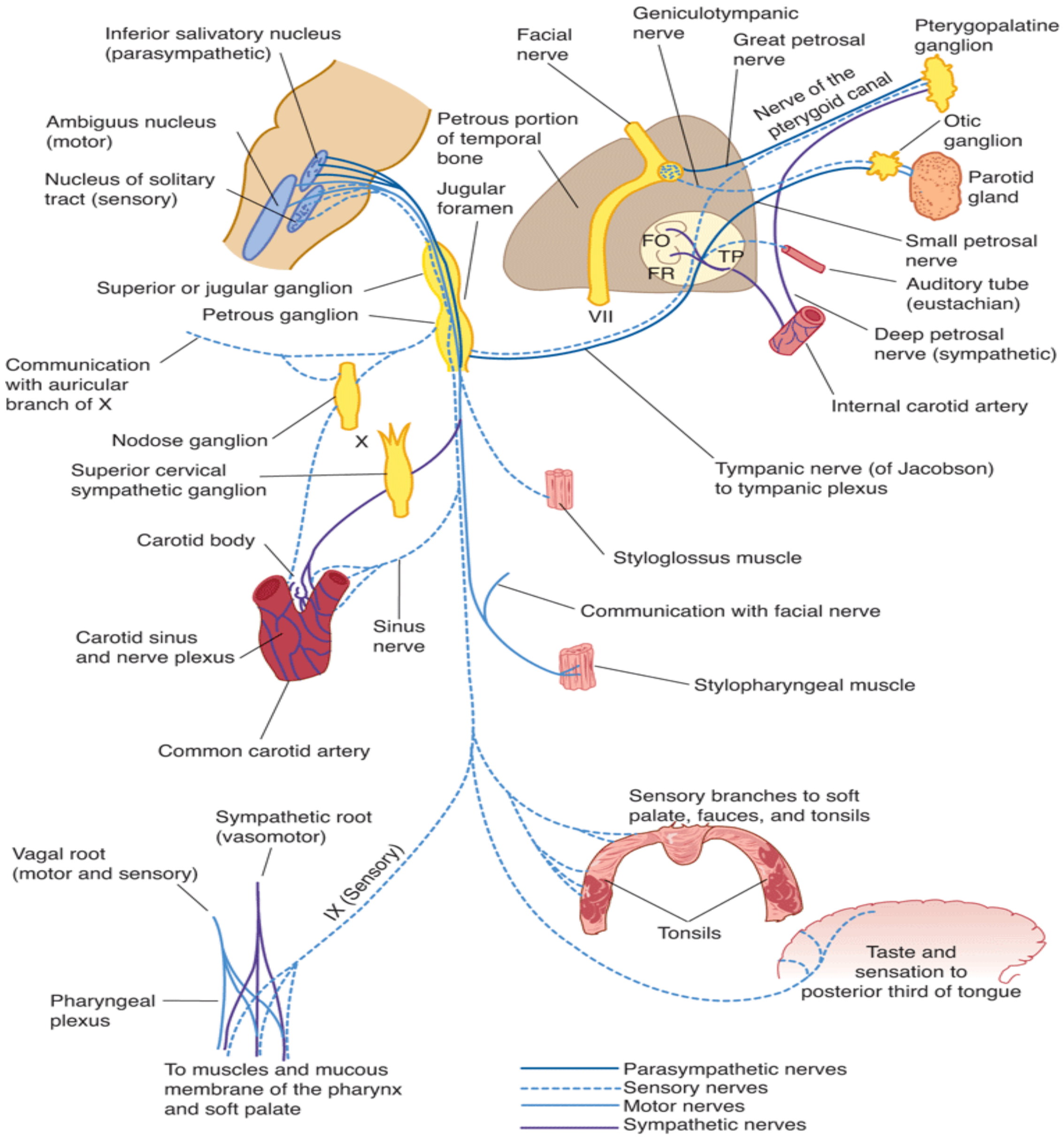
