“Mechanisms of Sound Localization in Mammals”
B. Grothe, M. Pecka, D. McAlpine (2010).

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Introduction

This paper seeks to demonstrate three ways in which our understanding of sound localization in mammals has changed with recent studies.
Introduction: The Three

1. Source location is represented by a bilateral population of broadly tuned spatial channels, not a topographic “space-map.”
2. ITD is not processed by exclusively excitatory “delay lines” in mammals.
3. Binaural mammalian audition is not as “hard wired” as previously thought, and can dynamically adjust its tuning properties.
Background

- ITD
- ILD
- HRTF
Acoustic Cues for Sound Localization in Mammals, Part A

- Phenomena investigated since mid 19th century
- Rayleigh (1907) confirmed research done by Thompson (1882) to create a duplex theory of sound localization:
  - ILDs → high-frequency noise localization
  - ITDs → low-frequency noise localization
Acoustic Cues for Sound Localization in Mammals, Part A

To the listener, audio sources A and B, and sources C and D have identical Interaural Time Difference and Interaural Level Difference.
Acoustic Cues for Sound Localization in Mammals, Part A

- Head-related transfer function (HRTF): Describes spectral modification generated by pinna and concha of outer ear.
- Birds and mammals can adapt to altered cues, as in the concha mold experiment:
  - Ear mold changes the HRTF cues.
  - After several weeks, humans adapt
  - When molds removed, no residual effects.
  - Learned behavior?
Acoustic Cues for Sound Localization in Mammals, Part B: Human Localization

● Humans have remarkable spatial hearing capabilities
  ○ Accuracy within 1-2 degrees in angular location of a sound source
  ○ Thresholds of 10 µs ITDs and 1-2 db ILDs in earphone studies

● Significance of ITD: action potentials take milliseconds, so 10 µs is impressive.
Acoustic Cues for Sound Localization in Mammals, Part B: Human Localization

- Steven & Newman (1934) investigated absolute localization in humans:
  - Performance was best below ~2kHz and above 5kHz, large inaccuracies in between.
  - Suggests **incomplete representation** of either cue over this range
Range of ITDs found in psychophysical studies using headphones:

- Range roughly consistent around frequencies below 1.5 kHz
- Set by physiological range ± 700 µs in humans but up to ± 3,000 µs.
  - (ITDs longer than physiological range found when multiple sources of sound interact & in acoustic reflections.)
Neural Mechanisms in mammals
Neural mechanisms in mammal

- Central auditory system consists of different ascending, segregated pathways
- First stop up is the ventral cochlear nucleus.
  - Bushy cells respond to fine structure of sounds, are critical for binaural and project to the superior olivary complex, where ITD and ILD are processed.
Neural mechanisms in mammal

- Central auditory system consists of different ascending, segregated pathways
- First stop up is the ventral cochlear nucleus.
  - Monaural cues pathways project onto lateral lemniscus and contralateral inferior colliculus.
Neural mechanisms in mammal

- IC is a necessary station for all pathways
- IC is highly convergent, and it seems that all acoustic cues have already been processed
Neural mechanisms: vertical localization

- Dorsal Cochlear Nucleus seems specialized for processing spectral cues; some spectral cues seem to be processed in IC as well.

- Type IV neurons in DCN are sensitive to a circuit in the DCN, and show an “island” of near-threshold activity immediately around their characteristic frequency, and have a large CIA at higher sound intensity.
Neural mechanisms: vertical localization

- Type IV neurons get their functionality from convergence of excitatory synapses with auditory nerve fibers, and inhibitory from type II DCN neurons.

- Type II neurons are thought to respond to Onset-C inhibition.

- This makes TIV neurons sensitive, inhibitorily, to acoustic “notches.”
Neural mechanisms: vertical localization

- Type IV neurons project to type O neurons.
- Type O neurons feature a frequency-versus-intensity response area.
- Respond similarly to tIVs for pure tones, but have essentially the opposite response, excitatory, across the notch-center map.
- tIV to tO interneurons might be specialized for processing directional dependence of cues.