

# Medical Neuroscience | Tutorial Notes

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## Auditory System—Peripheral Mechanisms

### MAP TO NEUROSCIENCE CORE CONCEPTS<sup>1</sup>

- NCC1. The brain is the body's most complex organ.
- NCC3. Genetically determined circuits are the foundation of the nervous system.
- NCC6. The brain makes it possible to communicate knowledge through language.
- NCC7. The human brain endows us with a natural curiosity to understand how the world works.

### LEARNING OBJECTIVES

After study of the assigned learning materials, the student will:

1. Describe the biomechanics of sensory transduction in the middle and inner ear, including the tonotopy of the basilar membrane.
2. Characterize the neurophysiology of sensory transduction in auditory hair cells.

### TUTORIAL OUTLINE

- I. Introduction to the Auditory System
  - A. overview of auditory function: *the auditory system transduces sound waves into distinct patterns of neural activity that are then integrated with other sensations and motivations to guide behavior*
    1. sound waves are collected and amplified by physical structures in the external and middle ear for transfer to neural elements in the inner ear
    2. the biomechanical properties of the inner ear decompose complex sound waves into sinusoidal components, so that component frequencies, their amplitude, and their phase can be encoded in the firing of the receptor cells
    3. in the inner ear and throughout central processing stations, **tonotopy** is preserved; i.e., the systematic representation of sound frequency
    4. in the brainstem, the auditory information is first processed and divided into several parallel pathways, some of which compare the signals derived from the two ears, a process that allows for the localization of sounds in space
    5. in addition to local processing of auditory signals, brainstem centers relay information to the midbrain, which in turn projects to the auditory thalamus

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<sup>1</sup> Visit [BrainFacts.org](https://www.brainfacts.org) for Neuroscience Core Concepts (©2012 Society for Neuroscience ) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

6. the auditory cortex then receives input from the thalamus and processes more complex aspects of sounds, such as those related to human speech
- II. Sound
- A. comes from spherical pressure waves generated by vibrating air molecules (see [Figure 13.1](#)<sup>2</sup>) that can be characterized by their amplitude (loudness), frequency (pitch) and phase (temporal displacement) (see [Figure 13.2](#))
  - B. most natural sounds (human speech, for example) are acoustically complex
  - C. humans can detect sound in the frequency range of **20 Hz to 20 kHz**
- III. The ear
- A. external ear (pinna, concha, auditory meatus) (see [Figure 13.3](#))
    1. gathers sound energy and focuses it on the **tympanic membrane** (ear drum)
    2. filters different sound frequencies to provide cues about sound localization
  - B. middle ear (tympanic membrane, ossicles)
    1. transmit acoustic energy from air to the inner ear
    2. amplifies the pressure of acoustic energy some 200-fold
  - C. inner ear (cochlea, auditory nerve)
    1. two-fold function:
      - a. biomechanical: decompose complex acoustic energy into component sinusoidal waveforms
      - b. neural (sensory transduction): transduce this mechanical energy into neural signals that are then communicated to the brain
    2. **cochlea** (Greek, *cochlos* = snail)
      - a. basic anatomy (see [Figure 13.4](#))
        - (i) small, coiled structure surrounded by bone
        - (ii) bisected by the cochlear partition into two, large fluid filled channels (scala vestibuli, scala tympani)
        - (iii) the cochlear partition contains the **organ of corti**, which consists of the **basilar** and **tectorial membranes**
        - (iv) the basilar membrane supports inner and outer hair cells; the **inner hair cells** are the sensory receptor cells of the cochlea
        - (v) the cochlear partition contains a smaller, fluid filled channel (scala media), which is important for maintaining the proper ionic environment for neural signaling
        - (vi) the cochlear partition terminates before the apical end of the cochlea, allowing for continuity between the scala vestibuli and scala tympani (at the helicotrema)

<sup>2</sup> Figure references to Purves et al., *Neuroscience*, 5<sup>th</sup> Ed., Sinauer Assoc., Inc., 2012. [[click here](#)]

