UNIVERSIDAD DE GRANADA

TOURITAGE – Tourism-led Heritage Development

Blended Intensive Programmes

School of Architecture | 1—6 July 2025

Brainwaves and beyond: EEG tools for auditory evaluation and emotion analysis

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Structure

1. **Fundamentals of EEG**
    1. Electroencephalography (EEG)
    2. Hardware elements
    3. EEG recording systems
    4. Neural oscillations
    5. Evoked potentials
2. **The hearing process**
    1. The external and middle ear
    2. The cochlea
    3. The basilar membrane
    4. The Organ of Corti
    5. The outer hair cells (OHC)
    6. The inner hair cells (IHC)
    7. The auditory pathway
    8. The brain
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4. **Cognitive measures**
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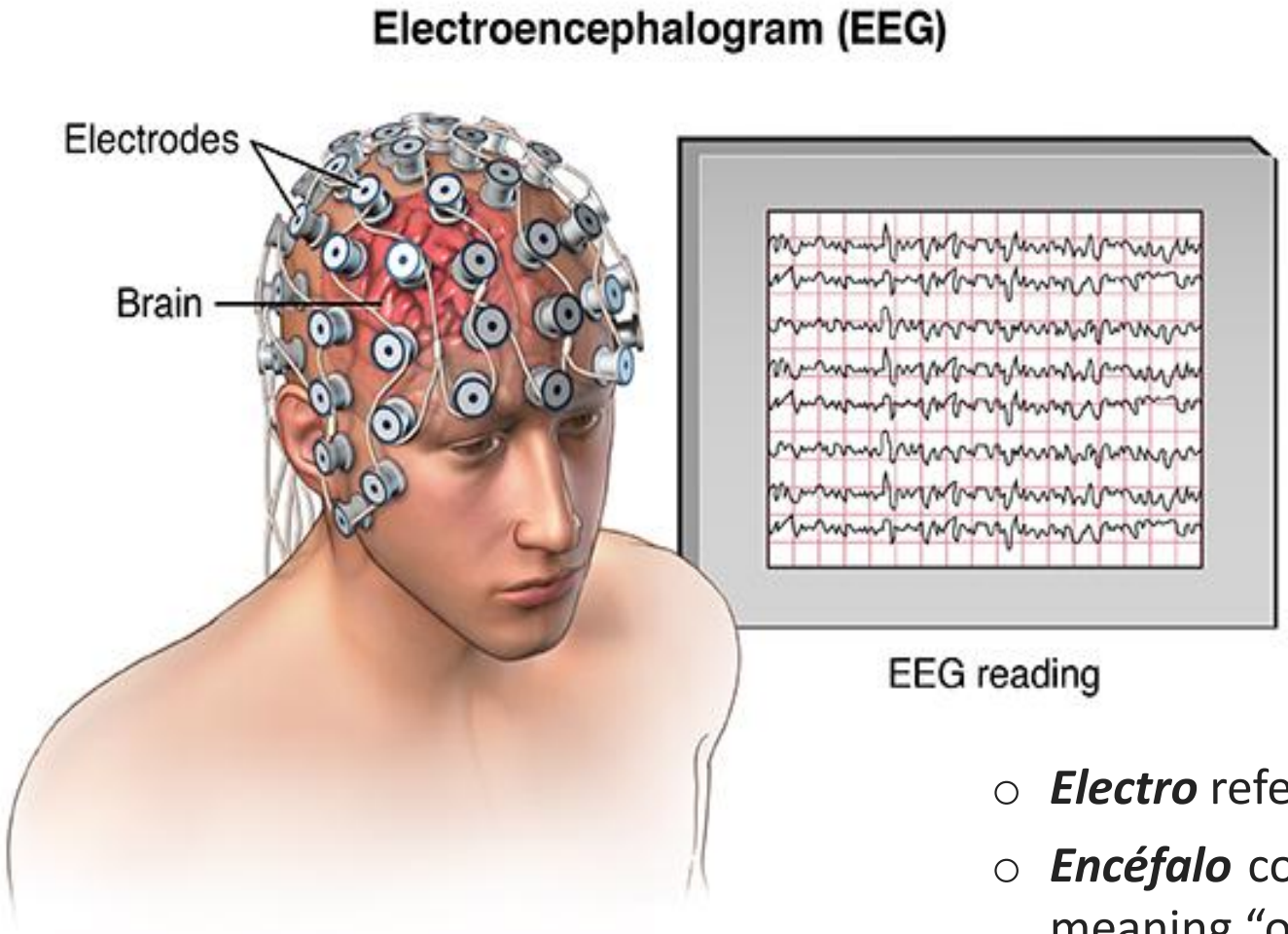
    3. Emotions recognition

1. Fundamentals of EEG

1. *Electroencephalography (EEG)*
2. *Hardware elements*
3. *EEG recording systems*
4. *Neural oscillations*
5. *Evoked potentials*

1.1. Electroencephalography (EEG)



- ***Electro*** refers to an electrical component.
- ***Encéfalo*** comes from the Greek word *en-kephale*, meaning “of the head”, and refers to the brain.
- ***Gram*** represents the act of measuring.

Image: https://www.brightbraincentre.co.uk/electroencephalogram-eeg-brainwaves/

1.2. Hardware elements

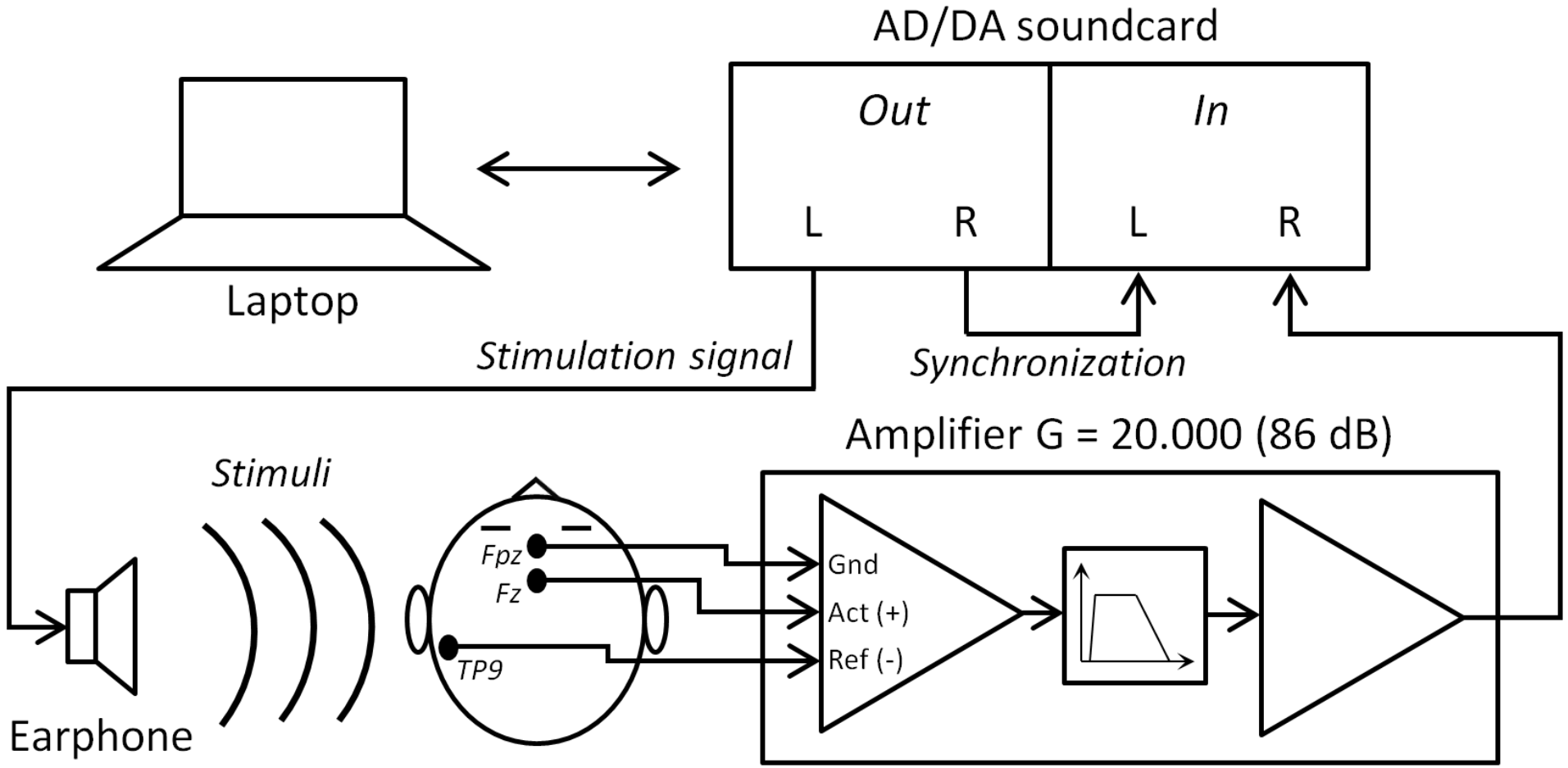
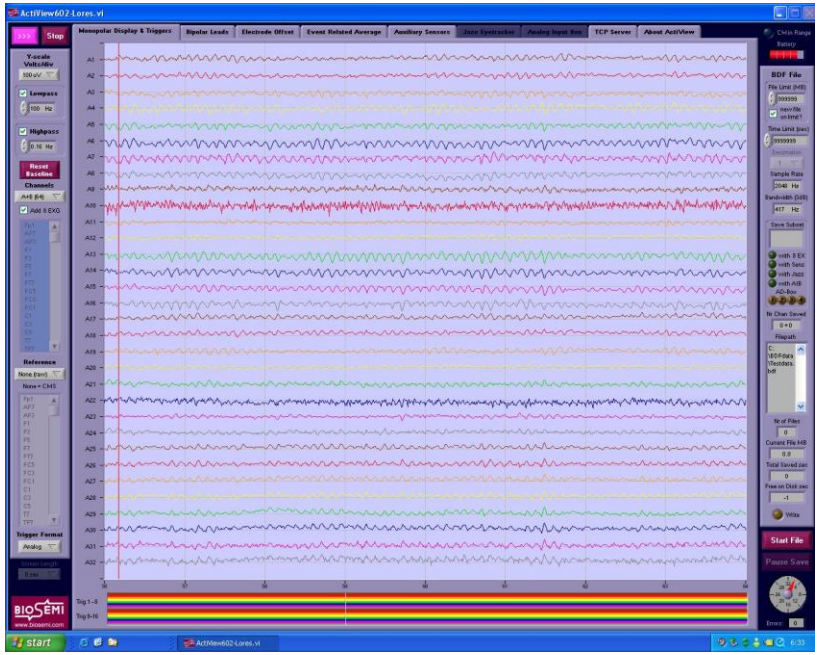


