Chapter 13 – Senses

Objectives

Given the synopsis in this chapter, competence in each objective will be demonstrated by responding to multiple choices or matching questions, completing fill-in questions, or writing short answers, at the level of 75% or greater proficiency for each student.

A. To locate and name parts of the body that initiate general somatic senses.
B. To locate and name parts of the body that initiate special senses.
C. To locate and name the major layers of skin and the cutaneous receptors.
D. To explain how general sensory neurons detect sensory information.
E. To locate and name the major parts of the eye.
F. To explain how the eye detects visual information.
G. To locate and name the major parts of the ear.
H. To explain the ear detects auditory information.

The primary purpose of the nervous system is to collect sensory information, process information, generate representations of our experience, and produce motor responses. Sensory neurons and sensory receptors are essential for collecting sensory information.

Sensory Receptors

Anatomical classes of receptors and sensory neurons

Sensory receptors are either specialized dendrites of sensory neurons or separate cells that synapse with the dendrites of sensory neurons. The three major anatomical classes of sensory receptors are illustrated in Figure 13.1.

- Free nerve endings are the dendrites of sensory neurons.
- Encapsulated nerve endings are the dendrites of sensory neurons enclosed in fibrous connective tissue.
- Accessory sensory receptor cells are separate cells that synapse with the dendrites of sensory neurons.

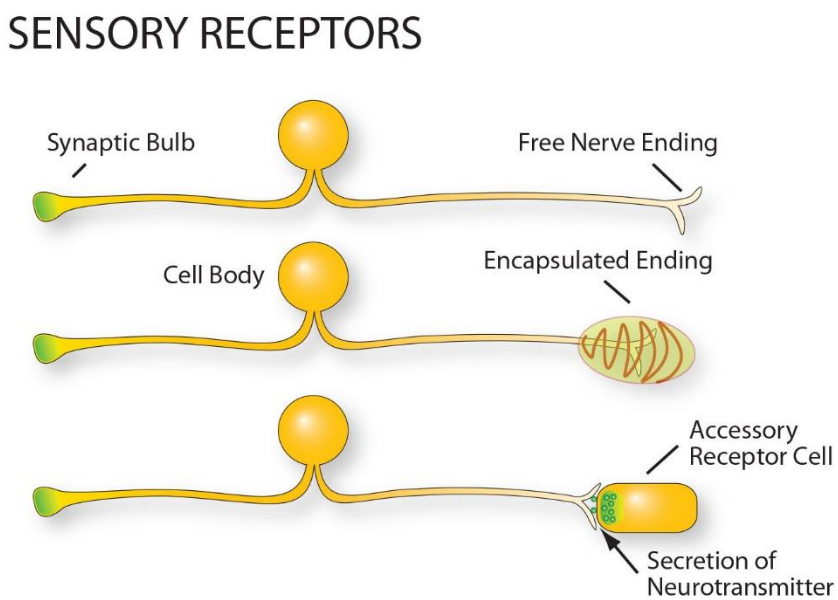


Figure 13.1 © 2014 David G. Ward, Ph.D.

Functional classes of receptors

Sensory receptors fall into five major categories:

- Mechanoreceptors – directly respond to local movement; use ion channels.
- Thermoreceptors – directly respond to temperature; use ion channels.
- Chemoreceptors – respond to local chemistry; directly or indirectly use ion channels
- Nociceptors – respond to tissue damage; directly or indirectly use ion channels.
- Photoreceptors – respond to light; indirectly use ion channels.

Receptors for General senses (Somatosensory, Viscerosensory)

General senses usually refer to sensations related to the skin, muscle, or internal organs. These sensations are typically touch, pressure, temperature, pain, and body chemistry. Sensations related to skin and muscles are called **somatosensory**. Thermoreceptors, chemoreceptors, and nociceptors usually use <u>free nerve endings</u>. Cutaneous mechanoreceptors usually use <u>encapsulated nerve endings</u>.

- **Thermoreceptors** respond to temperature and are responsible for detecting hot and cold,
- **Chemoreceptors** respond to chemical changes and are responsible for detecting such things as glucose or hydrogen ions.
- **Nociceptors** respond to tissue damage and are responsible for detecting pain.
- **Cutaneous Mechanoreceptors** respond to movement and are responsible for detecting touch, pressure and vibration.

