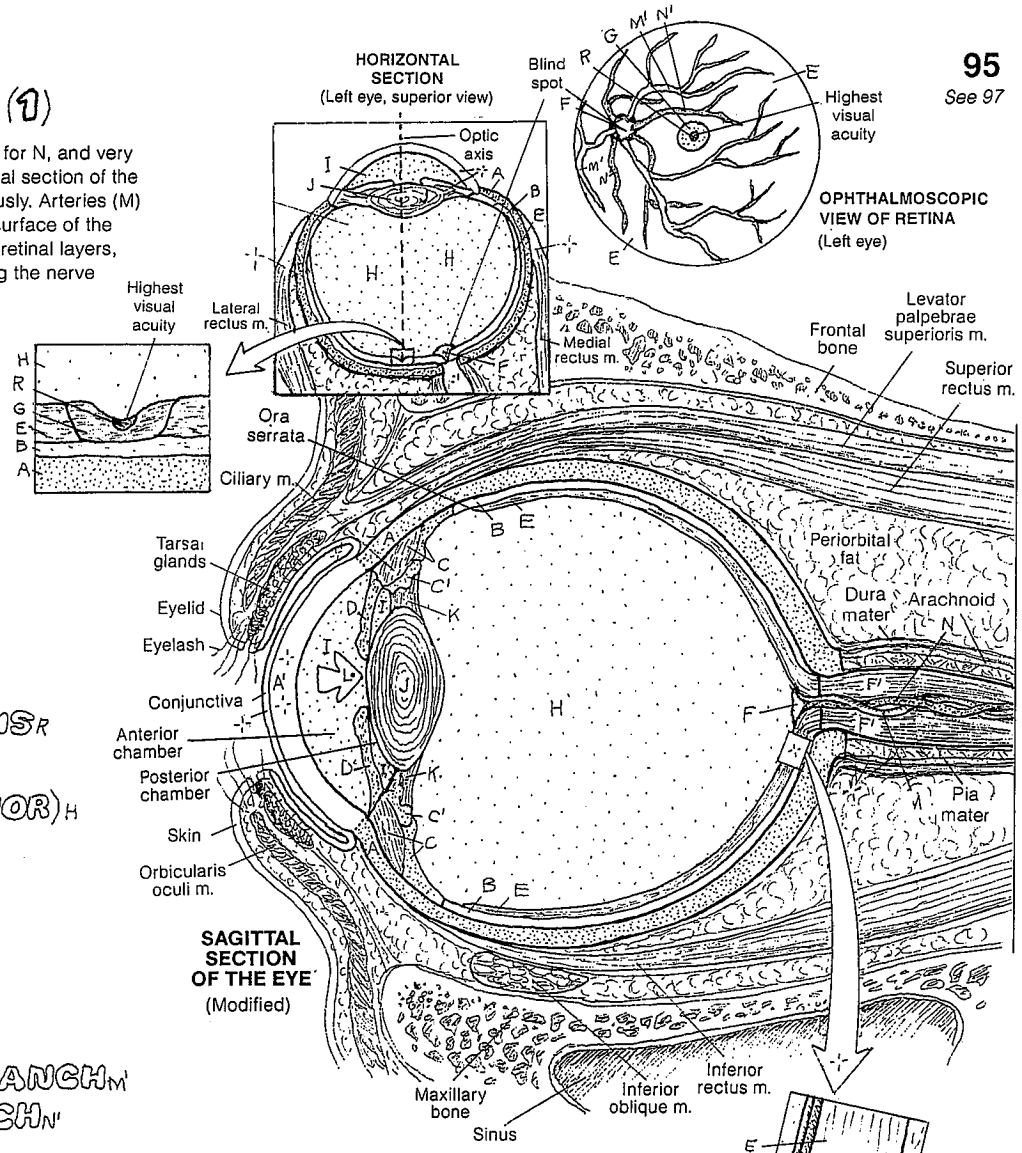
VISUAL SYSTEM (1)

CN: Use orange for E, yellow for G, red for M, blue for N, and very light colors for C, H, I, J, and K. (1) Color the sagittal section of the eyeball and the uppermost illustrations simultaneously. Arteries (M) and veins (N) are too narrow to be colored on the surface of the retina in the sagittal section. (2) When coloring the retinal layers, color gray the arrows (in dark outlines) representing the nerve impulse.



EYE LAYERS

- SCLERA A /
  - CORNEA A'
- CHOROID B
- CILIARY BODY C
  - PROCESS C'
  - IRIS D
- RETINA E
  - OPTIC DISC F
  - MACULA LUTEA G
    - FOVEA CENTRALIS R

FLUIDS

- VITREOUS BODY (HUMOR) H
- AQUEOUS HUMOR I

OTHER STRUCTURES

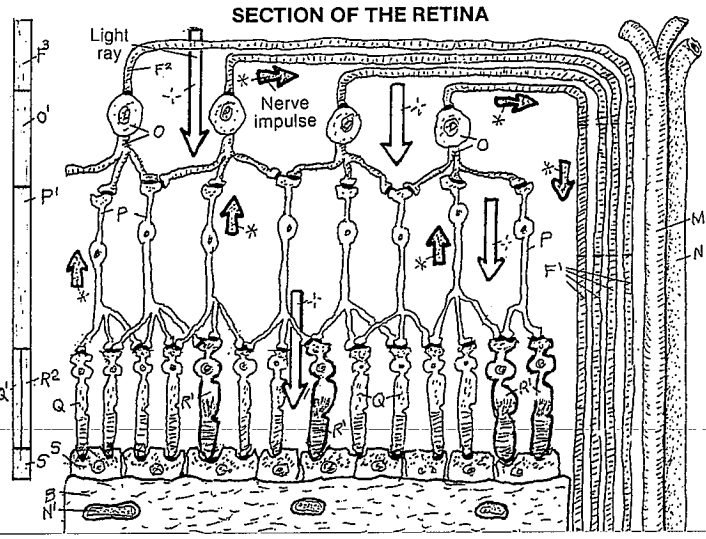
- LENS J
  - SUSPENSORY LIG. K
- PUPIL L
- OPTIC NERVE F'
- RETINAL ARTERY M / BRANCH M'
- RETINAL VEIN N / BRANCH N'