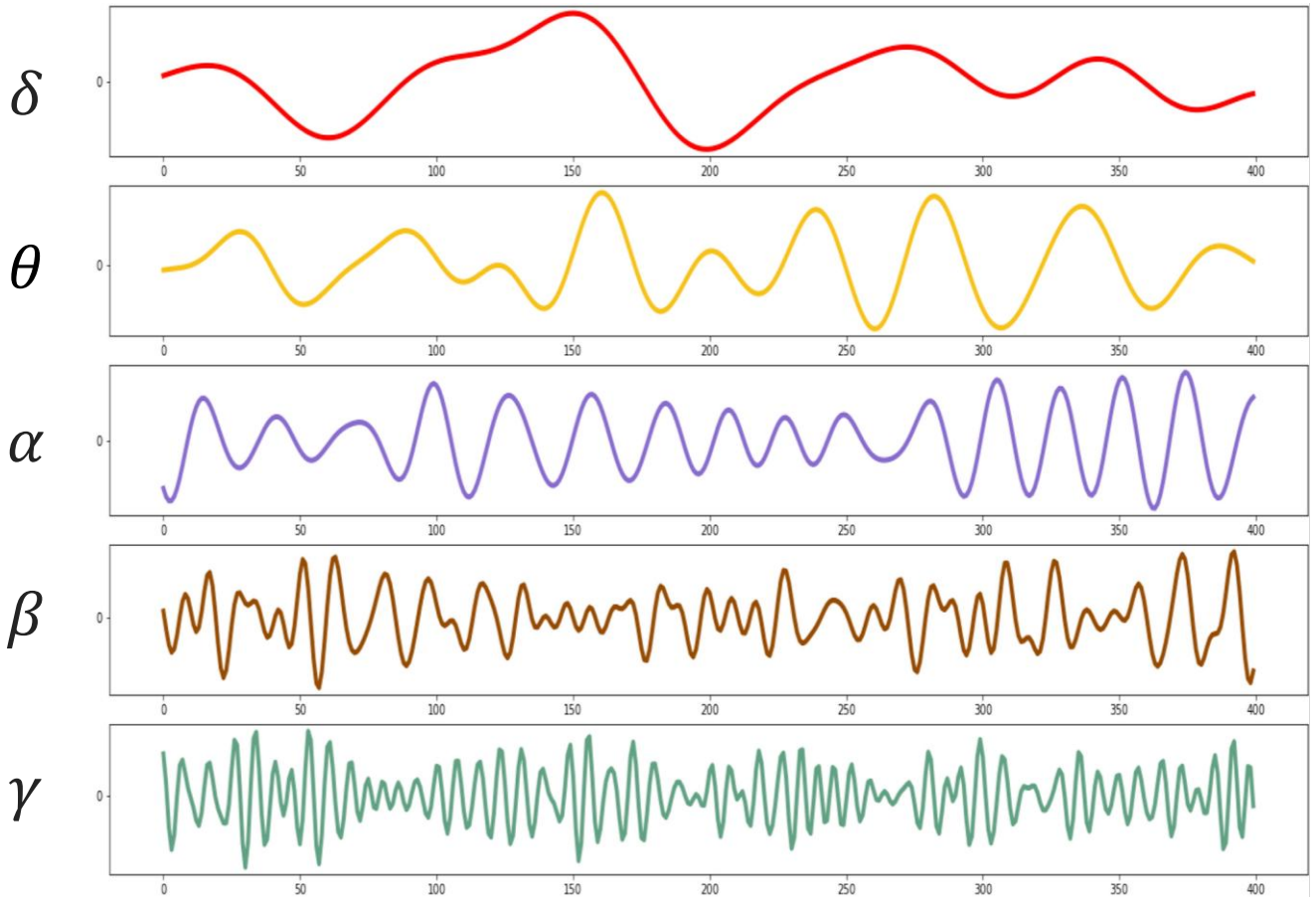
Image: Valderrama et al. (2014). Biomedical Engineering / Biomedizinische Technik.

1.3. EEG recording systems



Images (left): https://www.biosemi.com/pin_electrode.htm | Images (right): https://www.bitbrain.com/es

1.4. Neural oscillations



Delta (0.5—4 Hz).

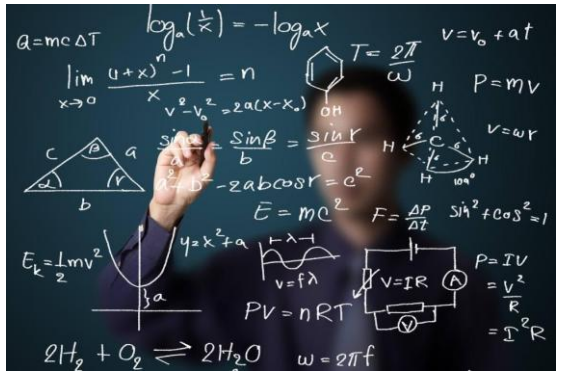
- *Main function*: Regulation of deep sleep, memory consolidation, and brain restoration processes.
- *Associated state of consciousness*: Occurs during slow-wave sleep (NREM), a state of deep unconsciousness crucial for nervous system recovery.
- *Clinical implications*: A decrease in delta waves may be associated with insomnia or sleep disturbances, while an abnormal increase during wakefulness may be related to brain damage or coma states.

Image: Pandey et al. (2022). Brain Informatics.

- **Theta** (4—8 Hz).
  - *Main function*: Processing of episodic memory, learning, spatial navigation, and emotional regulation.
  - *Associated state of consciousness*: Deep relaxation, meditative states, light sleep, and hippocampal activity related to memory.
  - *Example in brain activity*: In the hippocampus, theta oscillations facilitate the encoding and retrieval of memories, playing a key role in memory consolidation.
  - *Clinical implications*: Alterations in theta activity may be associated with neurodegenerative diseases and learning disorders.

- **Alpha** (8—12 Hz).
  - *Main function*: Regulation of attention and alertness, inhibition of irrelevant information, and facilitation of sensory processing.
  - *Associated state of consciousness*: Relaxation without drowsiness, mental calmness, and reduced cortical activity when not actively processing external stimuli.
  - *Example in brain activity*: Alpha activity increases when we close our eyes and decreases when we focus on demanding cognitive tasks.
  - *Clinical implications*: Decreased alpha activity may be associated with anxiety, stress, and disorders such as ADHD.

