Binaural Phenomena

Aim

To understand binaural hearing

Objectives

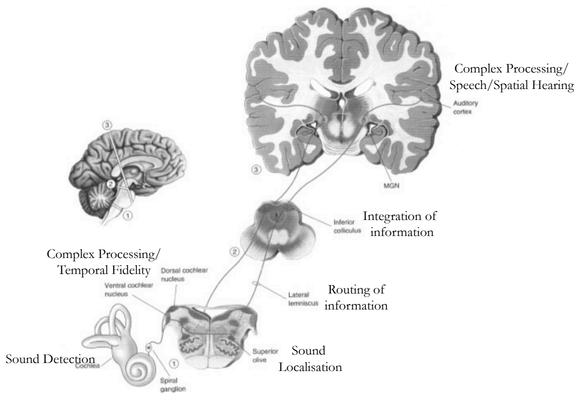
Understand the cues used to determine the location of a sound source

Understand sensitivity to binaural spatial cues, including interaural time differences (ITDs) and interaural level differences (ILDs)

Understand binaural unmasking

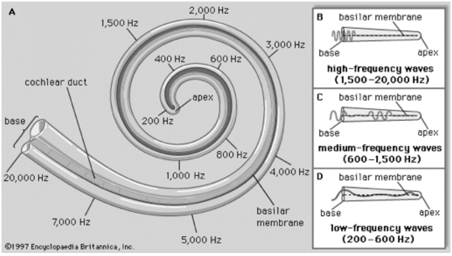
Learn about the precedence effect

Learn about neural mechanisms underpinning binaural hearing

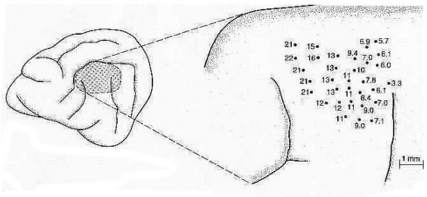


The primary representation in the auditory system

The BM is tuned for sound frequency



Sound frequency is mapped at many levels in the CNS



The percept of auditory space is computed in the CNS from information that is not spatial per se

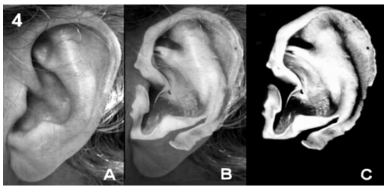
Spatial Hearing

For normal-hearing listeners it is clear that sounds can be ascribed a spatial position

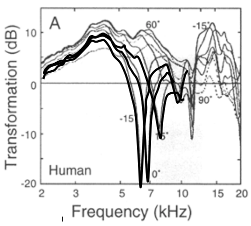
Two main mechanisms for achieving this:-

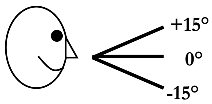
1) The filter properties of the outer ear

2) Binaural hearing



Acoustic Properties of the Outer Ear





the amount of sound amplification (or loss!) depends upon the location of the sound source in the vertical plane (elevation)

Binaural Hearing

The ability to extract specific forms of auditory information using two ears, that would not be possible using one ear only.

sound-source localisation

signal detection in noise (binaural unmasking)

sound-source grouping and segregation

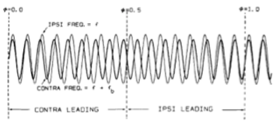
Binaural hearing: a historical context

Lord Rayleigh – first formalised the <u>duplex theory</u> of binaural hearing

provided evidence that timing differences between the ears were detectable

Sensitivity to binaural beats

Presenting different frequencies to each ear creates binaural beats



This is how Rayleigh discovered human sensitivity to ITDs

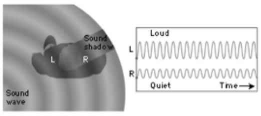
Two binaural cues...

A sinusoidal sound source located off to one side of the head will be delayed in time and will be less intense at the ear farthest from the sound source relative to the ear closest to the sound source

Owing to the physical nature of sound, these cues are not equally effective at all frequencies

The duplex theory of binaural hearing

Sensitivity to **I**nteraural **L**evel **D**ifferences (ILDs)

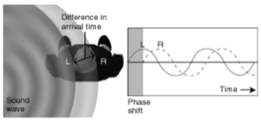


Frequency-dependent – the effect is larger at higher frequencies

Head-size dependent – larger heads create bigger ILDs for the same frequency

The duplex theory of binaural hearing

Sensitivity to **I**nteraural **T**ime **D**ifferences (ITDs)



onset time difference

ongoing phase difference

Largely frequency-**in**dependent

Head-size dependent – larger heads create bigger range of ITDs

Requires extraordinarily exquisite temporal mechanisms (10 – 20 μs sensitivity)