The eye is a layer of photoreceptor cells and associated neurons (retina) packaged within a white, fibrous, rubberlike protective globe (*sclera*) that is transparent in front (*cornea*). The cornea, composed of five layers of epithelia and fibrous tissue, is the chief refractive medium of the eye, focusing light rays onto the retina. The *lens* (tightly packed, encapsulated non-elastic lens fibers derived from epithelial cells) also refracts light, and up to middle age, it can vary its shape (and refractive index). The *aqueous humor* (extracellular fluid) filling the anterior and posterior chambers of the eye, and the more gelatinous (99% water) *vitreous humor* taking up 80% of the globe's volume, function as refractive media. The inner surface of the posterior two-thirds of the sclera is lined with a vascular, highly pigmented layer (*choroid*) that absorbs and prevents scattering of light. The choroid thickens anteriorly as the pigmented, fibromuscular *ciliary body* that surrounds the lens. The ciliary body projects outpocketings (*processes*) to which *suspensory ligaments* from the lens attach. On the anterior aspect of the ciliary body, a thin, pigmented, epithelial and fibromuscular layer (*iris*) circumscribes the hole (*pupil*) in front of the lens.

The retina lines the posterior half of the interior of the globe, and a bit more, ending anteriorly at the ora serrata. At the retinal end of the optic axis, there is a yellow pigmented area (*macula lutea*) within which is a depressed area called the *fovea centralis*. Under lighted conditions, this is the center of greatest visual acuity (clarity of form and color), reflecting a dense accumulation of color-sensitive cells (cones). About 3 mm to the nose side of the macula, axons of the nerve fiber layer stream out through the optic disc to become the *optic nerve*. The *optic disc* is devoid of light-sensitive cells and is therefore a blind spot. The *pigmented layer* of the retina (refreshing pigment to the adjacent rods/cones) is closest to the choroid. The photoreceptor layer consists of *cone cells* (sensitive to form and color) and color-insensitive *rod cells* possessing great sensitivity to light. *Bipolar cells* receive and mediate input from rod and cone cells and conduct resultant impulses to the *ganglion cell layer*. Among these two more-peripheral layers are interwoven numerous horizontal cells (not shown for visual clarity) that influence neuronal activity. The axons of the ganglion cells, the final common pathway of retinal activity, form the fibers of the optic nerve.

LAYERS OF RETINA E

- AXON F² / NERVE FIBER LAYER F³
- GANGLION CELL O / LAYER O'
- BIPOLAR CELL P / LAYER P'
- ROD CELL Q
- CONE CELL R'
- LAYER Q' R²
- PIGMENTED EPITHELIAL LAYER R



See 95

VISUAL SYSTEM (2)

CN: Use the same colors as were used on the previous plate (with different subscripts) for structures J, K, L, M, N', and O. Use light colors for A, G, H, and I. Note that various structures in the central illustration also appear in the illustration below it.

ACCESSORY STRUCTURES

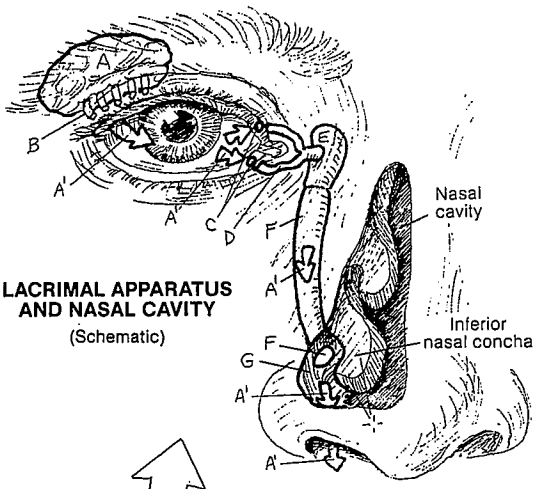
- LACRIMAL APPARATUS
  - LACRIMAL GLAND A
    - TEAR A'
      - DUCT B
  - LACRIMAL PUNCTA C
    - CANAL D
      - LACRIMAL SAC E
  - NASOLACRIMAL DUCT F
- INFERIOR MEATUS OF NASAL CAVITY G
- TARSAL PLATE/GLAND H
- CONJUNCTIVA I

Fluid (tears) interfacing the conjunctivae of the eyelid (palpebra) and the cornea facilitate easy movement of the lids over the cornea without inducing irritation. Tears also function as a vehicle for moving epithelial debris and microorganisms from the corneal surface and undersurface of the eyelids into the nasal cavity via the lacrimal apparatus. Thus, there is an anatomic basis for blowing your nose after a good cry. The absence of tears can cause remarkable pain and even blindness. The principal gland for tears is the *lacrimal gland*, located in the anterior, superior and lateral (temporal) aspect of the orbit. Other glands and sources of tears include unicellular (goblet) glands of the conjunctiva and *tarsal glands* of the lids. Episodic blinking (rapid cycle of lid approximation and retraction) maintains a film of tears on the conjunctiva and resists "dry eye." Routine closing of the lids occurs with muscle relaxation; energetic closure requires the orbicularis oculi muscle. Retraction of the eyelids is accomplished by smooth muscle fibers (tarsal muscle of Müller; sympathetic innervation) and the levator palpebrae muscle in the upper lid.

