BASIC NOTIONS OF HEARING AND PSYCHOACOUSICS

Educational guide for the subject Communication Acoustics
VIHIAV 035

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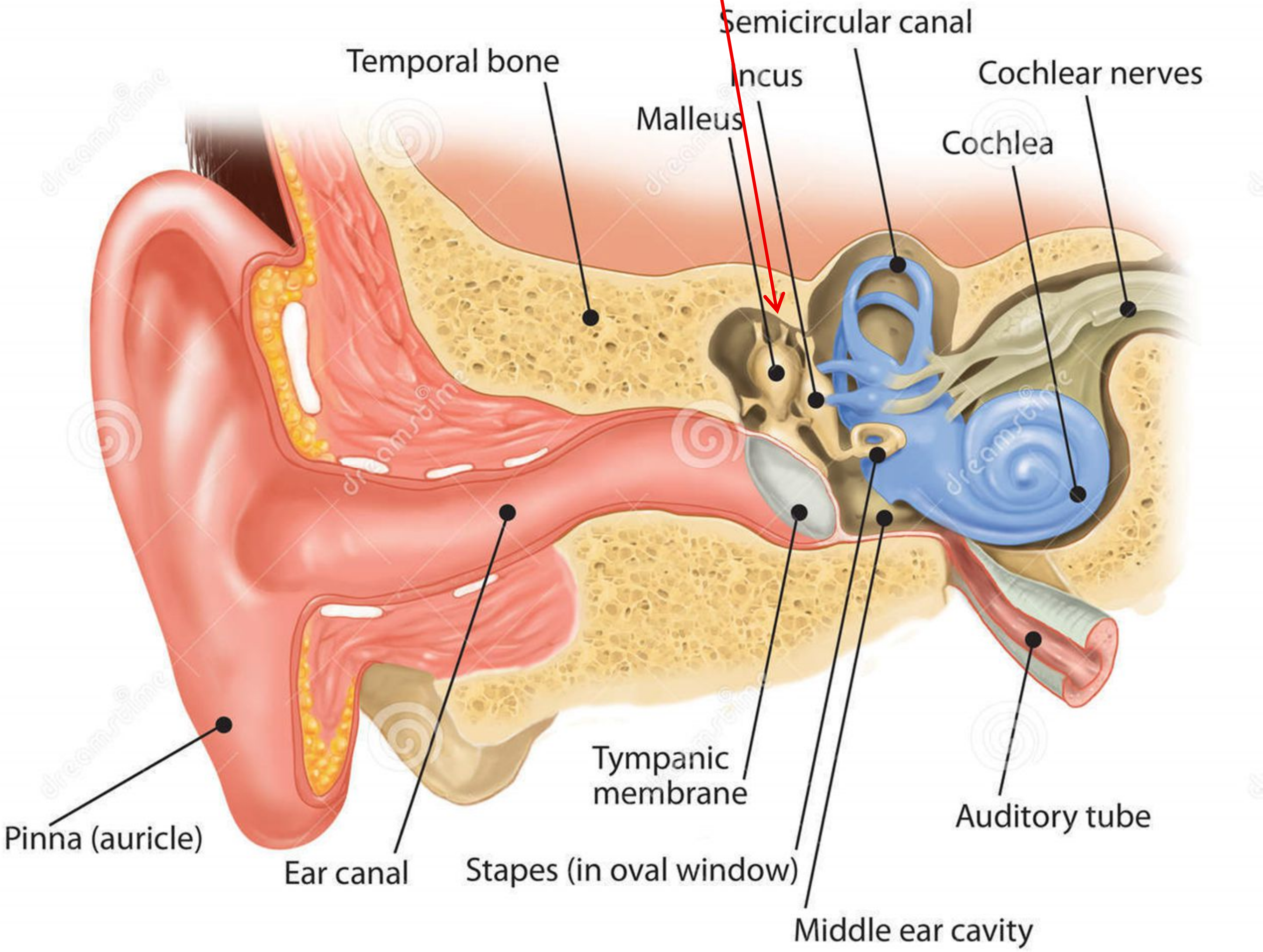
Psychoacoustic phenomena

- Sensing thresholds
- Masking
  - in time
  - in frequency
- Pitch [bark]
- **Cricital bands**
- **Loudness [phon]**
- Sharpness [acum]
- Fluctuation [vacil]
- Roughness [asper]
- Annoyance
- Binaural hearing
  - lateralization (1D)
  - localisation (3D)

How do we hear?