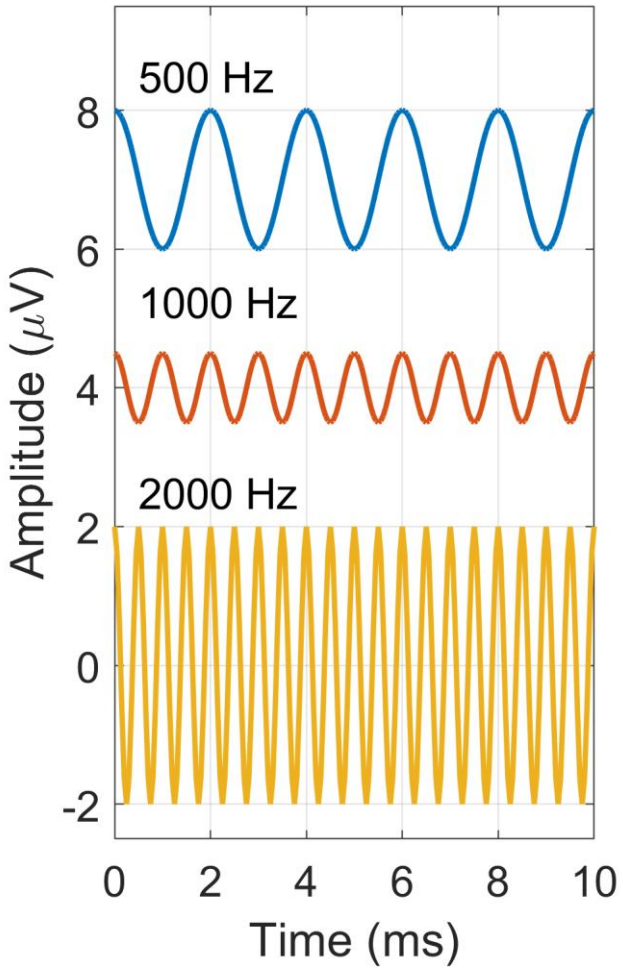
- **Beta** (12—30 Hz).
  - *Main function*: Active information processing, motor control, and coordination of complex cognitive tasks.
  - *Associated state of consciousness*: Active wakefulness, logical thinking, decision-making, and concentration.
  - *Example in brain activity*: Beta activity increases during problem-solving in mathematics or while learning new motor skills.
  - *Clinical implications*: Excessive beta activity may be associated with anxiety and stress, while reduced beta activity is linked to movement disorders such as Parkinson's disease.

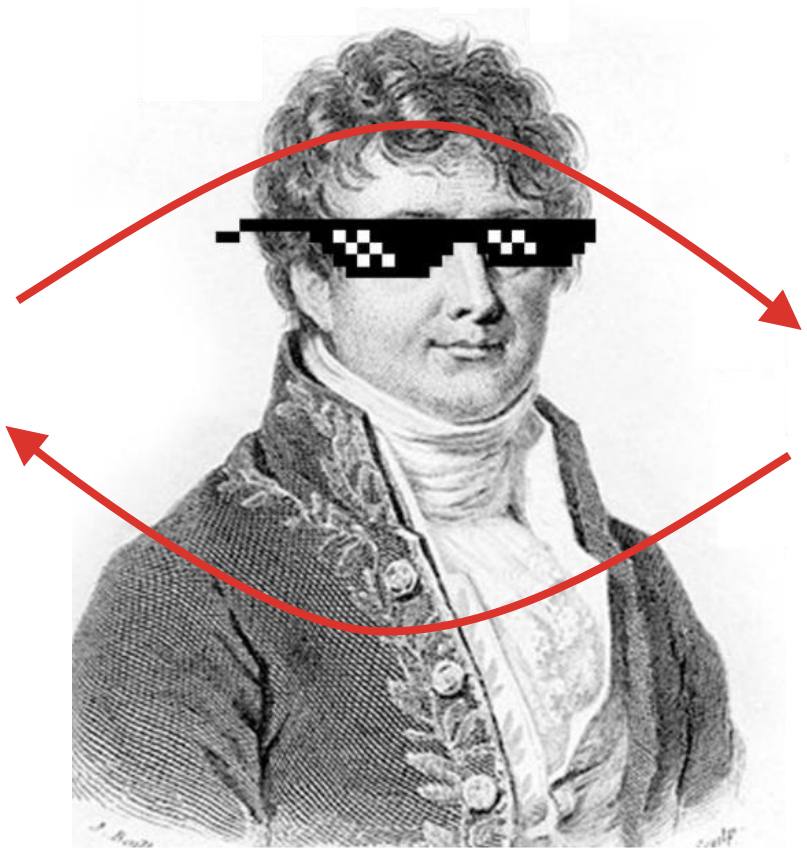


- **Gamma** (30—100 Hz).
  - *Main function*: Integration of multisensory information, conscious perception, working memory, and higher cognitive functions.
  - *Associated state of consciousness*: Peak attention, high-level information processing, and full awareness.
  - *Example in brain activity*: Observed during conscious perception processes, such as when we identify an object in a split second.
  - *Clinical implications*: Dysfunction in gamma activity has been linked to disorders such as schizophrenia and Alzheimer's disease.