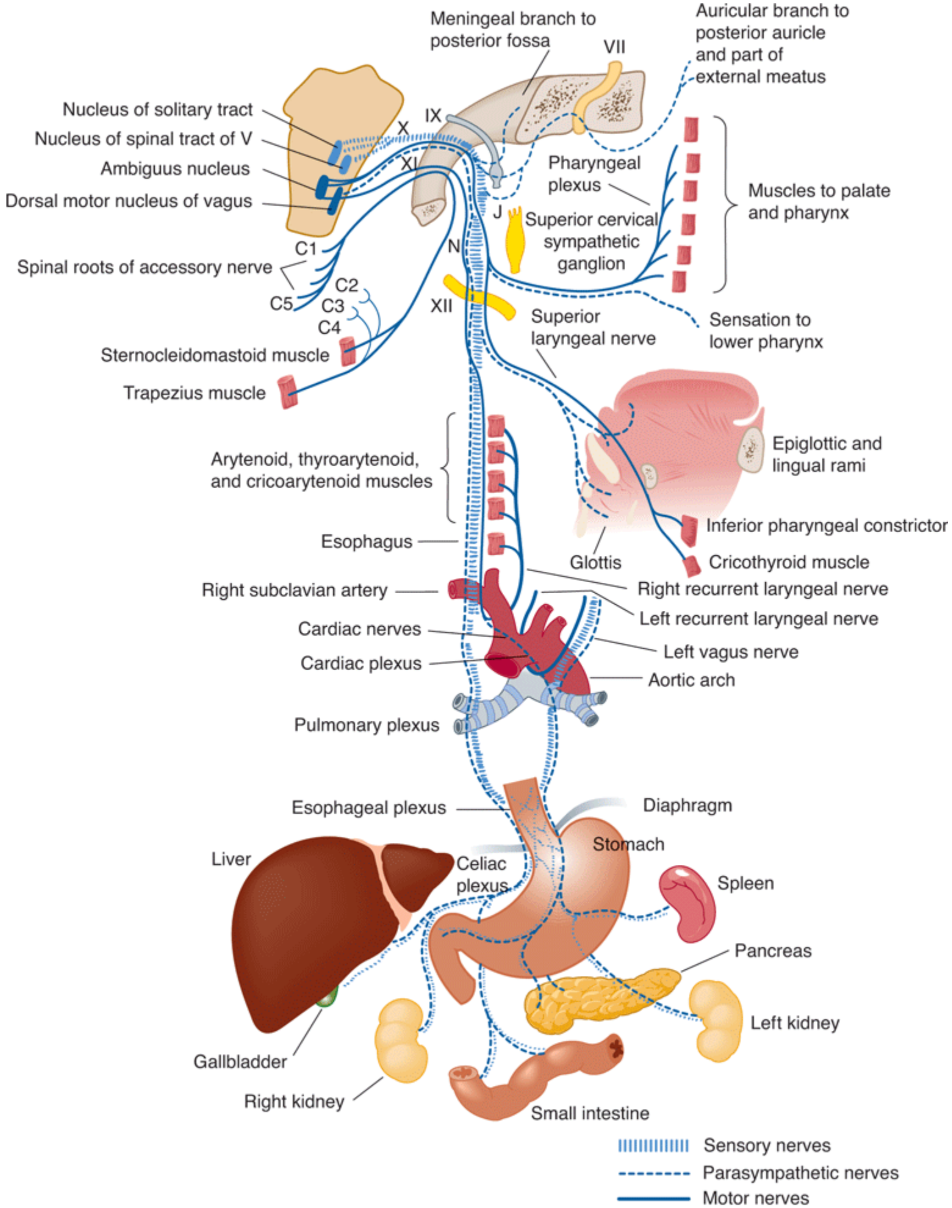


