# Binaural Hearing

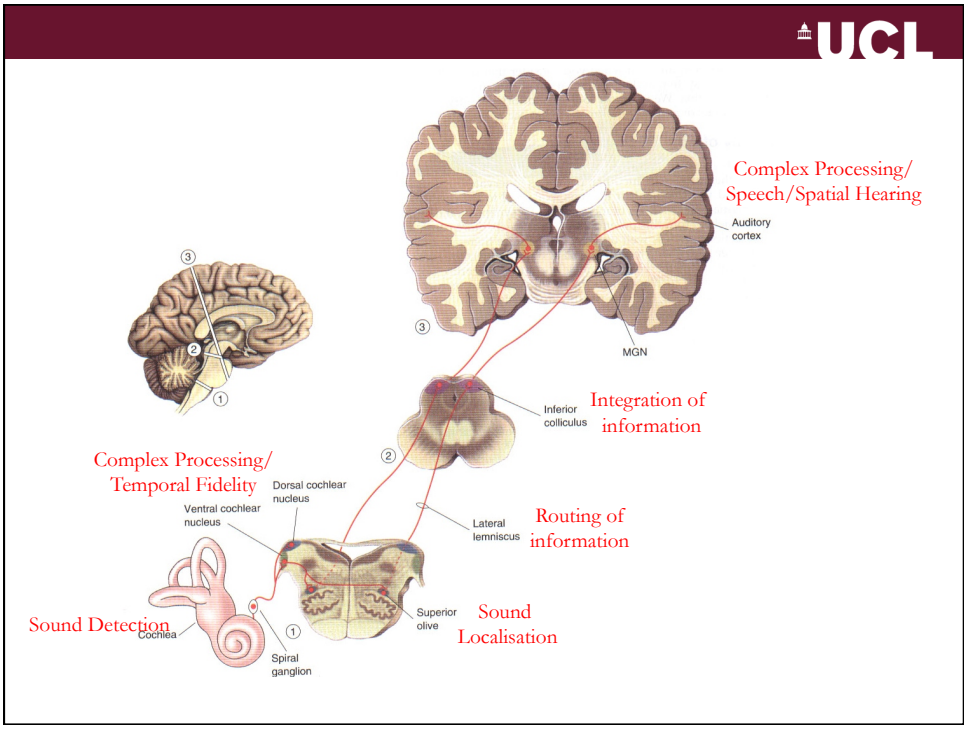
Aim

To understand binaural hearing

Objectives

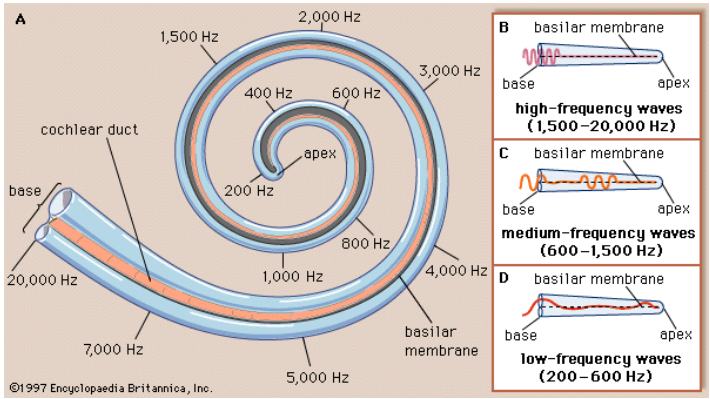
Understand the cues used to determine the location of a sound source

