

Speech Science

Exercise evaluation link:

<https://qualis.uni-saarland.de/eva/?l=1445872&p=8nor9q>

lecture evaluation link:

<https://qualis.uni-saarland.de/eva/?l=1445871&p=xl8qyq>

Deadline: **31.01.2024**



Speech Science

WiSe 2023

Exercise 9: Auditory System/Pitch Perception

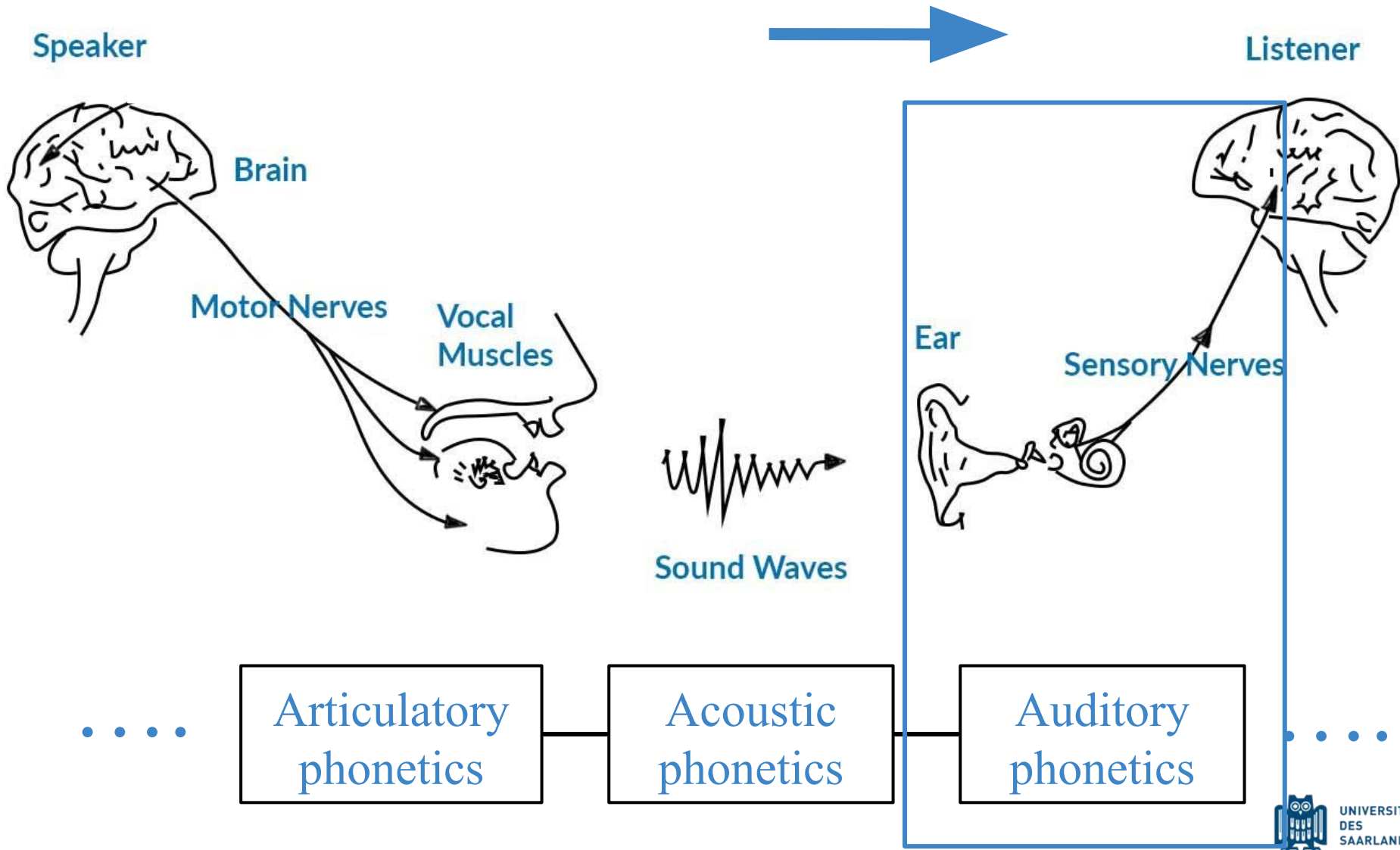
Jan 22, 2024

Bernd Möbius & Omnia Ibrahim

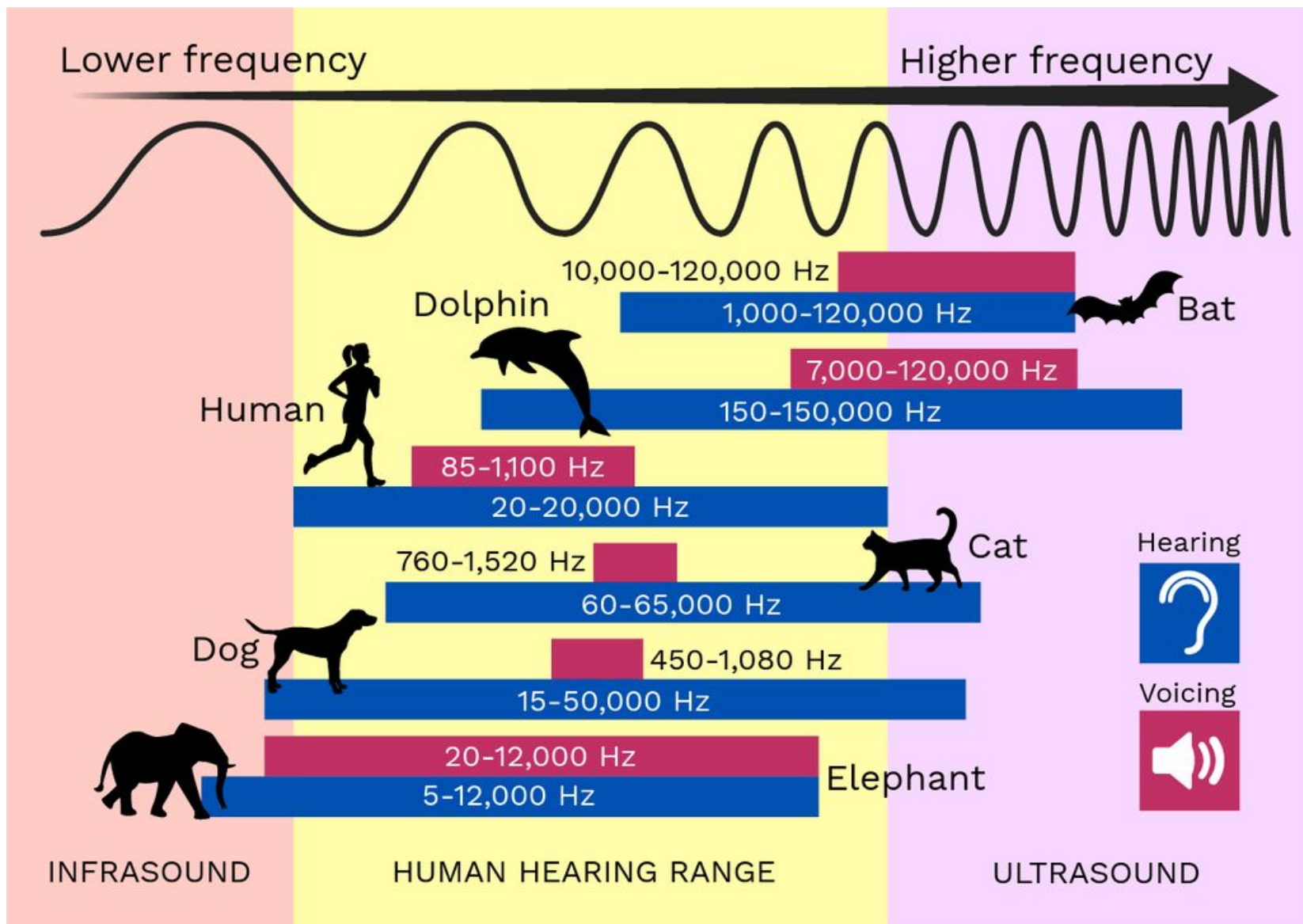
Language Science and Technology
Saarland University