malleus, incus, stapes = hammer, anvil and stirrup

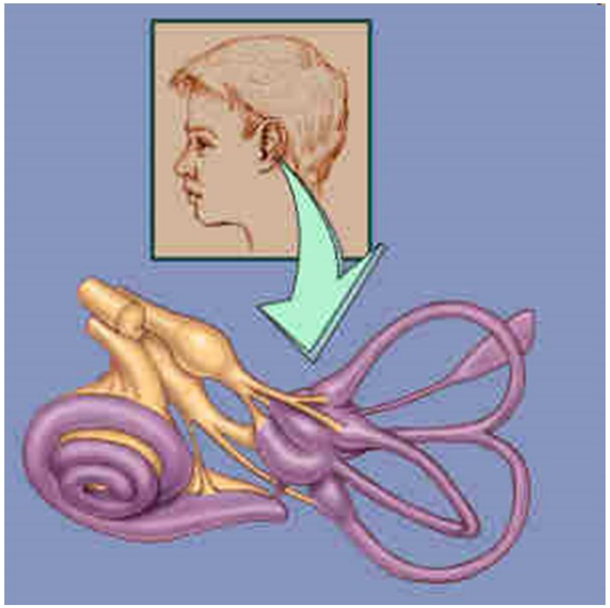


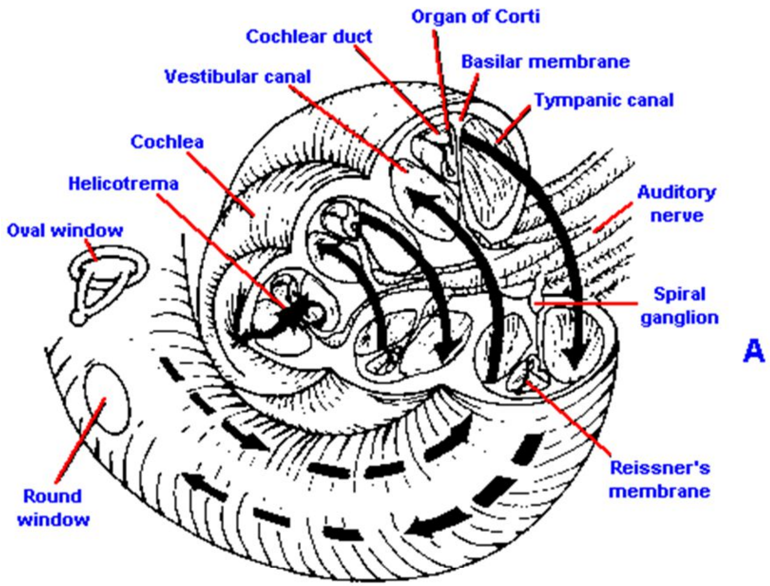
Parts of the middle ear - analogies

The inner ear

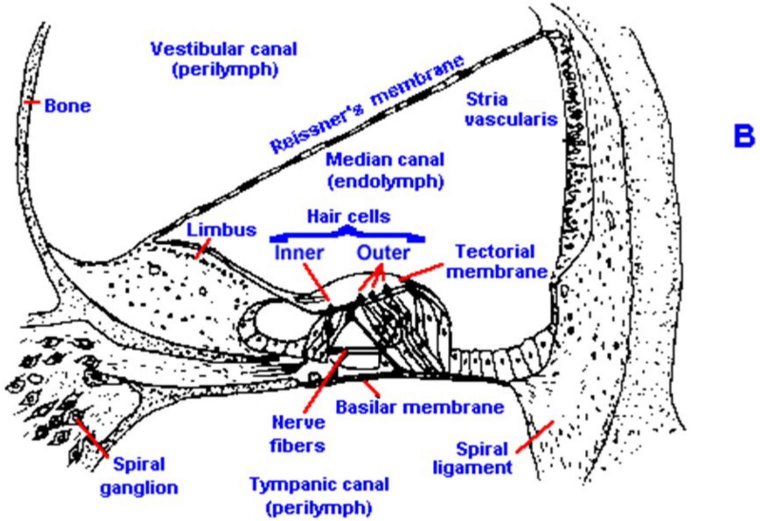
- cochlea

- Construction of the inner ear

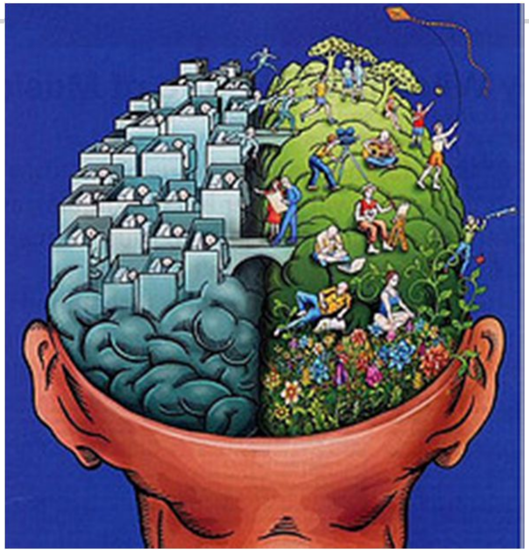




- The Corti organ



Relationship of the inner ear and the brain/ 1



Left cerebral hemisphere	Right cerebral hemisphere
Time domain decoding, speech processing	Spatial domain decoding, spectral processing (music)
Rational and logical critical and objective problem solver sense of time	Creative and fanciful, musical and emotional sense of humour no sense of time

Relationship of the inner ear and the brain/ 2

Left cerebral hemisphere

Time domain decoding, speech processing

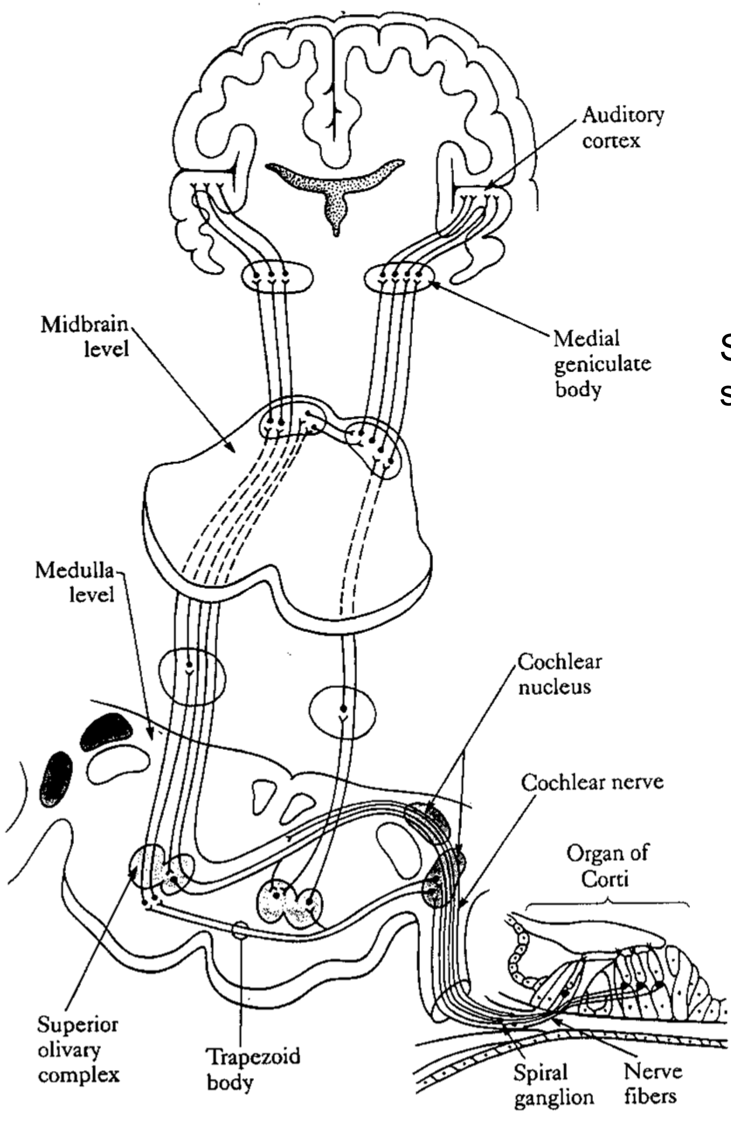
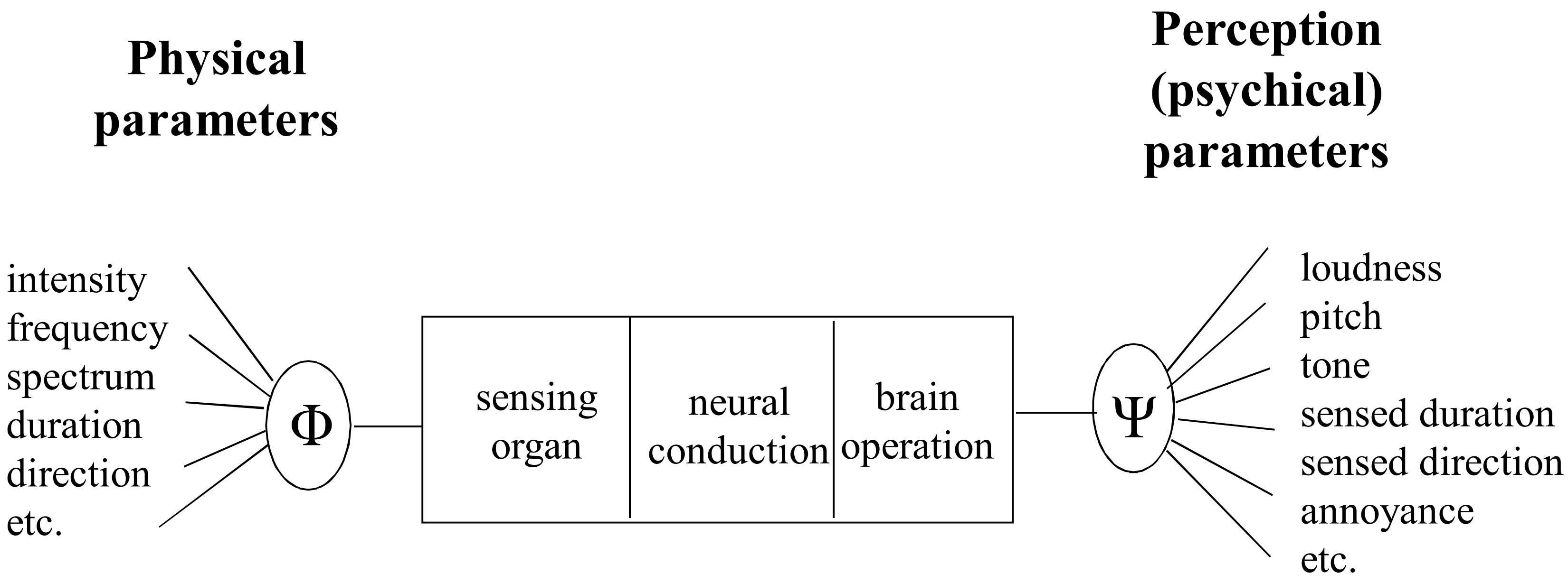


Diagram of the auditory pathways linking the ear with the brain.

