Auditory System & Hearing
(Chapters 10)

Lecture 18

Jonathan Pillow
Sensation & Perception (PSY 345 / NEU 325)
Spring 2017
Q: How do you detect the location of a sound?

Main answer:
- timing differences
- loudness differences

Position detection by the visual and auditory systems
3 planes:
• Horizontal (azimuth)
• Vertical (elevation)
• Distance
The sound at microphone #1 will:
- be more intense
- arrive sooner
Sound Localization

First Cue: timing

**Interaural time differences (ITD):** The difference in time between a sound arriving at one ear versus the other
Interaural time differences for sound sources varying in azimuth

azimuth = angle in the horizontal plane (relative to head)

Measured values (5 subjects)
Interaural time differences for different positions around the head

-20°: ITD = -200 μs
-60°: ITD = -480 μs
-90°: ITD = -640 μs
-120°: ITD = -480 μs
-160°: ITD = -200 μs

0°: ITD = 0 μs
20°: ITD = 200 μs
60°: ITD = 480 μs
90°: ITD = 640 μs
120°: ITD = 480 μs
160°: ITD = 200 μs
180°: ITD = 0 μs
Q: how would you design a system to detect inter-aural time differences?

(Think back to Reichardt detector)

Hint: “delay lines”
Jeffress Model

Tapped delay lines

Coincidence detectors

spike trains from left auditory pathway

spike trains from right auditory pathway

Coincidence counters

Right ear leads

No time delay

Left ear leads
Jeffress Model

Responds to sounds arriving first to right ear

Responds to sounds arriving first to left ear
Physiology of ITD processing

- **Medial superior olive (MSO):**
  - ITDs processed (first place where binaural information combined)
  - form connections during the first few months of life
  - interpretation of ITD changes with age (as head grows, ears get further apart!)
Second cue: Loudness (or “level”) differences (ILDs)

**ILD**: difference in level (intensity) between a sound arriving at one ear versus the other

- For frequencies >1000Hz, the head blocks some energy
- correlates with angle of sound source, but not quite as reliable as with ITDs
ILDs for tones of different frequencies
Lateral superior olive (LSO): relay station in the brainstem where inputs from both ears contribute to detection of ILDs.

After a single synapse, information travels to medial and lateral superior olive.
After a single synapse, information travels to medial and lateral superior olive

Auditory Localization Demo
(try with headphones)  https://wolfe4e.sinauer.com/wa10.01.html
Why 2 cues?

High frequencies
>1600 Hz

Low frequencies
<800 Hz

Both cues contribute for 800-1600 Hz
Summary of ITD and ILD

ITD: good for low frequencies (processed in MSO)
ILD: good for high frequencies (processed in LSO)
Problem with using ITDs and ILDs for sound localization:

- **Cone of confusion**: A region of positions in space where all sounds produce the same ITDs and ILDs

**Q**: where is the cone of confusion for a point directly in front of your head?
Head-related transfer function (HRTF)

- describes how pinnae, ear canals, head, and torso change the intensity of sounds with different frequencies as the sound location changes

- Each person has his/her own HRTF (based on his/her own body) and uses it to help locate sounds
HRTF: can be measured with microphone in ear canal

**HRTF for one sound source location**

(30° to left, 12° above horizontal)

some frequencies attenuated; others amplified
HRTF varies with sound source elevation (& azimuth)

- provides information about source location in 3D
Head-related transfer function (HRTF)

- Hofman et al 1998: inserted plastic molds into pinnae, altering subjects’ HRTFs
- sound localization performance abruptly degraded

Findings:
- Can learn a new HRTF in about 6 weeks (shown experimentally using inserted artificial pinna)
- Old HRTF is stored (can return to old one instantaneously)
Auditory distance perception

Several Cues:

• **Loudness** (“inverse square law”) - Intensity decreases as square of the distance: (quieter = farther away) (duh.)

• **Spectral composition** - Higher frequencies decrease in energy more than lower frequencies as sound waves travel

*Example*: distant vs. nearby thunder.
- This cue only works for long distances (d > 1000m)
Auditory properties of complex sounds
Harmonics

- Objects tend to vibrate at multiple “resonant frequencies” (integer multiples of some fundamental frequency)
- Most vibrations die down, but some persist because their wavelength is reinforced by the object’s physical properties
- Auditory system acutely sensitive to harmonics

Example: guitar string

Fundamental F1 (1st harmonic) 2nd harmonic F2 (2 x F1) 3rd harmonic F3 (3 x F1)
Many sounds, including voices, are harmonic
If the fundamental of a harmonic sound is removed, listeners will still hear its pitch.

demo:
http://sites.sinauer.com/wolfe4e/wa10.02.html
• only 3 harmonics are needed
Complex Sounds

**Timbre**: Psychological sensation by which a listener can judge that two sounds with the same fundamental loudness and pitch are dissimilar

- conveyed by harmonics and other frequencies
- Perception of timbre depends on context in which sound is heard

Timbre demo:  [http://sites.sinauer.com/wolfe4e/wa10.03.html](http://sites.sinauer.com/wolfe4e/wa10.03.html)
Auditory Scene Analysis

What happens in natural situations?

- Acoustic environment can be a busy place with multiple sound sources
- How does the auditory system sort out these sources?

- **Source segregation** - processing an auditory scene consisting of multiple sound sources into its separate sources
Waveforms from all sounds are summed into a single waveform arriving at the ears

(a) Frog

(b) Bird

(c) Splash

(d) Frog + bird + splash
Cocktail party effect

• We can “select out” and attend to one conversation even when many are present simultaneously

• first documented by Colin Cherry, 1953
Cocktail party effect

Cherry’s findings:
• Same voice speaking, Presented to Both ears ⇒ Very Difficult
• Same voice speaking, Separate ears ⇒ Easy
Cocktail party effect

However, subjects:

• couldn’t identify a single phrase from non-attended ear
• couldn’t say for sure if it was English
• didn’t notice a change to German
• didn’t notice speech being played backward

• Did notice: change from male to female speaker
Cocktail party effect

• Suggests we can easily use spatial, timing, and spectral cues to separate sound streams, but cannot attend to multiple sound streams at the same time!
Continuity and Restoration Effects

How do we know that listeners hear sounds as continuous?

• Principle of *good continuation*: in spite of interruptions, one can still “hear” a sound

• Experiments (e.g., Kluender and Jenison, 1992) suggest that missing sounds are restored and encoded in the brain as if they were actually present!
Continuity Effects

Occlusion – Restoration

Gaps – No Restoration
Also true for speech: Adding noise can improve comprehension
Continuity and Restoration Effects in Music

Beat-box tutorial:

http://www.youtube.com/watch?v=8D7hCqGm0X0
Summary

- Interaural timing differences (ITD)
- Interaural level differences (ILD)
- MSO, LSO
- cone of confusion
- head-related transfer function (HRTF)
- harmonics
- missing fundamental
- timbre
- auditory scene analysis
- cocktail party effect
- continuity and restoration effects