Speech chain



Hearing and Voicing Ranges



- **Auditory system**

 - anatomy

- **Pitch perception**

 - Just Noticeable Difference - Critical Bandwidth

- **Pitch scales**

 - Mel, Bark, ERB, semitone

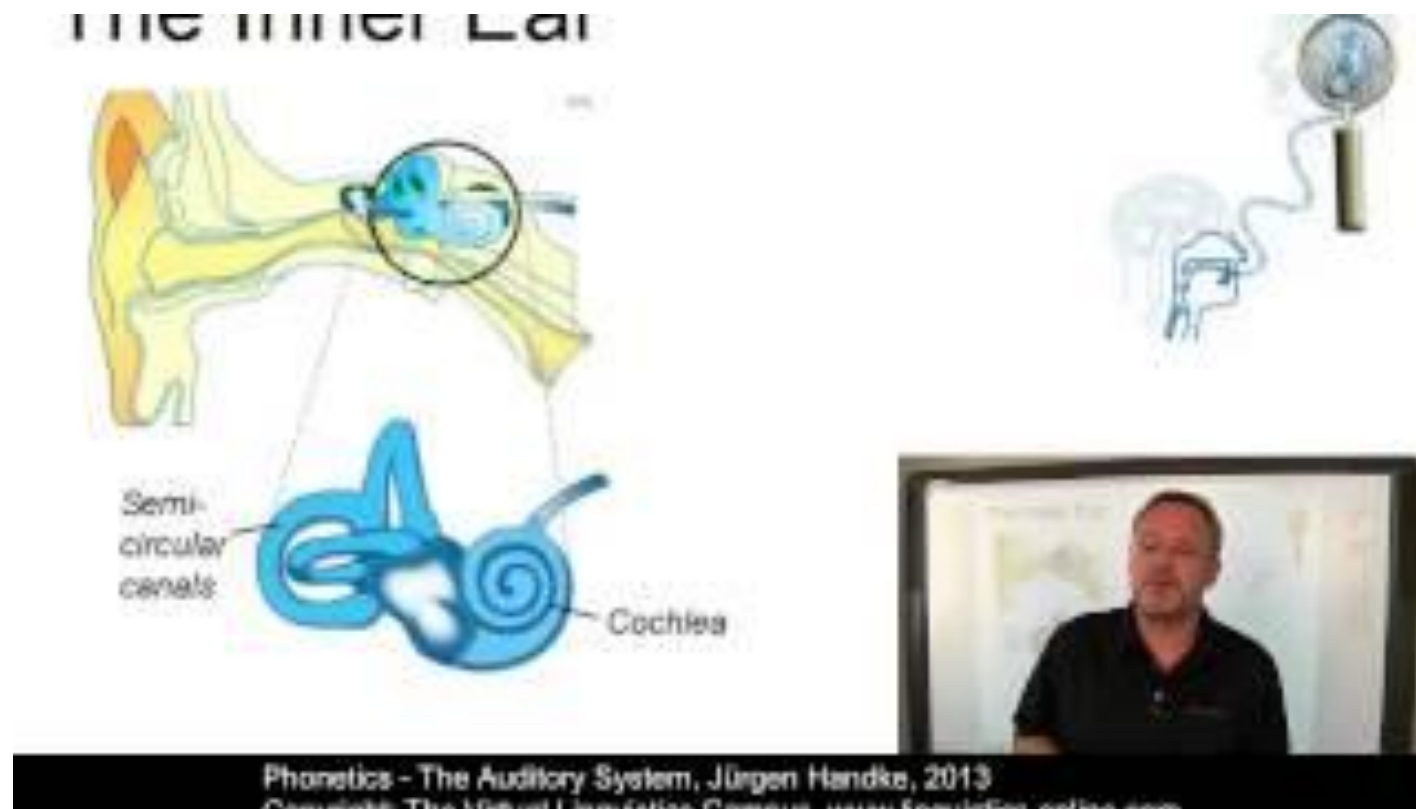
- **Loudness**

 - dB, sensation levels



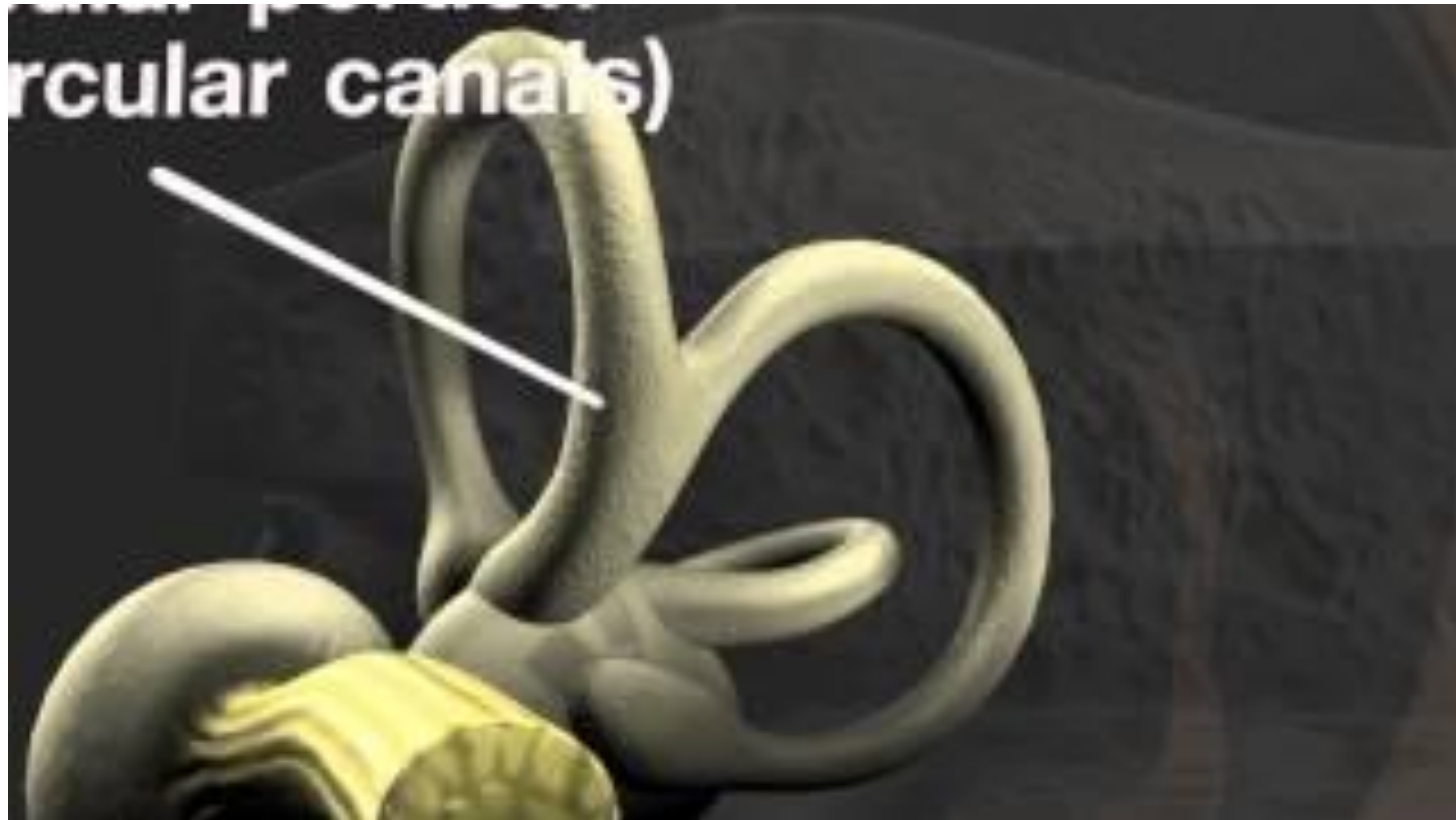
<https://www.youtube.com/watch?v=LkGOGzpbrCk>

Resources: Auditory System



https://www.youtube.com/watch?v=PQEWp_Ms1Ao

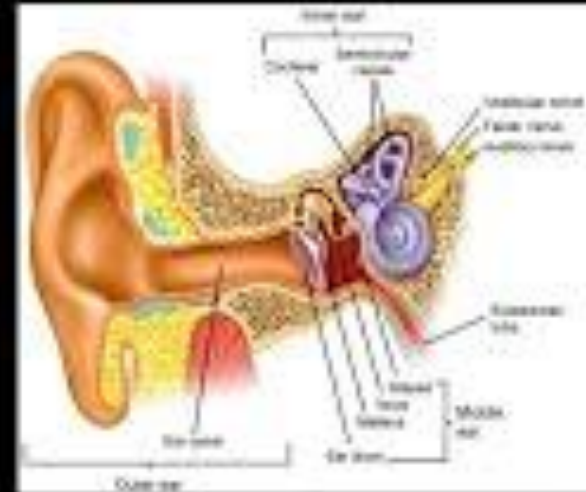
Resources: Auditory System (Extra)



<https://www.youtube.com/watch?v=3G5jiXI2LSM>

Hearing Science!