Right cerebral hemisphere

Spatial domain decoding, spectral processing (music)

Relationship of the inner ear and the brain/3

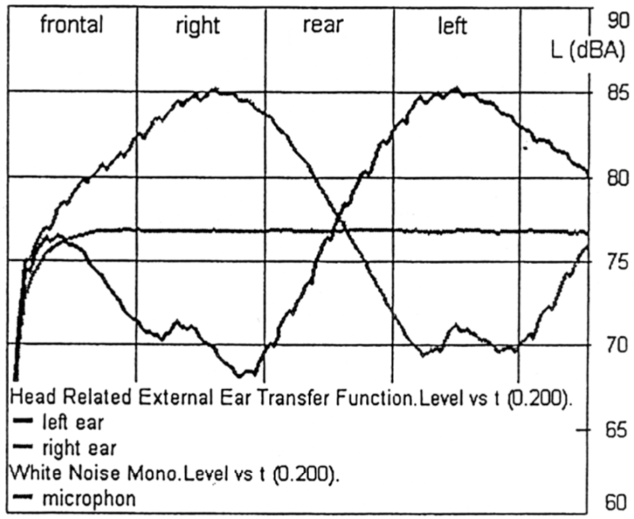


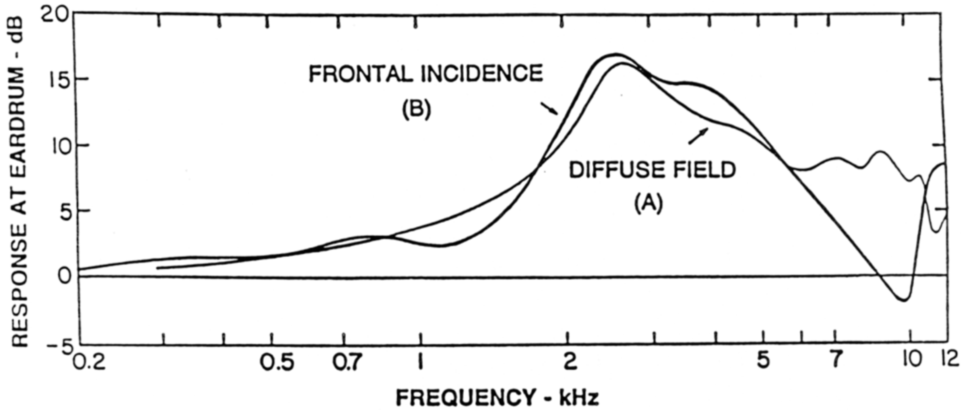
Sensing of direction by two ears

- Basis of direction sensing: the two ears hear different sounds, both in amplitude and in phase

- Description of the different hearing by the two ears is expressed by the HRTFs (Head Related Transfer Function)

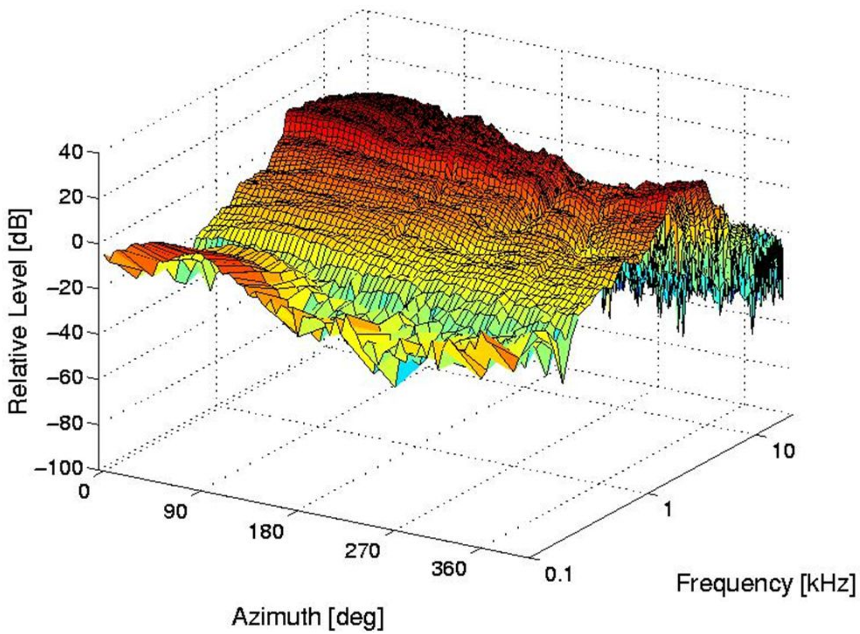
- … and if sound is arriving from all directions?