Fig. 8-16 Accessed 02/01/2010

Cranial nerve X

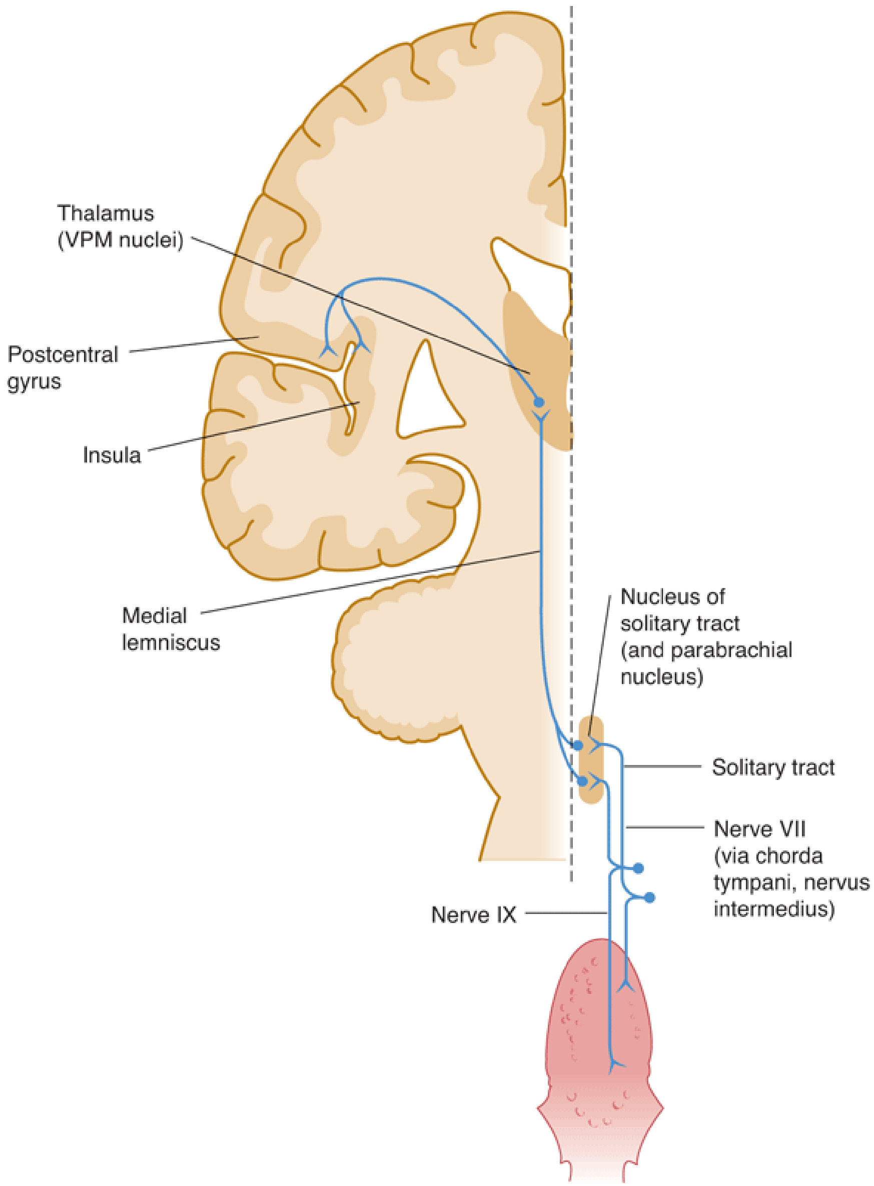
The vagus nerve. J, jugular (superior) ganglion; N, nodose (inferior) ganglion.

Fig. 8-19 Accessed 02/01/2010



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Taste



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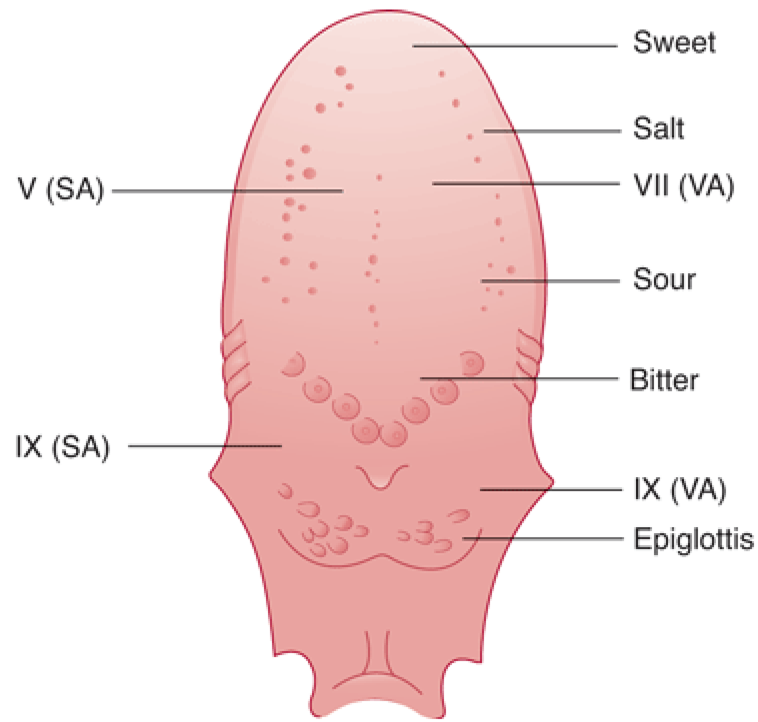
http://www.accessmedicine.com



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*:
http://www.accessmedicine.com

Figs. 8-18 and 8-17Accessed 02/01/2010

Taste

- A single taste bud contains 50–100 taste cells representing all taste sensations.
- Each taste cell has receptors (transmembrane proteins) on its surface. A single taste cell seems to be restricted to expressing only a single type of receptor (except for bitter receptors).
- A single sensory neuron can connect to taste cells in more than one taste bud.
- Taste receptor binds molecule, activating G-protein (gustducin). α subunit activates adenlyl cyclase, leading to cAMP production. Phosphokinase A activated by cAMP, phosphorylates K^+ channel in the basolateral membrane, closing the channel. Cell depolarizes.