How do all those acoustic changes get encoded by our ears?



<https://www.youtube.com/watch?v=zBlxRI62HSU>

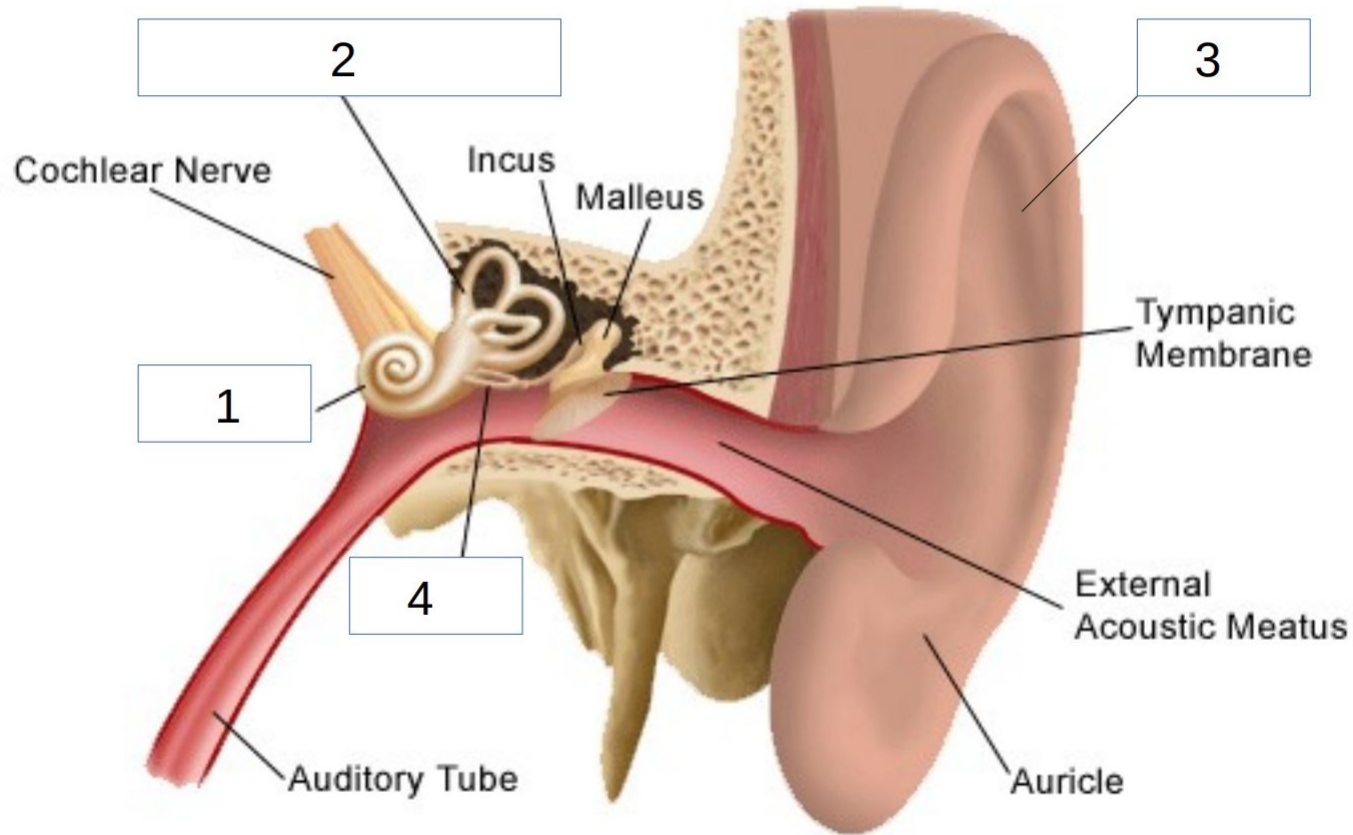
Resources: Auditory System (Extra)



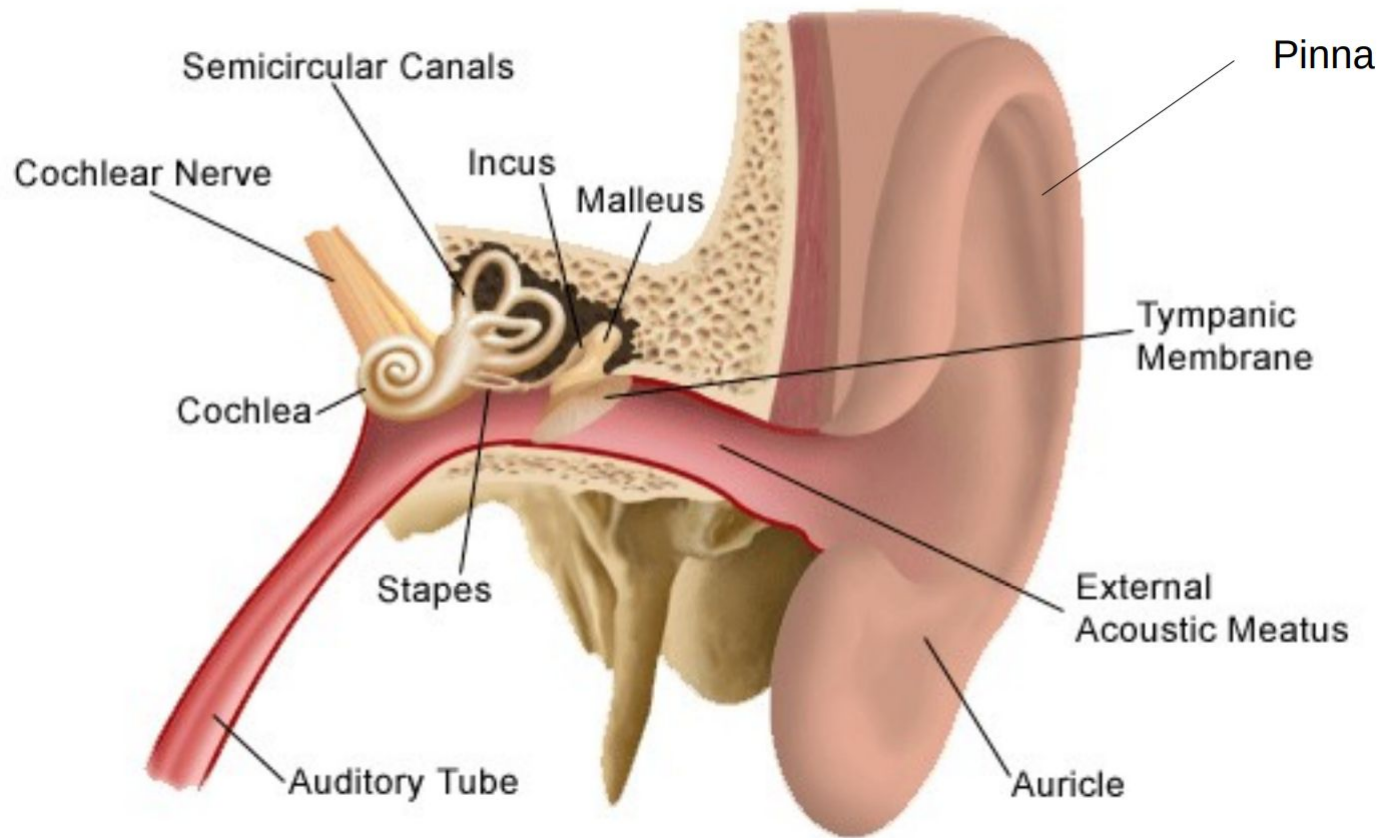
<https://www.youtube.com/watch?v=7Bs2HeE6XH0>