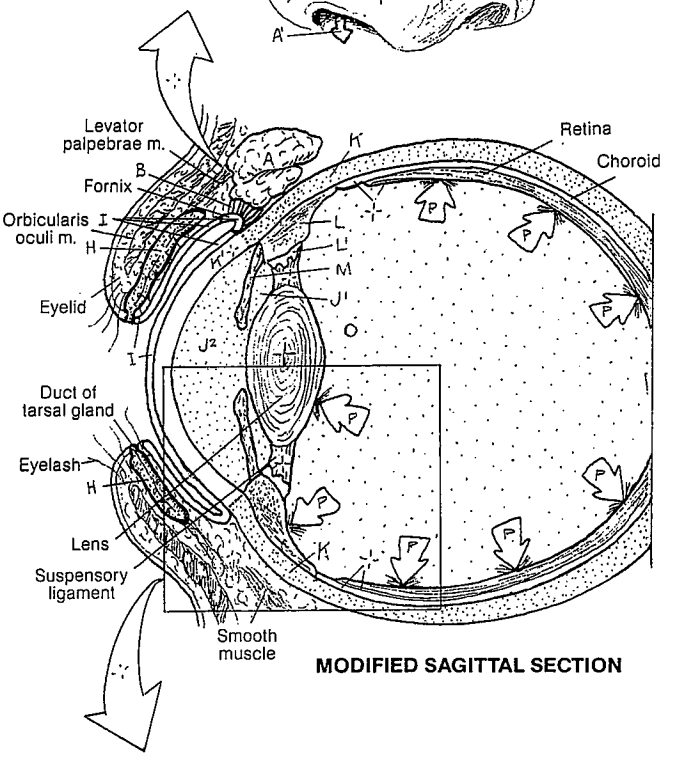
SECRETION/DRAINAGE OF AQUEOUS HUMOR

- FLOW OF AQUEOUS HUMOR J
  - SCLERA K
    - CORNEA K'
  - CILIARY BODY L
    - PROCESS L'
  - POSTERIOR CHAMBER J'
  - IRIS M
  - ANTERIOR CHAMBER J²
  - CANAL OF SCHLEMM N
    - VEIN N'
- VITREOUS BODY O
- INTRAOCULAR PRESSURE (IOP) P

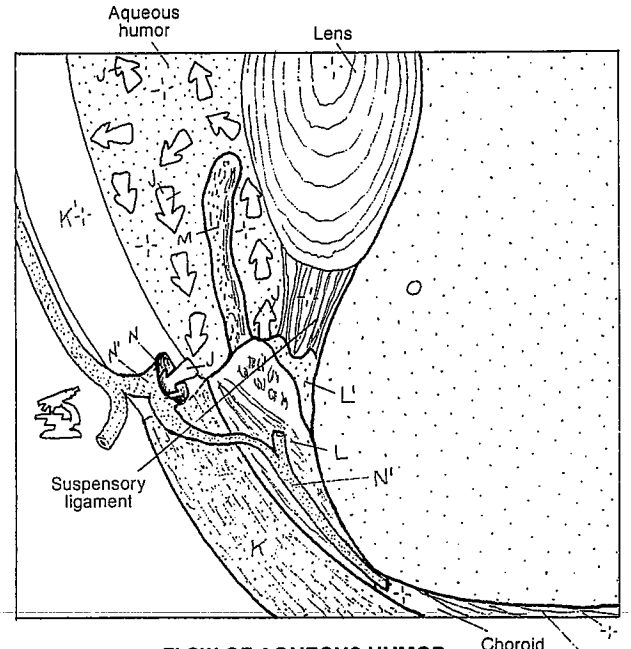
Aqueous humor is a fluid in the anterior and posterior chambers of the eye, secreted by cells of the *ciliary processes* (see lowest drawing). Fluid and electrolytes also enter by diffusion from the *ciliary body*. Aqueous humor is a clear, plasma-like fluid (but constituted differently). It is filtered into the *canal of Schlemm* (scleral venous sinus), a modified vein filled with fibrous trabeculae, located at the sclero-corneal junction. Fluid in the canal drains into nearby *veins*. Obstruction to drainage is one of several causes of increased *intraocular pressure*, in which the increasing pressure in the anterior/posterior chambers presses on the lens, which presses on the *vitreous* (99% water) body. As water cannot be compressed, pressure is applied to the contiguous retina. Unrelenting pressure compresses vessels to the axons and neurons of the retina, damages neurons, and can result in blindness (glaucoma).



