Speech Science

WiSe 2024/2025

Exercise 9: Auditory system / pitch perception

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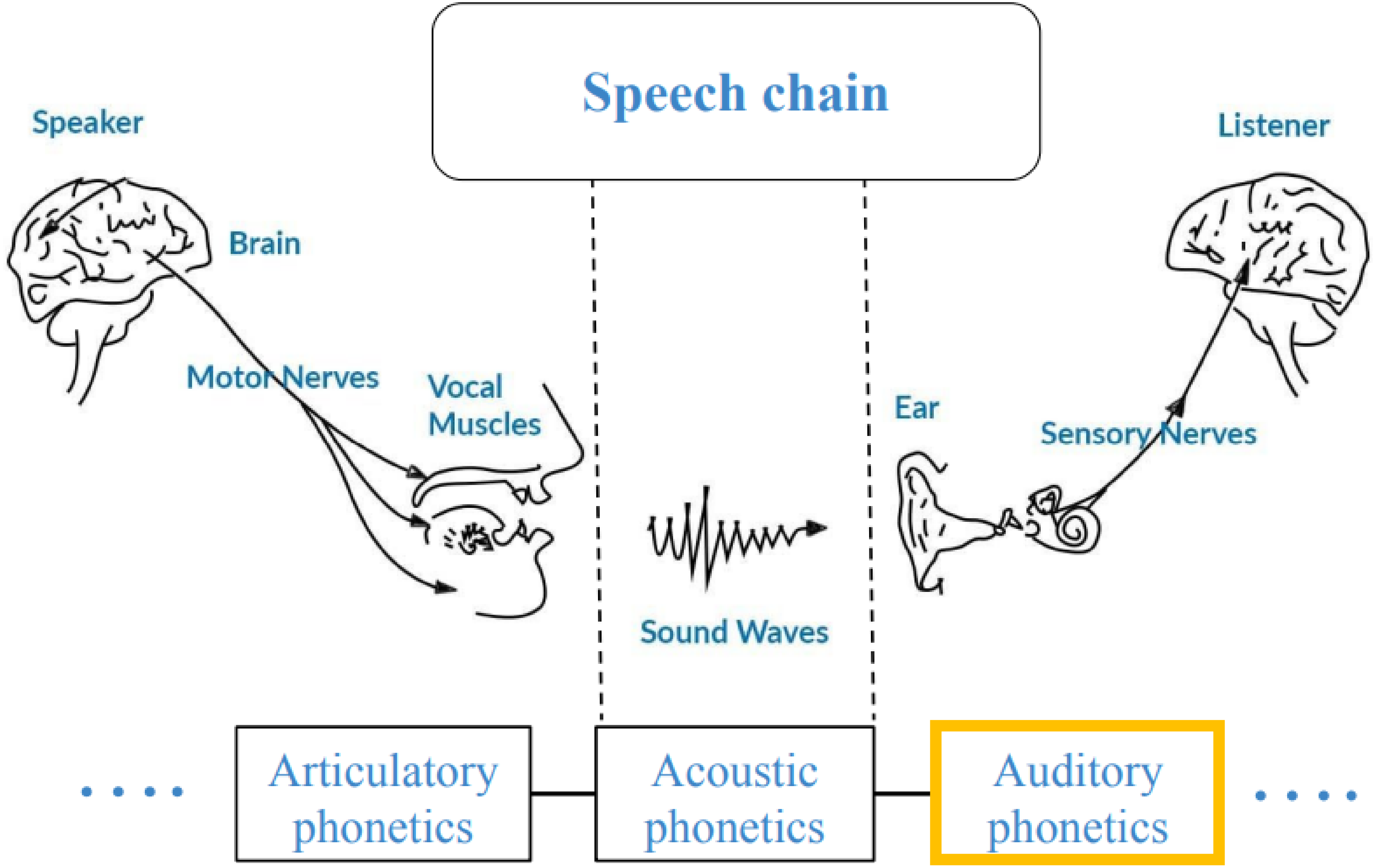
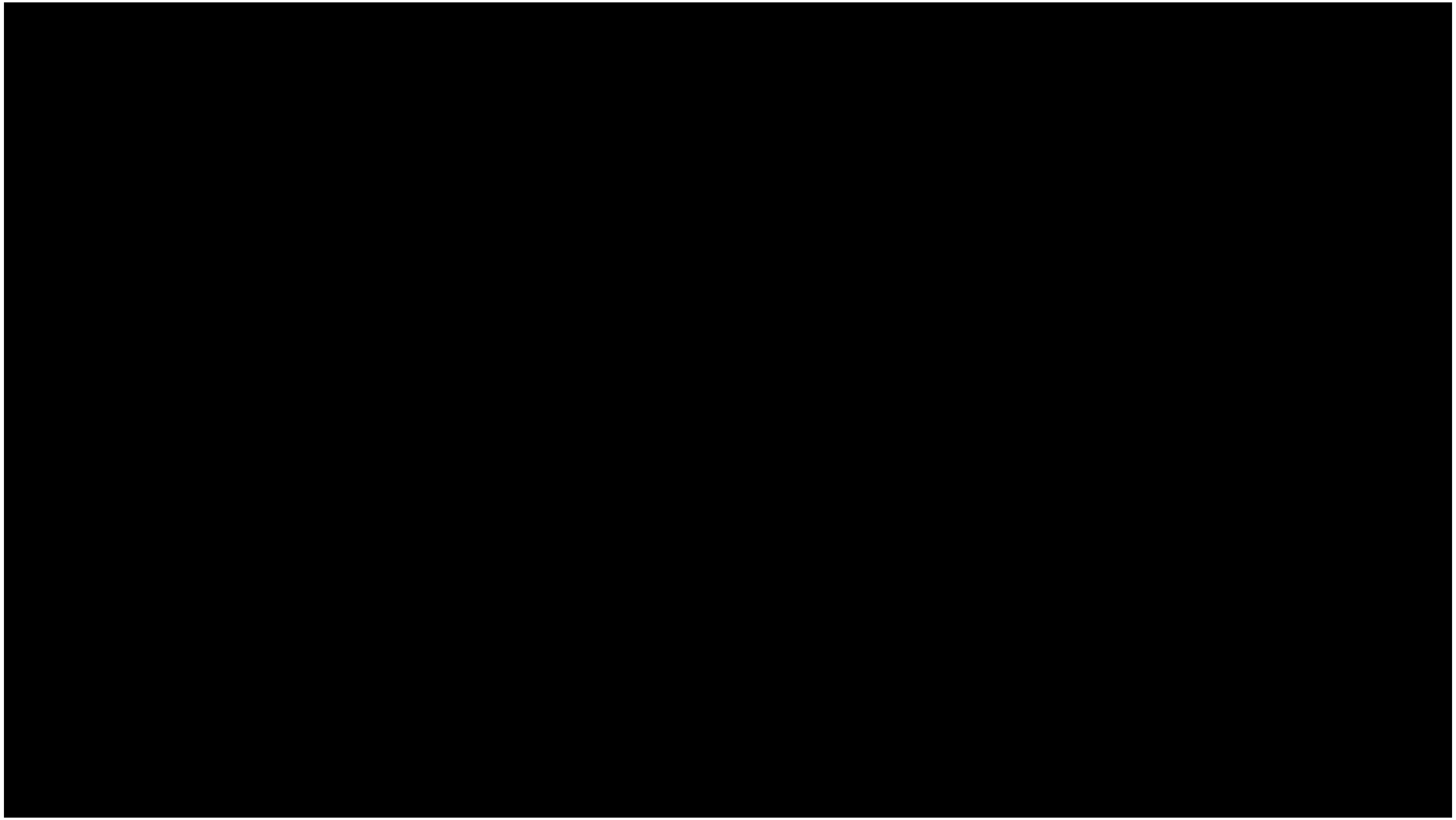
Recap: Prosody

- Study of elements of speech that are not individual phonetic segments (suprasegmentals)
- Properties of syllables and larger units of speech:
  - Intonation
  - Stress
  - Rhythm
- Aspects to measure:
  - F0 over time, pitch contour
  - Intensity (over time, patterns)
  - Quantity (duration of speech units)

Auditory System


Speech chain
Speaker
Brain
Motor Nerves
Vocal Muscles
Sound Waves
Ear
Sensory Nerves
Listener
. . . .
Articulatory phonetics
Acoustic phonetics
Auditory phonetics
. . . .