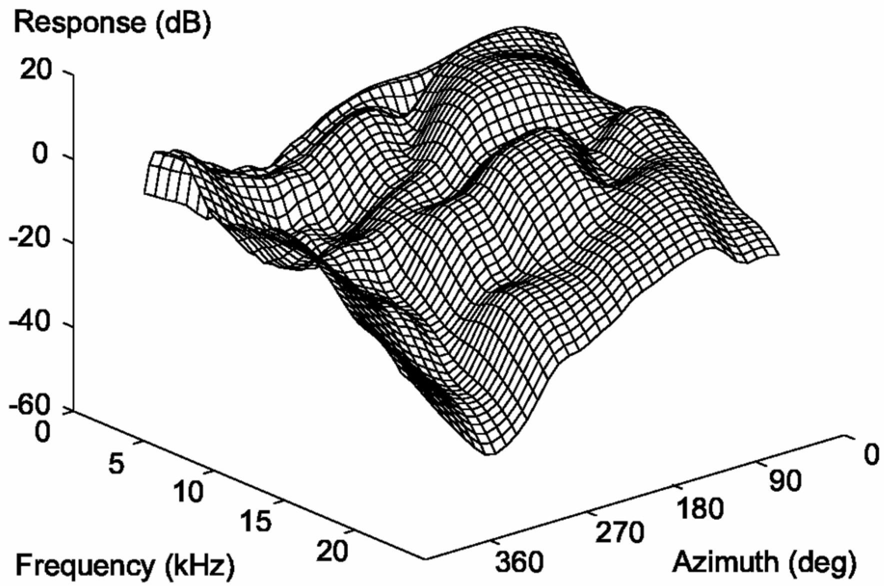




The binaural hearing

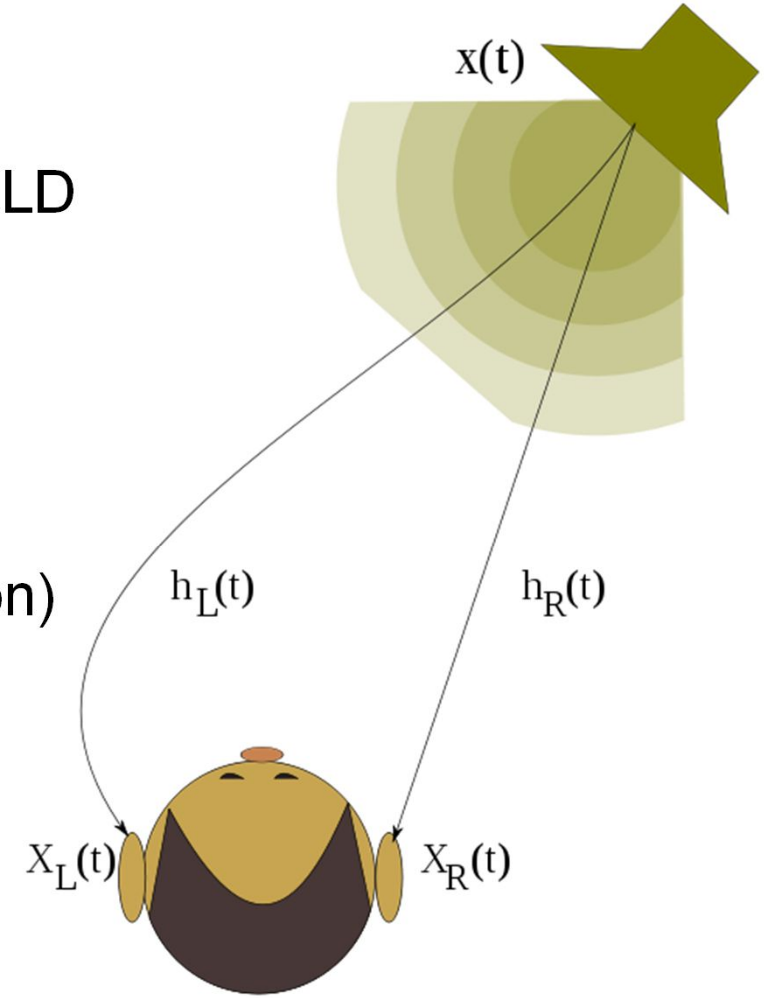
- Directional hearing (perception vs. Azimuth) strongly depends on the frequency
  - bad diection differentiation for low frequencies
  - much better for high frequencies





Basics of the directional hearing

- Two differences:
  - inter-aural time difference, ITD
  - inter-aural intensity difference, ILD
- Implication:
  - Distinct transmissions from source to left & right ears
  - Ratio of the two FRFs: HRTF (Head Related Transfer Function)



Directional hearing

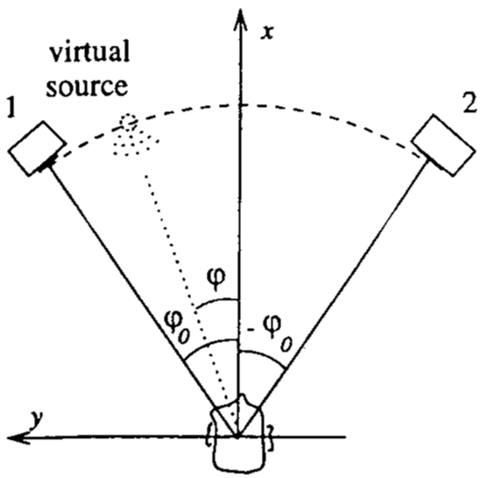
- Operating mechanisms for various frequencies:
  - For low frequencies the relative intensity differences are not relevant (due to the diffraction effect)
  - For high frequencies the phase differences are not relevant/useful, if the travel time delays are in the order or magnitude of the wavelength, or higher

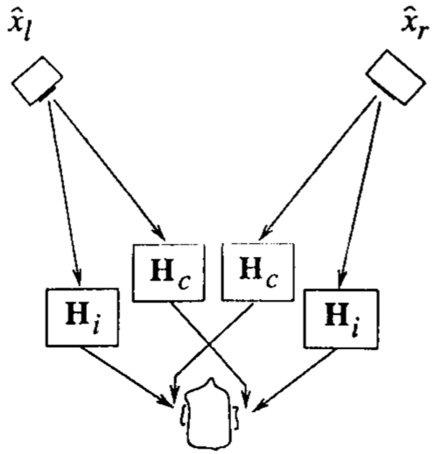
  Therefore
  - For low frequencies it is ITD while for high frequencies it is ILD which is more appropriate
  - Unfortunately, according to newer experiments the problem is not so simple

Directional hearing aids

Use of binaural hearing for virtual (acoustic) reality

- Time delay panning
- Amplitude rendering (panning)
- Head Related Transfer Function (HRTF) technique



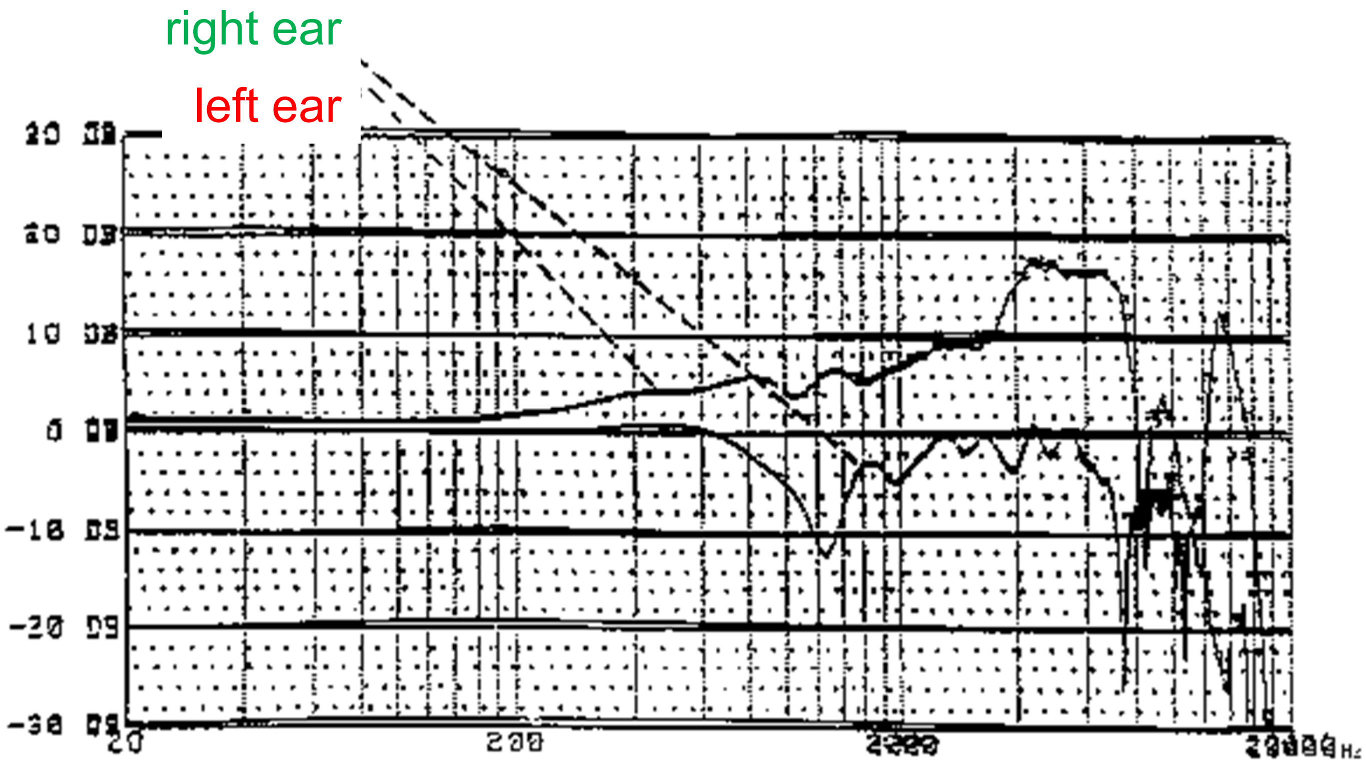


The measurement of HRTF

- sound is radiated from various directions
- ear response is measured by means of a miniature mic in the ear canal