LACRIMAL APPARATUS AND NASAL CAVITY
(Schematic)



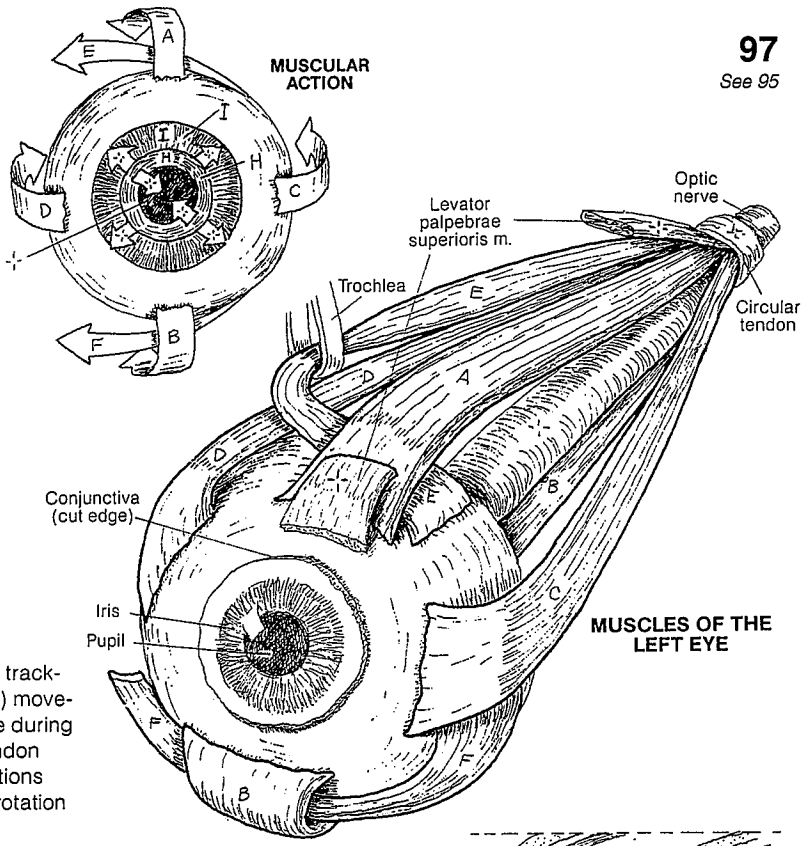
MODIFIED SAGITTAL SECTION



FLOW OF AQUEOUS HUMOR

VISUAL SYSTEM (3)

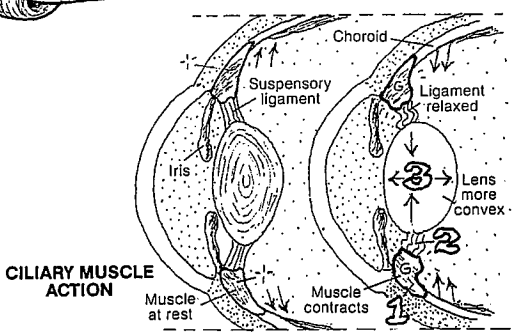
CN: Use light colors for A–F, H, and I. Use contrasting colors for J and K. (1) After coloring each eye muscle, color its functional arrow in the upper diagram. (2) In the drawing on ciliary action, color only the contracted ciliary muscles. (3) Carefully color the diagram below, noting that only the first titles (visual field) receive J and K colors. The rest of the titles are left uncolored, but use the two colors on the structures to which they refer.



EXTRAOCULAR MUSCLES

- SUPERIOR RECTUS (ELEV.) A
- INFERIOR RECTUS (DEPR.) B
- LATERAL RECTUS (ABD.) C
- MEDIAL RECTUS (ADD.) D
- SUPERIOR OBLIQUE (ROT. R.) E
- INFERIOR OBLIQUE (ROT. L.) F

The extraocular (extrinsic) muscles of the eye provide for a remarkable tracking capacity of the eye. CNS mechanisms permit conjugate (binocular) movement of both eyes. Slowed, incomplete, or absent movement of one eye during tracking movements suggests cranial nerve dysfunction or muscle/tendon incarceration, as might occur in an orbital plate fracture. The true functions of these muscles is more complex than shown, one reason being eye rotation and torsion requiring multiple muscle action. Deviation from co-equal alignment of the eyes is called strabismus.



INTRINSIC MUSCLES

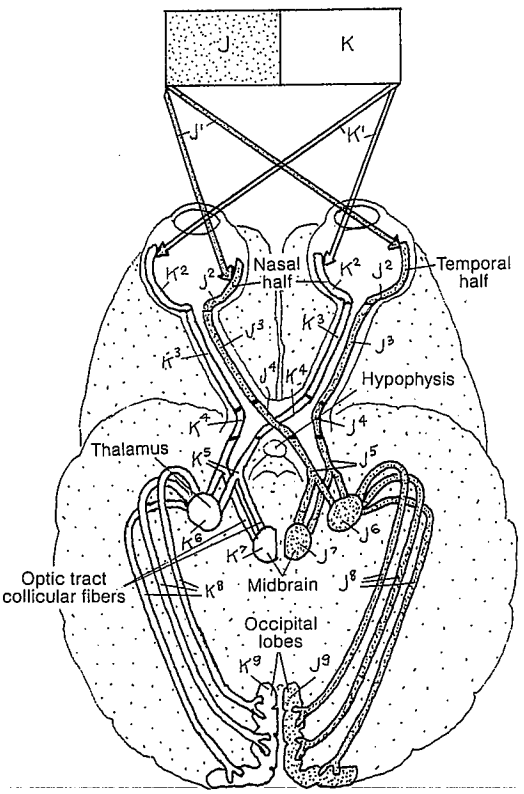
- CILIARY G
- SPHINCTER PUPILLAE H
- DILATOR PUPILLAE I

The intrinsic muscles are located in the ciliary body (ciliary muscle) and the iris (pupillary dilator and sphincter). Contraction of the *ciliary muscles* (1) wrinkles the ciliary body tissue and puts slack in the processes, giving laxity to the suspensory ligaments (2) and permitting the lens to round up on its own accord (tension in lens fibers) (3). These muscles function (by parasympathetic innervation) during near vision in which greater refractivity is desired. The *dilator pupillae* consists of myoepithelial cells that pull the iris toward the ciliary body, dilating the pupil (sympathetic innervation). The *sphincter pupillae* circumscribes the inner iris; its contraction constricts the iris, narrowing the pupil (parasympathetic innervation). See the uppermost drawing.