Exercise 1: Outer, Middle, Inner Ear Anatomy

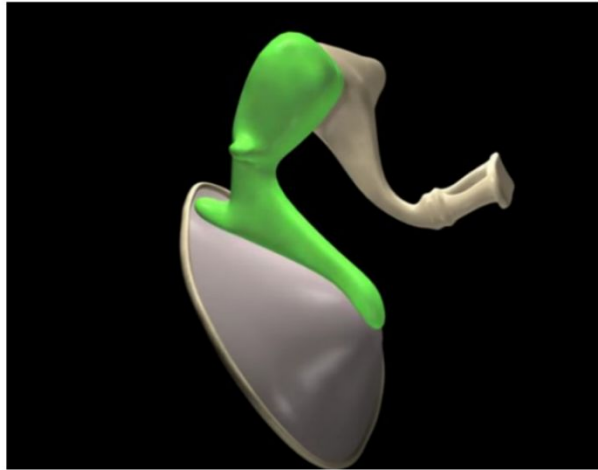
Name the parts and shortly describe their functions



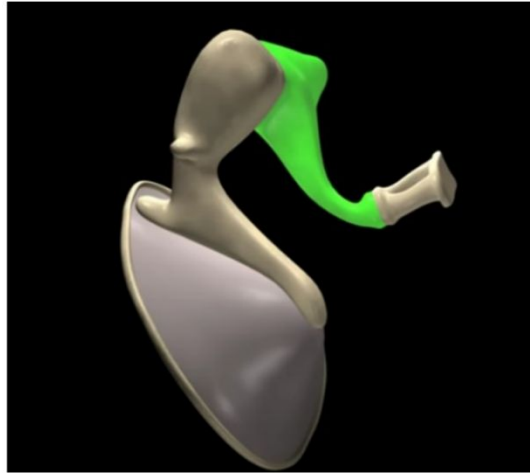
Exercise 1: Anatomy Answer



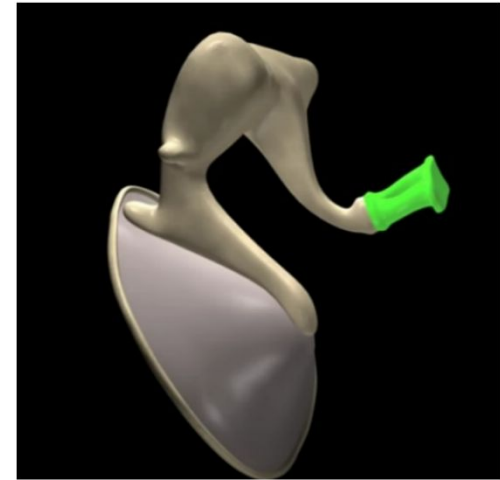
Exercise 2: Ossicles Anatomy



1)

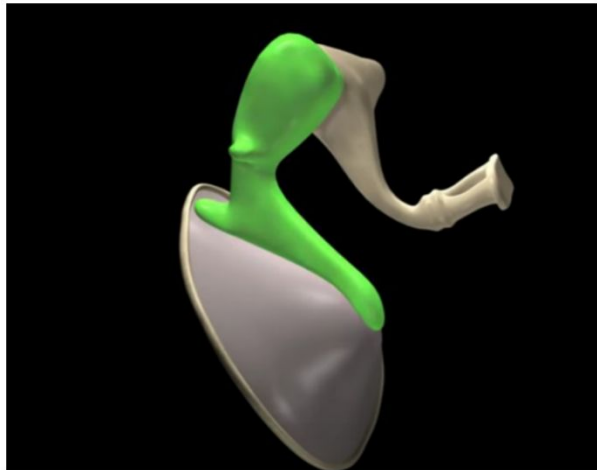


2)

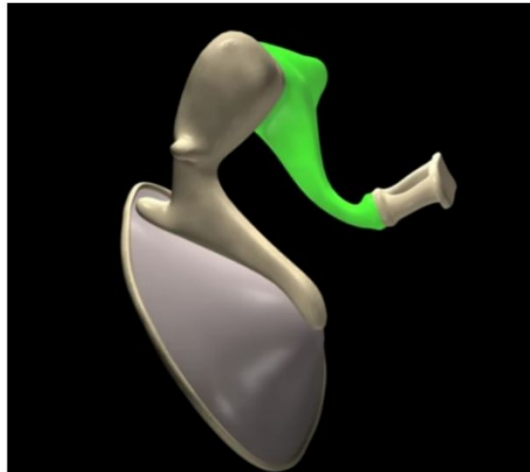


3)

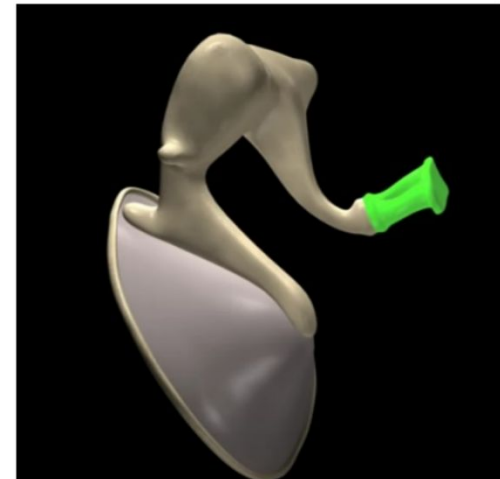
Exercise 2: Ossicles Anatomy Answer



1) Maleus / Hammer



2) Incus / Anvil



3) Stapes / Stirrup

Exercise 3: Outer, Middle, Inner Ear Functions

Instructions:

Discuss the function of different components of the ear:

- Outer ear: pinna, auditory canal, eardrum (tympanic membrane)
 - Middle ear: ossicles, oval window
- Inner ear: scala vestibuli/scala tympani/scala media, organ of corti, inner/outer hair cells

Exercise 3: Functions Answer

	Component	Function
Outer ear	Pinna	Localization of sound source
	Auditory canal	Protection; enhance 2 – 4 kHz
	Eardrum (tympanic membrane)	Register sound pressure changes
Middle ear	Ossicles (malleus, incus, stapes)	Reinforce eardrum vibrations
	Oval window	Interface air → fluid
Inner ear	Scala vestibuli, tympani, media	Container of perilymph (sc.v./t.), endolymph (sc.m.)
	Organ of Corti, with bas./tect. membranes, inner/outer hair cells	Register fluid pressure changes, spectral analysis, transformation to neural signals