Receptors for Special senses (Smell, Taste, Hearing, Balance, Vision)

Special senses usually refer to sensations related to the ears, tongue, nose, and eyes: hearing (**Auditory**), balance (**Vestibular**), taste (**Gustatory**), smell (**Olfactory**), and sight (**Visual**). All receptors for special senses use <u>accessory sensory receptor cells</u>.

- **Auditory Mechanoreceptors** (Hair cells) respond to movement in the cochlea and are responsible for the detection of sound
- **Vestibular Mechanoreceptors** (Hair cells) respond to movement in the vestibule and are responsible for the detection of balance.
- **Gustatory Chemoreceptors** (Taste Cells) respond to chemical changes and are responsible for the detection of tastes.
- **Olfactory chemoreceptors** (Olfactory Cells) respond to chemical changes and are responsible for the detection of odors.
- **Visual Photoreceptors** (Rods and Cones) respond to light and are responsible for the detection of visual images.

Sensory Transduction and Coding

Sensory transduction

A sensory stimulus, such as touch acting on movement gated channels of a tactile receptor, causes a small change in the membrane potential that is proportional to the stimulus. Please refer to Chapter 12. If the graded potential reaches about -60 mV to -55 mV in the axon, an action potential is generated and then propagated to the central nervous system.

Sensory coding

Receptors for specific sensory modalities are connected, in general, to specific regions of the brain. (This pattern of organization is often referred to as a "Labeled line.")

The pattern of the action potentials provides information about strength, duration, and other characteristics of the sensory stimuli. Some sensory receptors are rapidly adapting and others are slowly adapting. As shown in Figure 13.2, different types of receptors respond differently to the same stimulus.

- Rapidly adapting receptors produce transient responses to the stimulus.
- Slowly adapting receptors produce responses that are more proportional to the stimulus.

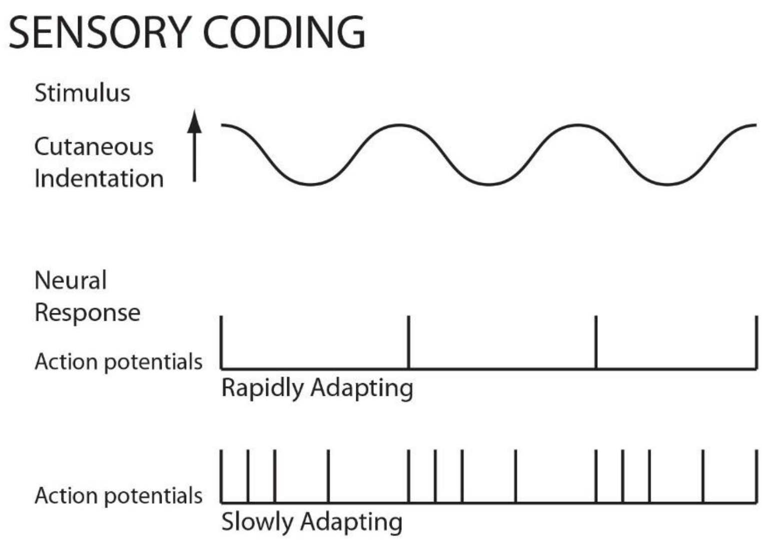


Figure 13.2 © 2014 David G. Ward, Ph.D.

Adaptation and central processing

Sensory stimulation frequently goes unnoticed. The reason for this is due to reductions in responsiveness of the sensory receptors and /or to the neurons in the central nervous system. First, as noted above, sensory stimulation of rapidly adapting receptors will cause only a transient response in the sensory neuron. Second, continued activity in a sensory neuron often causes only a transient response of the target neuron in the central nervous system.

- Reduced sensitivity of the receptor is called Sensory Adaptation.
- A reduced response of neurons in the central nervous system is called Central Adaptation (Habituation).