Time vs Frequency analysis

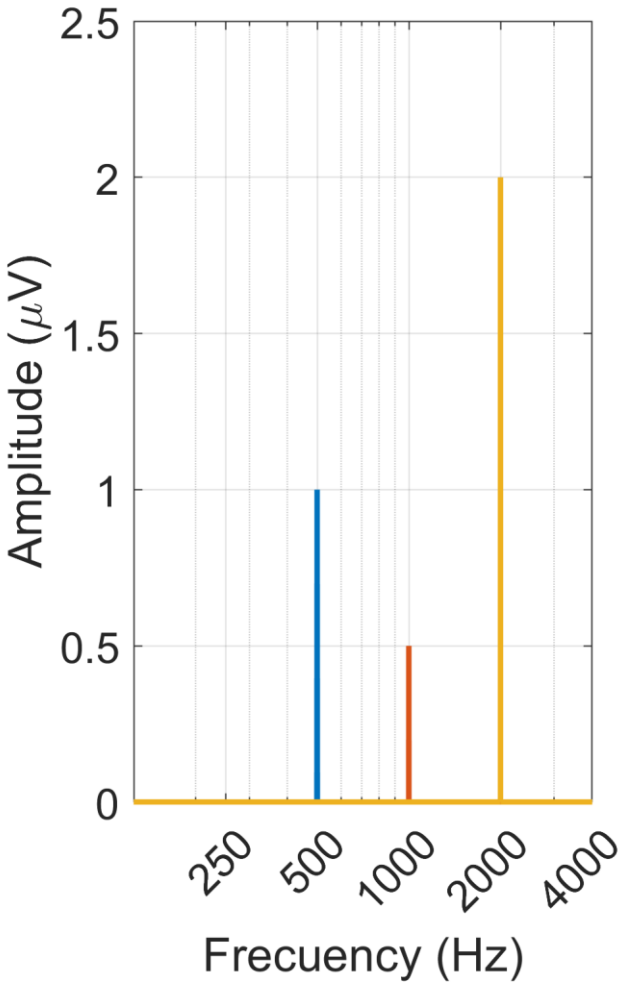
Time domain

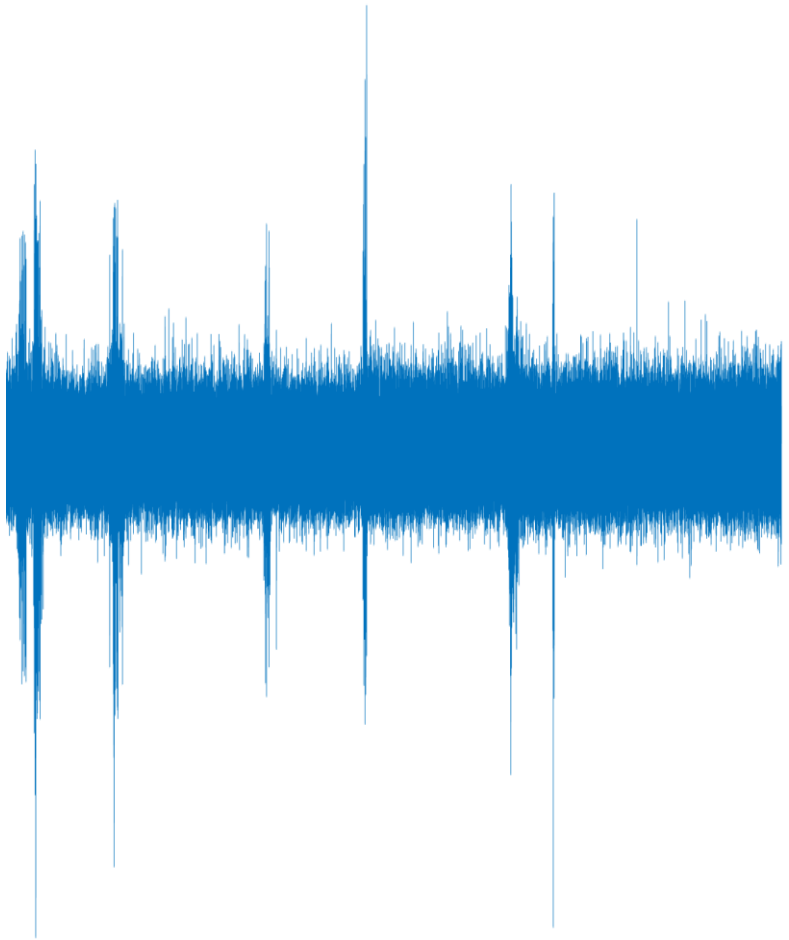


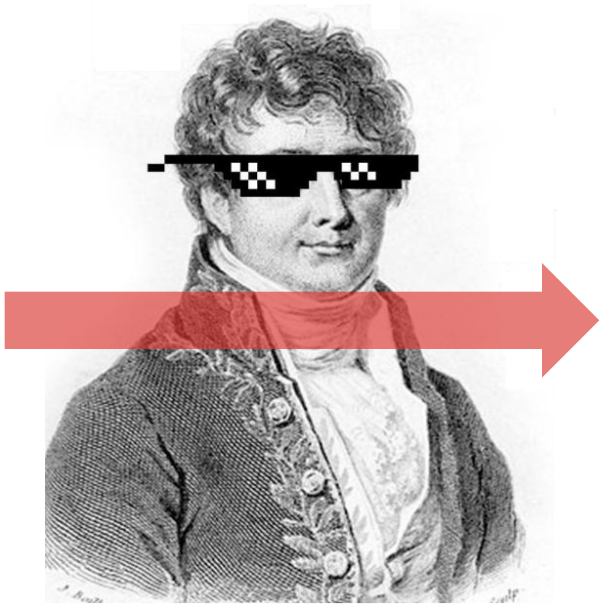


Fourier Transform

Frequency domain







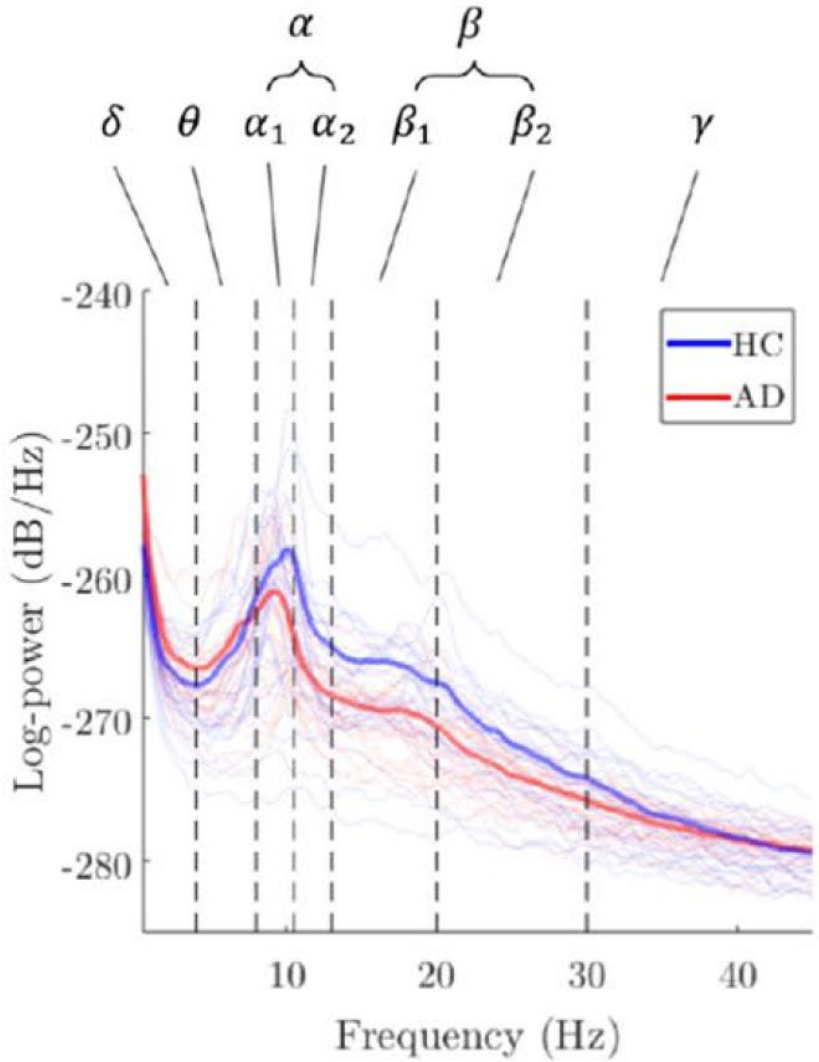


Image: Gillon et al. (2017). Scientific Reports.

- **Ejemplo 1.** Identificación automática de emociones (Pandey et al., 2022).

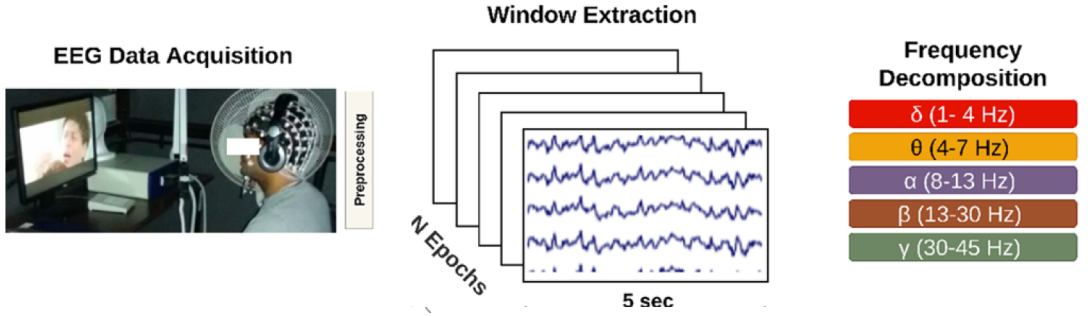
Pandey *et al. Brain Informatics* (2022) 9:15
https://doi.org/10.1186/s40708-022-00163-7

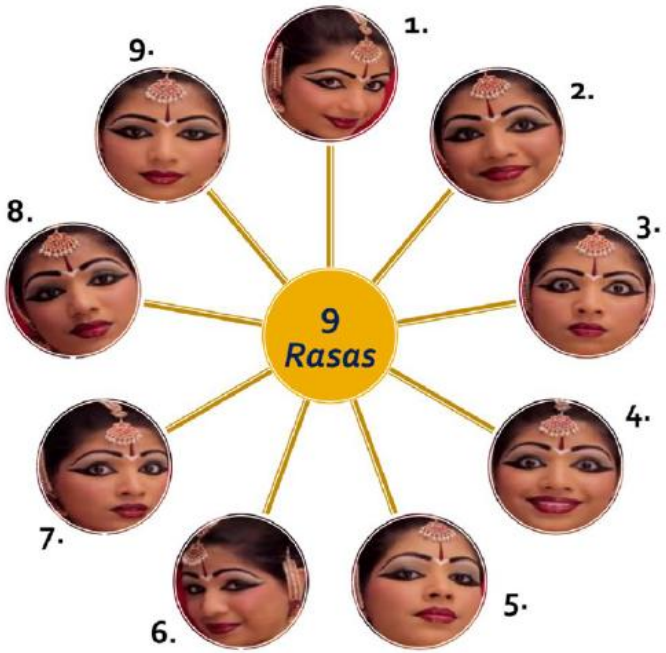
Brain Informatics

RESEARCH Open Access

Classifying oscillatory brain activity associated with Indian *Rasas* using network metrics

Pankaj Pandey[1*], Richa Tripathi[2] and Krishna Prasad Miyapuram[1,3]





Navarasas (Nine *Rasas*)	Corresponding Dominant state
1. *Sringaram* (Erotic)	*Rati* (Love)
2. *Hasyam* (Comic)	*Hasyabhava* (Mirth)
3. *Raudram* (Rage)	*Krodha* (Anger)
4. *Adbhutam* (Marvellous)	*Vismay* (Astonishment)
5. *Veeram* (Heroic)	*Utsah* (Energy)
6. *Bibhatsam* (Odious)	*Jugupsha* (Disgust)
7. *Bhayanakam* (Terror)	*Bhay* (Fear)
8. *Karunayam* (Pathos)	*Shoka* (Sorrow)
9. *Santam* (Peace)	*Santabhava* (Peace)

Table 5 Distinguishable pairs ($p < 0.001$) of *Rasas* in different frequency bands

Rasa 1	Discriminated (*Rasas* 2)	Band
Bibhatsam	Santam, Veeram and Karunayam	Delta and Gamma
Bibhatsam	Hasyam and Adbhutam	Beta
Bhayanakam	Karunayam	Delta, Beta and Gamma
Sringaram	All	Delta, Beta and Gamma
Sringaram	except Bibhatsam and Bhayanakam	Theta
Sringaram	Santam and Hasyam	Alpha

1.4. Evoked potentials

- **Evoked potentials** (EP) are voltage waves that reflect the synchronized activity of neurons activated by an external stimulus.
- Depending on the type of external stimulus used, there are different **types**.