- **Auditory system**

anatomy

- **Pitch perception**

Just Noticeable Difference - Critical Bandwidth

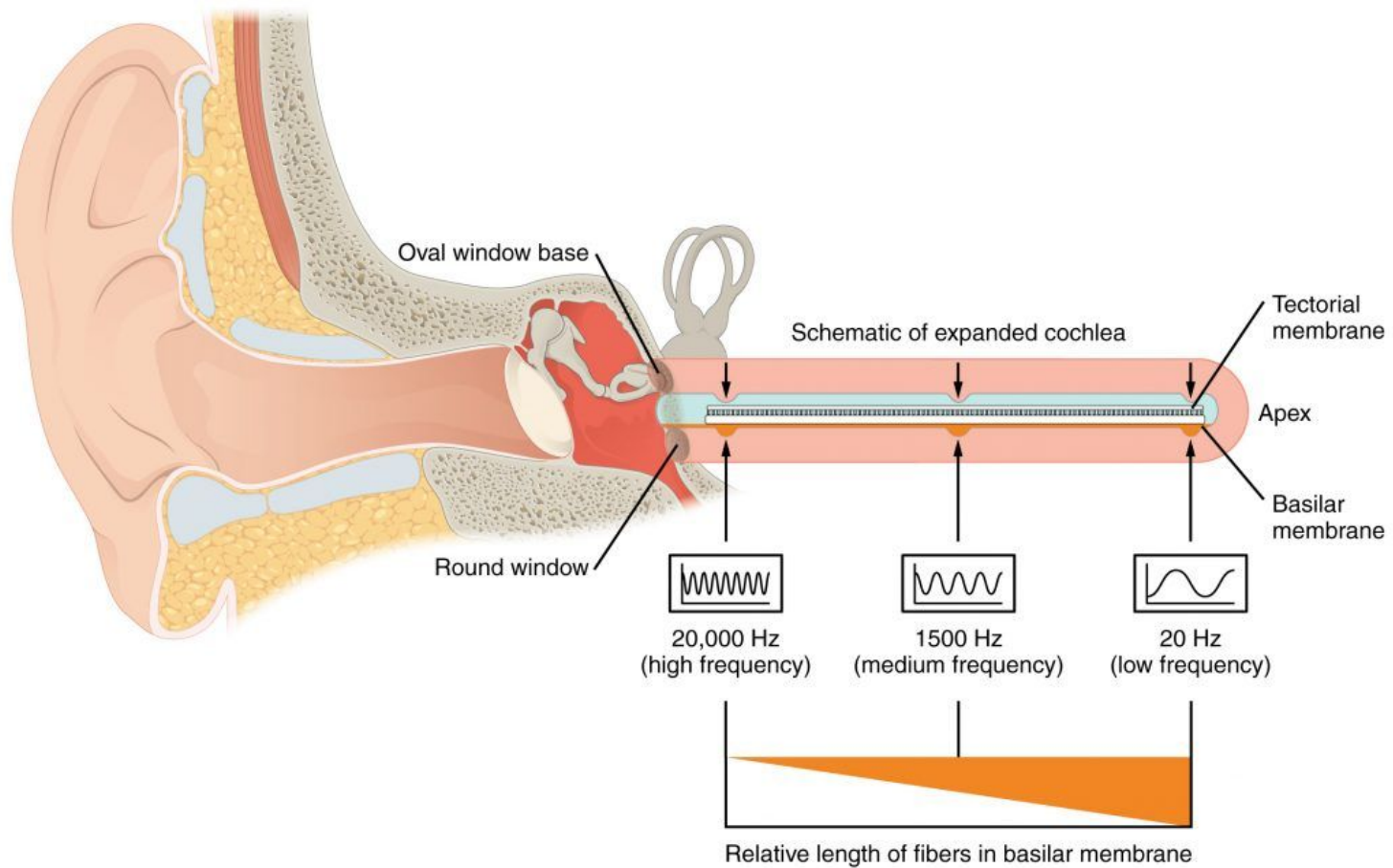
- **Pitch scales**

Mel, Bark, ERB, semitone

- **Loudness**

dB, sensation levels

Inner ear - Frequency coding in the cochlea



<https://pressbooks.umn.edu/sensationandperception/chapter/critical-bands-and-mask-draft/>

Just Noticeable Difference

Just noticeable difference: How much must a frequency change for the ear to notice the change in frequency? It turns out that for the ear, the **JND is about 0.5% or 0.005**.

Ex. At 1000 Hz, the JND is 5 Hz. So, if two tones are played *separately* at 1000 Hz and 1002 Hz, you would not be able to tell that the pitch has changed. However, if the tones are 1000 Hz and 1010 Hz, you should be able to tell the difference.

From: https://www.phys.uconn.edu/~gibson/Notes/Section7_2/Sec7_2.htm

Listen, Can you hear the difference?

- Sine waves 1000 Hz - 1002 Hz (2 Hz)
- Sine wave 1000 Hz - 1010 Hz (10 Hz)

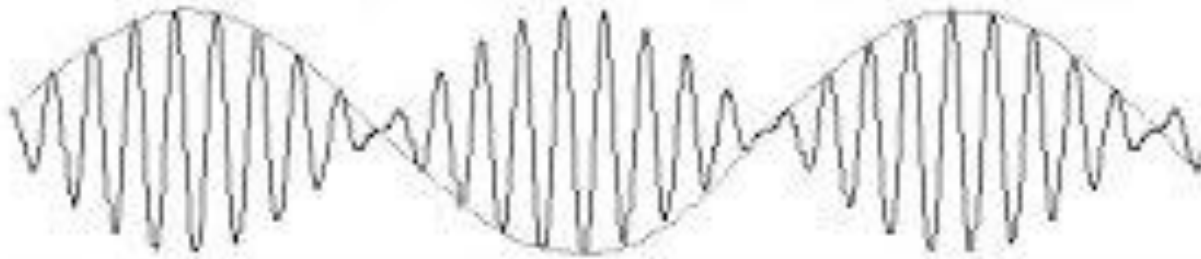
- Sine waves 100 Hz - 102 Hz (2Hz)

Critical Bandwidth: When a pure tone reaches the Basilar Membrane, the region of the membrane tuned to this frequency responds and activates the nerves at that point. However, more than one point on the membrane responds, and this range is called the Critical Bandwidth.

Ex: If a tone of 1000 Hz is heard, the area on the membrane tuned to 1000 Hz responds, but, in addition, the part of the membrane tuned to 950 Hz might respond.

From: https://www.phys.uconn.edu/~gibson/Notes/Section7_2/Sec7_2.htm

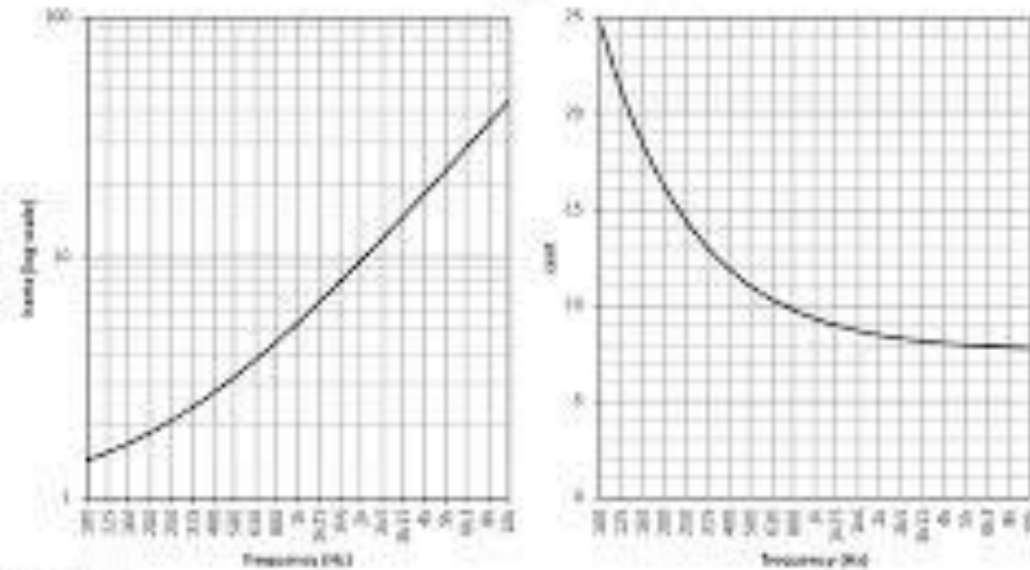
Beats & Just Noticeable Difference



<https://www.youtube.com/watch?v=TpBihRFVUG0>

Resources: Just Noticeable Difference (Extra)

JND (pitch)



Merijn van Veen

University of Groningen

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<https://www.youtube.com/watch?v=-bYeCR7VbsM>