Learn about neural mechanisms underpinning binaural hearing

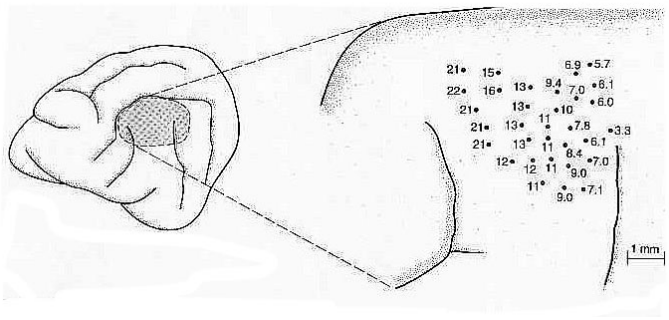



## The primary representation in the auditory system

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*

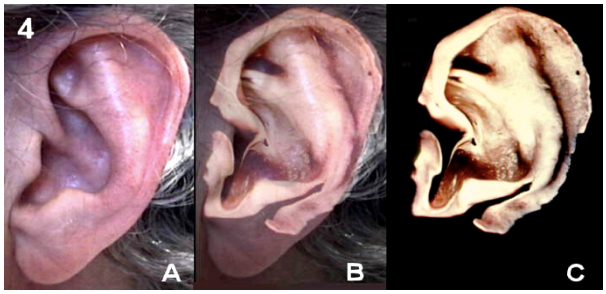
## Spatial Hearing

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

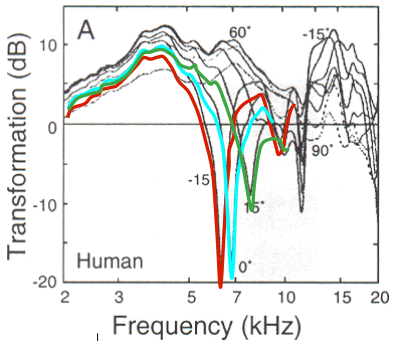
Two main mechanisms for achieving this:-

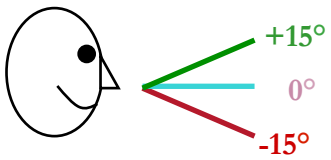
1) The filter properties of the outer ear

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)

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## 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

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## Binaural hearing: a historical context

Lord Rayleigh – first formalised the duplex theory of binaural hearing

*provided evidence that timing differences between the ears were detectable*

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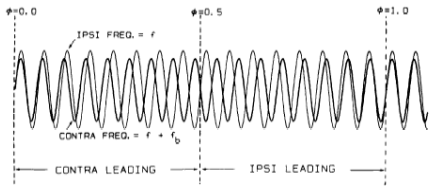
## Sensitivity to binaural beats

Presenting different frequencies to each ear creates binaural beats




*This is how Rayleigh discovered human sensitivity to ITDs*

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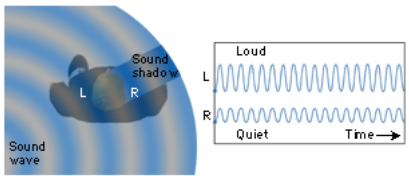
## Two binaural cues...

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)

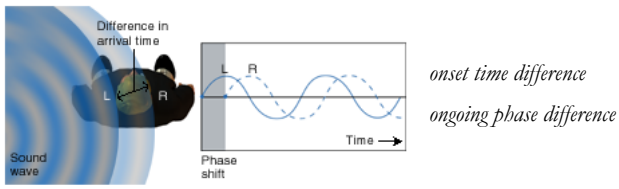



Frequency-dependent – the effect is larger at higher frequencies

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)




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

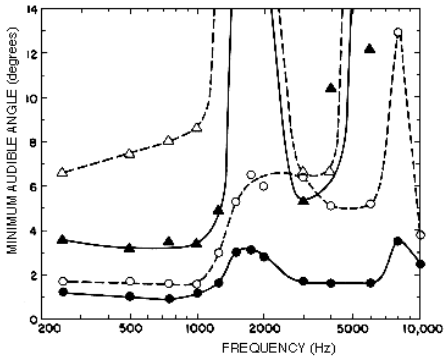
Stevens and Newman (1936) found that:-

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)

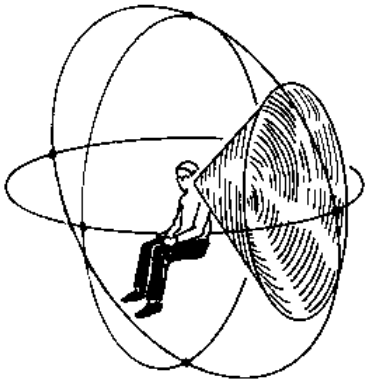
Minimum audible angle between successive pulses of tone as a function of the frequency and the direction of the source measured for angles (bottom to top at left hand side) 0°, 30°, 60° and 75° (from Mills, "Auditory Localization", in Tobias, ed. Foundations of Auditory Theory, Academic Press, 1972,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