Support for the duplex theory

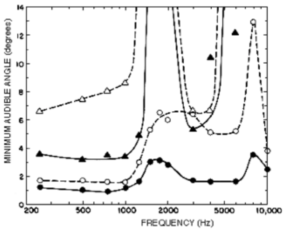
Stevens and Newman (1936) found that:-

1. Localisation was worst in the range 2-3 kHz
2. Front-back reversals were common, especially below 2 kHz

This suggests two binaural mechanisms, one for frequencies below about 2 kHz and one for frequencies above about 3 kHz

The minimum audible angle (MAA)

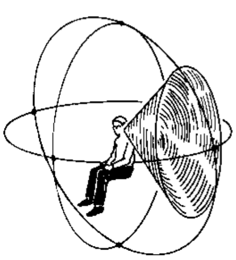
Minimum audible angle between successive pulses of tone as a function of the frequency and the direction of the source measured for angles (bottom to top at left hand side) 0°, 30°, 60° and 75° (from Mills, "Auditory Localization", in Tobias, ed. Foundations of Auditory Theory, Academic Press, 1972, p. 310, used by permission).



The MAA turns out to be about 1°, equivalent to about 10 μs of ITD.

The "cone of confusion"

Sounds presented from many different spatial positions can provide the same ITD – this leads to localisation errors



Measuring ITDs

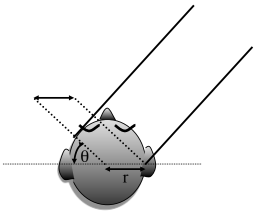
path difference between the ears

$d = r.\theta + r.\sin\theta$

for a radius of 9 cm and a sound source located **completely** off to one side...

$d = 9.(\pi/2) + 9.\sin(\pi/2)$

$d = 23.1\text{cm}$



if the speed of sound is 343 m/s...

ITD = 0.231/343 m/s

ITD = 0.231/343 m/s

ITD = .000673 s ***(673 μs)***

Measuring ITDs

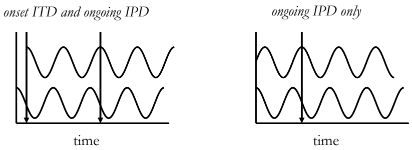
By convention:-

positive ITDs are those in which the sound is leading at the right ear…

and negative ITDs are those in which the sound is leading at the left ear…

Measuring ITDs

Presenting sounds over headphones enables independent control of binaural cues (and demonstrates sensitivity to IPDs *per se*)



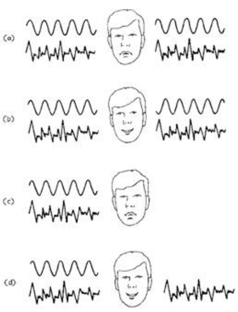
The binaural masking level difference (BMLD)

Discovered independently by Licklider and Hirsh in 1948

Describes the ability to detect a signal in background noise when there are differences in interaural configurations of the signal and/or noise.

BMLDs for tones can be as much as 15 dB.

BMLDs are a low-frequency phenomenon (< ~1500 Hz) and rely on mechanisms contributing to ITD sensitivity



UCL

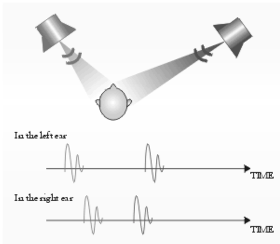
The precedence effect – echo suppression

(law of the first wavefront)

<u>Summing Localisation</u>: < 1ms delay between the two sounds and the perception is of a fused sound image with a perceived location of the weighted sum of the two

<u>Precedence Effect</u>: 1-5 ms delay between the two sounds and only one sound is perceived with the location of the first sound

<u>Echo Threshold</u>: >5 ms delay and two sounds are heard



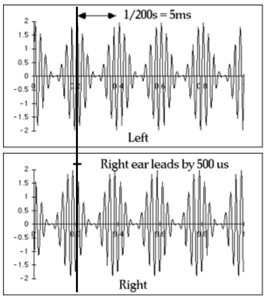
UCL

Sensitivity to high-frequency "envelope" ITDs

Modulating a high-frequency tone with a low-frequency modulation creates a modulated envelope

Sensitivity to ITDs between the envelopes of sounds was demonstrated by Henning (1974)

Thresholds for envelope ITDs are higher than for pure tones of the same frequency



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Binaural Sluggishness

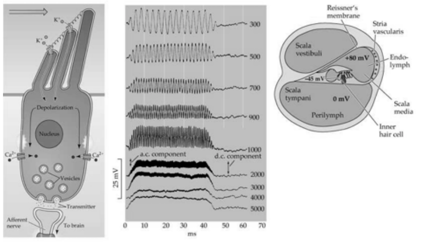
Although sensitivity to small ITDs is exquisite, sensitivity to moving sound sources, or changes in ITD, is "sluggish"

Binaural beats moving at > ~4 Hz are difficult to detect.

In fact, any change in the interaural signal that is faster than about 4 Hz is difficult to detect.

