Sensation & Perception

Ch. 11: Sound, The Auditory System, and Pitch Perception

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Main topics
- Sound stimuli, amplitude and frequency
- Sound quality (timbre)
- Ear (structure)
- Place theory
- Central auditory processing
Sound

• What is it?

• Something to do with air vibration?

• Why can we hear?
  – an object vibrates → the air changes its pressure → the air vibrates → we hear a sound.
– sound is a wave ????

????????????????

ch 11
What is a wave?

• A wave is something that goes back and forth, up and down, or ebbs and flows, comes and goes…
• When air vibrates, it doesn’t travel straight.

• The vibration propagates like a wave
  – Regular and organized manner.
  – Imagine when surface waves spread in a lake
Sound wave

- Figure 1: Graphic representations of a sound wave. (A) Air at equilibrium, in the absence of a sound wave; (B) compressions and rarefactions that constitute a sound wave; (C) transverse representation of the wave, showing amplitude (A) and wavelength (taken from Britannica Online)
A sound wave is determined by two factors

- **Magnitude**
  - Y axis

- **Frequency**
  - X axis
Sound wave

• The perceptual quality of a sound is related to the characteristics of a sound wave.
Specifying a sound stimulus

• Amplitude
  – Y axis
  – Decibel (dB)
  – Number of dB = 20 \times \log(P/P_0)
  – (P: the sound pressure of the stimulus, P_0: a standard pressure)
  – P_0:=the pressure of a 1000Hz tone at threshold.

• Frequency
  – X axis
  – Hertz (Hz) \rightarrow one cycle per second
dB: Decibel

- dB? With p=200, p0(standard pressure level)=20
  \[ \text{dB} = 20 \times \log \left( \frac{200}{20} \right) = 20 \times \log (10) \]
  \[ = 20 \times 1 = 20 \]

- with p = 2000
  \[ \text{dB} = 20 \times \log \left( \frac{2000}{20} \right) = 20 \times \log (100) \]
  \[ = 20 \times 2 = 40 \]

With p = 20000
  \[ \text{dB} = 20 \times \log \left( \frac{20000}{20} \right) = 20 \times \log (1000) \]
  \[ = 20 \times 3 = 60 \]
dB as function of P
What does this tell?

- Remember a psychophysics experiment?
Do you remember a psychophysics experiment we talked about?

- Magnitude estimation
• create a complex sound by combining simple sound waves
• \(\rightarrow\) Additive synthesis
• reduce a complex sound wave into a collection of simple sound waves.
• \(\rightarrow\) Fourier analysis
• A sound wave from clarinet.

• Simple sound waves that make a sound of clarinet
Figure 11.9 The frequency spectrum for the tone in Figure 11.8d. The heights of the lines indicate the amplitude of each of the frequencies that make up the tone.
Figure 11.10 Frequency spectra for a guitar, a bassoon, and an alto saxophone playing a tone with a fundamental frequency of 196 Hz.

The position of the lines on the horizontal axis indicates the frequencies of the harmonics and their height indicates their intensities.
Ear

- Pinna
- Auditory canal
- Eardrum
- Malleus
- Incus
- Stapes
- Oval window (under footplate of stapes)
- Round window
- Cochlea
- Semicircular canals
- Auditory nerve

Area of tympanic membrane
Area of stapes footplate

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What do they do?

- Sound → vibration of air
- → vibrate the eardrum, the malleus, the incus, and the stapes
- → the vibration spreads to the cochlea.
- → the vibration in the cochlea is captured by hair cells
- → transduction (physical vibration is transduced to neural energy)
Figure 10.20
A cross section of the organ of Corti, showing how it rests upon the basilar membrane. (Adapted from Dienes & Pinson, 1993.)
From vibration to neural energy, how does it happen?
A quick review: Vision
Figure 10.28
A cross section of the organ of Corti, showing how it rests upon the basilar membrane. (Adapted from Denes & Finson, 1993.)
• the tectorial membrane vibrates

• the hair cells’ cilia bend.