VISUAL PATHWAYS

- VISUAL FIELD J / VISUAL FIELD K
- LIGHT WAVE (J', K')
- RETINA (J^2, K^2)
- OPTIC NERVE (J^2, K^2) CHIASMA (J^4, K^4) TRACT (J^5, K^5)
- LATERAL GENICULATE BODY (J^6, K^6)
- SUPERIOR COLLICULUS (J^7, K^7)
- OPTIC RADIATION (J^8, K^8)
- VISUAL CORTEX (J^9, K^9)

As you color the lower diagram, note that the axons (K^2) from the *retinas* on the temporal side of the optic axis do not cross at the *chiasma*. Note further that an expanding tumor of the hypophysis is likely to impair visual acuity in the temporal visual fields only ("tunnel vision"). The *thalamus* functions as a visual relay center, informing multiple memory areas and other centers of the stimulus. The *superior colliculi* are visual reflex centers, making possible rapid head and body movements in response to a visual threat. Finally, note that the image of the stimulus impinging on the *visual cortex* (K/J) is the reverse of that which was actually seen (J/K). Integration of visual and memory centers at the visual cortex makes possible perception of the image as actually seen.



VISUAL PATHWAYS
(Horizontal brain section, schematic)

See 99

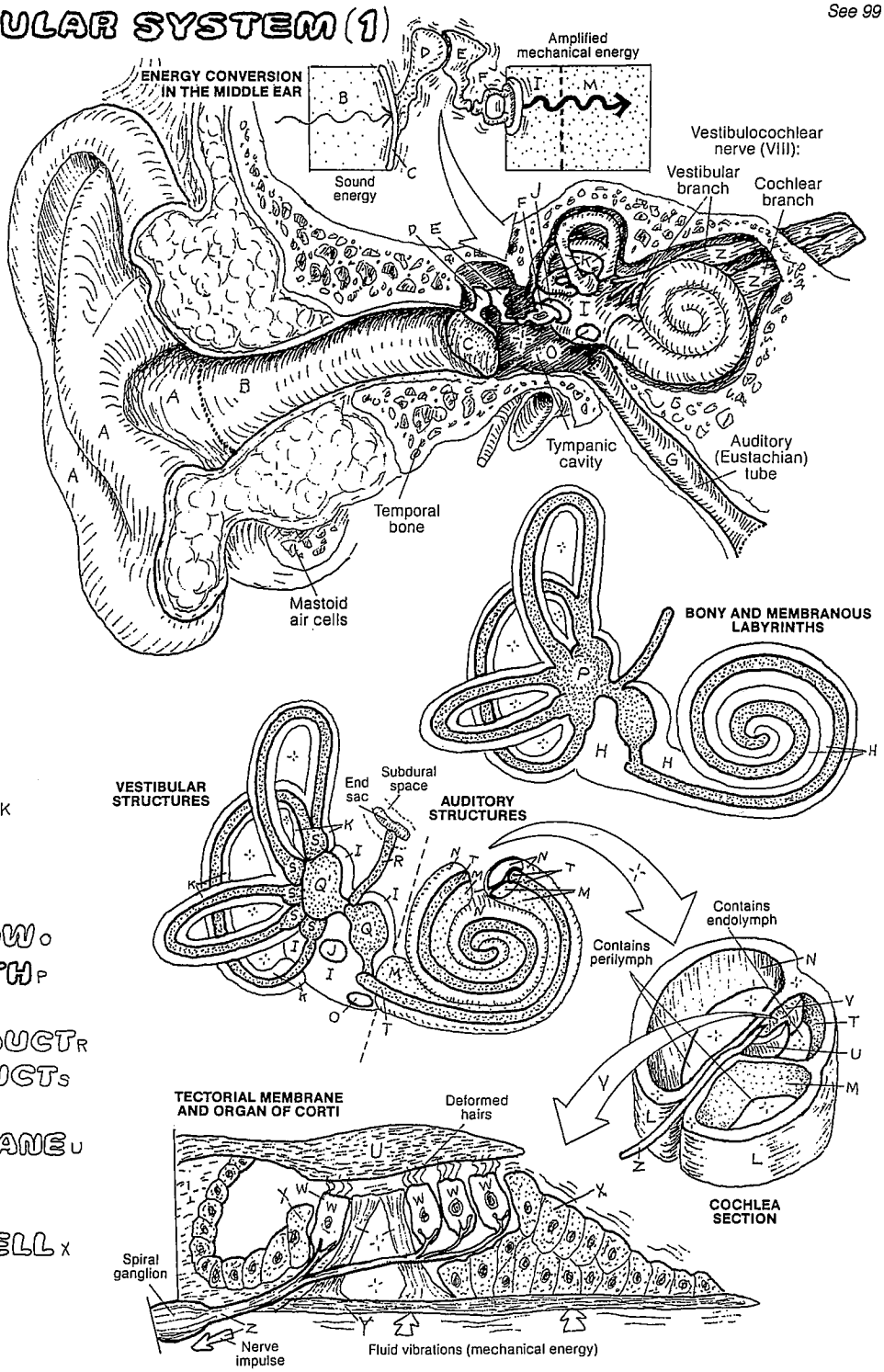
AUDITORY & VESTIBULAR SYSTEM (1)

CN: Use yellow for Z, and light colors for A, B, G, I, M, N, W, and X. The view of the internal ear is magnified in the upper illustration for coloring purposes. Color your way down the plate, beginning with the diagram at the top.