  - ***Visual evoked potentials***
    - These are elicited in response to visual stimuli such as light flashes or reversing patterns.
    - They are recorded in the occipital cortex and are used to assess visual function and diagnose conditions like multiple sclerosis.
  - ***Somatosensory evoked potentials***
    - These are generated after peripheral nerve stimulation using electrical impulses.
    - They reflect sensory conduction from the spinal cord to the somatosensory cortex and are used in the diagnosis of spinal cord injuries and neuropathies.

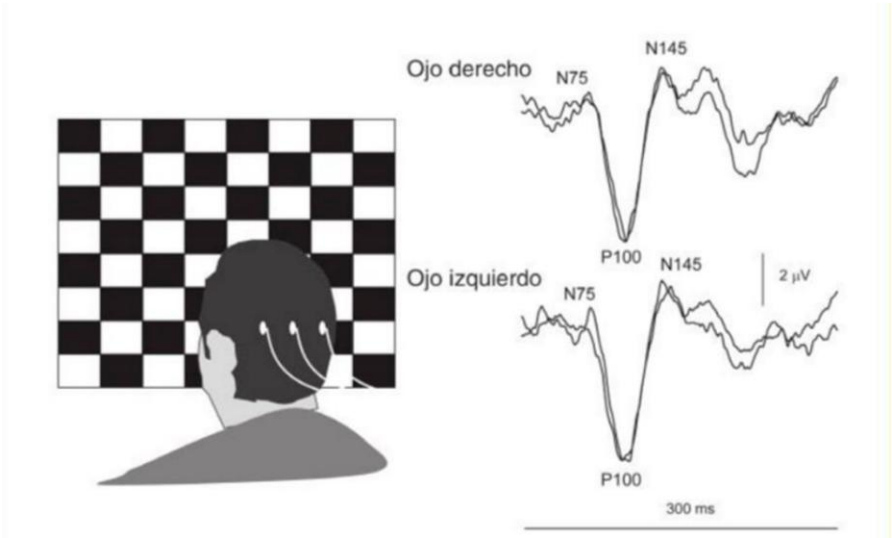
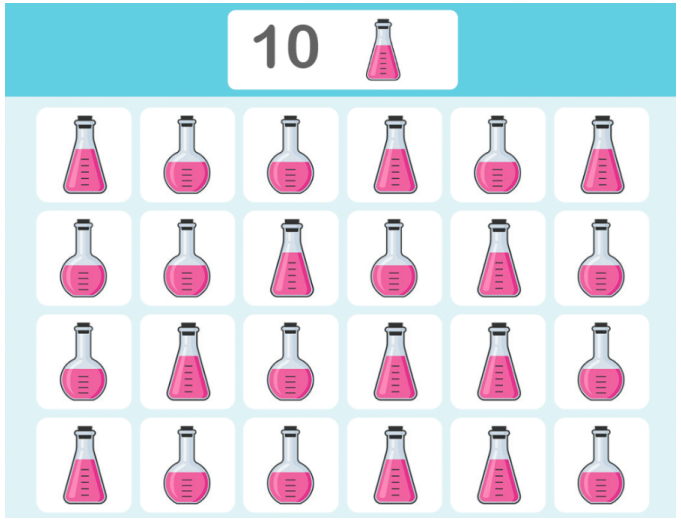


Image: https://neurofisiologiainfantil.com/potenciales-evocados-visuales-pev/

- ***Auditory evoked potentials***
  - These are responses from the brainstem or auditory cortex to sound stimuli such as clicks, brief tones, or more complex sounds.
  - They are used to assess hearing, especially in newborns, and to detect brainstem disorders.

- ***Cognitive evoked potentials***
  - These are generated in response to cognitive tasks such as detecting novel or meaningful stimuli.
  - They are used to study attention, memory, and speech comprehension.



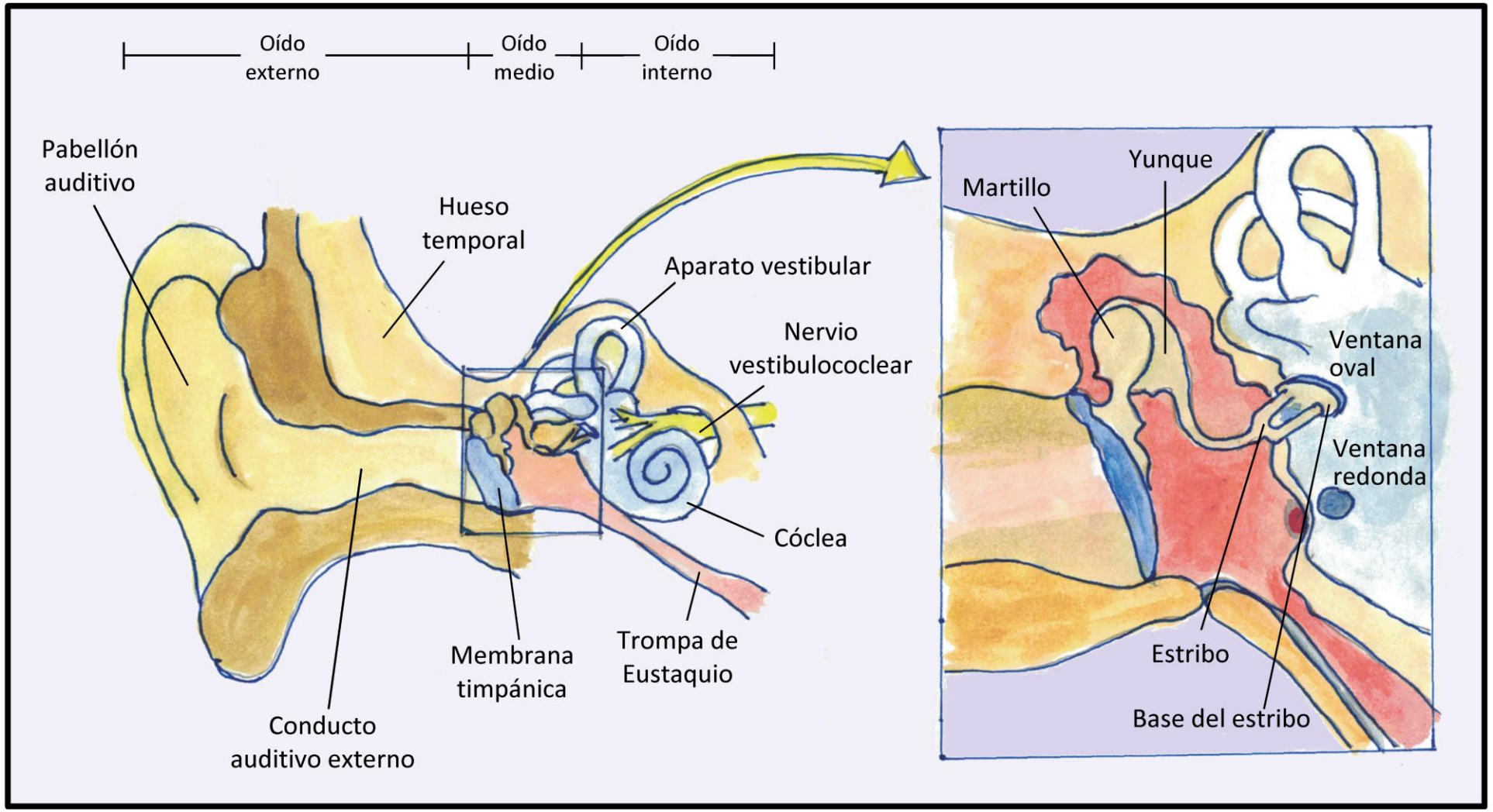
- ***Motor evoked potentials***
  - These are obtained by stimulating the motor cortex and recording responses from muscles.
  - They are essential for evaluating the motor pathway in diseases such as amyotrophic lateral sclerosis.