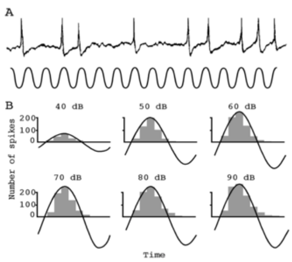
Neural Mechanisms of Binaural Hearing

binaural timing sensitivity requires monaural timing sensitivity



IHCs show a.c. potentials at low-frequencies

Temporal Sensitivity - Phase Locking

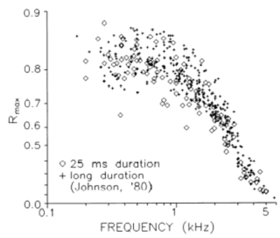


Movies

Phase-locking is a low-frequency phenomenon

Phase-locking decreases as a function of sound frequency

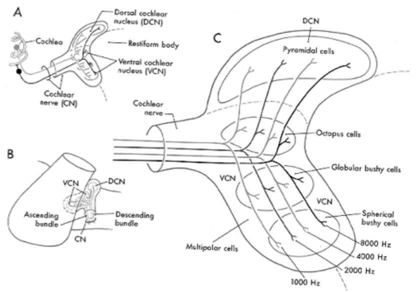
This means that information about the fine-time structure of a stimulus is lost at high-frequencies



Joris et al., *J. Neurophysiol.*, vol 71, (1994), pp1022-1036

The Cochlear Nucleus

ANFs terminate in the cochlear nucleus (CN) of the brainstem

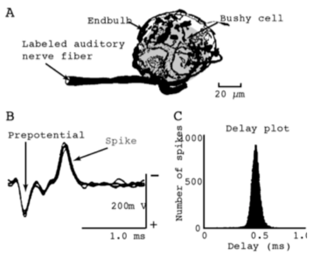


Spherical Bushy Cells

SBCs are the predominant neuron type in the AVCN

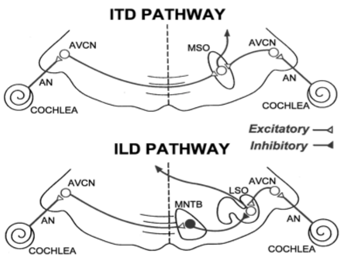
SBCs show primary-like responses (they respond like ANFs)

These synapses are responsible for maintaining the temporal processing capabilities of AVCN neurons



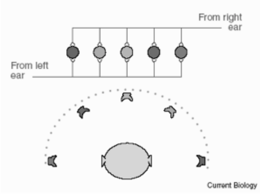
Physiological Basis of Binaural Hearing

The dichotomy between high- and low-frequency binaural hearing abilities is mirrored in an anatomical and physiological division



Jeffress model of binaural coincidence detection

ITD is the main cue used to localise the source of a sound

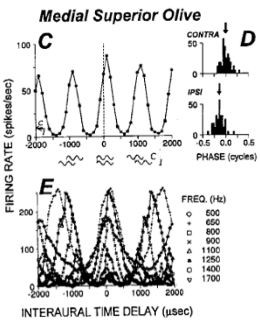


Neural elements act as binaural coincidence detectors

Differences in conduction delay from each ear offset equal and opposite external ITDs

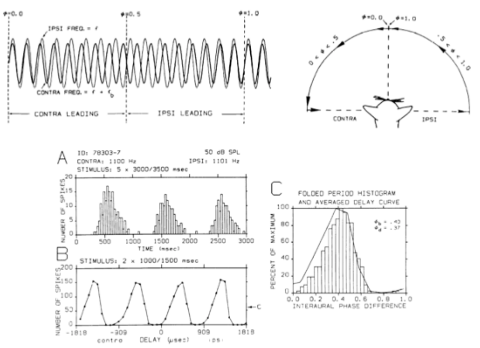
ITD is translated into a place code

Binaural coincidence detection in mammals

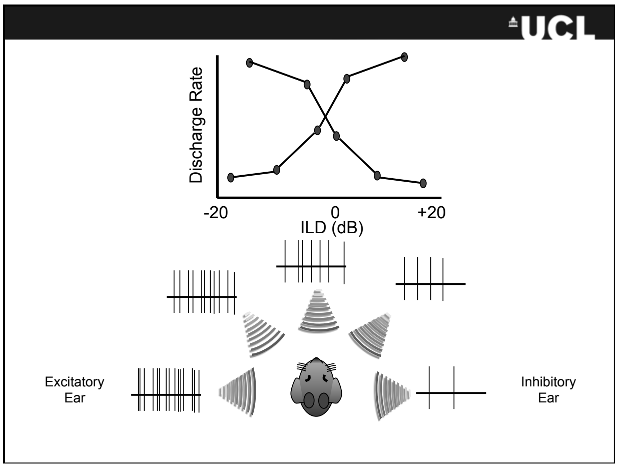


Yin and Chan , *J. Neurophysiol.*, vol 64, (1990), pp465-488

Sensitivity to interaural phase differences (IPDs)



Yin and Kuwada, *J. Neurophysiol.*, vol 50, (1983), pp1000-1019


UCL
Discharge Rate
-20
0
+20
ILD (dB)
Excitatory Ear
Inhibitory Ear