EXTERNAL EAR
- AURICLE A
- EXT. AUDITORY MEATUS B
- TYMPANIC MEMBRANE C

MIDDLE EAR
- MALLEUS (HAMMER) D
- INCUS (ANVIL) E
- STAPES (STIRRUP) F
- AUDITORY TUBE G

INTERNAL EAR
- BONY LABYRINTH H
  - VESTIBULE I
    - OVAL WINDOW J
  - SEMICIRCULAR CANAL K
  - COCHLEA L
    - SCALA VESTIBULI M
    - SCALA TYMPANI N
      - ROUND WINDOW O
- MEMBRANOUS LABYRINTH P
  - SACCULE Q / UTRICLE Q'
    - ENDOLYMPHATIC DUCT R
    - SEMICIRCULAR DUCTS S
  - COCHLEAR DUCT T
    - TECTORIAL MEMBRANE U
    - ORGAN OF CORTI V
      - HAIR CELL W
      - SUPPORTING CELL X
  - BASILAR MEMBRANE Y
  - CRANIAL NERVE VIII Z



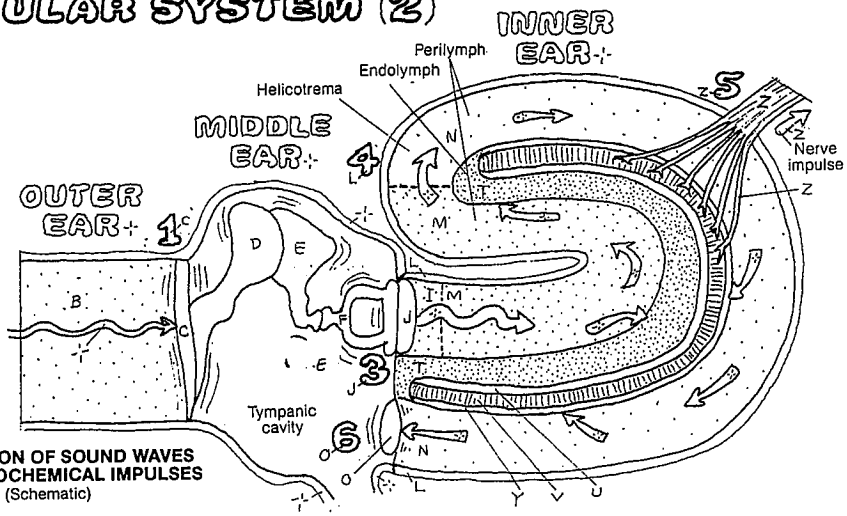
The ear is the organ of hearing and equilibrium (auditory and vestibular systems). It is organized into external, middle, and internal parts. The external ear includes the *auricle* (collector of sound energy) and the *external auditory meatus* or canal (a narrow passageway conducting sound energy to the *tympanic membrane*). This membrane, lined externally by skin and internally by respiratory mucosa, converts sound energy into mechanical energy by resonating in response to incoming sound waves.

The middle ear is a small area filled with much structure, including three small bones (*malleus, incus, stapes*) joined together by synovial joints. These ossicles vibrate with movement of the tympanic membrane, and amplify and conduct the mechanical energy imparted to them to the waters of the inner ear at the flexible, water-tight *oval window* (middle ear/inner ear interface). At the anterior-medial aspect of the middle ear cavity, the *auditory tube* runs to the nasopharynx, permitting equilibration of air pressure between nasal cavity (outside) and the middle ear.

The internal ear, carved out within the petrous portion of the temporal bone, consists of a series of interconnecting bony-walled chambers and passageways (*bony labyrinth: vestibule, semicircular canals,* and *cochlea*) filled with perilymph (extracellular-like) fluid. Within the bony labyrinth is a series of interconnecting membranous chambers and passageways (*membranous labyrinth: saccule, utricle, cochlear duct,* and *semicircular ducts*), filled with endolymph (intracellular-like fluid). The *endolymphatic duct*, derived from the *saccule*, ends in a blind sac under the dura mater near the internal auditory meatus (see Plate 25). It drains endolymph and discharges it into veins in the subdural space. Within the coiled, membranous *cochlear duct*, supported by bone and the fibrous *basilar membrane*, a ribbon of specialized receptor (*hair*) *cells* exists integrated with supporting cells, both covered with a flexible, fibrous glycoprotein blanket (*tectorial membrane*). This device (*Organ of Corti*) converts the mechanical energy of the oscillating tectorial membrane scraping against the receptor hair cells into electrical energy. The impulses generated are conducted along bipolar sensory (auditory) neurons of the *VIII cranial nerve.* (Continued on the next plate.)

AUDITORY & VESTIBULAR SYSTEM (2)

CN: Titles with subscripts 1, 2, and 3 require new colors; all other subscripts (A–Z) refer to titles and colors used on the preceding plate, which should be frequently referred to when using those same colors on this plate. (1) Color the numerals with the appropriate color as you follow the sequence of events in the simplified diagram to the right. See the previous plate for the more accurate anatomical structure. (2) Color the parts of the vestibular system concerned with the maintenance of dynamic and static balance.