Taste

- With **salt**, the receptor is an amiloride sensitive ion channel that permits direct entry of Na^+. This depolarizes the cell, allowing Ca^{2+} ion entry and the release of ATP at the neuronal synapse, generating an action potential.
- Aldosterone regulates the number of salt receptors.
- With **sour**, the receptor is an amiloride sensitive Na^+ channel that also admits H^+; closes K^+ channels in the sensory neuron.

Taste

- With **sweet**, the receptors are coupled to G-proteins (T1R2 and T1R3 subunits) whose activation leads to generation of cAMP and closure of K^+ channels in the cell via protein kinase A. Depolarizes.
- This is the same mechanism that operates with odor receptors.
- Leptin opens K^+ channels (hyperpolarizes) and inhibits the sensation.
- **Umami**. Amino acids bind to receptors couple to G-proteins (T1R1, T1R3). Glutamate release. Affects Na^+-Ca^{2+} exchange.

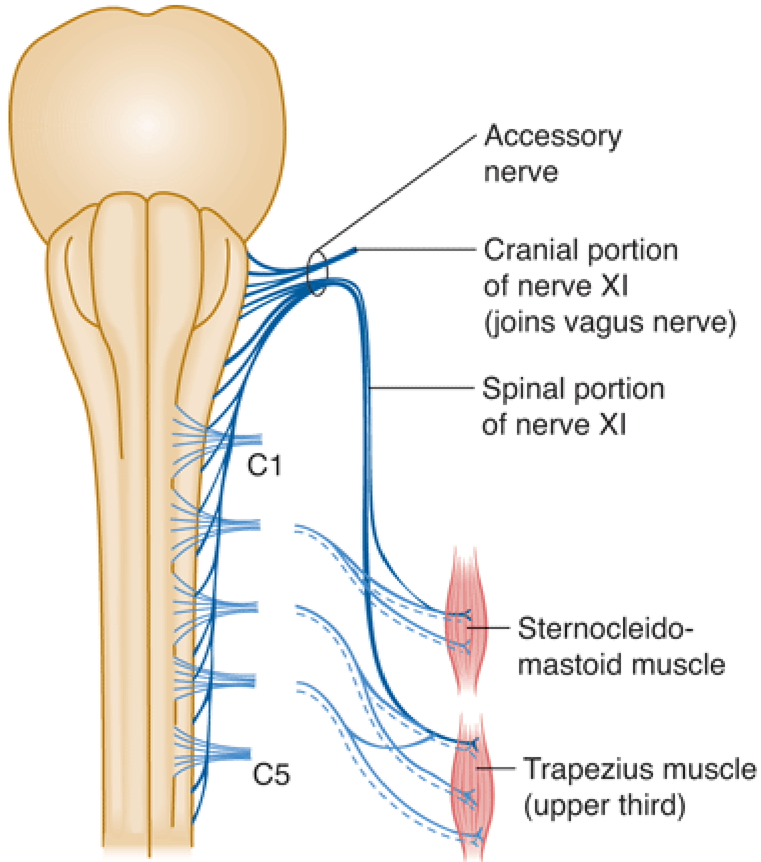
Taste

- With **bitter**, the receptors are coupled to G-proteins (T2R). IP_3 acts to release Ca^{2+} from the endoplasmic reticulum, which liberates neurotransmitter at the sensory neuron.
- A second path involves blocking K^+ channels in the sensory neuron. Depolarize.
- Each bitter taste receptor reacts to varied bitter stimuli. (Odor detecting cells express only to a single odor receptor.)
- Taste determined in the brain.

Taste

- Taste information in gustatory area of nucleus solitarus arise from VII, IX, X. Information relayed to ventral posterior medial nucleus of thalamus and to anterior insula-frontal operculum of cortex.