Image (top): https://multiacustica.com/blog/potenciales-evocados-auditivos-ventana-al-funcionamiento-del-oido-interno/
Image (bottom): https://neuronup.com/actividades-de-neurorrehabilitacion/actividades-para-funciones-cognitivas/actividades-de-atencion/ficha-para-trabajar-la-atencion-selectiva-con-ninos-objetos-exactos/

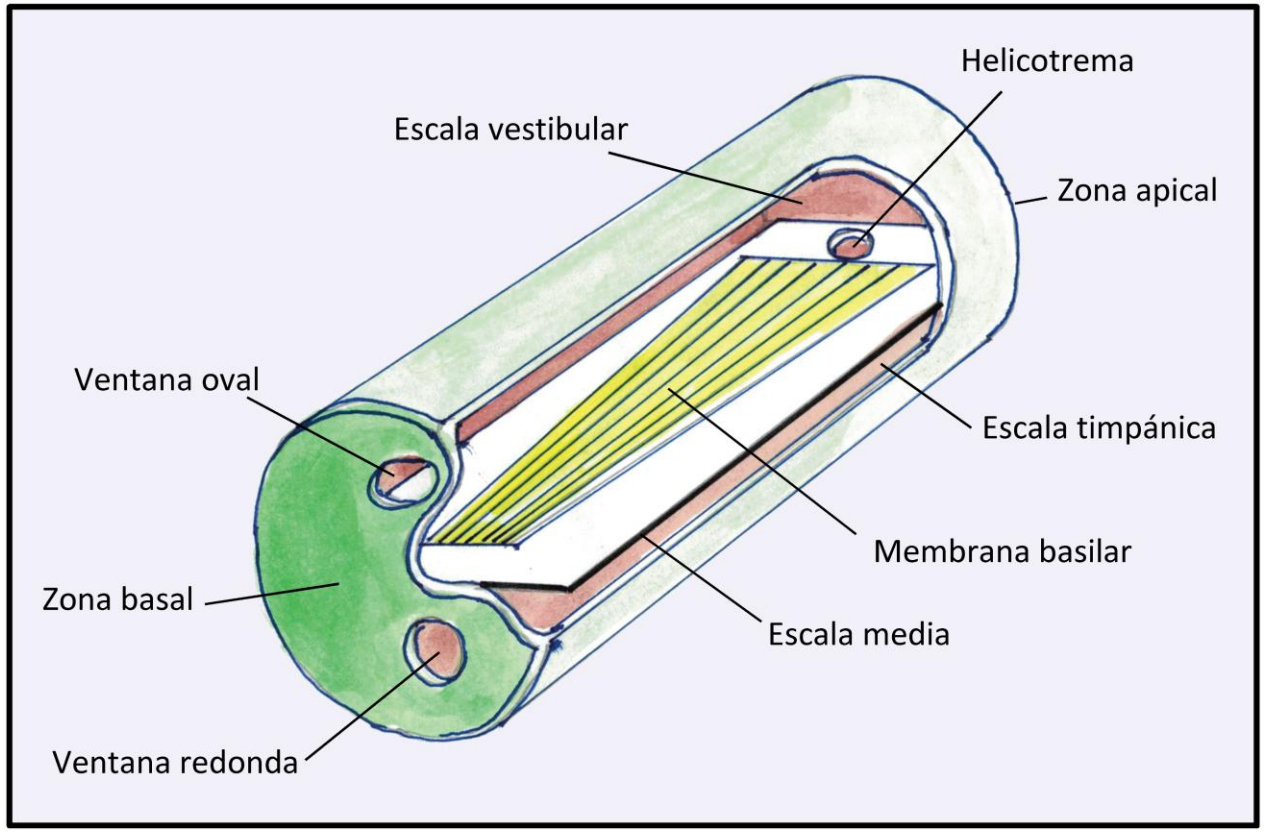
2. The hearing process

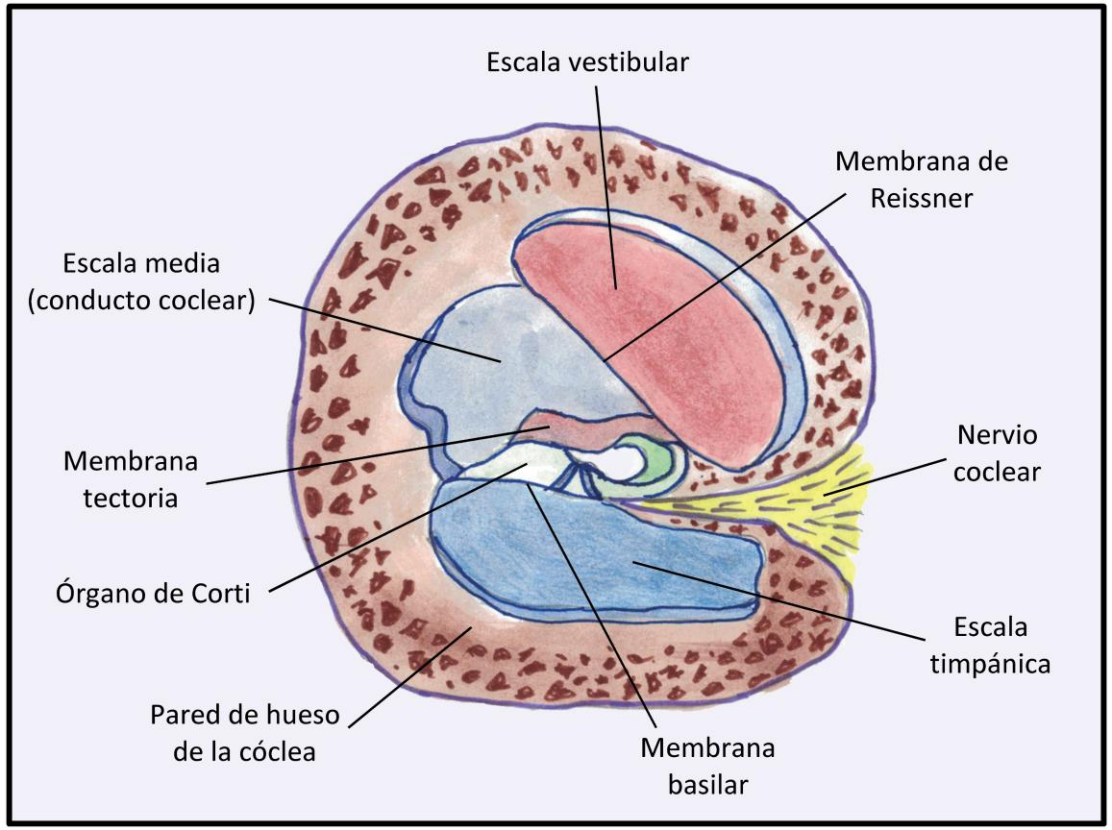
1. *The external and middle ear*
2. *The cochlea*
3. *The basilar membrane*
4. *The Organ of Corti*
5. *The outer hair cells (OHC)*
6. *The inner hair cells (IHC)*
7. *The auditory pathway*
8. *The brain*
9. *Hearing with a cochlear implant*