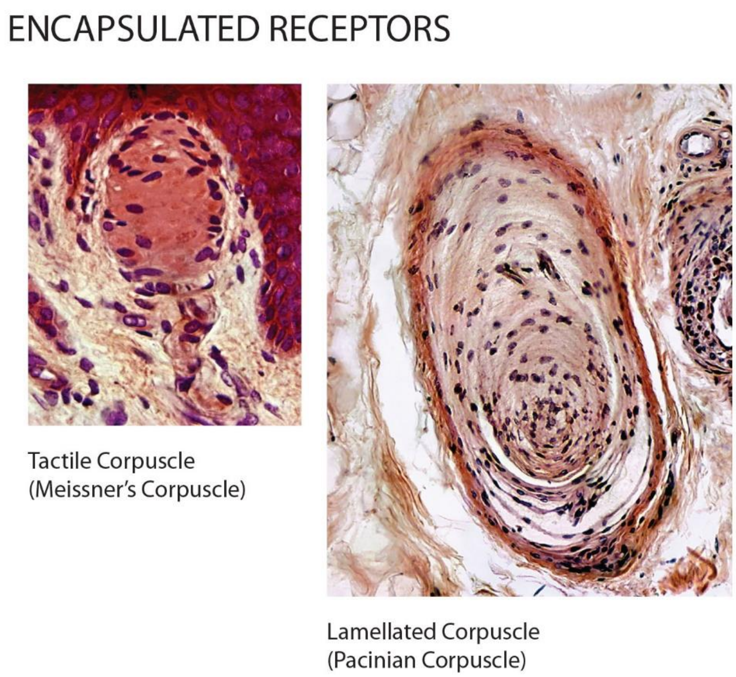
Central adaptation plays a critical role in our ability to filter and ignore irrelevant sensory information.

Somatosensory Sensation

Touch, vibration, pressure

Stimulation of cutaneous mechanoreceptors produces the sensation of touch, vibration, and pressure. Photomicrographs of two types of encapsulated mechanoreceptors, tactile corpuscles (Meissner's corpuscles) and lamellated corpuscles (Pacinian corpuscles), are shown in Figure 13.3. Please refer back to Chapter 3, especially Figure 3.5 for a review of the organization of skin.

- Tactile corpuscles (Meissner's corpuscles) are encapsulated receptors that detect light touch and vibration, and are rapidly adapting.
- Lamellated corpuscles (Pacinian corpuscles) are encapsulated receptors that detect pressure, and are rapidly adapting.
- Signals about touch, vibration, and pressure are mediated by myelinated neurons.



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Stretch of Muscle and Tendons

Mechanoreceptors also measure muscle stretch and provide signals to the spinal cord for reflex adjustment of muscle length, and to the brain for information about body position.

- Skeletal muscles contain specialized muscle spindles with free nerve endings that detect stretch of skeletal muscles.

- Tendons contain free nerve endings that detect stretch of tendons.

Pain

Stimulation of cutaneous nociceptors produce the sensation of pain, autonomic responses, fear and anxiety, and reflexive withdrawal.

- Fast or prickling pain that is easily localized is mediated by myelinated neurons.
- Slow or aching pain that is poorly localized is mediated by unmyelinated neurons.

Stimulation of nociceptors in the viscera also produces the sensation of pain. However, the pain often seems to be localized to a body surface and is called referred pain. This is because many neurons in the central nervous system often receive input from both somatic and visceral sensory neurons.

Central Pathways of Somatosensory Signals

The sensation of light touch, touch, pressure, vibration, temperature and pain are determined through a series of neural connections (pathways).

- Axons from the primary sensory neurons (first order neurons) synapse with neurons in the spinal cord or brainstem (second order neurons).
- Axons from neurons in the spinal cord or brainstem synapse with neurons in the thalamus in the opposite side of the brain (third order neurons).
- Axons from neurons in the thalamus synapse with neurons in the primary somatosensory cortex in the opposite side of the brain (fourth order neurons).
- Processing of somatosensory information continues far past the primary somatosensory cortex and continues into the parietal lobe (somatosensory association area).

Eye and Vision

Organization of the eye

The eye is composed of three major layers, as shown in Figure 13.4. These layers are shown in the following colors: white/tan, blue, and orange.