Head Related Transfer Functions

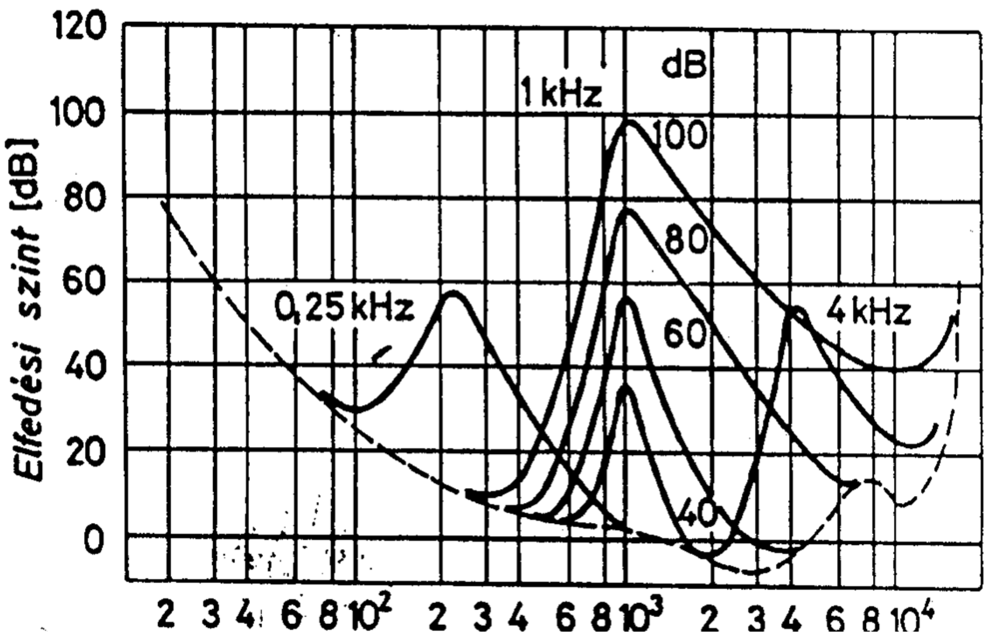
- Source at -60°, transfer function to the two ears



Virtual acoustics

Masking of narrow-band noise

Masking effects of noises of critical bands for 0.25, 1 (various levels) and 4 kHz



Hearing threshold shift for sounds of critical bandwidth, as a function of frequency and level.

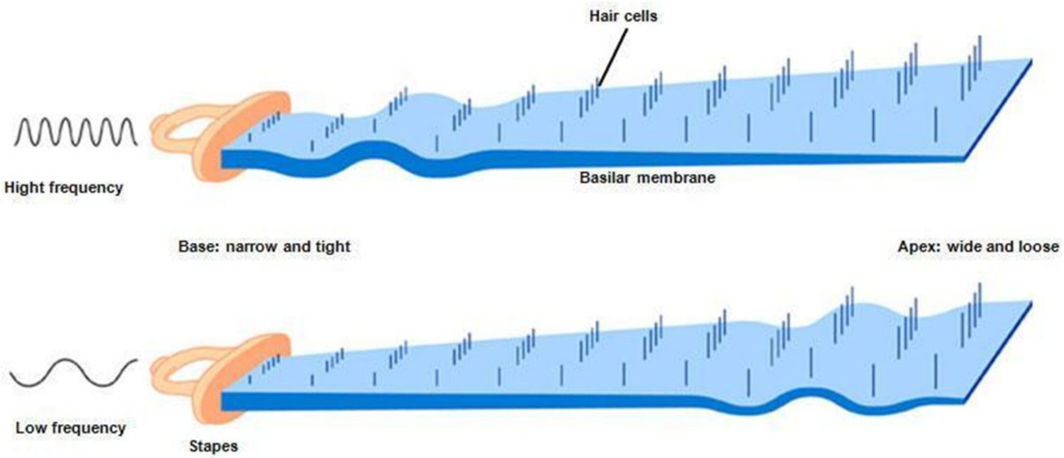
Conclusions:

masking is stronger for higher frequencies

asymmetry is increased for higher intensities

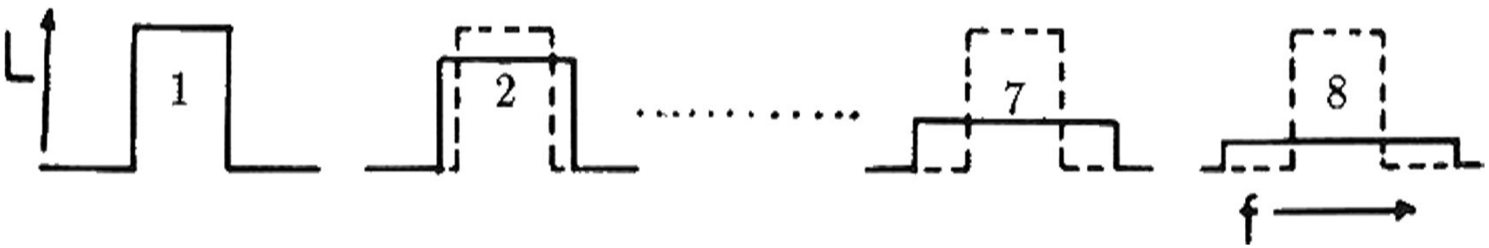
Masking for sinusoidal sounds: critical bands

- Masking in the frequency domain
  - the cochlea creates an „auditory filter”
  - Characterized by critical bands:
    - the band of audio frequencies within which a second tone will interfere with the perception of a first tone
    - the band within which increasing the bandwidth of narrow band excitation will not increase the percepted loudness
- Reason: geometry and characteristics of the basilar membrane