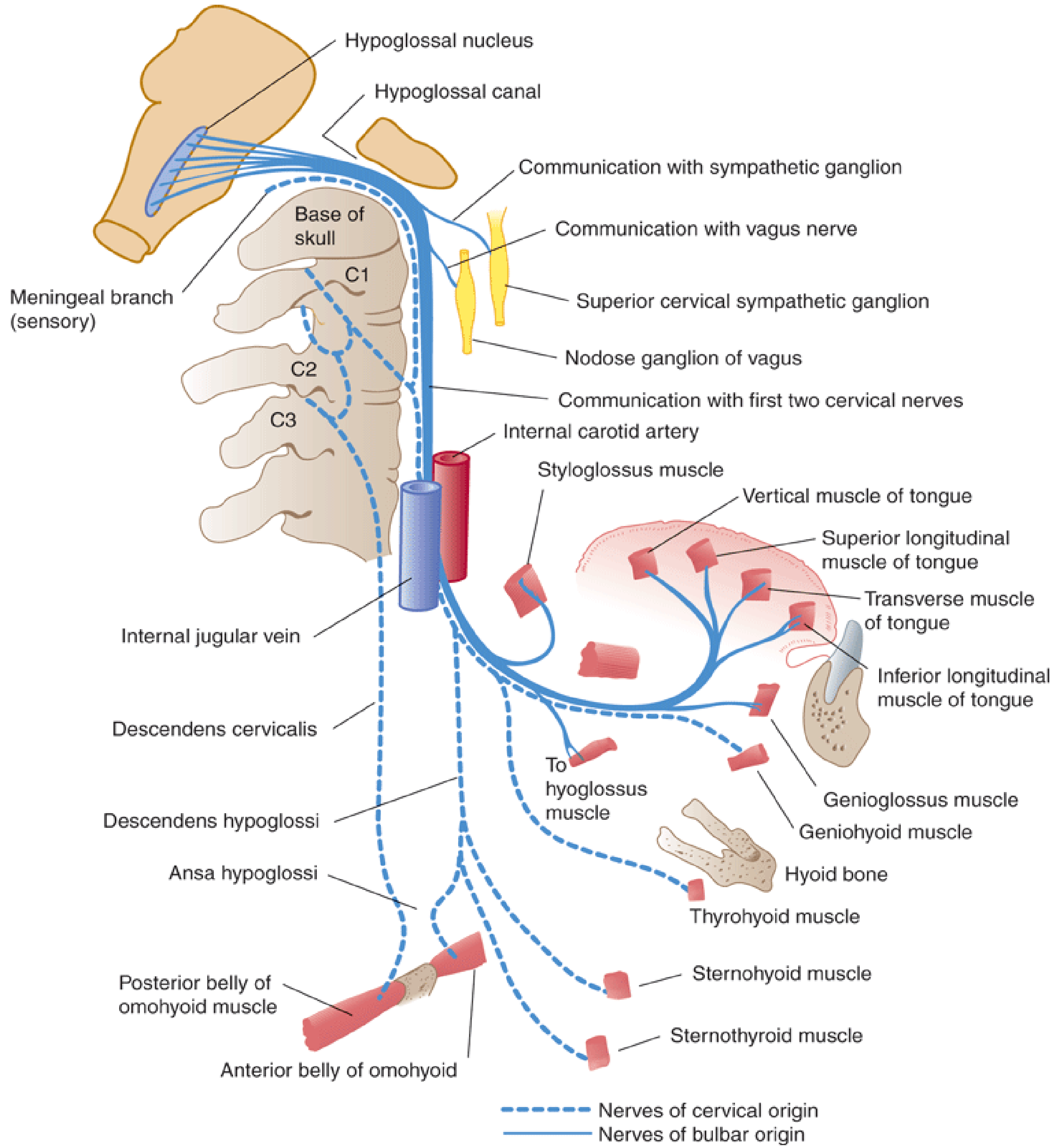
Cranial nerve XI



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*:
http://www.accessmedicine.com

Fig. 8-20
Accessed 07/01/2010

Cranial nerve XII



Source: Waxman SG: *Clinical Neuroanatomy, 26th Edition*: http://www.accessmedicine.com

Fig. 8-21
Accessed 07/01/2010

Cortico-nulcear tract asymmetries

- Innervation to the cranial nerve motor nuclei are mainly bilateral with these exceptions:
- Facial nucleus: the part that innervates the lower part of the face gets only contralateral input
- Hypoglossal nucleus: the neurons that innervate the genioglossus muscle only get contralateral input
- Nucleus Ambiguus: neurons that innervate the soft palate and uvula get only contralateral input
- Spinal Accessory – mainly ipsilateral input

Lower motor neuron injury

- The rubrospinal tract and vestibulospinal tract innervate α-motor neurons that control distal muscles (delicate, precise movements).
- With an upper motor neuron lesion there is interruption of descending inhibitory pathways with increased activity of γ-motor neurons.
- Spasticity involves a lesion of both the corticospinal tract and the reticulospinal tract.
- Spasticity involves a velocity-dependent increase in resistance of muscles to passive stretch.

Somato-sensory pathways

- Primary afferents occupy posterior root ganglia.
- Somas of second order neurons are on the
same side as first order neurons.
- Second order axons cross midline to ascend
 to thalamus.
- Third order neurons project to somatic sensory cortex.
- Both pathways are somatotopic.
- Synaptic transmission can be modulated by other neurons.