Journey of sound to the brain



https://www.youtube.com/watch?v=eQEaiZ2j9oc

Exercise 1: Hearing and voicing ranges in nature

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dog

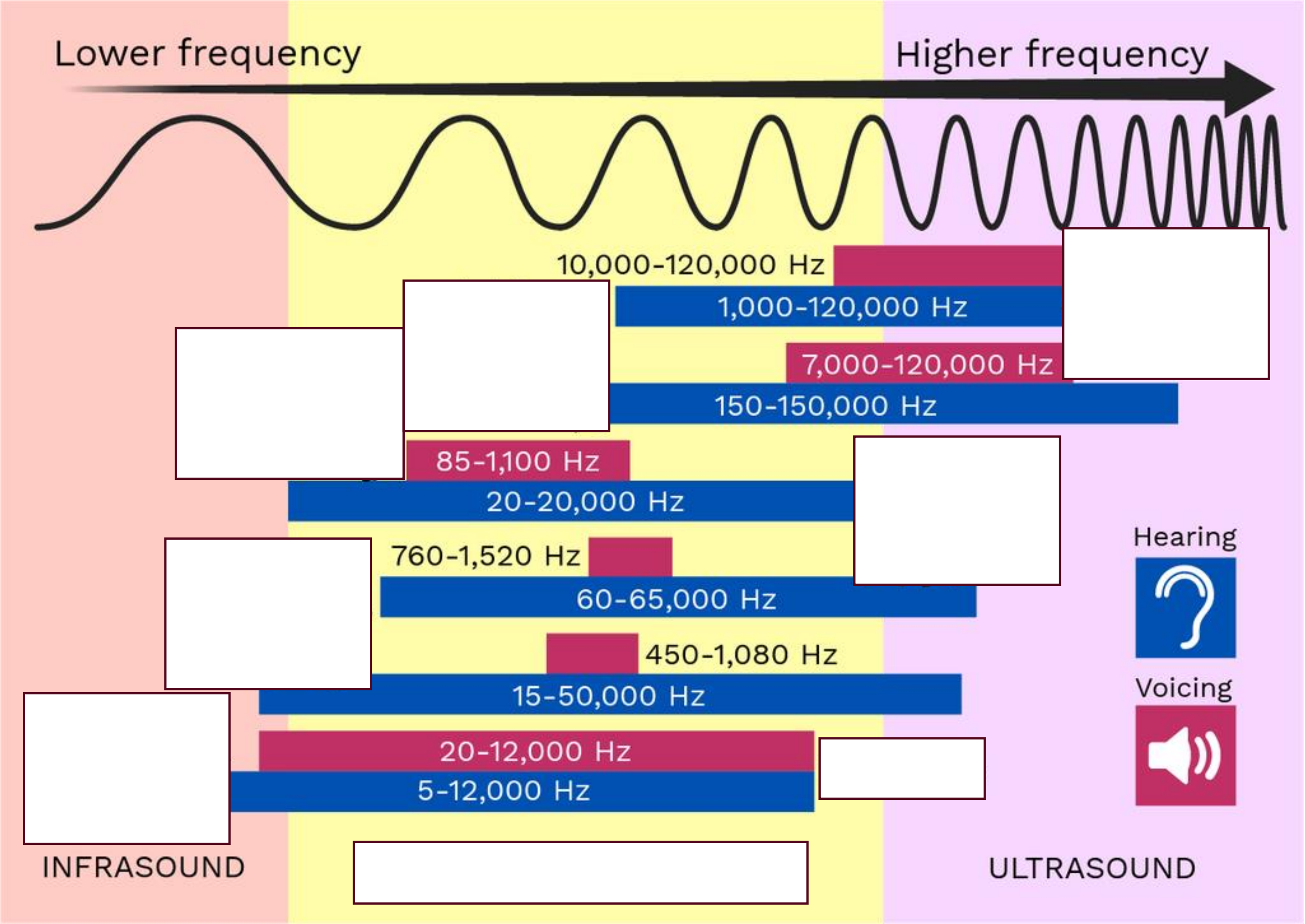
bat

cat

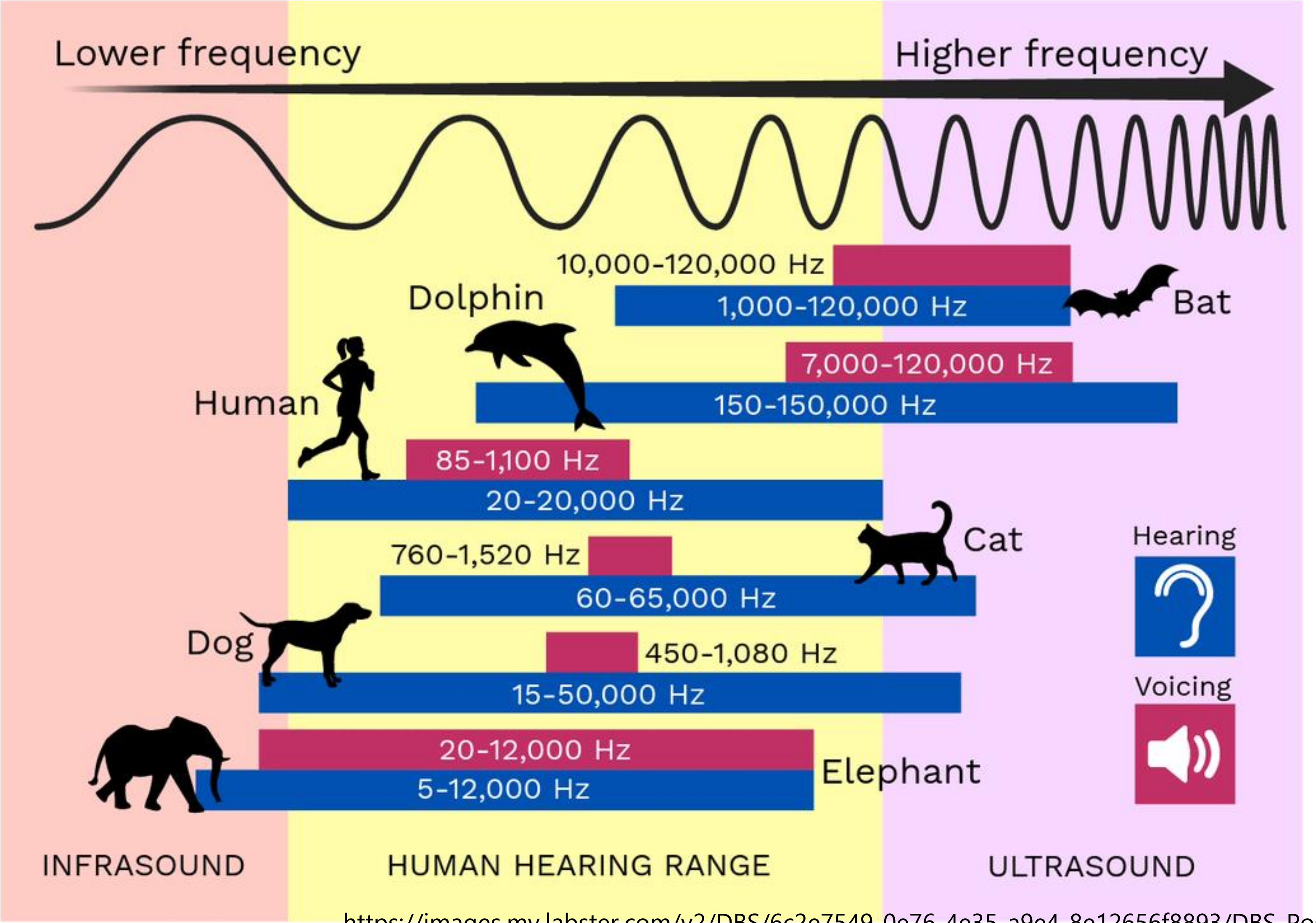