Critical bandwidth vs. center frequency

- Demo: increasing the bandwidth with constant energy

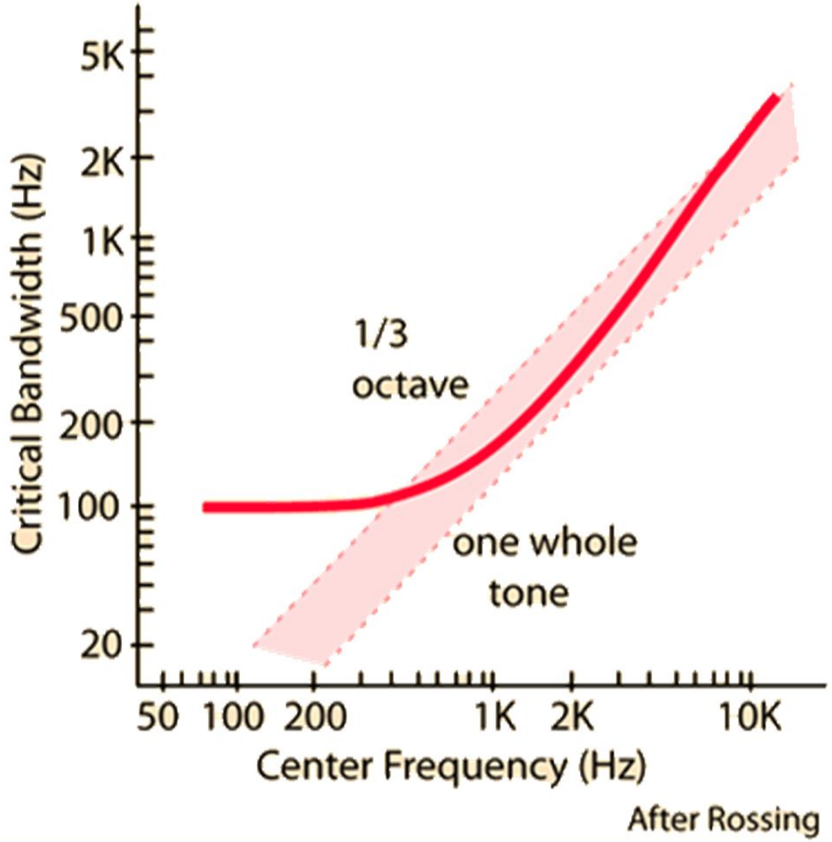


Critical band frequencies

- Each critical bandwidth corresponds to constant, 1,3 mm along the basilar membrane

but

- Each critical bandwidth corresponds to varying frequency bandwidth



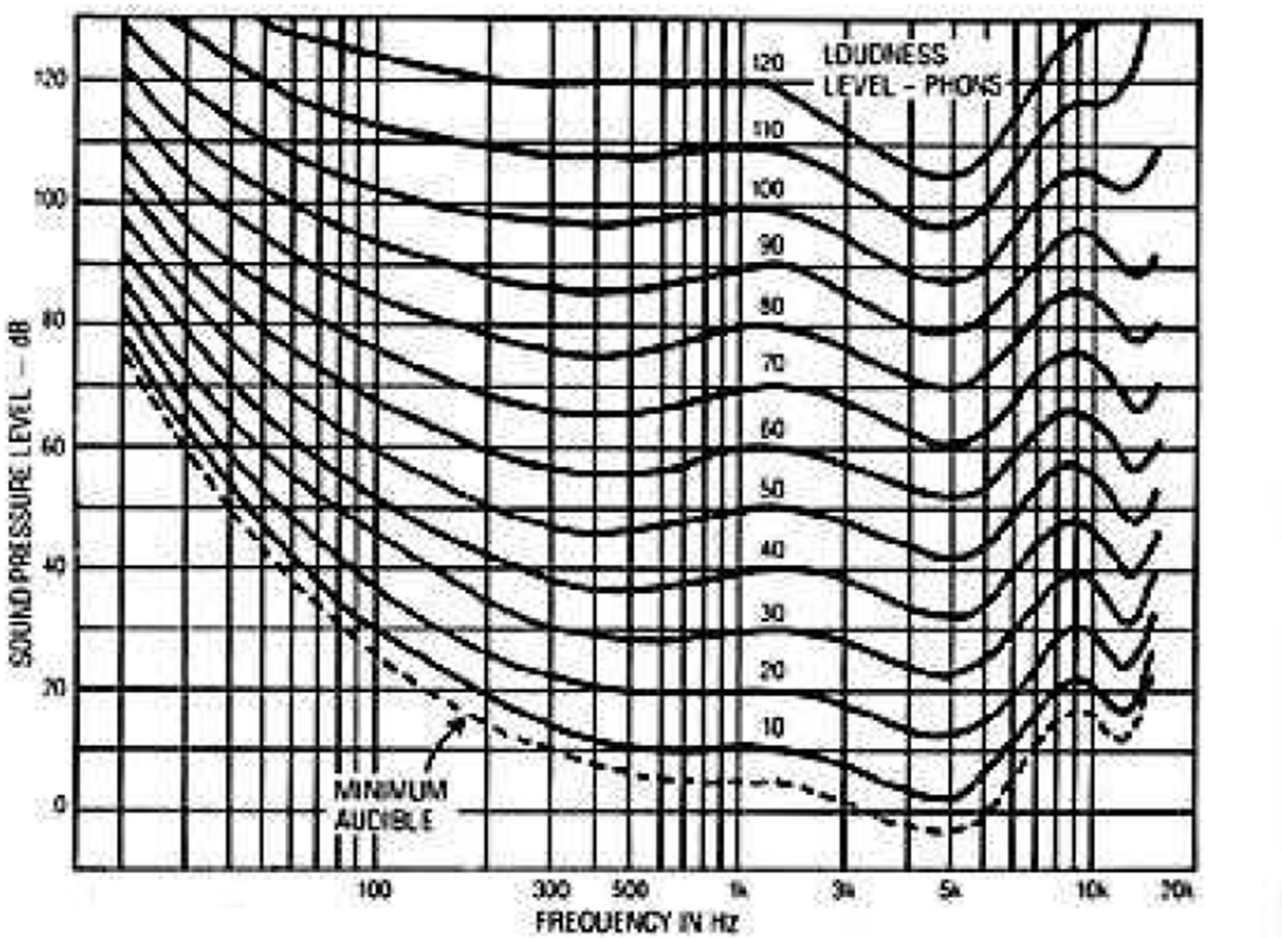
Critical bands

Critical Band	Frequency (Hz) Low	High	Width	Critical Band	Frequency (Hz) Low	High	Width
0	0	100	100	13	2000	2320	320
1	100	200	100	14	2320	2700	380
2	200	300	100	15	2700	3150	450
3	300	400	100	16	3150	3700	550
4	400	510	110	17	3700	4400	700
5	510	630	120	18	4400	5300	900
6	630	770	140	19	5300	6400	1100
7	770	920	150	20	6400	7700	1300
8	920	1080	160	21	7700	9500	1800
9	1080	1270	190	22	9500	12000	2500
10	1270	1480	210	23	12000	15500	3500
11	1480	1720	240	24	15500	22050	6550
12	1720	2000	280				

Standard octave and third-octave bands

Oktávsávok			Tercsávok		
Közép-érték	Átfogás	Sáv-szélesség	Közép-érték	Átfogás	Sáv-szélesség
			20	18–22,5	4,5
31,5	22,5–45	22,5	25 31,5 40	22,5–28 28–35,5 35,5–45	5,5 7,5 9,5
63	45–90	45	50 63 80	45–56 56–71 71–90	11 15 19
125	90–180	90	100 125 160	90–112 112–140 140–180	22 28 40
250	180–355	175	200 250 315	180–225 225–280 280–355	45 55 75
500	355–710	355	400 500 630	355–450 450–560 560–710	95 110 150
1000	710–1400	690	800 1000 1250	710–900 900–1120 1120–1400	190 220 280
2000	1400–2800	1400	1600 2000 2500	1400–1800 1800–2250 2250–2800	400 450 550