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

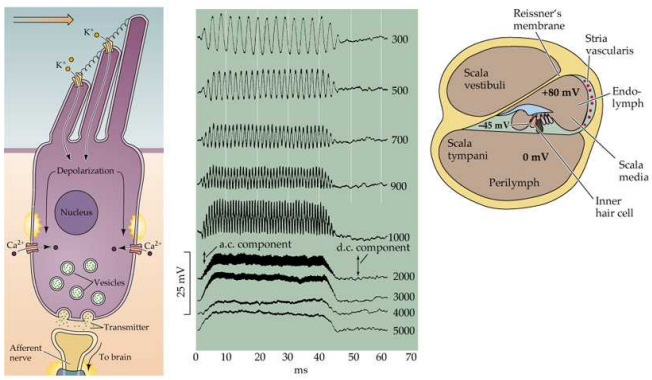
## The "cone of confusion"

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



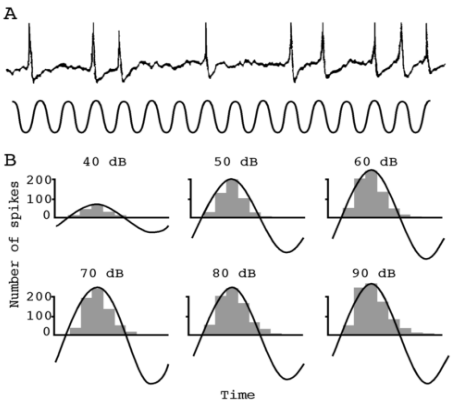
## Neural Mechanisms of Binaural Hearing

binaural timing sensitivity requires monaural timing sensitivity




*IHCs show a.c. potentials at low-frequencies*

## Temporal Sensitivity - Phase Locking

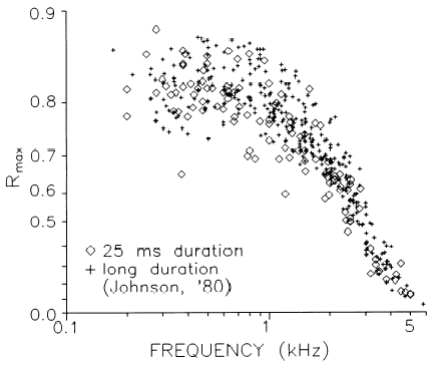



Movies

## Phase-locking is a low-frequency phenomenon

Phase-locking decreases as a function of sound frequency

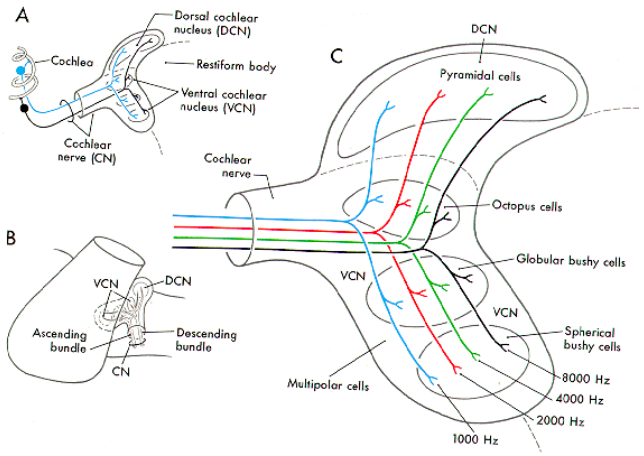
*This means that information about the fine-time structure of a stimulus is lost at high-frequencies*