elephant

human

dolphin

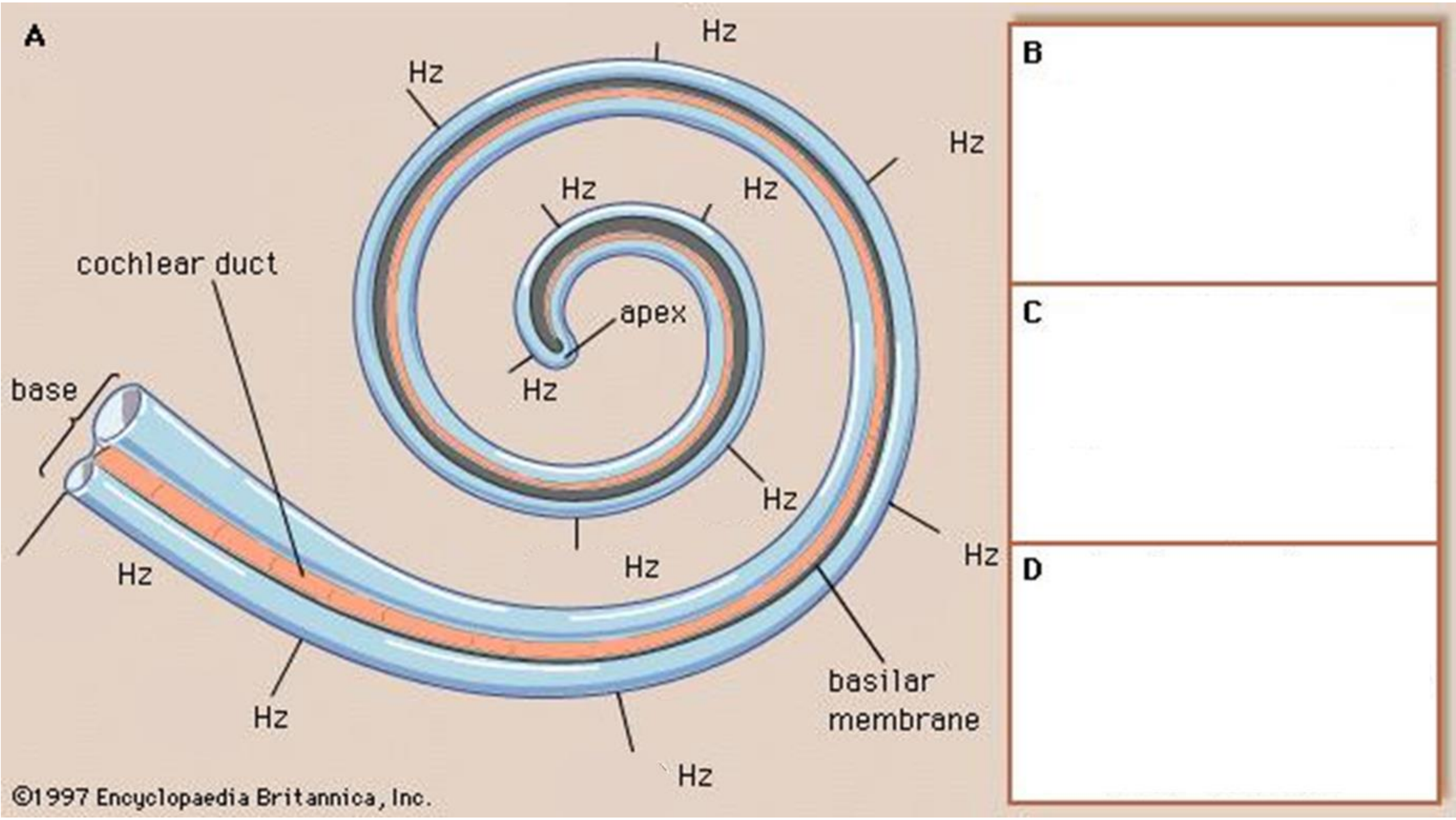


Hearing and voicing ranges in nature



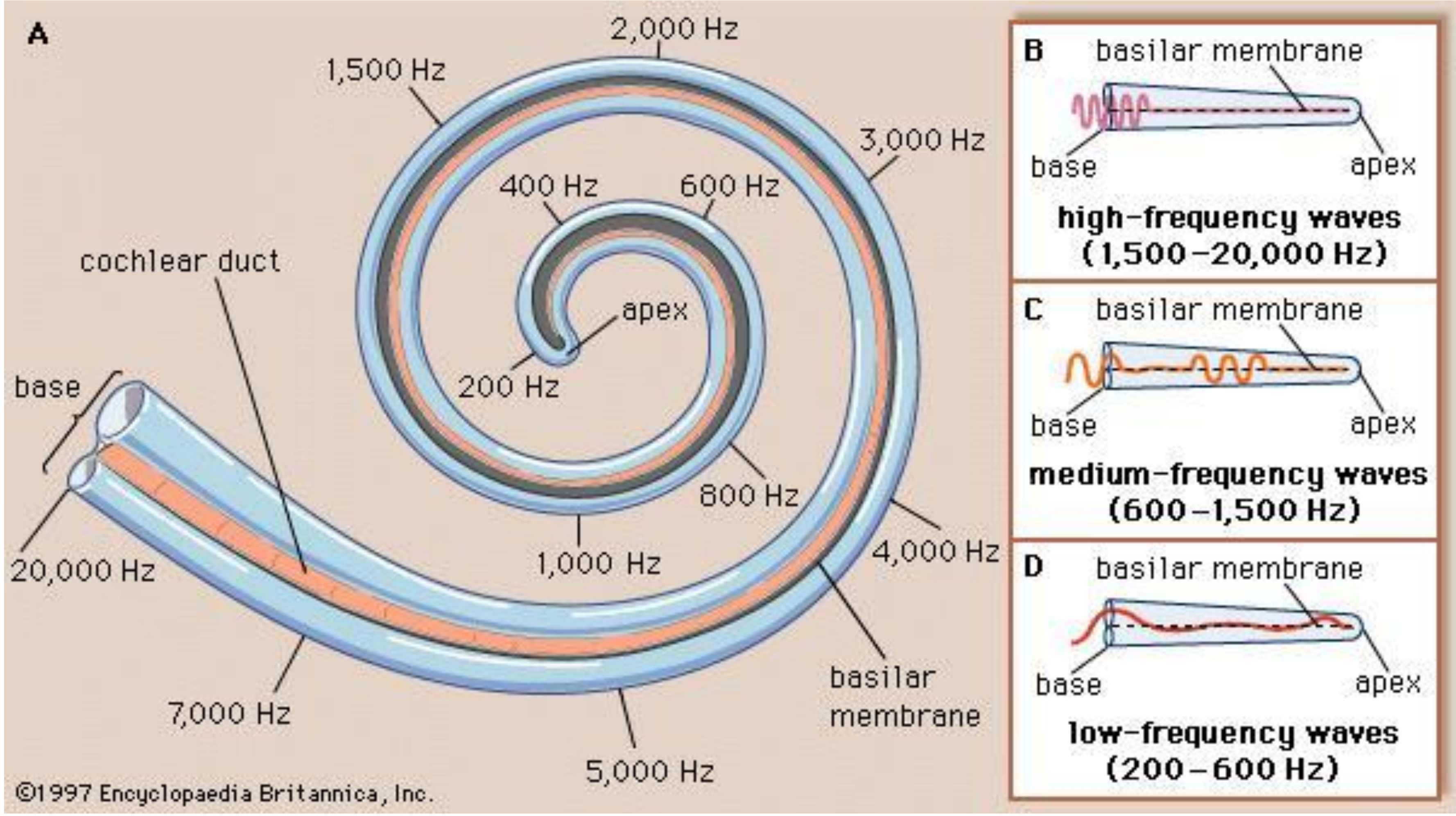
https://images.my.labster.com/v2/DBS/6c2e7549-0e76-4e35-a9e4-8e12656f8893/DBS_PosterHearingVoicingRange.en.x1024.png