• depending on how they bend, the hair cells release neurotransmitter
• Transduction
• The neurotransmitters released in the hair cell are captured in nerve fibers.

→ The neural energy is sent to the brain.
• Transduction

• The neurotransmitters released in the hair cell are captured in nerve fibers.

→ The neural energy is sent to the brain.
Perceiving sound

• How do we perceive sound?
• How do we represent different sound waves?
A sound wave is determined by two factors

- Amplitude
  - Y axis

- Frequency
  - X axis
Bekesy’s place theory
How does the basal membrane vibrate?

- Demonstration:
- Jumping rope
• A wave spreads.
• The wave reached the peak at a particular location.

The height of the wave reaches the peak at P, and then gradually subsides.
• Different locations of vibration peak are produced by different spatial frequencies.
• Different frequencies of sound waves activate hair cells in different locations
• This wave bends hair cells of this area most.

• When hair cells bend most, they fire most.

• So, hair cells are tuned to different frequencies.
Some physiological and psychophysical findings that support the place theory

- Tonotopic map on the cochlea (Fig. 10.30)
- Different parts of the cochlea respond maximally to different frequencies (Fig 10.30)
- The tuning curve of a single hair cell in the guinea pig cochlea.

What do these graphs tell you?

- Frequency tuning curves of cat auditory nerve fibers
Auditory masking and psychophysical experiments.

- Ss listen to tones of various frequencies.
- Masking is placed at a particular frequency.
- Ss have difficulty in identifying the tone at which masking is placed.

![Diagram of Auditory Masking](image)

**Figure 10.34** Results of Egan and Hake's (1950) masking experiment. The threshold increases the most near the frequencies of the masking noise, and the masking effect spreads more to high frequencies. (Listen to WebTutor: Masking High and Low Frequencies.)
The intensity of the masking tone

The frequency of the masking tone

The intensity of the masking tone

The frequency of the masking tone

Psychophysical tuning curve

- The sound level of masking tone necessary to mask a 2kHz tone.
- Note that the minimum masking intensity is needed to mask a tone of 2000Hz.

Dots: The frequency of the test tone
What does this tell you?

➔ Tonotopic maps

➔ A nice correspondence between the frequency of a sound wave and the cochlea location at which the sound is captured.
• Remember retinotopic map?

• What is it?
Retinotopic map: the locational information of retina is preserved in the LGN cells.
How about a complex sound (a mixture of sound waves with different frequencies?)
• A complex tone (440Hz, 880Hz, and 1320Hz).

• The auditory system basically carry out a “Fourier analysis” → treat a complex sound as a composite of simple waves.
Hierarchical Processing:

Core $\rightarrow$ belt $\rightarrow$ Parabelt

Complex sounds are processed later

**What vs. Where system:**

Where: dorsal pathway
$\rightarrow$ Sound localization

What: ventral pathway
$\rightarrow$ Identifying sounds
Tonotopic map in the cortex

- The Tonotopic relation is maintained in the auditory cortex as well (A1)

This figure indicates the locations of neurons that are responsive to particular frequencies (see the number -- kHZ)

(See page 48 for more details.)
The effect of the missing fundamental

Example

http://en.wikipedia.org/wiki/Missing_fundamental
Figure 11.9 The frequency spectrum for the tone in Figure 11.8d. The heights of the lines indicate the amplitude of each of the frequencies that make up the tone.
Figure 11.10  Frequency spectra for a guitar, a bassoon, and an alto saxophone playing a tone with a fundamental frequency of 196 Hz.

The position of the lines on the horizontal axis indicates the frequencies of the harmonics and their height indicates their intensities.
Removing fundamental frequencies change their timbre. But their pitch remains the same.

The perception of the pitch of complex tones cannot be explained by the place theory alone.