1.1. The external and middle ear

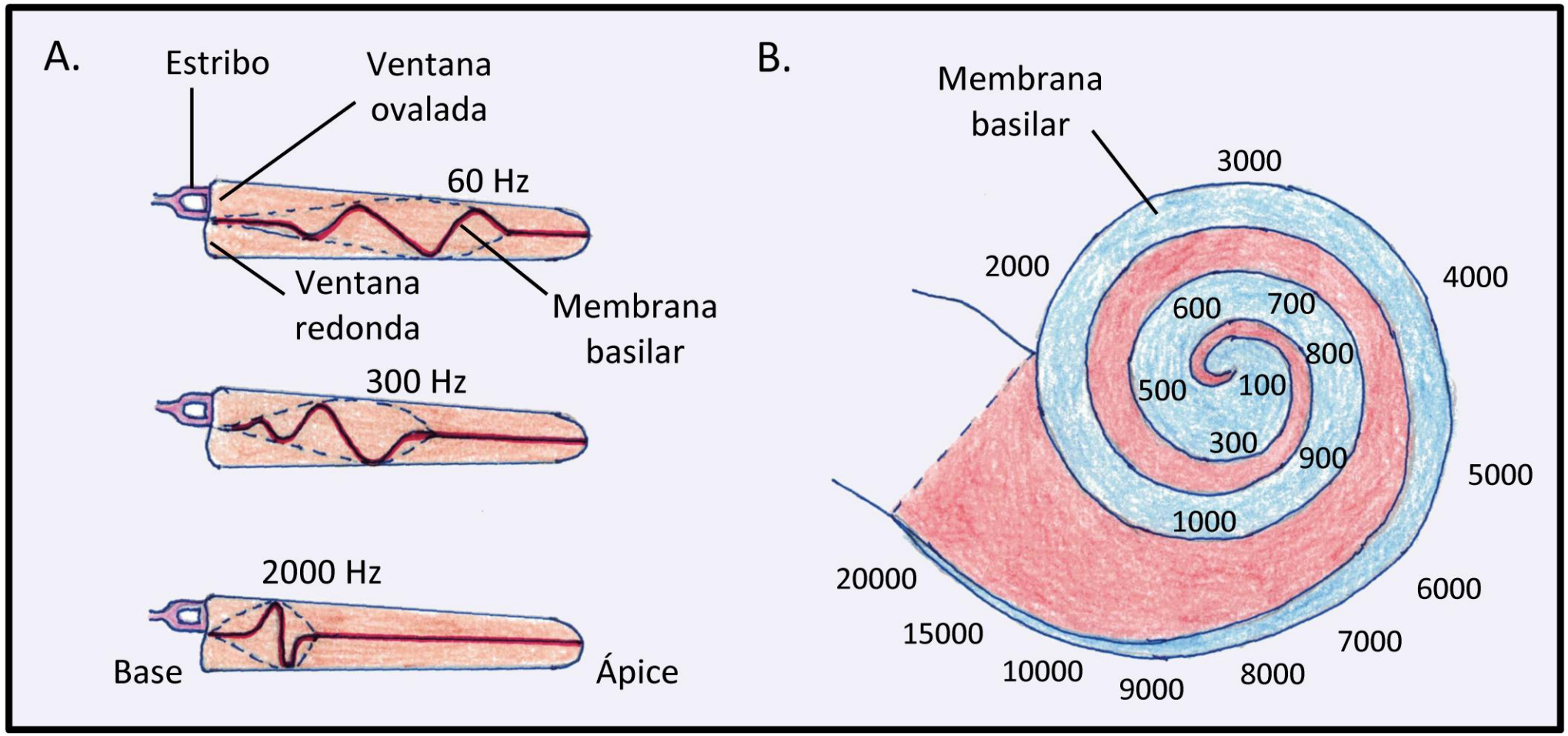


1.2. The cochlea

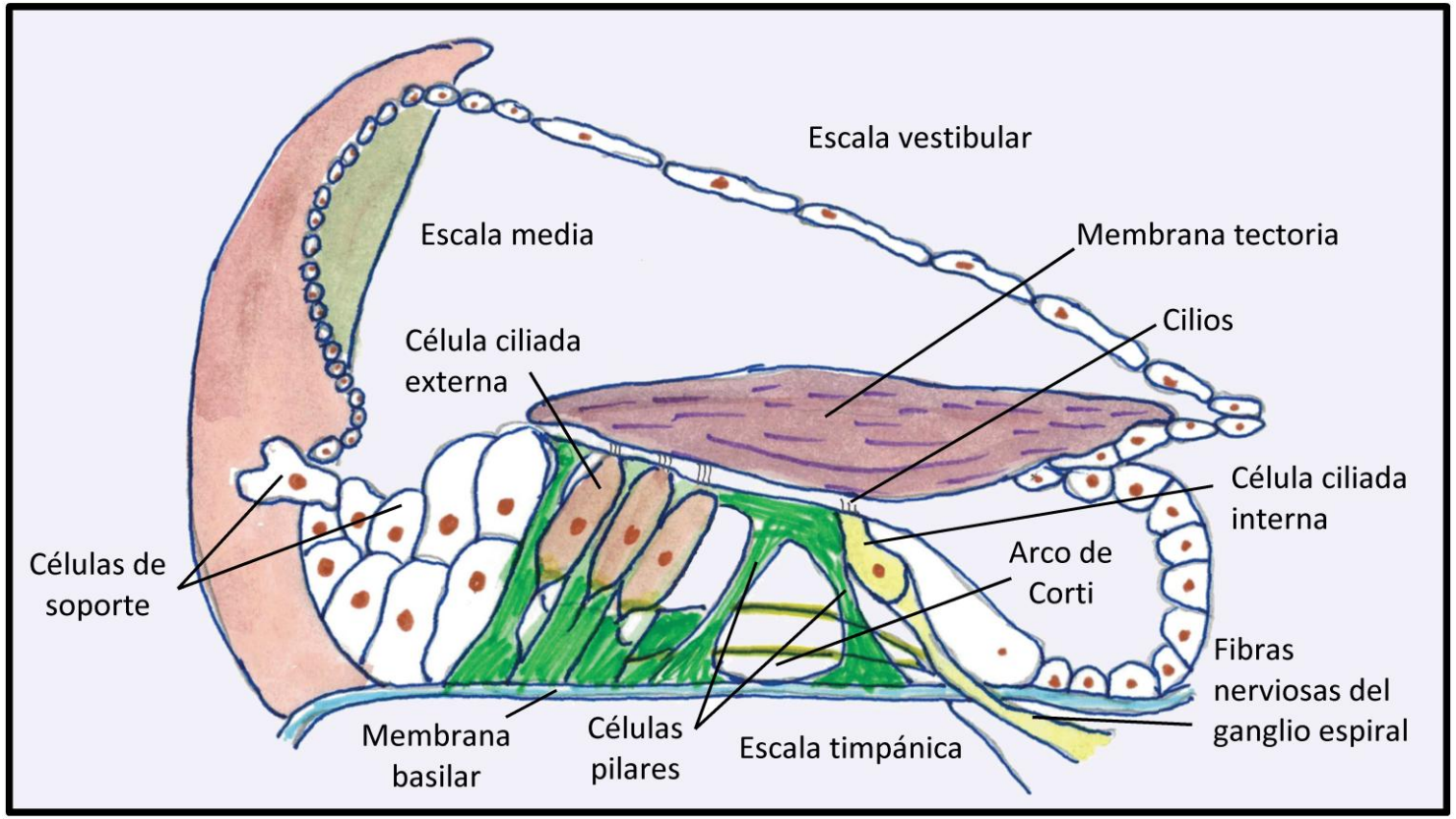


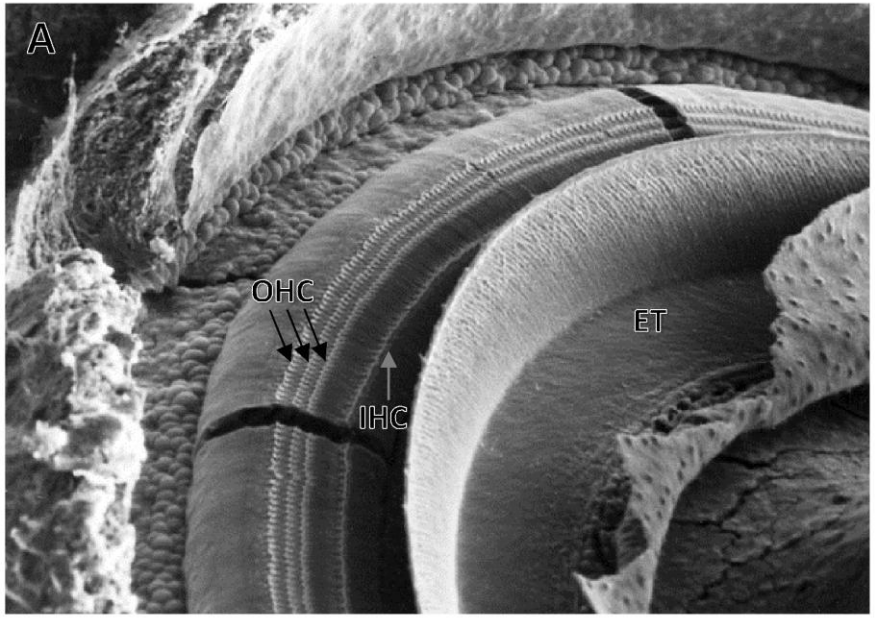


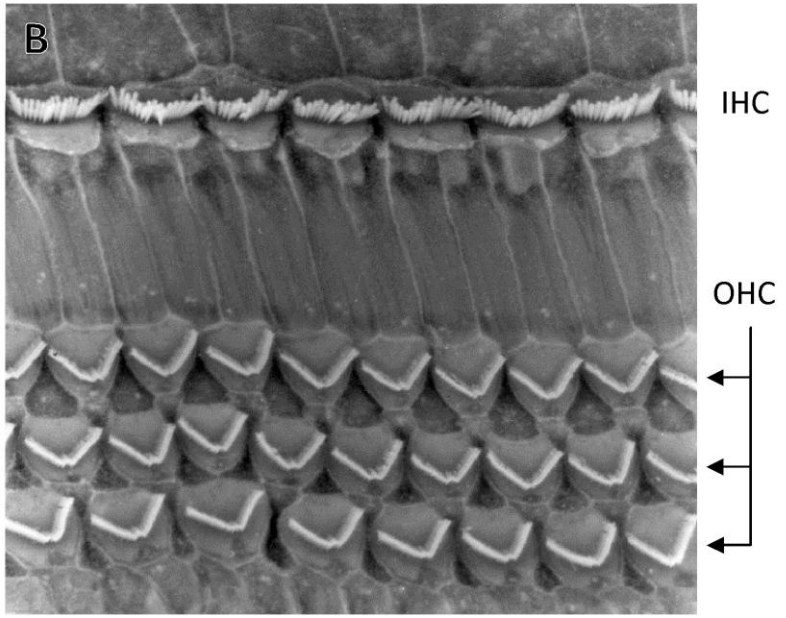
1.3. The basilar membrane