Spatial encoding of frequency components



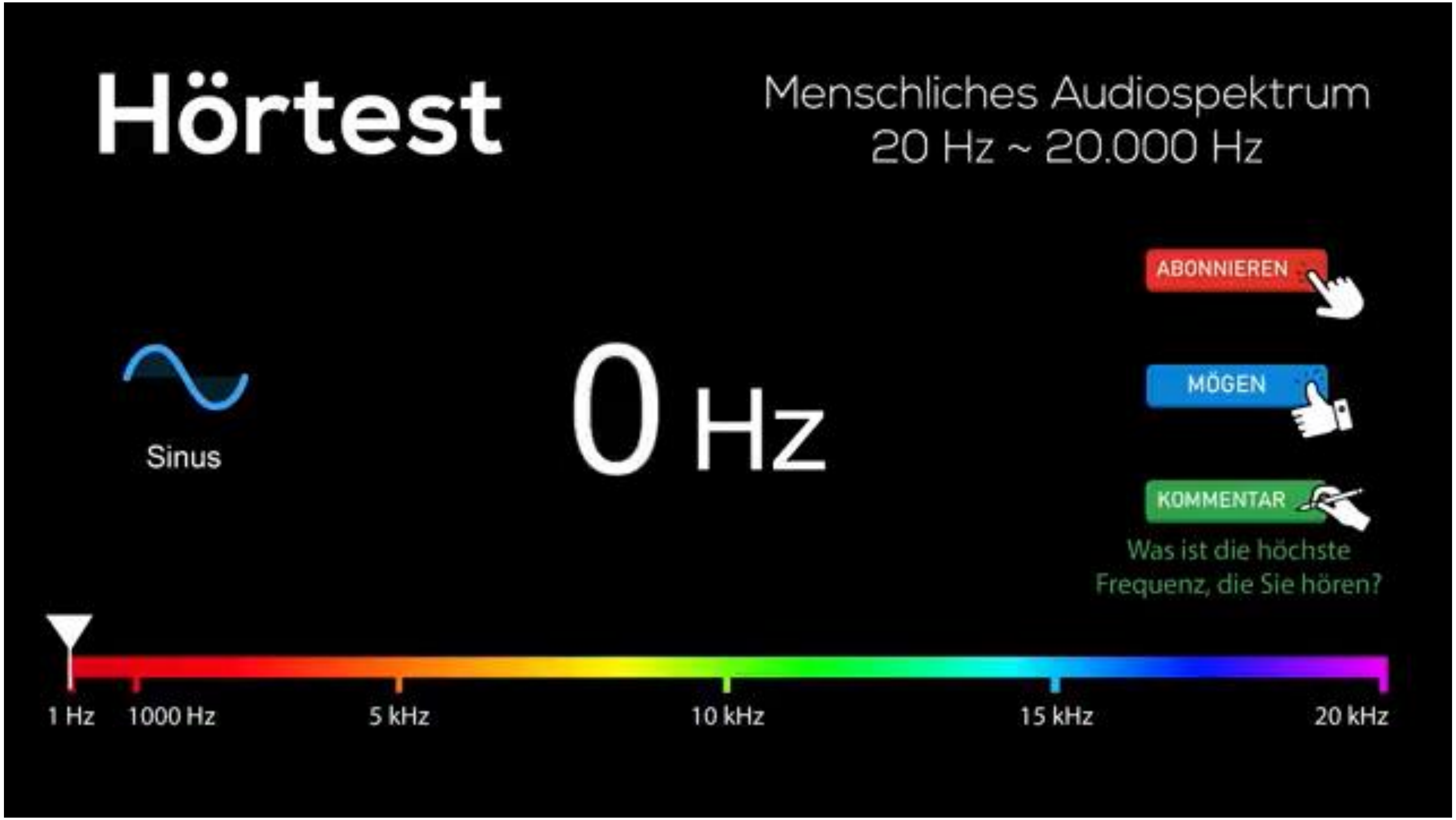
Encyclopedia Britannica, 1997

Spatial encoding of frequency components



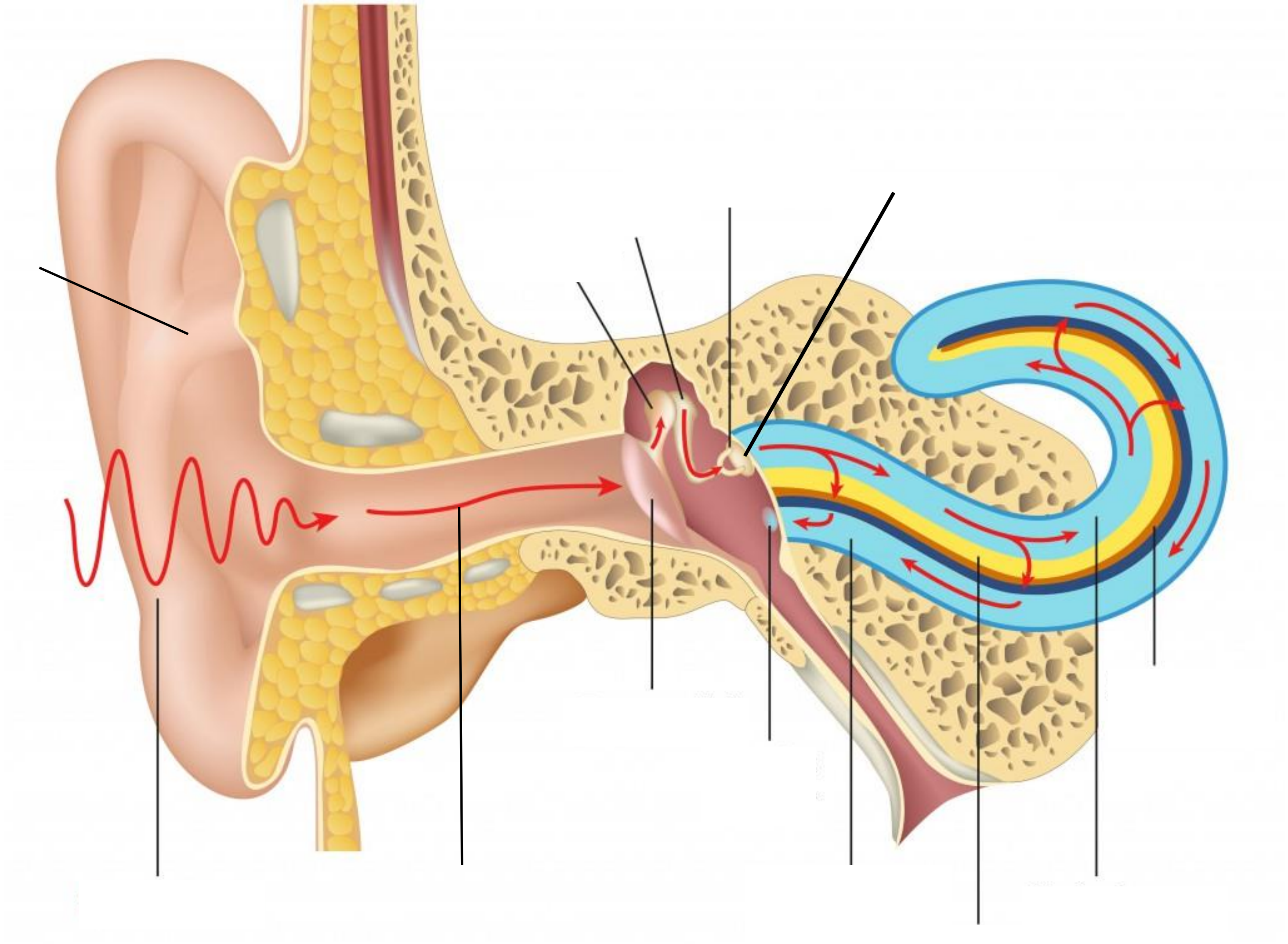
Encyclopedia Britannica, 1997

Exercise 2: Hearing test