- **Auditory system**

anatomy

- **Pitch perception**

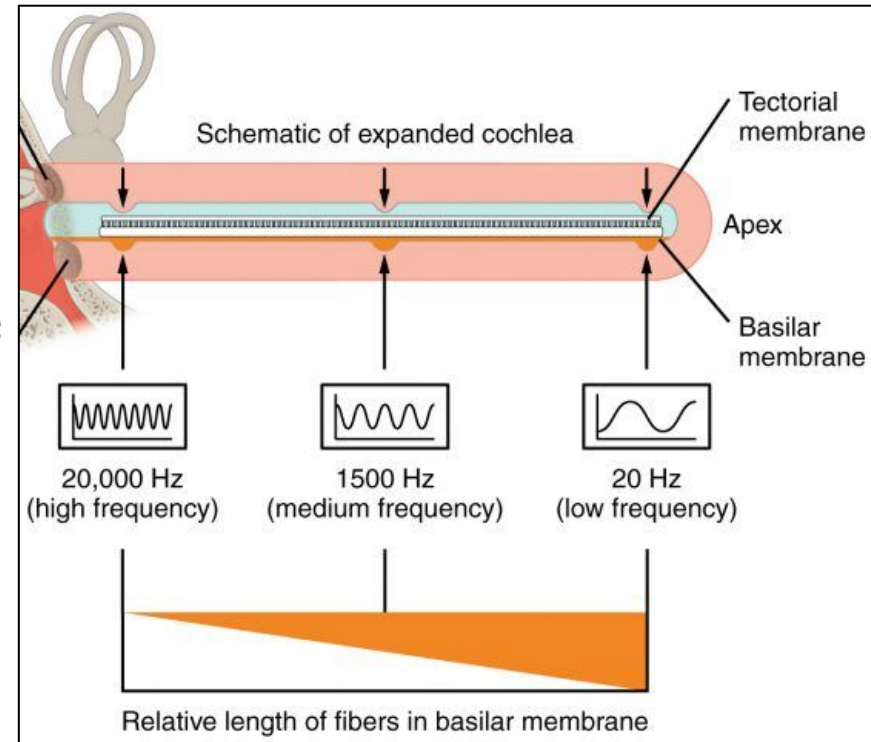
Just Noticeable Difference

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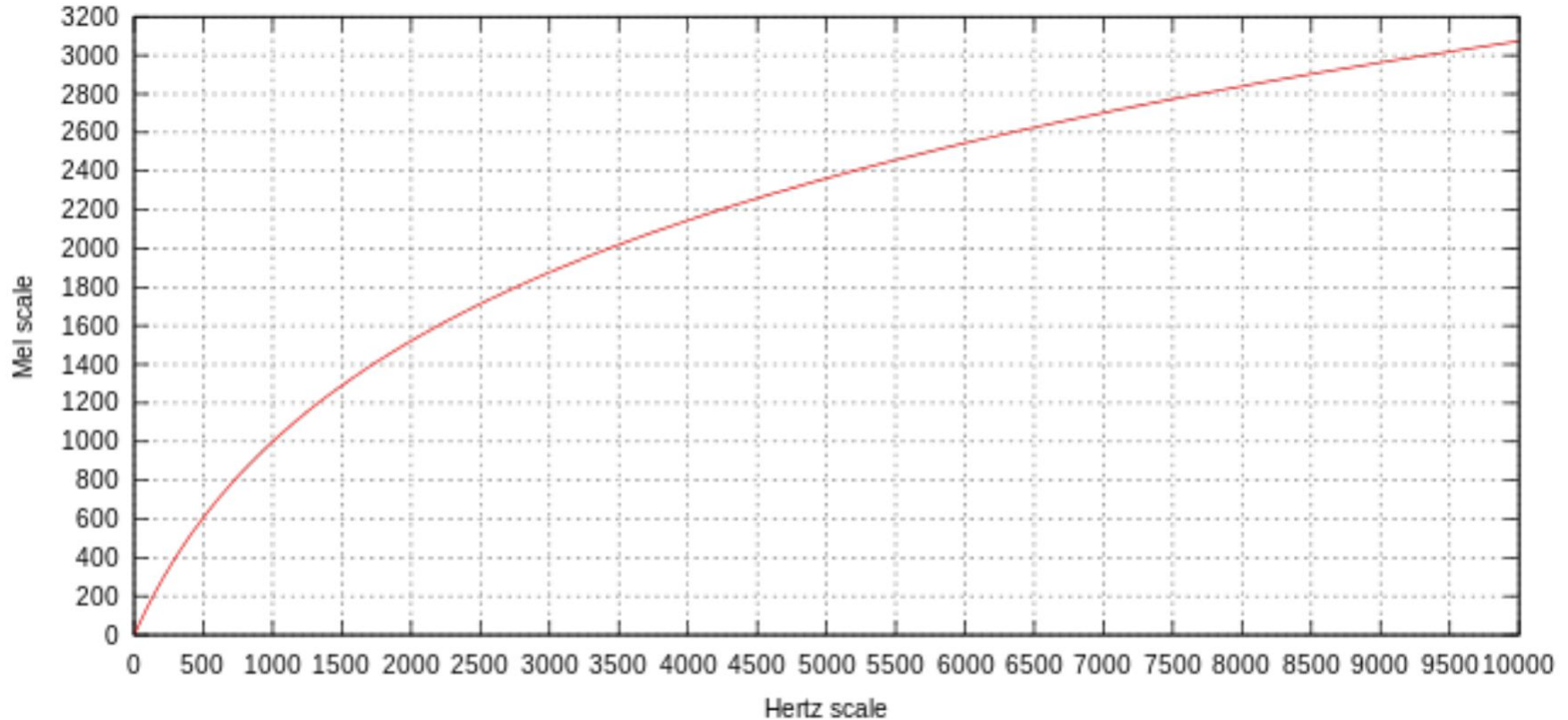
Pitch & Loudness Scales

	PHYSICAL		PERCEPTUAL	
	<i>NAME</i>	<i>UNIT</i>	<i>NAME</i>	<i>UNIT</i>
Wave length	frequency	Hertz (HZ)	Pitch	mel Bark ERB [semitone]
Wave excursion	amplitude	Pascal (Pa) Decibel (dB)	Loudness	Sone / phone

Based on how subjects divided series of simple tones into 'equal intervals'

(Traunmüller, 1997)