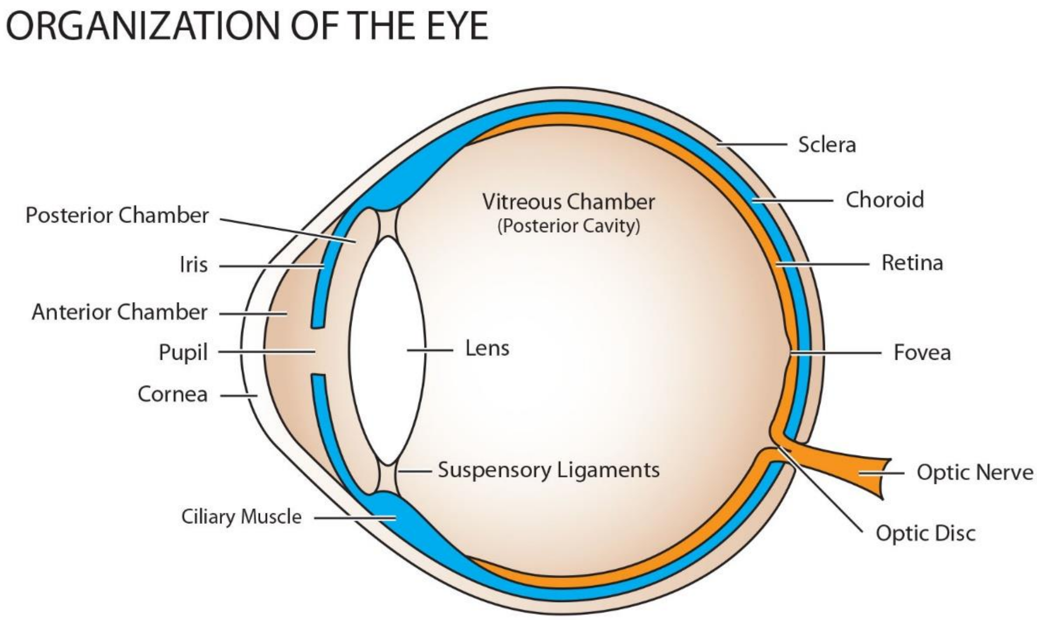

Figure 13.4 © 2014 David G. Ward, Ph.D.

The outmost layer (white/tan) includes the cornea and the sclera. The cornea is the transparent front of the eye. The sclera is opaque and the "white" of the eye.

- The cornea is responsible for the coarse focusing of light.

The middle layer (blue) includes the choroid, ciliary body, and iris. The choroid is a vascular layer under the sclera. The ciliary body and iris extend anteriorly from the choroid. The **lens** (also named **crystalline lens**) is suspended by ligaments from the ciliary body. The iris continues behind the cornea. The **pupil** is the opening of the iris.

- The crystalline lens is responsible for the fine focusing of light.
- The ciliary body contains muscle to change the shape of the lens.
- The iris contains muscles to change the size of the pupil.

The innermost layer (orange) includes the **retina**. The retina is generally under the choroid, and is separated from the choroid by a pigment layer.

- Axons from the retina merge together at the optic disk to form the optic nerve.
- The highest density of photoreceptors is found in the fovea.

The space in front of the lens is called the **anterior chamber** (**cavity**), and is filled with a watery fluid. The space behind the lens is called the **posterior cavity**, and is filled with a gelatinous fluid.

Role of Eye Length and Shape of Crystalline Lens in Focusing

In order to see images in focus at different distances, either the eye has to change length or the lens has to change shape. Most commonly the length of the eye stays relatively constant and the crystalline lens changes shape. The light from structures at a distance requires the least bending of the light to produce an image that is in focus. In contrast, light from structures that are near requires the most bending of the light to produce an image that is in focus.

- When the eye is shorter than normal eye (**hyperopia**), focusing the image of a near object on the retina is typically <u>not possible</u>. However, focusing on a distant object is possible. Thus, a person with hyperopia is said to be "**farsighted**."
- When the eye is longer than normal eye (**myopia**), focusing the image of a near object on the retina is usually possible. However, focusing on a distant object is not possible. Thus, a person with hyperopia is said to be "**nearsighted**."

The term **lens accommodation** is used to refer to changes in the curvature of the crystalline lens that occur when we look at objects at different distances

- Positive Accommodation – change in lens curvature that occurs when an object is moved from a far distance to a close distance
    - Lens becomes more convex
- Negative Accommodation – change in lens curvature that occurs when an object is moved from close distance to a far distance
    - Lens becomes less convex

Central Pathways of visual signals

Axons from the ganglion cells of the retina provide the only route through which information leaves the retina.

Thalamus and Primary Visual (Striate) Cortex

The major visual pathways between the retina and the thalamus and between the thalamus and primary visual cortex are shown in Figure 13.5

- Axons from the retinal ganglion cells travel through the optic nerves, optic chiasm, and optic tracts to synapse with neurons in the thalamus
- Axons from the retinal ganglion cells also synapse with neurons in the midbrain to coordinate orientation of the eyes, head and neck.
- Axons from neurons in the thalamus synapse with neurons in the primary visual cortex
- Processing of visual information continues far past the primary visual cortex and continues into parietal and temporal lobes (visual association areas).

