Chapter 9: Hearing: Physiology and Psychoacoustics

Chapter Overview

This chapter covers the basic physics, physiology, and psychophysics of audition (hearing). We first learn about sound waves—pressure fluctuations in the air (if we are on dry land) or water (if we are in the ocean or a swimming pool). The two most prominent features of these waves, their frequencies and amplitudes, translate into the perceptual properties of pitch and loudness.

The human auditory apparatus is divided into three parts: the outer ear collects sound waves, the middle ear amplifies them, and the inner ear transduces them into neural signals via a remarkable mechanism called the organ of Corti.

Sound frequencies are sent to the brain using the combination of a place code, where each auditory nerve fiber responds most strongly to the presence of a different frequency, and a timing code, where the firing rate of a group of neurons corresponds to the frequency being perceived. Psychophysical experiments have established that while loudness generally varies according to sound wave intensity and pitch according to sound wave frequency, the two perceptual qualities interact, because our auditory apparatus is set up to respond more vigorously to some frequencies than to others.

Finally, several different sources of hearing loss are discussed, along with their potential remedies.

Chapter Outline

The Function of Hearing

What Is Sound?

Basic Qualities of Sound Waves: Frequency and Amplitude
Sine Waves and Complex Sounds

Basic Structure of the Mammalian Auditory System
Outer Ear
Middle Ear
Inner Ear
The Auditory Nerve
Auditory Brain Structures

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Basic Operating Characteristics of the Auditory System

Intensity and Loudness

Scientists at Work: Why Don’t Manatees Get Out of the Way When a Boat Is Coming?

Frequency and Pitch

Hearing Loss

Treating Hearing Loss

Using versus Detecting Sound

Sensation & Perception in Everyday Life: Electronic Ears

Chapter Learning Objectives

Upon successful completion of this chapter, students will be able to:

1. Describe the nature of sound waves, including the aspects of amplitude and frequency.
2. Understand how the physical characteristics of amplitude and frequency are related to the psychological characteristics of loudness and pitch.
3. Know and describe the biological parts of the outer, middle, and inner ear, and the functioning of those parts.
4. Understand how the mammalian auditory system codes amplitude and frequency in the cochlea.
5. Understand the properties of auditory nerve fibers, including their characteristic frequency, two-tone suppression, rate saturation, and the volley principle.
6. Understand and describe human auditory brain structures.
7. Describe some of the auditory processing problems studied by the psychoacousticians and the experimental methods they use.
8. Identify and discuss the various causes of hearing loss and their potential remedies.
9. Describe how hearing abilities change over the lifespan.

Chapter Summary

1. Sounds are fluctuations of pressure. Sound waves are defined by the frequency, intensity (amplitude), and phase of fluctuations. Sound frequency and intensity correspond to our perceptions of pitch and loudness, respectively.
2. Sound is funneled into the ear by the outer ear, made more intense by the middle ear, and transformed into neural signals by the inner ear.
3. In the inner ear, cilia on the tops of inner hair cells pivot in response to pressure fluctuations in ways that provide information about frequency and intensity to the auditory nerve and the brain. Auditory nerve fibers convey information through both the rate and the timing patterns with which they fire.
4. Different characteristics of sounds are processed at multiple places in the brain stem before information reaches the cortex. Information from both ears is brought together very early in the chain of processing. At each stage of auditory processing, including primary auditory cortex, neurons are organized in relation to the frequencies of sounds (tonotopically).

5. Humans and other mammals can hear sounds across an enormous range of intensities. Not all sound frequencies are heard as being equally loud, however. Hearing across such a wide range of intensities is accomplished by the use of many auditory neurons. Different neurons respond to different levels of intensity. In addition, more neurons overall respond when sounds are more intense.

6. Series of channels (or filters) process sounds within bands of frequency. Depending on frequency, these channels vary in how wide (many frequencies) or narrow they are. Consequently, it is easier to detect differences between some frequencies than between others. When energy from multiple frequencies is present, lower-frequency energy makes it relatively more difficult to hear higher frequencies.

7. Hearing loss is caused by damage to the bones of the middle ear, to the hair cells in the cochlea, or to the neurons in the auditory nerve. Although hearing aids are helpful to listeners with hearing impairment, there is only so much that can be done to help after damage to hair cells that cannot be repaired.

References for Lecture Development

[Detailed review of auditory system at earliest levels.]


[Comprehensive treatment psychoacoustics, plus a modest amount of auditory physiology and hearing impairment.]

[Collection of authoritative chapters covering each stage of auditory physiology, from cochlea to cortex.]

Video and Image Resources from the Internet

*Sound Waves*

What Does Sound Look Like?
You can actually see sound waves as they travel through the air, thanks to a clever photographic trick.

Standing Wave Visualized
https://i.imgur.com/3FacWpN.gifv
A gif of a standing wave being played in a clear plastic tube filled with styrofoam balls. You can see the places where the air pressure bunches up and spreads out.

Pyro board: 2D Rubens’ Tube!
http://youtu.be/2awbKQ2DLRE
Rubens’ Tube is an awesome demo and here we take it to the next level with a two-dimensional “Pyro Board.” This shows unique standing wave patterns of sound in the box. The pressure variations due to the sound waves affect the flow rate of flammable gas from the holes in the Pyro Board, and therefore affect the height and colour of flames. This is interesting for visualizing standing wave patterns, and simply awesome to watch when put to music!

Amazing resonance experiment!
http://youtu.be/wvJAgrUBF4w
Sound waves vibrate a plate of metal with salt sprinkled on it. At certain frequencies, beautiful and complicated patterns are formed by the grains of salt.

Vibration: See the unseen up close
https://youtu.be/W4s2UwKm7dc
Slow-motion images of vibrating surfaces as they are struck to produce noise and music.

Mega bass 40,000 watts
https://youtu.be/ZQjVN13dI10
The effect of 40,000 watts of mega bass on a woman’s hair are immediate. Watch to see the electrifying effect while she prudently covers her ears from the heavy sound.

**Auditory Biology**

Auditory Transduction (2002)
http://youtu.be/PeTriGTENoc
A seven-minute video by Brandon Pletsch takes viewers on a step-by-step voyage through the inside of the ear, to the acoustic accompaniment of classical music.

Cochlear Implants: Deaf toddler hears his dad’s voice for the first time
https://youtu.be/GhC_By9GMv0
A deaf child hears for the first time due to having an auditory brain stem implant. Video goes into the details of the ground-breaking surgery.

29 years old and hearing myself for the 1st time!
https://youtu.be/LsOo3jzkhYA
Sloan Churman was born deaf and received a hearing implant. This is the video of them turning it on and her hearing herself for the first time.

A deaf woman who can finally hear meets Ellen
https://youtu.be/fp4usWroDew
Ellen talks with Sloan Churman who was able to hear for the first time only a week ago. And Ellen has an amazing surprise for her!