https://www.youtube.com/watch?v=0RwUYC0Q4Lw

Exercise 3: Anatomy



Exercise 3: Anatomy

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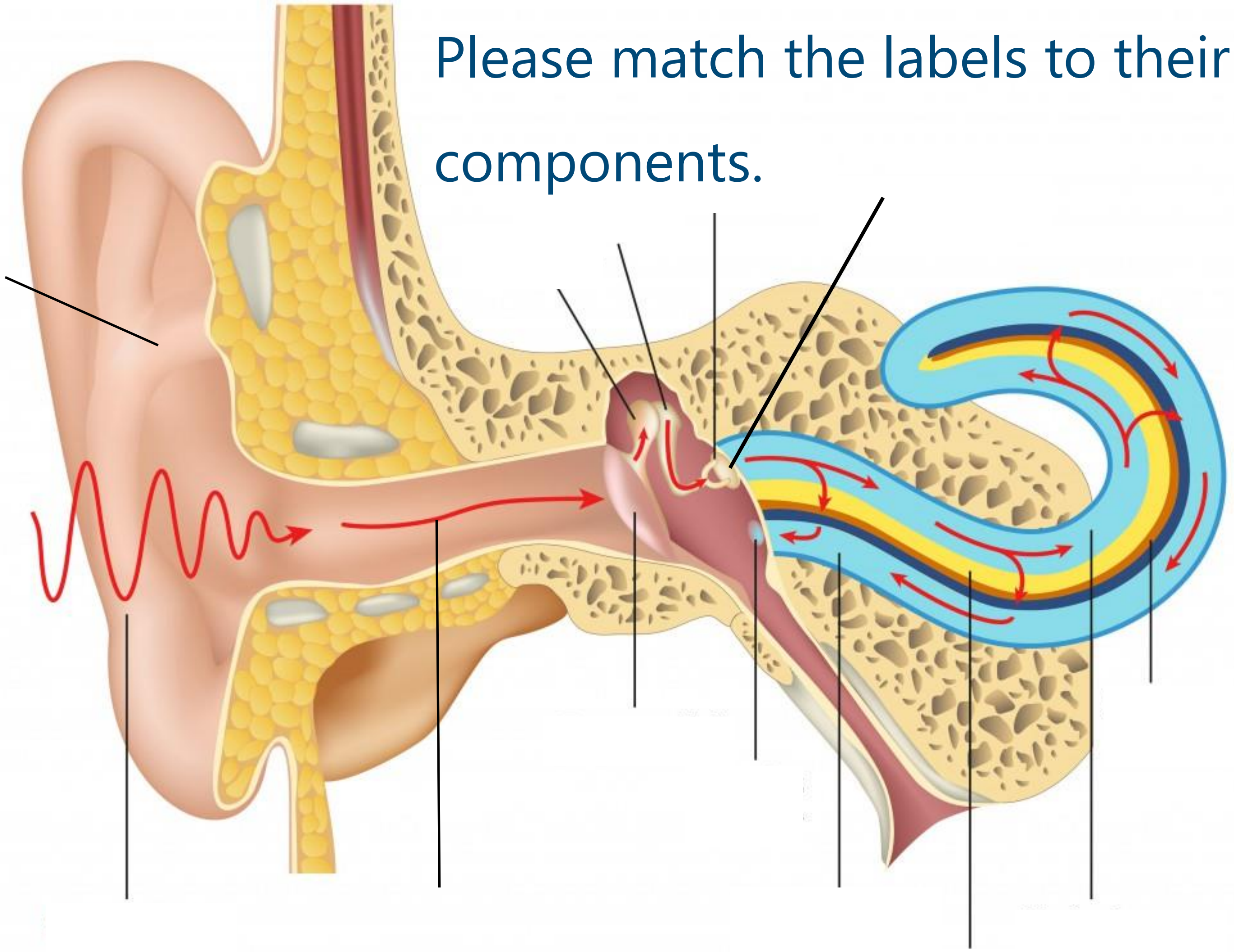
Please match the labels to their corresponding components.