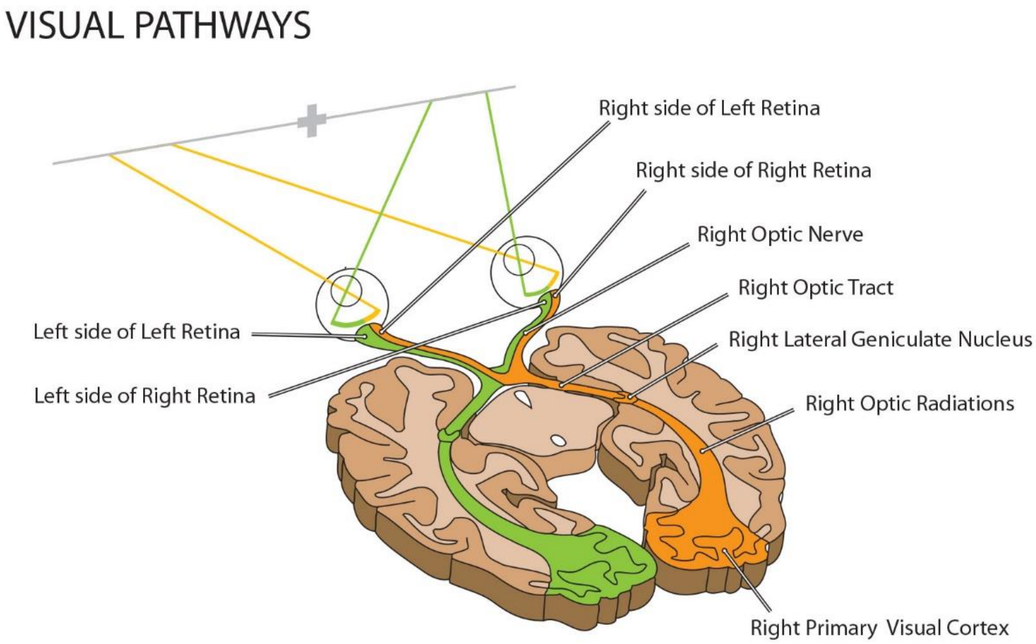

Figure 13.5 © 2014 David G. Ward, Ph.D.

The responses of neurons of the primary visual cortex are similar to many of the neurons of the lateral geniculate nucleus that feed them. There are three distinguishable pathways:

- A pathway that is involved in the analysis of the movement of an object.
- A pathway that is involved in analysis of fine shape of an object.
- A pathway that is involved in analysis of the color of an object.

Ear, Cochlea and Hearing

Organization of the Ear

The ear is composed of three major regions, as shown in Figure 13.6. These regions are commonly called the outer ear, the middle ear, and the inner ear.