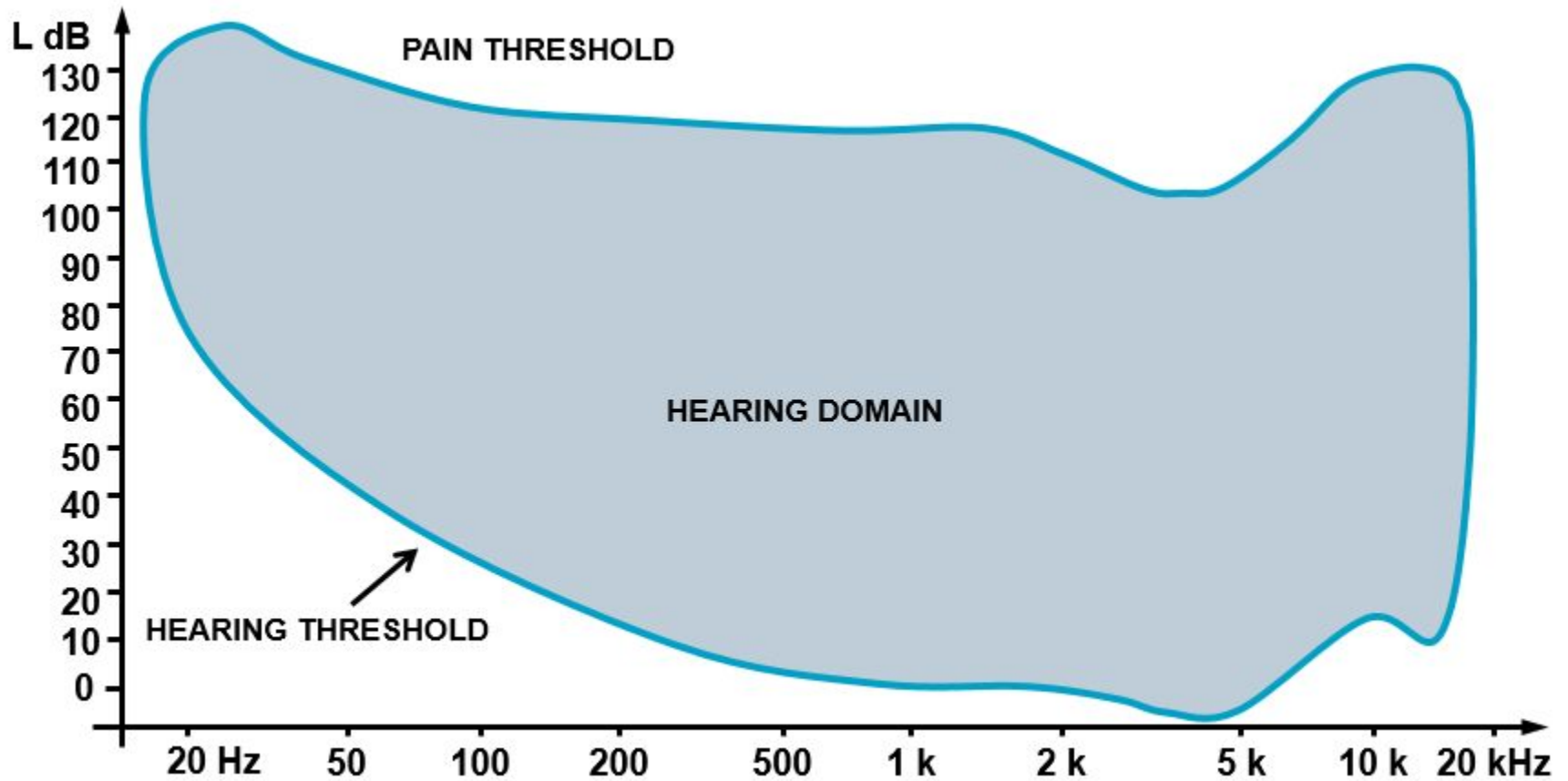
Pitch Scales: Mel



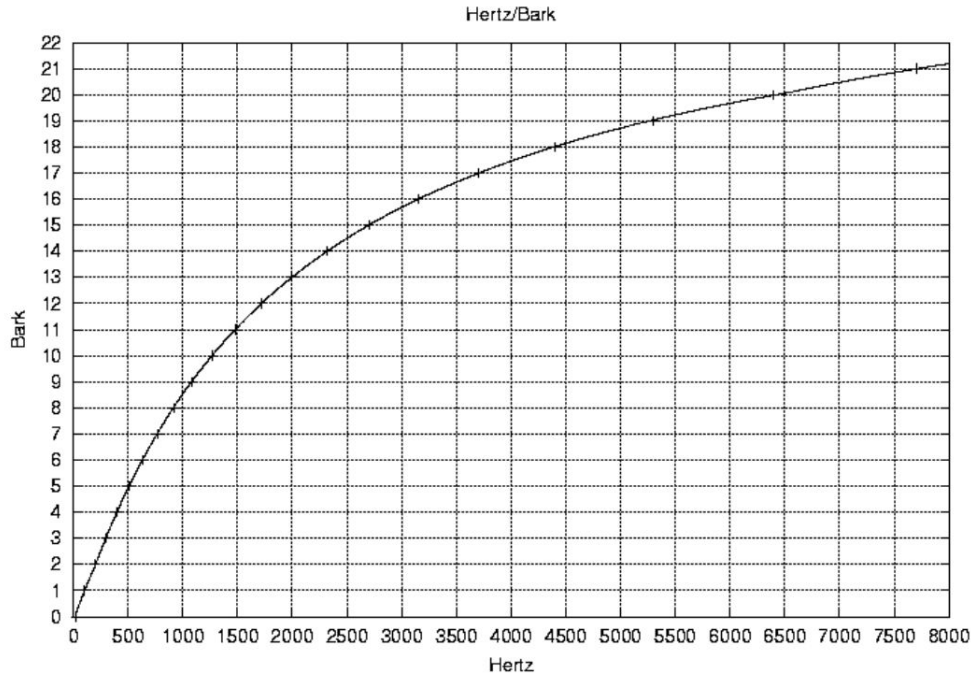
$$m = 1127 \ln (1+Hz/700)$$

From: https://commons.wikimedia.org/wiki/File:Mel-Hz_plot.svg

Pitch Scales: hearing threshold



Pitch Scales: Bark



Designed as an improvement to mel scale

→ interaction of frequency and loudness

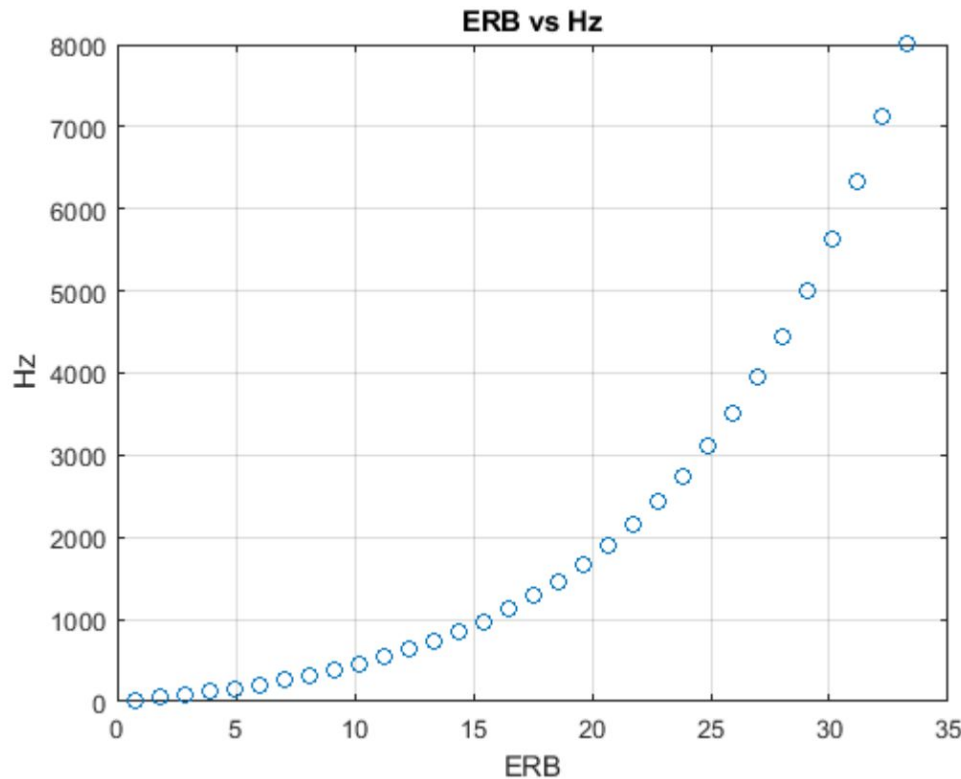
* formula corrections below 2 Bark (~200 Hz) and over 20.1 Bark (6.550 Hz)

$$\text{Bark} \quad Z = 26.81 / (1+(1960/f)) - 0.53$$

Taking into account the property of the human auditory system, the Bark scale is a perceptually realistic scale of frequency.