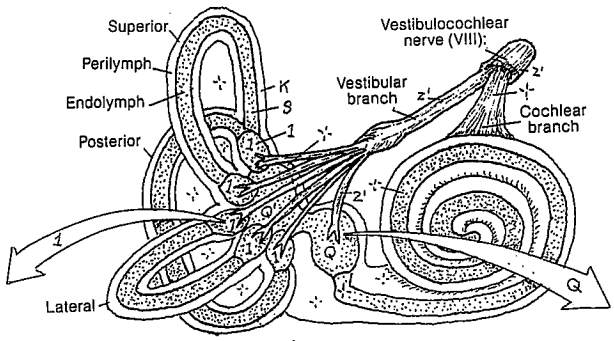


CONVERSION OF SOUND WAVES TO ELECTROCHEMICAL IMPULSES
(Schematic)

In review: the external ear collects sound waves and rifles them to the *tympanic membrane*, which converts the sound energy into mechanical energy. The linkage of *ossicles* increases the amplitude of the energy and transmits the force to the *oval window* of the bony labyrinth of the inner ear. Vibratory movements of the *stapes* in the window are transmitted to the perilymph of the *vestibule* of the bony labyrinth, creating wave-like motions of the fluid. These waves spread throughout the vestibule, then enter and move through the *scala vestibuli* of the *cochlea* to the helicotrema at the apex of the cochlea (2½ turns) and on around to the *scala tympani*, which terminates at the *round window*. Here, fluid waves and vibrations are dampened. The fluid motion in the scala vestibuli vibrates the roof of the membranous *cochlear duct*, creating endolymph waves in the cochlear duct. This motion stirs the *tectorial membrane*, which rubs against and bends the hair-like processes of the *receptor (hair) cells*, depolarizing them and inducing electrochemical impulses. These impulses are conducted by the sensory neurons of the cochlear division of the *VIII cranial nerve*. Stimulation of the hair cells from the apex of the cochlea to the base produces a continuum of increasingly high-pitched sound perceptions.

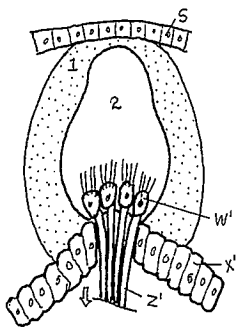
VESTIBULAR SYSTEM/EQUILIBRIUM

AMPULLA 1
CRISTA
CUPOLA 2
HAIR CELL W'
NERVE FIBER Z'
SUPPORTING CELL X'

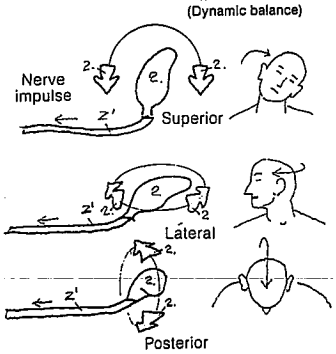


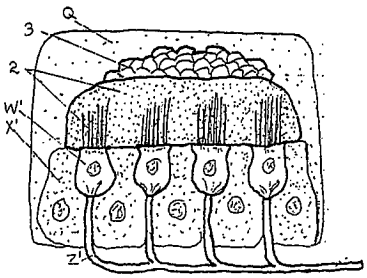
SEMICIRCULAR CANAL K
SEMICIRCULAR DUCT S

SACCULE Q UTRICLE Q'
MACULA
GELATINOUS LAYER 2
OTOLITH 3
HAIR CELL W'
NERVE FIBER Z'
SUPPORTING CELL X'

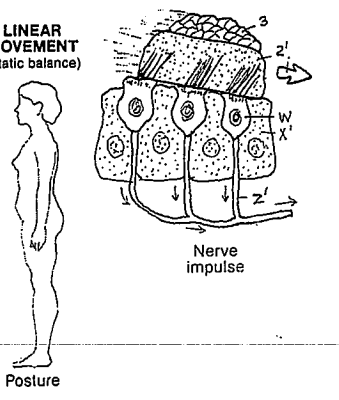


ROTATIONAL MOVEMENT
(Dynamic balance)





LINEAR MOVEMENT
(Static balance)



In review: the vestibular system is located in the inner ear. The bony *semicircular canals* are oriented at 90° to one another. Within these canals are the membranous *semicircular ducts*. Directly communicating with the utricle at one end, each duct terminates at the other end in an *ampulla*. Within the *saccule/utricle* and the ampullae are sensors responsive to fluid (endolymph) movement. Each ampulla has a hillock of cells (*crista* or crest) consisting of receptor (*hair*) and *supporting cells*. The hair-like processes of these receptor cells are embedded in a top-heavy, gelatinous *cupola* (like an inverted cup). Movement of endolymph in response to head turning, and especially rotation, pushes these cupolas, bending the hair cells and causing them to depolarize, generating an electrochemical impulse. The impulses travel out the vestibular part of the *VIII nerve* to the vestibular nuclei in the lower brain stem. When the body is rotated rapidly, horizontal, oscillatory eye movements occur (nystagmus). These eye movements are mediated by ampullary sensory input to the brain stem. Such movements represent the brain's attempt to maintain spatial orientation (by momentary visual fixation) during head and/or body rotation. Sensations of rotational movement in the absence of body rotation are called vertigo.

Within the utricle/saccule, *hair cells* and their *supporting cells* are covered with a *gelatinous layer* in which are embedded small calcareous bodies (*otoliths*). Movement of the endolymph induces movement of the gelatinous layer against the hair cells, with responses identical to those of the ampullary receptors. Receptor activity in the utricle/saccule is influenced by linear (horizontal and vertical but non-rotational) acceleration of the body. Vestibular receptors have strong neural connections with cranial nerve nuclei concerned with eye movement and with postural motor centers.