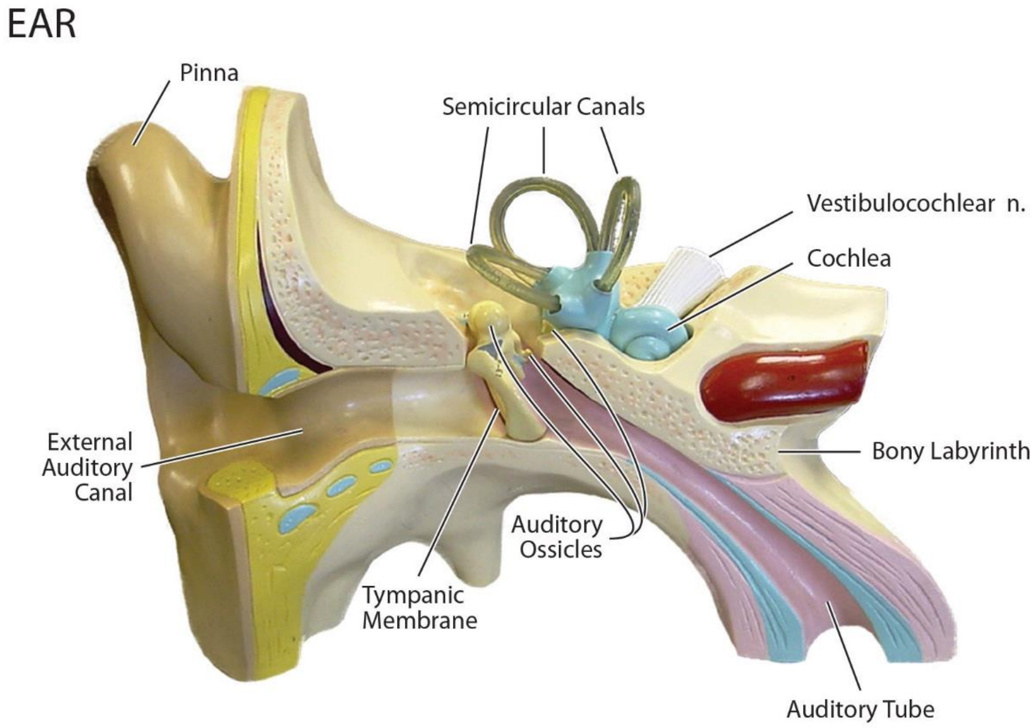

Figure 13.6 © 2014 David G. Ward, Ph.D.

The outer ear includes the **external auditory canal** and the **tympanic membrane**. The middle ear includes the **auditory ossicles** (**malleus, incus and stapes**) and the **auditory tube** (Eustachian tube). The inner ear includes the **cochlea**, the **vestibule** (**semicircular canals**), and the **vestibulocochlear** nerve. The inner ear and portions of the middle and outer ear are surrounded by the **bony labyrinth** of the temporal bone.

- Sound waves enter the external auditory canal where they are funneled to the tympanic membrane.

Auditory Ossicles

- The malleus, incus, and stapes transfer and mechanically amplify movement of tympanic membrane to the oval window of the cochlea.

Cochlea

A diagram of the cochlea is shown Figure 13.7. The upper right hand side shows the cochlea in its normal coiled shape within the bony labyrinth of the temporal bone. The lower part of the diagram shows the cochlea uncoiled. . The cochlea contains three ducts: the vestibular duct, the tympanic duct, and the cochlear duct.

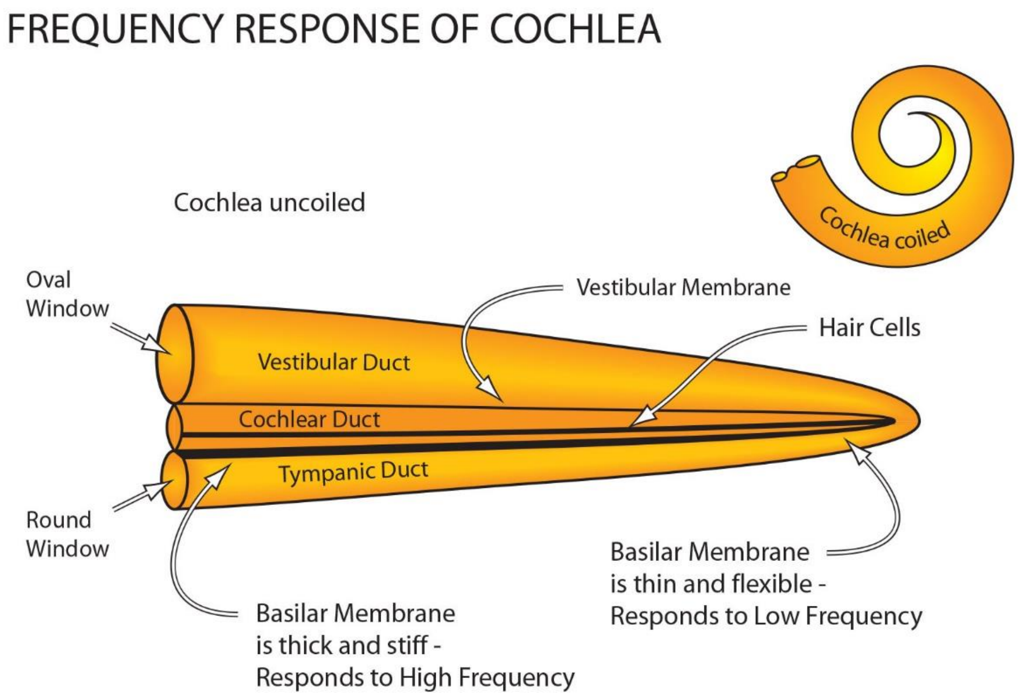

Figure 13.7 © 2014 David G. Ward, Ph.D.