- b. functional overview
  - (i) pressure transmitted by the ossicles of the middle ear causes the **oval window** to bulge inward
  - (ii) this pressure is conducted throughout the fluid of the scala vestibuli (called perilymph), around the helicotrema and into the scala tympani, and is relieved by the outward bulging of the **round window**
  - (iii) passage of pressure throughout the channels of the cochlea sets up vibrations in the basilar membrane (see [Figure 13.5](#))
  - (iv) movements of the basilar membrane deform the ends of the inner hair cells leading to the transduction of mechanical energy into neural impulses (see [Figure 13.6](#))
- c. basilar membrane
  - (i) frequency tuning (refer back to [Figure 13.5](#))
    - the membrane is stiffer, thicker and narrower at the base of the cochlea and wider, thinner and more flexible at the apex of the cochlea
    - thus, the base is tuned for (responds best to) high frequencies and apex is tuned for low frequencies
    - complex sounds cause vibrations of different parts of the basilar membrane
    - tuning is sharpened by an active process involving the outer hair cells
  - (ii) sensory transduction (see [Figure 13.7-13.10](#))
    - the stereocilia of hair cells protrude into the scala media, which contains **endolymph** – a solution that contains high concentrations of  $K^+$
    - vibration of the basilar membrane causes a shearing motion between the basilar and tectorial membranes
    - motion bends the **stereocilia** that protrude from the apical ends of the **inner hairs cells**
    - deformation of the stereocilia *toward* the longest stereocilia leads to inward flow of current through  $K^+$  channels and *depolarization* of the hair cell membrane
    - depolarized hair cells release more neurotransmitter on afferent endings, resulting in an increase in action potential firing in the auditory nerve
    - deformation of the stereocilia *away from* the longest stereocilia leads to closure of  $K^+$  channels and *hyperpolarization* of the hair cell membrane

- hyperpolarized hair cells release less neurotransmitter on afferent endings, resulting in a decrease in action potential firing in the auditory nerve
- (iii) hearing loss (see **Boxes 13A & 13C**)
- 3. for an excellent review of the anatomy and physiology of these peripheral components of the auditory system, see the animation on the textbook's companion website [\[click here\]](#)
- 4. for a more aesthetically satisfying experience (featuring Bach's Toccata & Fugue in D minor), see also this fantastic animation produced by James Huspeth (Rockefeller University), one of the world's leading auditory neurophysiologists [\[click here\]](#)
- 5. sensory coding in the auditory nerve (see **Figures 13.9 & 13.11**)
  - a. temporal code: hair cell potentials and action potentials in the auditory nerve can follow an acoustical stimulus up to about 3 kHz
  - b. "labeled-line" code: preserves information about frequency since the afferent fibers that innervate different parts of the basilar membrane inherit their tuning (from the basilar membrane)

## STUDY QUESTIONS

- Q1. Which of the following is the primary function of the three bones in the middle ear?
- A. Selective transmission of high-frequency sounds
  - B. Selective transmission of low-frequency sounds
  - C. Amplification of sound pressure waves to increase auditory sensitivity
  - D. Dampening sound pressure waves to prevent damage to the ear
  - E. Facilitation of fluid drainage from the Eustachian tube
- Q2. Which of the following statements about sensory transduction by hair cells is most accurate?
- A. Bending of the cilia toward the shortest cilium produces depolarization.
  - B. Bending of the cilia toward the longest cilium produces hyperpolarization.
  - C. Neurotransmitter is released by hair cells when the calcium that rushes into the cilia reaches the active zone at the base of the hair cells.
  - D. The firing of action potentials in second-order sensory neurons can be either up- or down-regulated, depending on the direction in which the bundle of cilia (of the afferent hair cell) is bent.
  - E. Hair cells are postsynaptic to second-order sensory neurons.
- Q3. What explains the tonotopy that is present in the auditory division of CN VIII?
- A. The amount of myelin wrapping any given axon: the more myelin, the higher the pitch encoded by the axon.
  - B. The location of the cell body in the spiral ganglion: the closer to the center of spiral, the lower the pitch encoded by the axon.
  - C. The location of where the peripheral process receives contact from hair cells along the basilar membrane.
  - D. The average rate of action potential generation: the higher the average rate of action potential generation, the higher the pitch encoded by the axon.
  - E. The number of AMPA receptors in the postsynaptic process: the more AMPA receptors, the higher the pitch encoded by the axon.