See 83, 137

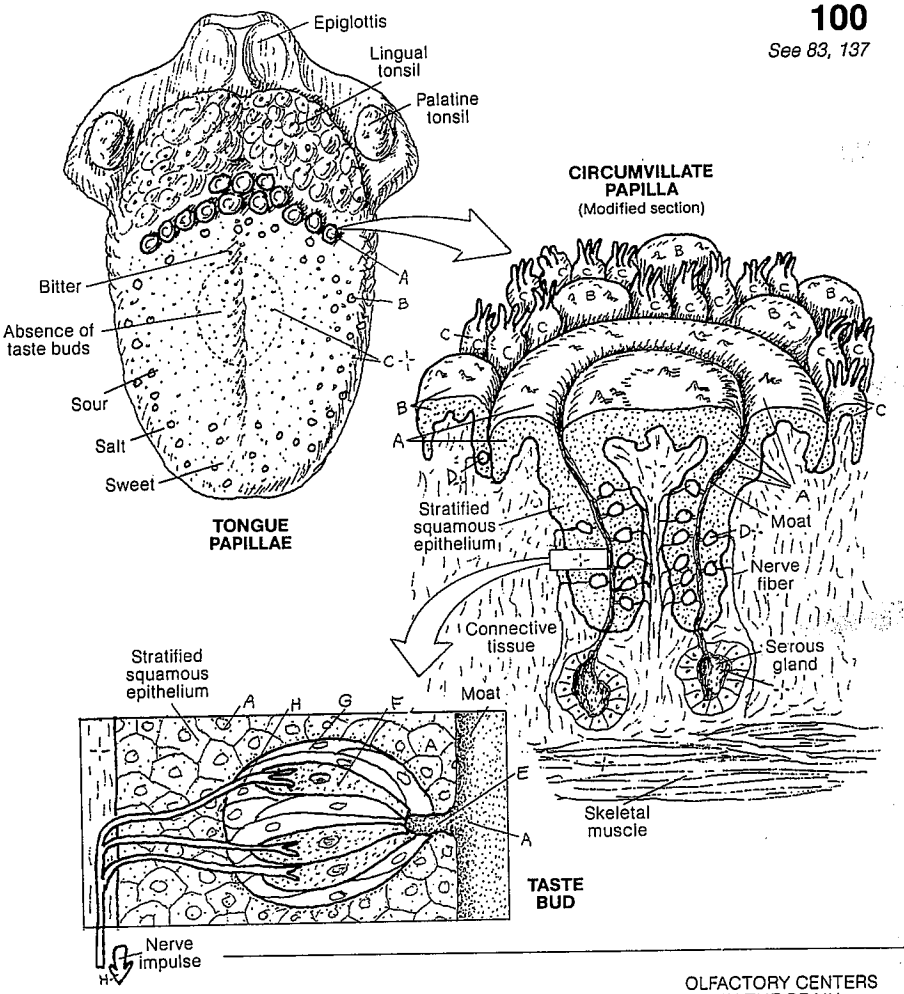
TASTE & OLFACTION

CN: Use yellow for H and light colors for A, B, C, G, and I. (1) Do not color the taste buds in the circumvallate papillae in the modified section at right. (2) In the lowest illustration, color over the neurons within the olfactory bulb.

PAPILLAE
- CIRCUMVALLATE A
- FUNGIFORM B
- FILIFORM C

TASTE BUD D
- PORE CANAL E
- RECEPTOR CELL F
- SUPPORTING CELL G
- NERVE FIBER H

Taste receptors (taste buds) are located within the stratified squamous epithelial lining of the sides (moats) of *circumvallate*, *foliate* (not shown), and *fungiform papillae* on the tongue and, to a lesser extent, on the soft palate and lingual side of the epiglottis. They are not seen in the tiny filiform papillae. Each taste bud consists of a number of *receptor cells* and their *supporting cells*. The apex of this oval cell complex faces the moat; here it opens on to the papillary surface via a taste pore or *pore canal*. Dissolved material enters the pore, stimulating the chemoreceptor (gustatory) cells. The impulses generated are conducted along *sensory axons* that reach the brain stem via the VII, IX, and X cranial nerves (recall Plate 83). Taste interpretation occurs at the lower reaches of the sensory cortex (post-central gyrus). Basic tastes (sweet, sour, salt, and bitter) notwithstanding, interpretation of taste, as a practical matter, is a function of smell, food texture, and temperature in association with taste bud sensations.



OLFACTION (SMELL)
- OLFACTORY GLAND I
  - OLFACTORY MUCOSA I'
    - OLFACTORY NEURON J
      - OLFACTORY HAIR (CILIA) K
    - SUPPORTING CELL G'
- OLFACTORY BULB H'
  - OLFACTORY TRACT H²

Olfactory receptors are *olfactory hairs* or cilia (actually modified peripheral processes) of *olfactory bipolar (sensory) neurons* buried in the *olfactory mucosa* at the roof of the nasal cavity. The olfactory mucosa also has tubulo-alveolar *olfactory glands* that function to keep the chemoreceptor endings clean and, along with nasal mucous secretions, dissolve the chemicals that are sensed by these receptors. The olfactory neurons ascend the roof of the nasal cavity, through the cribriform plate of the ethmoid bone, and their central processes synapse with second-order neurons in the *olfactory bulb*. The axons of these neurons form three olfactory bundles (stria) as part of the *olfactory tract*, terminating in the inferior frontal lobe and medial temporal lobe. Here exists the neural basis for olfactory relationships with memory, eating, survival, sex, and other emotional behavior.