- The **oval window** is connected to the beginning of the **vestibular duct**.
- At the center of the cochlea, the vestibular duct makes a hair-pin turn and becomes the **tympanic duct**, which terminates at the **round window**.
- The cochlear duct contains the **organ of Corti** and the **hair cells**.

Detection of sound, pitch and amplitude

Movement of the oval window of the cochlea leads to movement of fluid (perilymph) in the vestibular duct and tympanic duct. Movement of the perilymph moves the basilar membrane and moves the vestibular membrane which will move the fluid (endolymph) in the cochlear duct. Movement of the basilar membrane and the endolymph moves the stereocilia of the hair cells. As shown in Figure 13.7, the basilar membrane is stiffest near the oval window (the base) and most flexible far away from the oval window (the apex).

- High frequency sound vibrates the basilar membrane preferentially near the oval window where the membrane is stiffest.
- Low frequency sound vibrates the basilar membrane preferentially further from the oval window where the membrane is most flexible.

Detection of movement by the hair cells

Deformation of the basilar membrane leads to movement of the stereocilia of the hair cells, as shown in Figure 13.8. In the absence of distortion, the stereocilia of the hair cells are pulled straight.

- Upward movement of the basilar membrane and movement of the endolymph are responsible for moving the stereocilia of the hair cells.

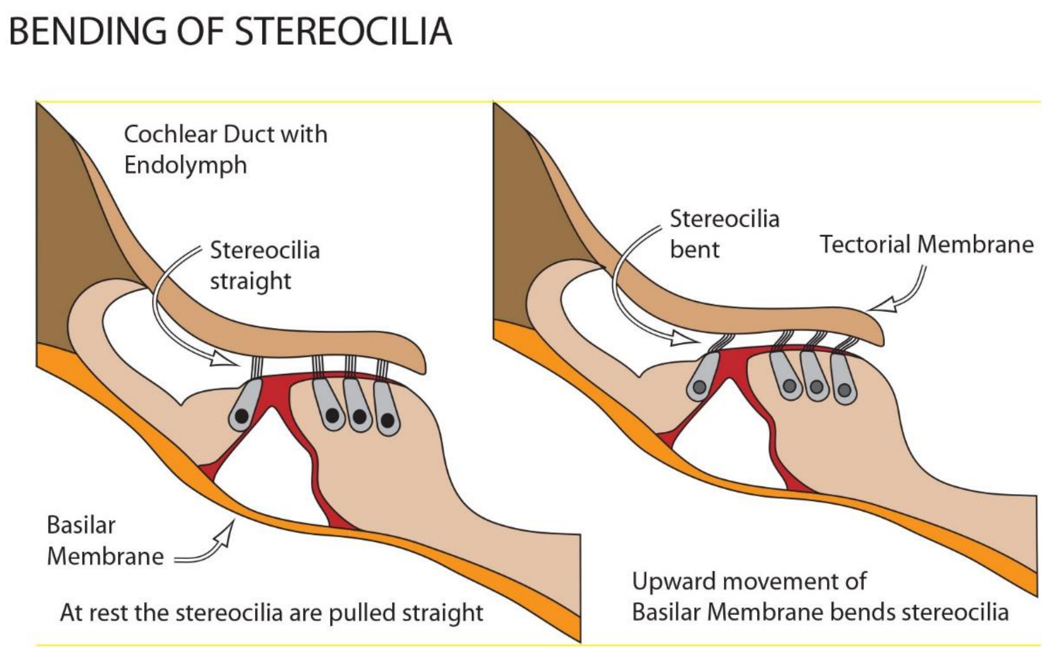

Figure 13.8 © 2014 David G. Ward, Ph.D.

Central pathways of auditory signals

Spiral ganglion cells transmit signals by way of actions potentials generated in response to glutamate from the hair cells. The major auditory pathways are shown in Figure 9.14.

- Hair cells synapse with the dendrites of spiral ganglion cells (first order neurons).
- Axons from the spiral ganglion cells synapse with neurons in various nuclei of the medulla of the brainstem.
- The axons of the neurons in the medulla synapse with neurons in the thalamus.
- The axons of the neurons in the thalamus synapse with neurons in the primary auditory cortex (temporal lobe).
- Processing of auditory information continues far past the primary auditory cortex and continues into parietal and temporal lobes (auditory association areas).