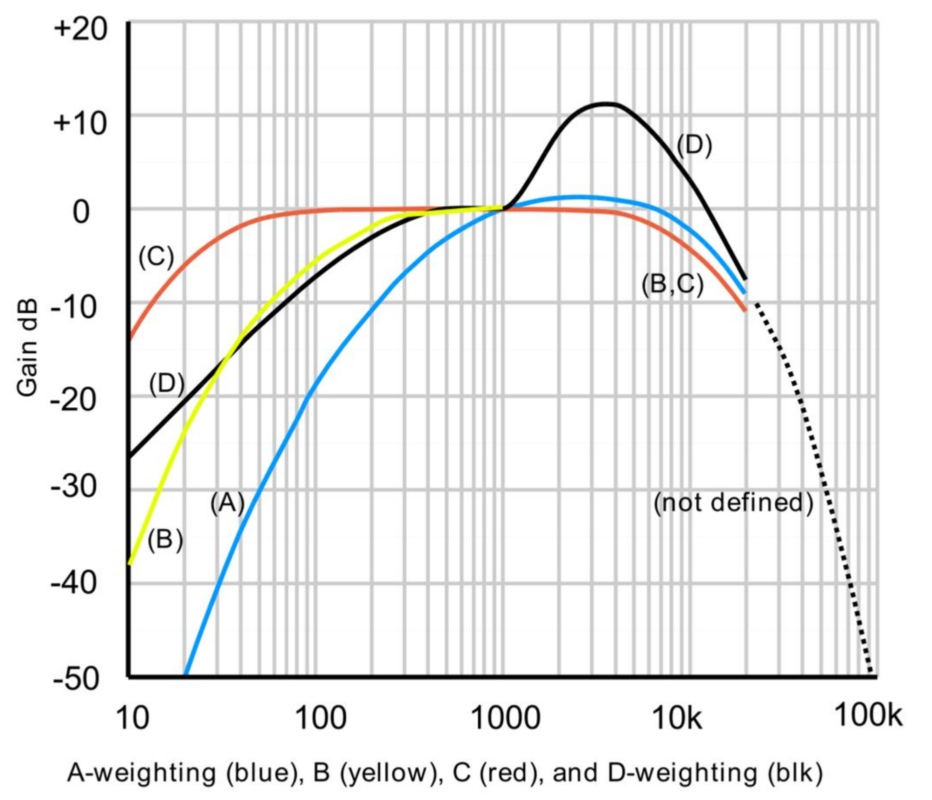
Loudness



Subjective loudness of a 1000 Hz sinusoidal sound equals the physical quantity: sound pressure level.

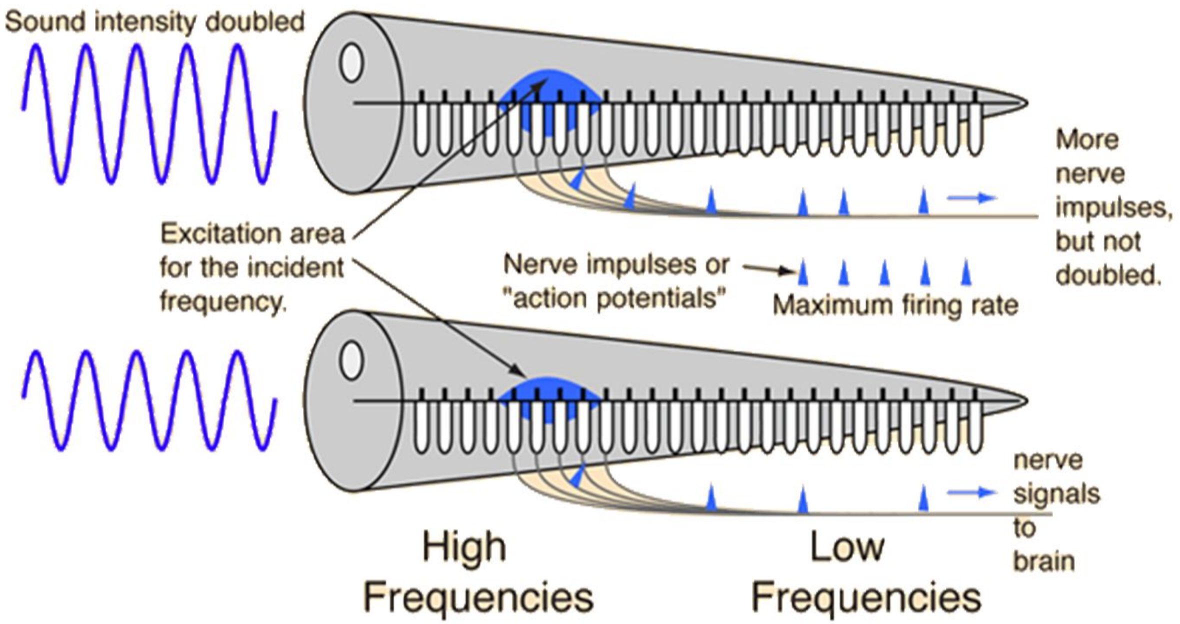
Simulation of loudness by weighting functions

- Historical development: inverse curves of the 40, 70 and 100 phon loudness curves (1928)
- Very easy to implement by simple RC circuits
- Obviously very rough approximation, still not yet obsolete
  - A is generally used nowadays
  - B has died out
  - C is only used for hearing impairment checks
  - D is used for jet aircrafts



Summation of loudness /1

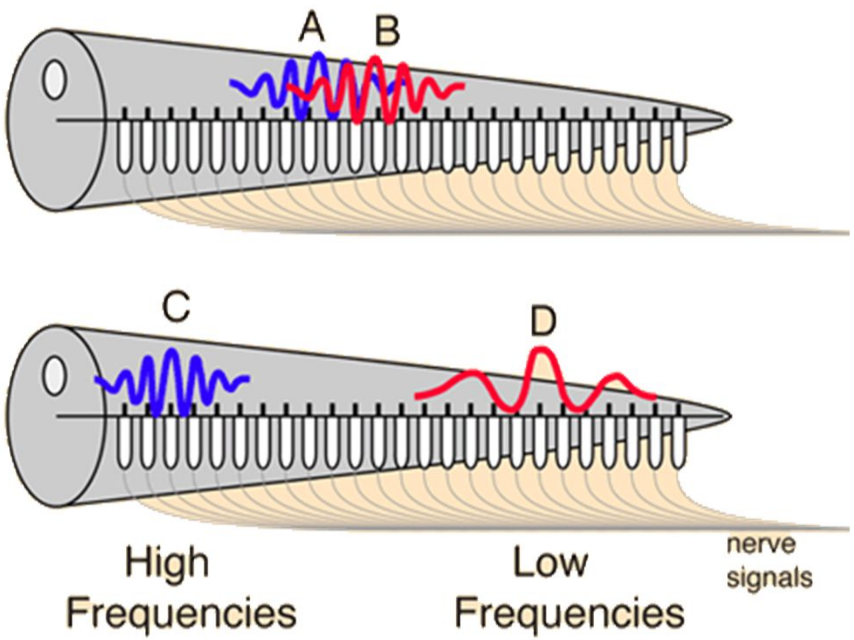
- What happens, if sounds of various frequencies are summed?
  - 1 pc 1000 Hz 60 dBSPL sinusoidal sound ⇒ 60 phon
  - 10 pc of 60 dBSPL sounds of various frequencies ⇒
    - Physically summed: 70 dB
    - Loudnesses summed: 90 phon!
- Why?



