Intro to Audition & Hearing

Lecture 16
Chapter 9, part II

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Sensation & Perception (PSY 345 / NEU 325)
Fall 2017
**Sine wave**: one of the simplest kinds of sounds: sound for which pressure as a function of time is a sine function

- **Period**: The time required for one cycle of a repeating waveform (frequency = 1 / period)
- **Phase**: The relative position of two or more sine waves
  - There are 360 degrees of phase across one period

**But**: sine waves are a very *unnatural* kind of sound

- complex natural sounds can be broken down into a sum of sine waves
Complex sounds can be described by Fourier analysis

- **Fourier analysis**: mathematical theory by which any sound can be divided into a sum of sine waves

example: generating a square wave from a sum of sine waves

http://sites.sinauer.com/wolfe3e/chap1/fourierF.htm
**Fourier spectrum:** shows the amplitude for each sine wave frequency present in a complex sound.

![Waveform and Spectrum Diagram](image)
Harmonic spectrum: Typically caused by a simple vibrating source (e.g., guitar string, saxophone reed)

- Also referred to as a “harmonic stack”

![Diagram of harmonic spectrum: fundamental frequency multiplied by 2, 3, 4, 5, 6, ... determines the perceived pitch.](image-url)
**Timbre**: psychological sensation by which a listener can judge that two sounds with the same loudness and pitch are dissimilar

- timbre quality is conveyed by harmonics and other high frequencies

(more on this when we get to “music”)
Harmonic sounds with the same fundamental frequency can sound different (i.e., have different timbre) due to differences in high harmonics.
Part 2: The Auditory System
Figure 9.10 Structures of the human ear (Part 3)

Outer ear collects and transforms sound

Middle ear

3 bones: amplifies sound

Inner ear transduces sound (i.e., converts mechanical energy to neural responses)
Outer ear

- Sound first collected from environment by the **pinnae**
- Sound waves funneled by the pinnae into the **ear canal**
- Length and shape of ear canal enhances certain frequencies
Pinna size and shape vary greatly
Collects and transforms sound

Inner ear

Transduces sound (i.e., converts mechanical energy to neural responses)

Outer ear

Middle ear

3 bones: amplifies sound
Basic Structure of the Mammalian Auditory System

Middle ear
Middle ear

• **Tympanic membrane** (eardrum): border between outer and middle ear

• middle ear consists of three tiny bones, ossicles, that amplify and transmit sounds to the inner eardrum

**Ossicles**: The smallest bones in the body

• **Malleus**: Receives vibrations from the eardrum

• **Incus**: The middle ossicle

• **Stapes**: Connected to the incus on one end and the oval window of the cochlea on the other

• **Oval window** is border between middle and inner ear
Two ways in which sound is amplified in middle ear:

- **Ossicles** have hinged joints that work like levers to amplify sounds
- **Tympanic membrane** has much larger surface area than base of the stapes (where it pushes on oval window)
  
  (think of a snow-shoe vs. a high-heeled shoe)

- Inner ear consists of fluid-filled chambers
  - Takes more energy to move liquid than air

  “impedance matching”
  (it’s hard for air to move water)
Figure 9.10 Structures of the human ear

**muscles**
- tensor tympani
- stapedius

- smallest muscles in human body
- tighten to reduce amplification of loud sounds

However, acoustic reflex has delay of 200 ms, so cannot protect against abrupt sounds (e.g., gun shot)
Figure 9.10 Structures of the human ear

- Concha
- Ear canal
- Pinna
- Tympanic membrane
- Ossicles (Malleus, Incus, Stapes)
- Semicircular canals
- Oval window
- Vestibular nerve
- Cochlear nerve
- Cochlea
- Round window
- Eustachian tube
**Cochlea** - Spiral structure filled with fluids in three parallel canals

- breaks down sound by frequency
- transduction (mechanical -> neural energy)

Cochlear animation: [http://www.youtube.com/watch?v=dyenMluFaUw](http://www.youtube.com/watch?v=dyenMluFaUw)
Figure 9.11 The cochlea

- Cochlea
- Auditory nerve
- Oval window
- Round window
- Vestibular nerve
- Auditory nerve
- Cross section of cochlea
  - Tectorial membrane
  - Reissner’s membrane
  - Middle canal
  - Vestibular canal
  - Tympanic canal
  - Inner hair cells
  - Spiral ganglion
  - Basilar membrane
  - Outer hair cells
The three canals of the cochlea:

- **Vestibular canal:** extends from oval window at base of cochlea to *helicotrema* at the apex

- **Tympanic canal:** from round window at base to helicotrema at the apex

- **Middle canal:** between the tympanic and vestibular canals
Membranes separating these chambers

• **Basilar membrane:** separates middle and tympanic canals
Getting the basilar membrane to shake (without breaking the cochlea)

Vibrations cause stapes to push and pull flexible **oval window** in and out of vestibular canal at base of cochlea.

Remaining pressure: transmitted through **helicotrema** and back to cochlear base through tympanic canal, where it is absorbed by the **round window**.
A simplified Cochlea
showing the effects of pressure

Stapes

Oval Window

Round Window
Organ of Corti: A structure on the basilar membrane of the cochlea composed of hair cells and dendrites of auditory nerve fibers

- contains structures that translate movements of basilar membrane into neural signals
Figure 9.11 The cochlea (cont’d)

Stereocilia of inner hair cells

Stereocilia of outer hair cells
• **Tectorial membrane**: extends into the middle canal, floating above inner hair cells and touching outer hair cells

• Vibrations cause displacement of the tectorial membrane, which bends stereocilia attached to hair cells and causes the release of neurotransmitters
• **hair cells** - arranged in four rows

• **stereocilia**: Hairlike extensions on the tips of hair cells that initiate the release of neurotransmitters when they are flexed

• each tip connected to its neighbor by a tiny filament called a **tip link**
The *displacement threshold* of a hair cell is small. Very small. Really, really, really small.
• **Inner hair cells**: Convey almost all information about sound waves to the brain (using afferent fibers).

• **Outer hair cells**: Convey information from the brain (using efferent fibers).
  - involved in an elaborate feedback system
  - amplify sounds by increasing mechanical deflections of the basilar membrane
Mechanical energy flow in the ear:

- pinna → ear canal → tympanic membrane (outer ear)
- malleus → incus → stapes (middle ear)
- oval window → vestibular canal → helicotrema → tympanic canal → round window (inner ear)

Auditory Transduction cascade:

Standing wave in basilar membrane
→ movement of organ of corti & tectorial membrane (amplified by outer hair cells)
→ inner hair cell displacement → tip links → channel opening
Cochlea: physical device tuned to frequency!

- **place code**: tuning of different parts of the cochlea to different frequencies.