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

## The Cochlear Nucleus

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

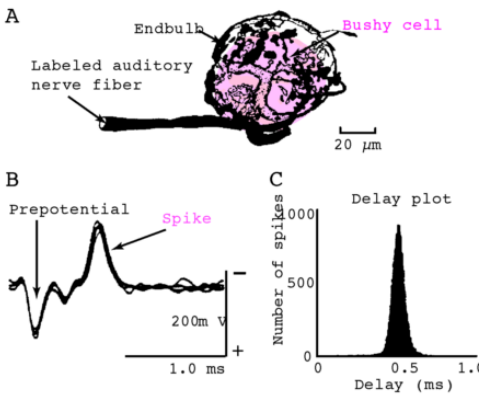



## Spherical Bushy Cells

SBCs are the predominant neuron type in the AVCN

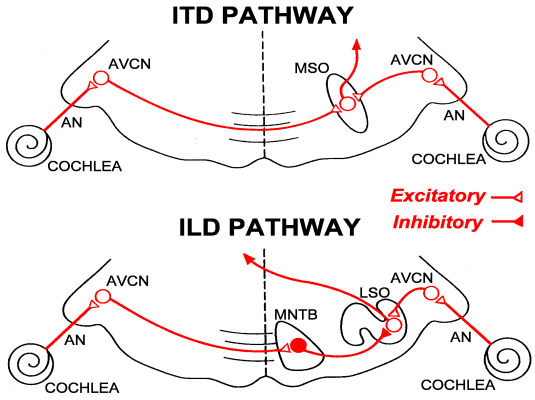
SBCs show primary-like responses (they respond like ANFs)

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



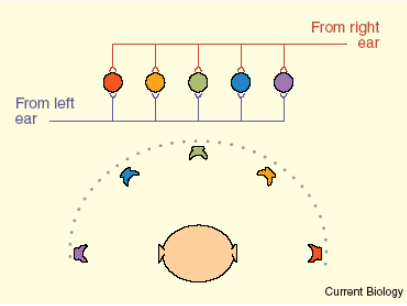
## Physiological Basis of Binaural Hearing

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

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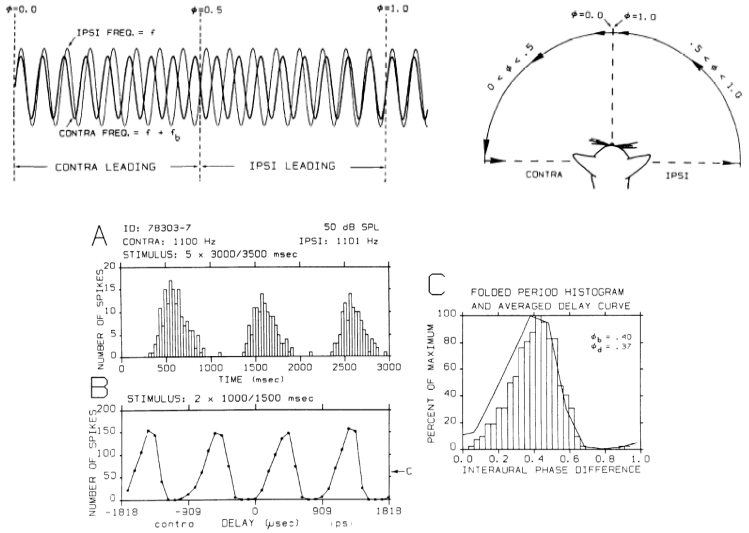
## Sensitivity to interaural phase differences (IPDs)




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

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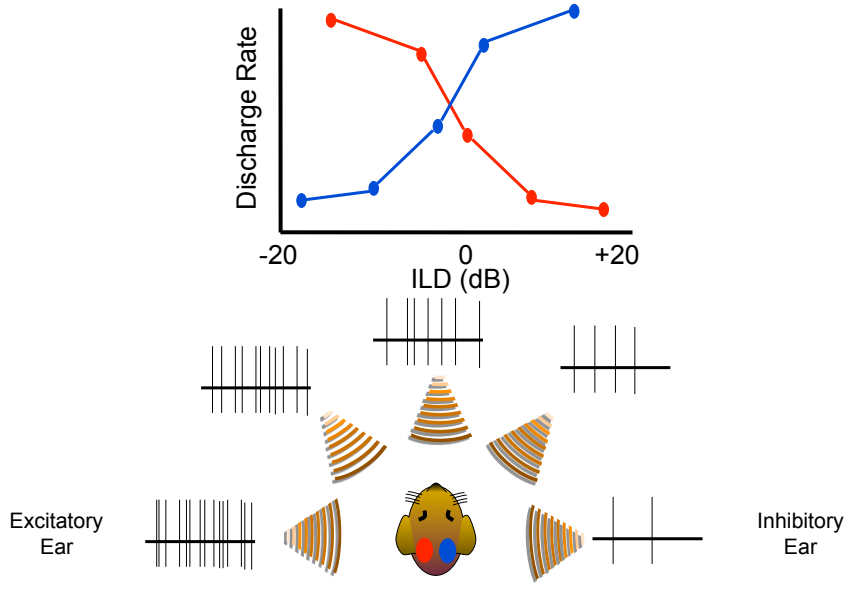

## On reflections