From: <https://ccrma.stanford.edu/courses/120-fall-2003/lecture-5.html>

Pitch Scales: Equivalent Rectangular Bandwidth (ERB)



Better resolution below 500 Hz
→ good for intonation studies

$$\text{ERB} = 19.7 \log_{10}(0.006046f + 1)$$

From: <https://se.mathworks.com/help//audio/ref/erb2hz.html>

A semitone is 1/12 of an octave

Not strictly perceptual, based on the musical scale

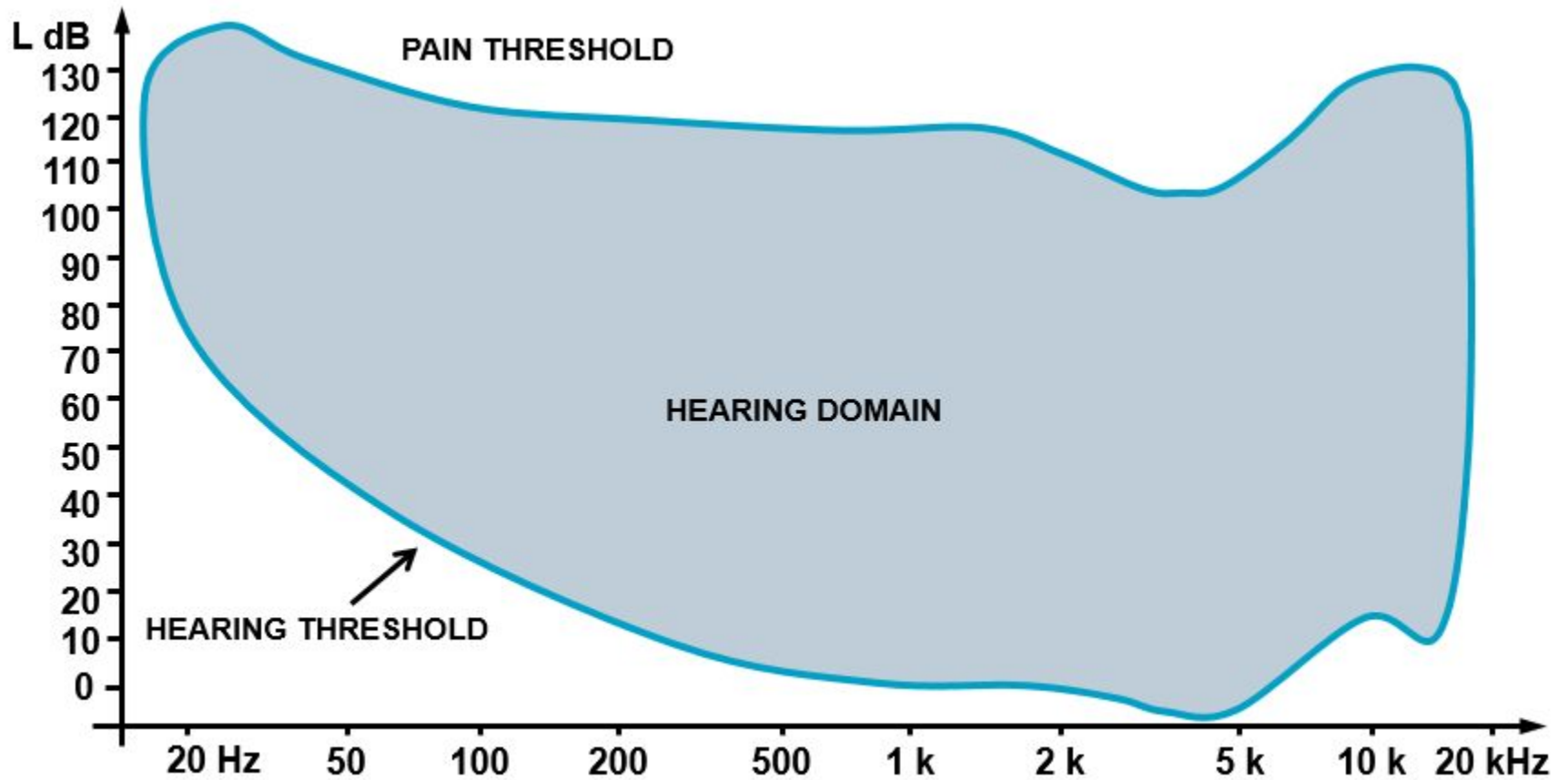
Refers to a difference of two sounds, does not describe a single sound

Used especially for F0 transformations

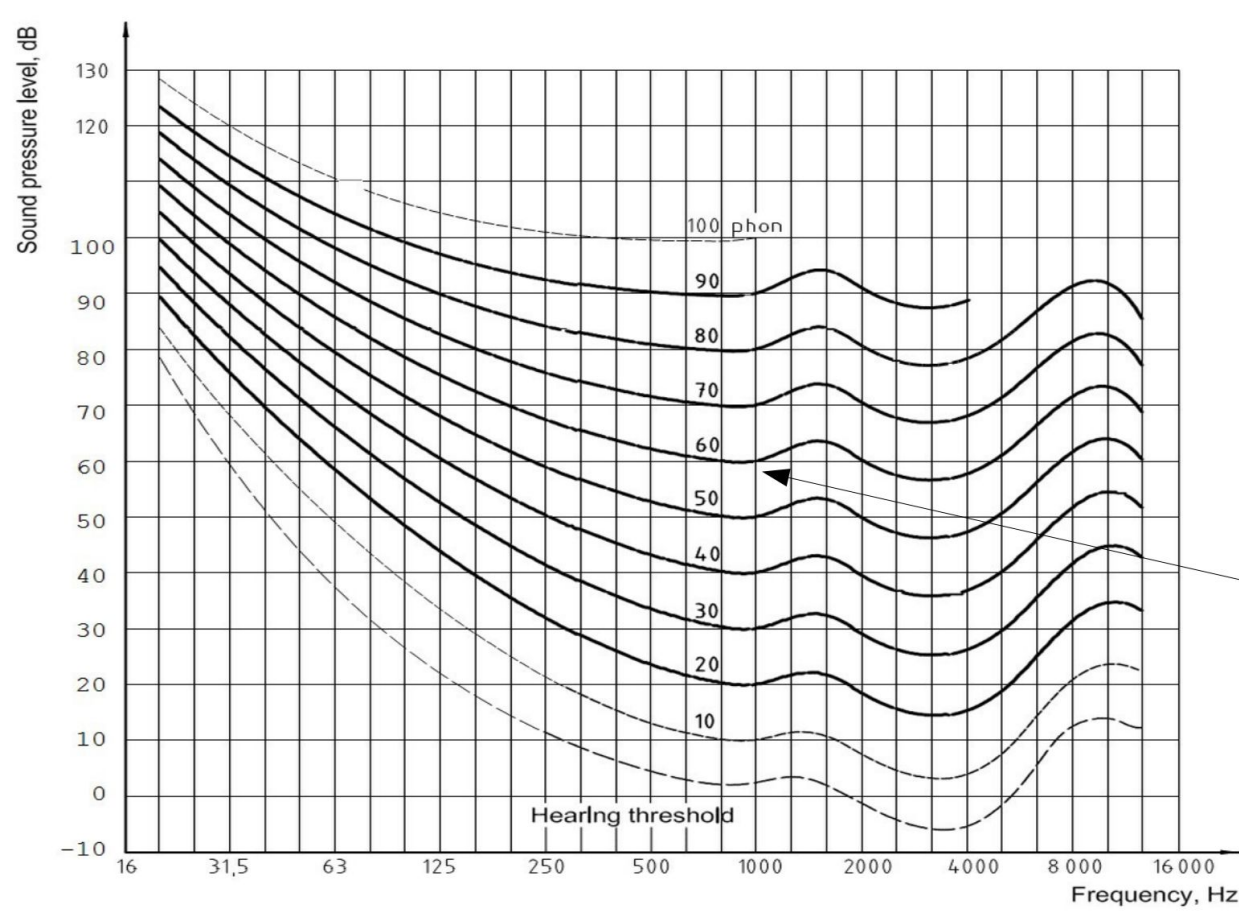
$$\text{Semitones} = 3.863 \times \log_{10}(\text{higher sound in Hz} / \text{lower sound in Hz})$$

Formula adapted from: Hewlett & Beck 2006:124

Loudness Scale: hearing threshold



Loudness Scale: Phon



This phenomenon is common in other sensory modalities, e.g. vision.

*Check the sensitivity curve to light

60 phons means:
"as loud as a 60 dB, 1000 Hz tone"

dB: Increase of power by 10 causes a sensation of doubled loudness

1. Shortly describe the auditory pathway
2. Describe a function of one chosen part of: outer, middle and inner ear
3. Short reading: *Psychophysical properties of the auditory system – CYF, p. 301-304*