Summation of loudness /2

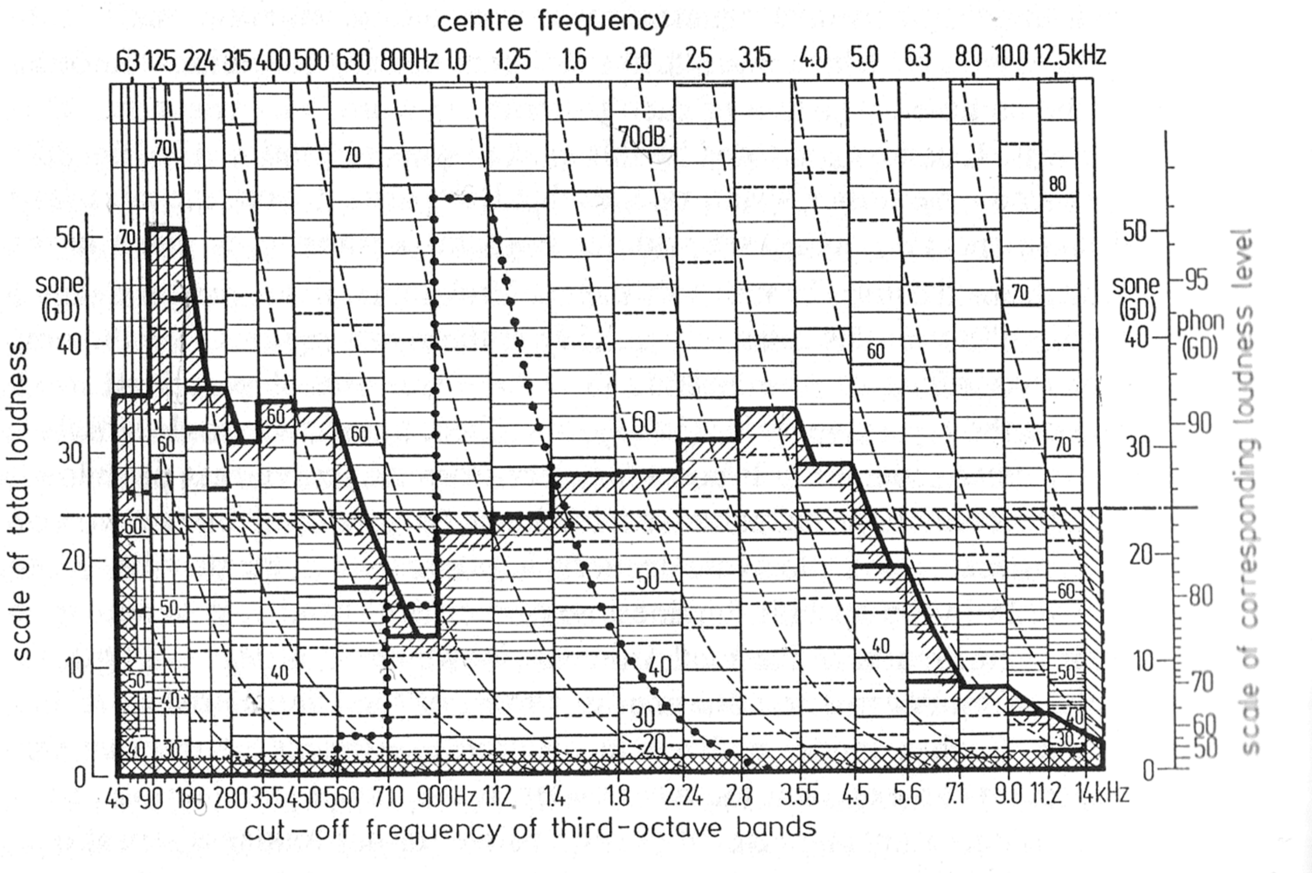
- Summation is different for slosely spaced and for faraway frequencies

If sounds A, B,C, D are adjusted to have identical loudnesses when sounded alone, then the combination C+D would be expected to sound louder than A+B because C and D are not competing for the same nerve endings in the inner ear.



Summation of loudness

- Tool for the summation: the Zwicker method

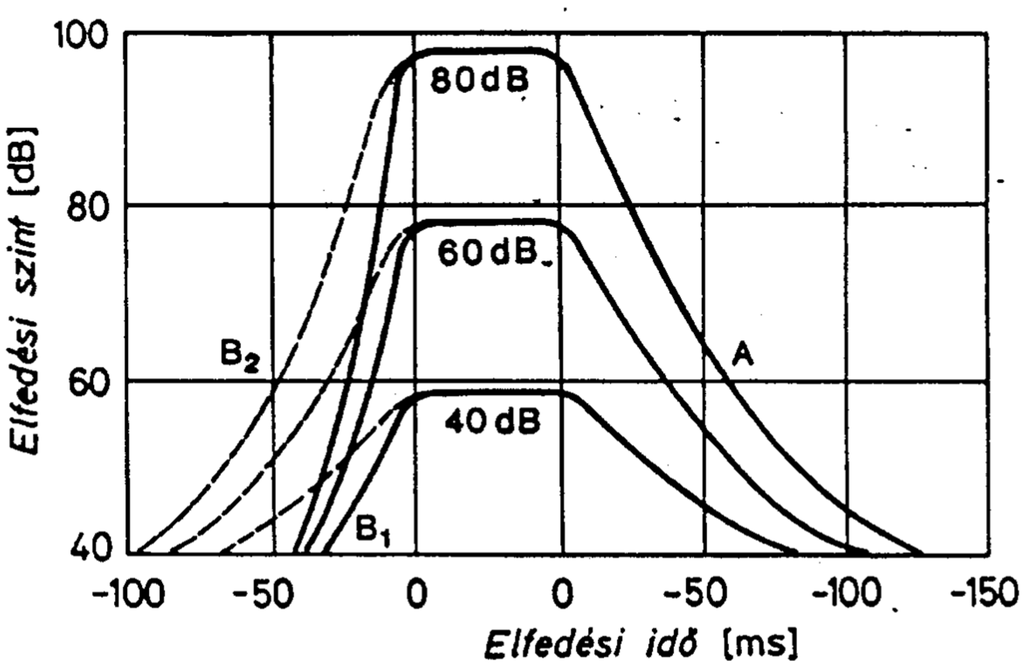


Temporal and frequency masking

Temporal masking:
https://www.youtube.com/watch?v=mpxOD_fQ0WA

Frequency masking:
https://www.youtube.com/watch?v=S5TJkAROSD8

Masking in time



Az elfedés időbeli alakulása 40, 60 és 80 dB intenzitású fehér zaj terhelésekor. Jobbra (*A*-görbék), az elfedő hang elhangzása után tapasztalható utó-elfedő hatás olvasható le. Balra (B_1-görbék) a különböző fülű és (B_2-görbék) az azonos fülű elő-elfedés folyamata tanulmányozható. Ez esetben egy később megjelenő elfedő hang hat egy már korábban elhangzott gyöngébb hangra.

- Consequence: a new sound arriving with short time delay is not sensed as a separate sound but appears as the original sound would be stronger (Haas-effect)

A short history of 2D stereo sound

- 1877 First recording by Thomas A. Edison, *Mary Had A Little Lamb.*
- 1888 The Gramophone, invention of Emile Berliner, American inventor: the flat record
- 1898 Invention of the magnetic sound recording (Valdemar Poulsen, Denmark)
- 1931 Stereo record (inventor Alan D. Blumlein, US)
- 1933 Bell Labs realizes the first stereo concert broadcast on a telephone line from Philadelphia to Washington
- 1940 Walt Disney first uses stereo sound for his movie *Fantasia c.*
- 1954 The stereo tape recorder is commercialized for home users
- 1958 Stereo LP record by using V-cut
- 1961 Outset or stereo radio broadcast
- 1969 Outset of the quadrophone (4-ch) radio broadcast
- 1970 Record industry changes entirely to stereo technology