Exercise 3: Anatomy

pinna/auricle

organ of Corti

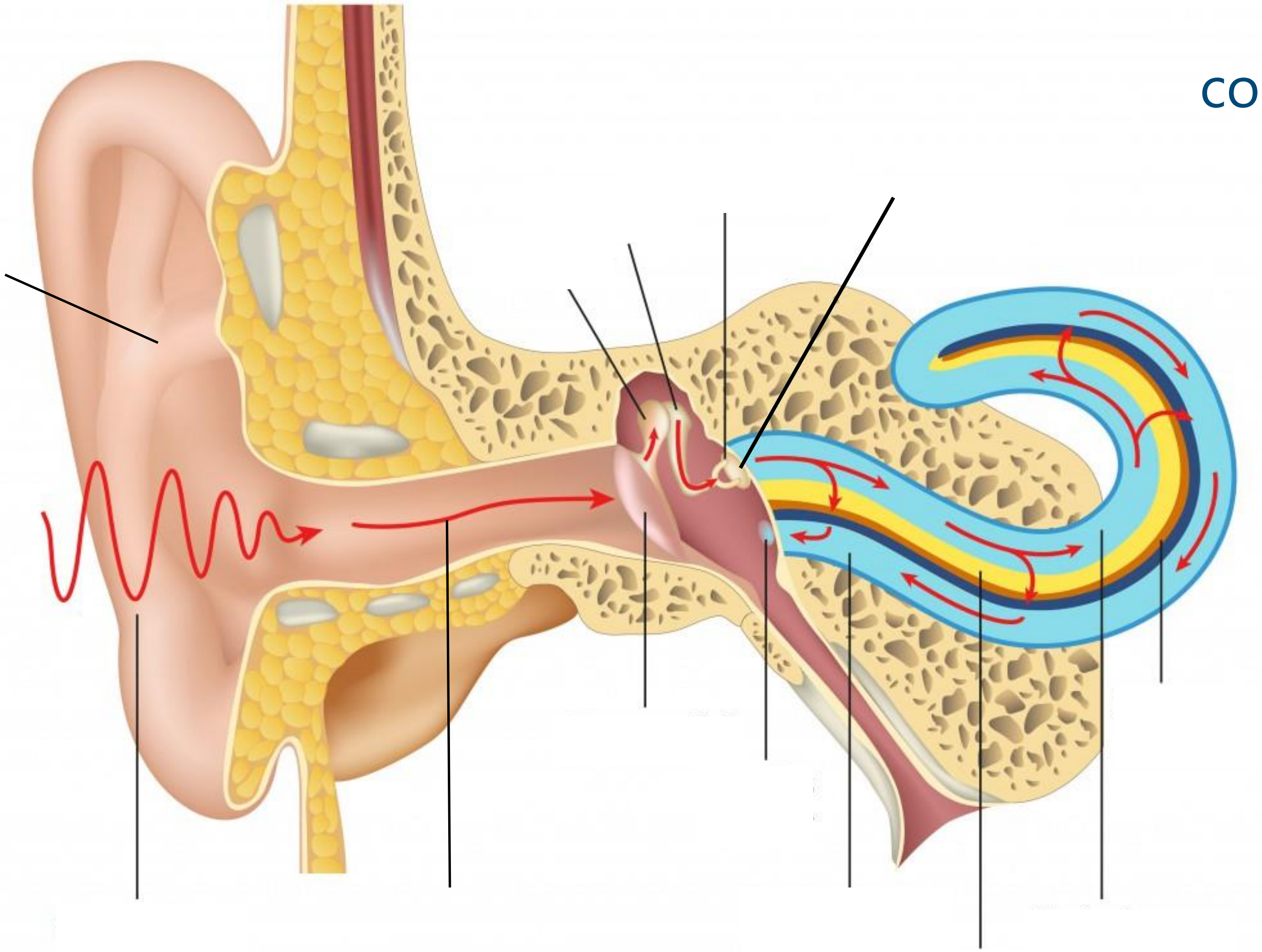
round window

incus

auditory canal

oval window

sound waves



cochlear membrane

eardrum

scala vestibuli

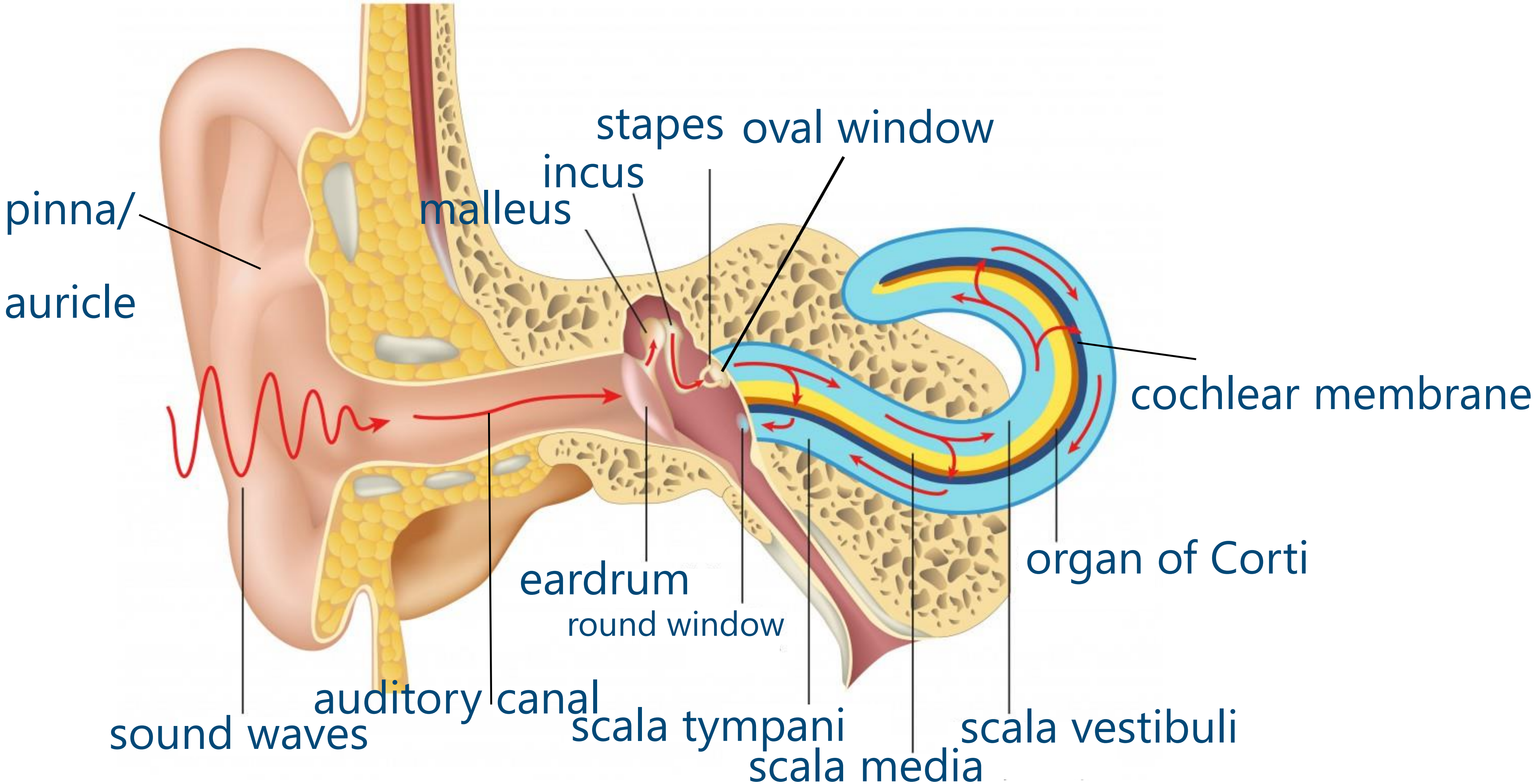
scala tympani

scala media

malleus

stapes

Exercise 3: Anatomy



Functions of ear components

	Component	Function
Outer ear	Pinna/auricle	
	Auditory canal	
	Eardrum (tympanic membrane)	
Middle ear	Ossicles (malleus, incus, stapes)	
	Oval window	
Inner ear	Scala vestibuli, tympani, media	
	Organ of Corti, with bas./tect. membranes, inner/outer hair cells	

Functions of ear components

	Component	Function
Outer ear	Pinna/auricle	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

Just Noticeable Difference

- How much must a frequency change for the ear to notice the change in frequency?

Exercise 4: Just Noticeable Difference (JND)

- In Praat: Listen to the audio files (difference.wav).
- Can you hear the difference between:
  - difference_1_1.wav and difference_1_2.wav?
  - 1000 Hz – 1002 Hz (2 Hz)
  - difference_2_1.wav and difference_2_2.wav?
  - 1000 Hz – 1010 Hz (10 Hz)
  - difference_3_1.wav and difference_3_2.wav?
  - 100 Hz – 102 Hz (2 Hz)

Just Noticeable Difference

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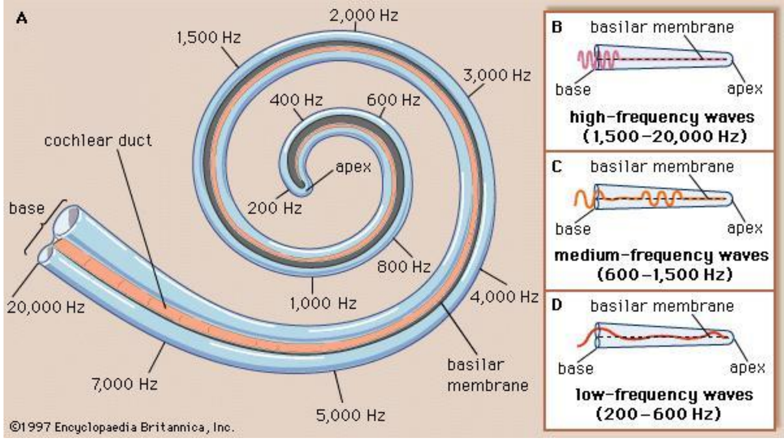
- How much must a frequency change for the ear to notice the change in frequency?
- JND: about 0.5%
- Ex.: At 1000 Hz, the JND is 5 Hz. So, if two tones are played separately at 1000 Hz and 1002 Hz, you would not be able to tell that the pitch has changed.
  However, if the tones are 1000 Hz and 1010 Hz, you should be able to tell the difference.

Critical Bandwidth

- A pure tone reaches Basilar Membrane:
  Region tuned to this frequency responds and activates nerves at that point
- However: More than just this one point responds:
  Ex.: If a tone of 1000 Hz is heard, area tuned to 1000 Hz responds + area tuned to 950 Hz might respond

→ Responding range: **Critical Bandwidth**



Beats

Beats and Just Noticeable Difference

Note #1 500 Hz

Note #2 500 Hz

Single Pitch

https://www.youtube.com/watch?v=TpBihrFVUG0

Pitch & Loudness Scales

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

Pitch Scales: mel

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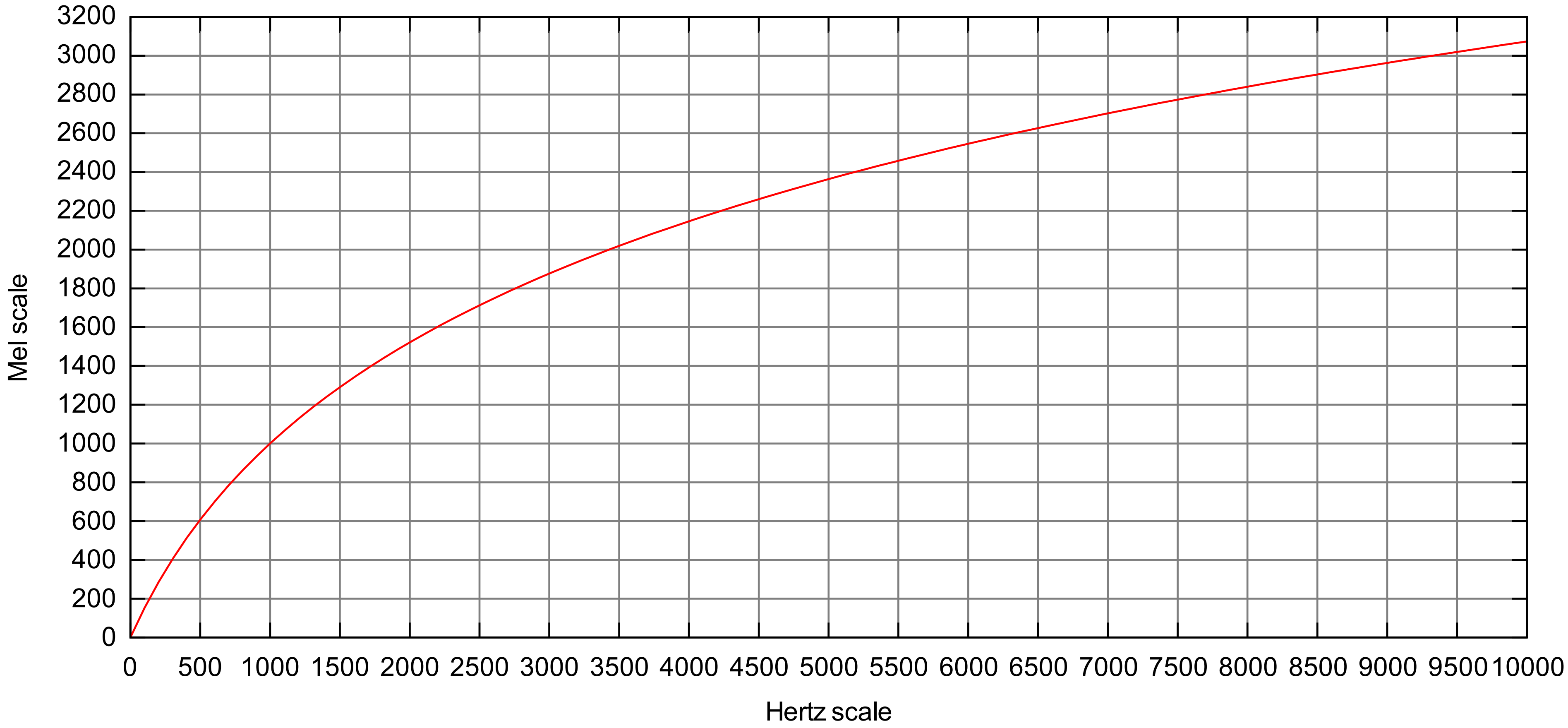
- Based on how subjects divided series of simple tones into "equal intervals" (Traunmüller, 1997)
- Based on **perception** experiment
- E.g. "Tone 1 is twice as high as Tone 2"
  (Tone1-mel = 2* Tone2-mel)
  "Tone 3 is three times higher than Tone 2"
  (Tone3-mel = 3* Tone2-mel)

→ Equal distances on the scale have same "perceptual" distance

Pitch Scales: mel



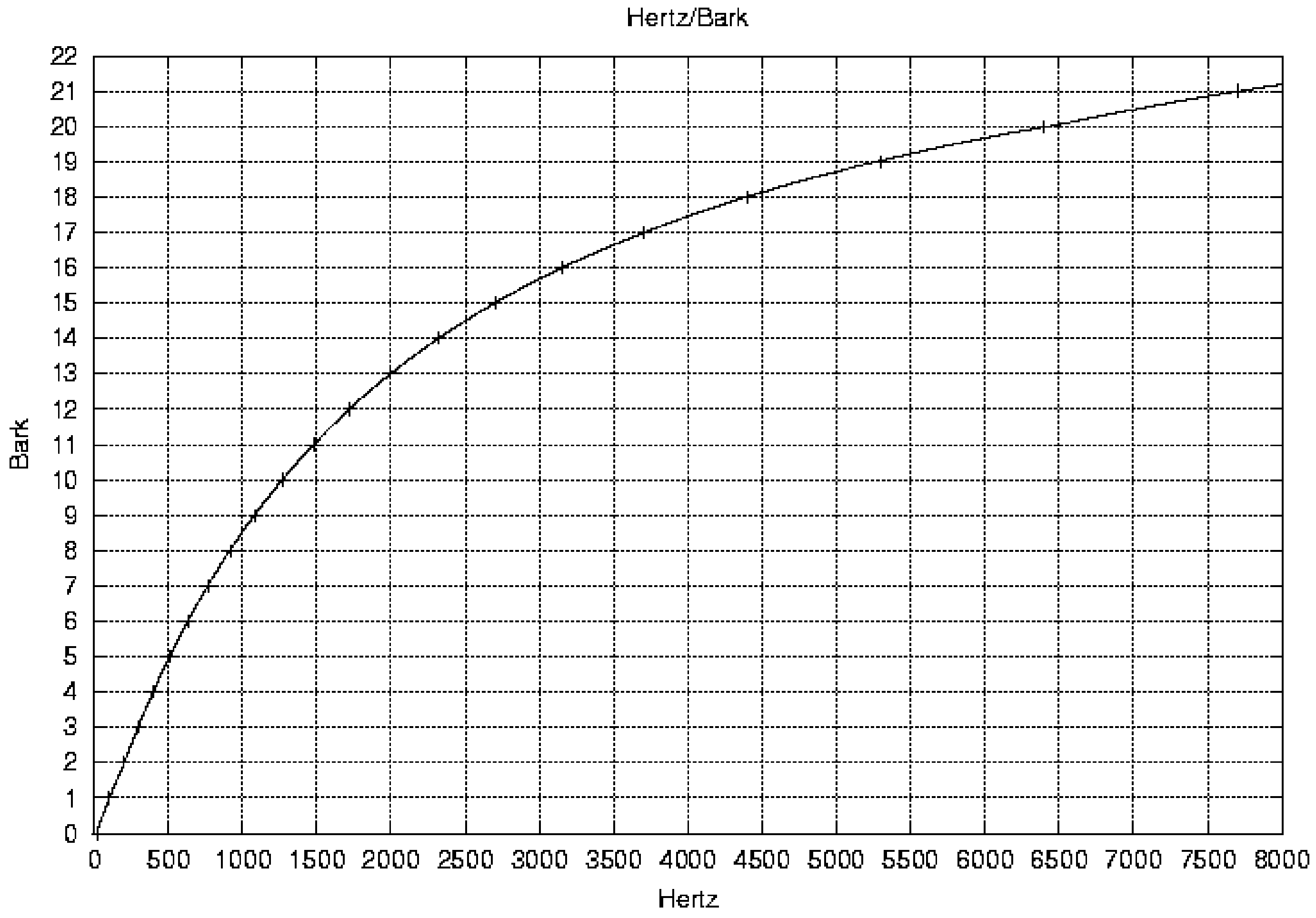
https://commons.wikimedia.org/wiki/File:Mel-Hz_plot.svg

Pitch Scales: Bark

- Based on the Mel scale: 100 Mel ≙ 1 Bark
- \+ Takes into account interaction of frequency and loundess

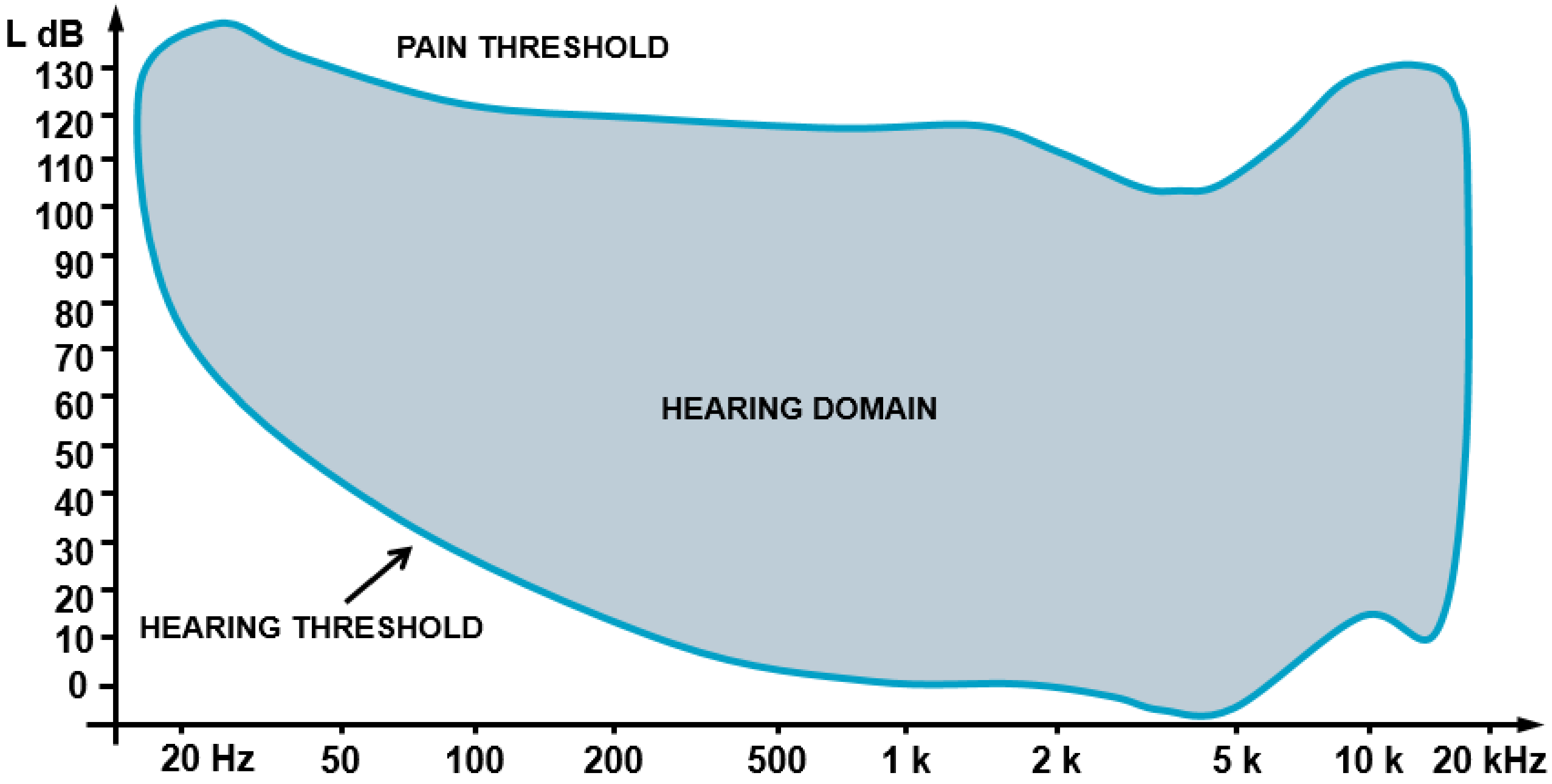
→ Formula corrections below 2 Bark (~200 Hz) and over 20.1 Bark (6550 Hz)

Pitch Scales: Bark



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

Loudness scale: Hearing threshold



https://community.sw.siemens.com/s/article/masking?c=106349

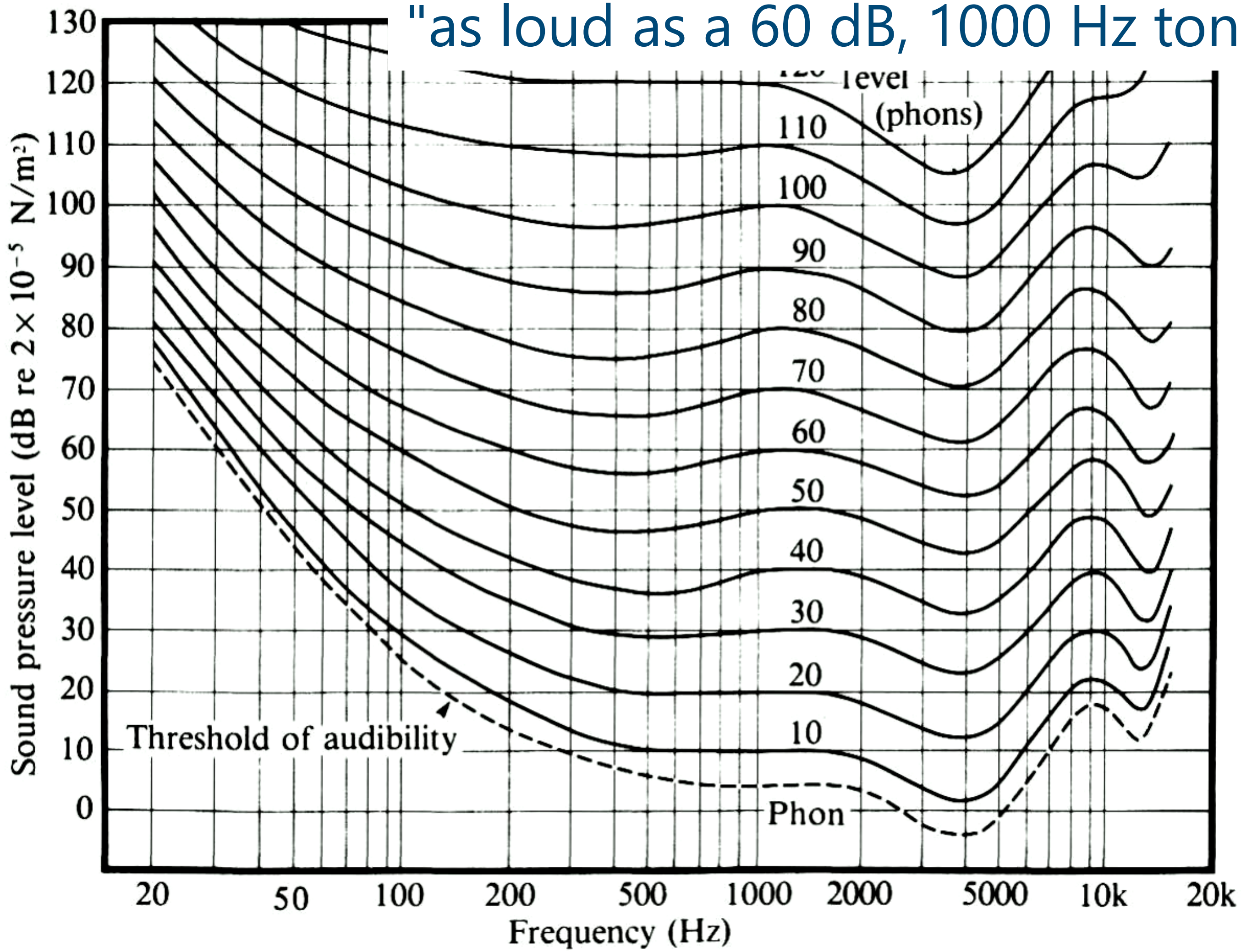
Loudness scale: Phon

- Based on equal loudness contours
- Decibel scale alone refers to actual sound pressure or sound intensity levels
- Phon scale devised to express subjective impression of loudness
- 0 phons at 1,000 Hz is set at 0 decibels: threshold of hearing at that frequency

Loudness scale: Phon

60 phons means:

"as loud as a 60 dB, 1000 Hz tone"



https://feinklang-mastering.de/loudness.html

Additional Resources

- Science of Hearing:
  https://www.youtube.com/watch?v=LkGOGzpbrCk
- Auditory System:
  https://www.youtube.com/watch?v=PQEWp_Ms1Ao https://www.youtube.com/watch?v=3G5jiXl2LSM
  https://www.youtube.com/watch?v=zBlxRI62HSU
  https://www.youtube.com/watch?v=7Bs2HeE6XH0
- Just Noticeable Difference:
  https://www.youtube.com/watch?v=-bYeCR7VbsM
- Bark Scale:
  https://ccrma.stanford.edu/courses/120-fall-2003/lecture-5.html
- Psychophysical properties of the auditory system:
  CYF, p. 301-304

Assignment 8:

- Shortly describe the auditory pathway
- Read CYF, p. 301-304 (8.3 Psychophysical properties of the auditory system)

Thank you for your participation!