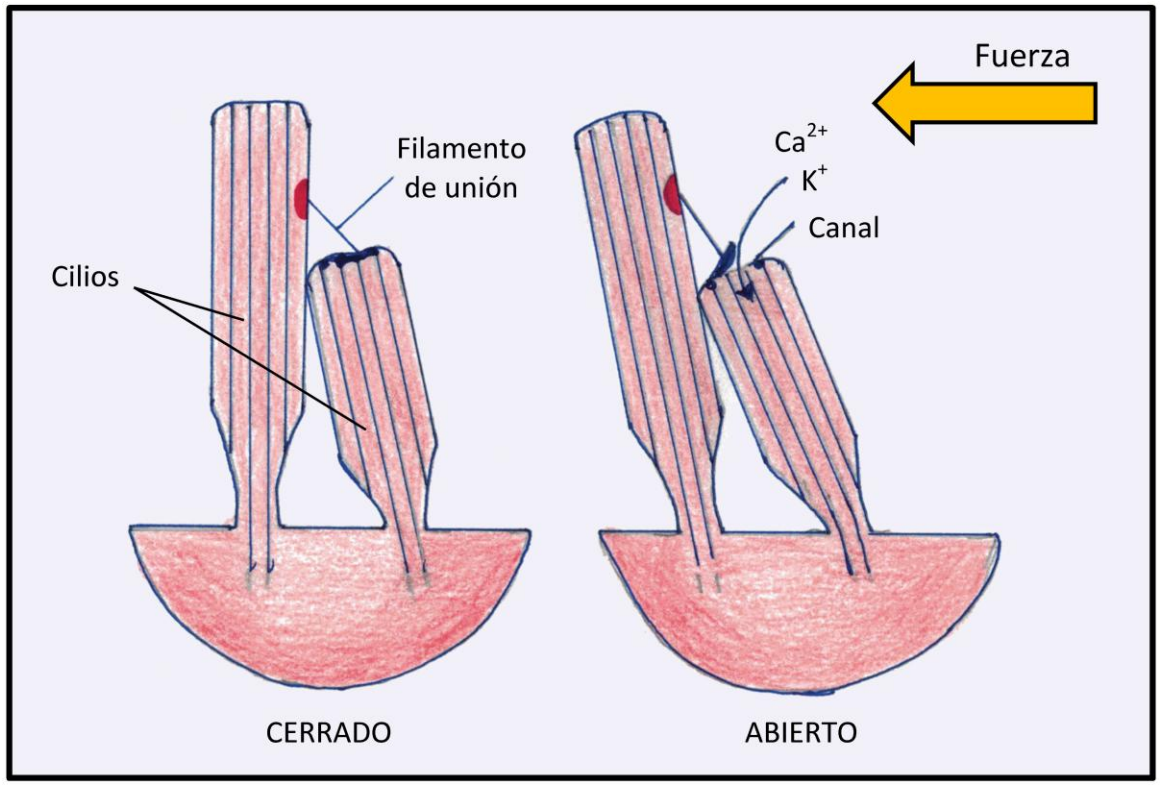
1.4. The Organ of Corti

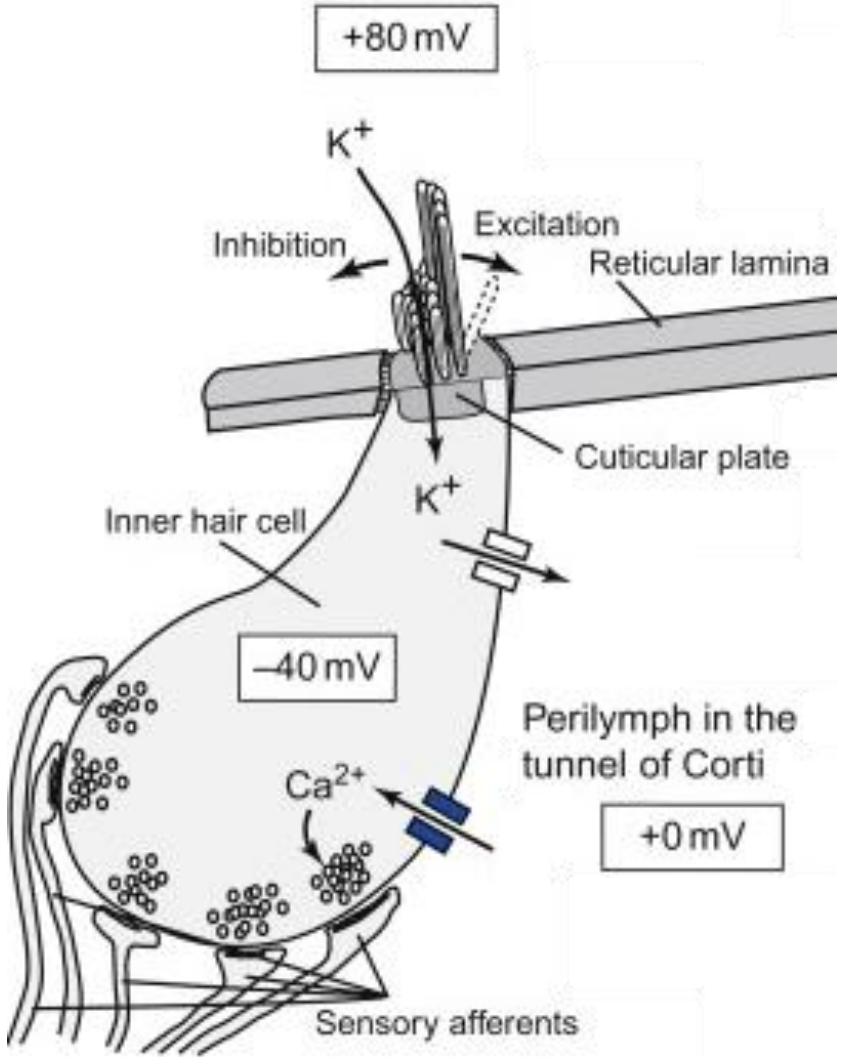




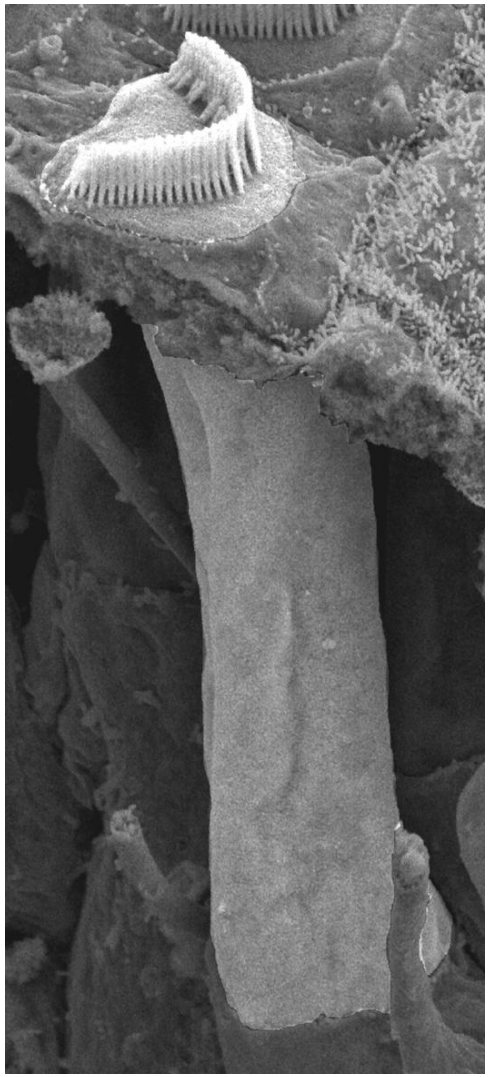


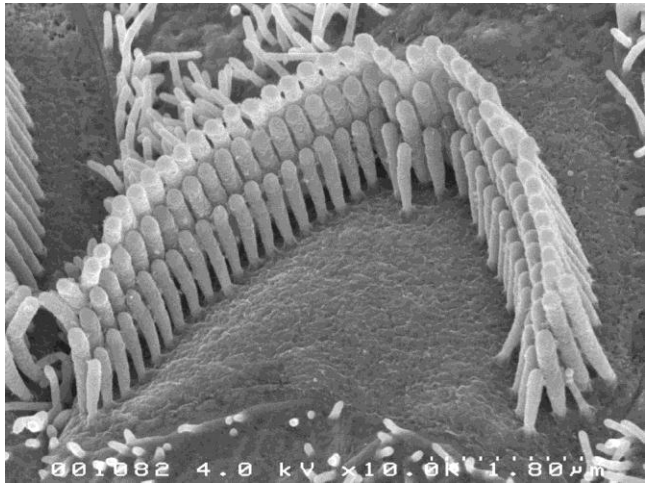
1.6. The inner hair cells (IHC)

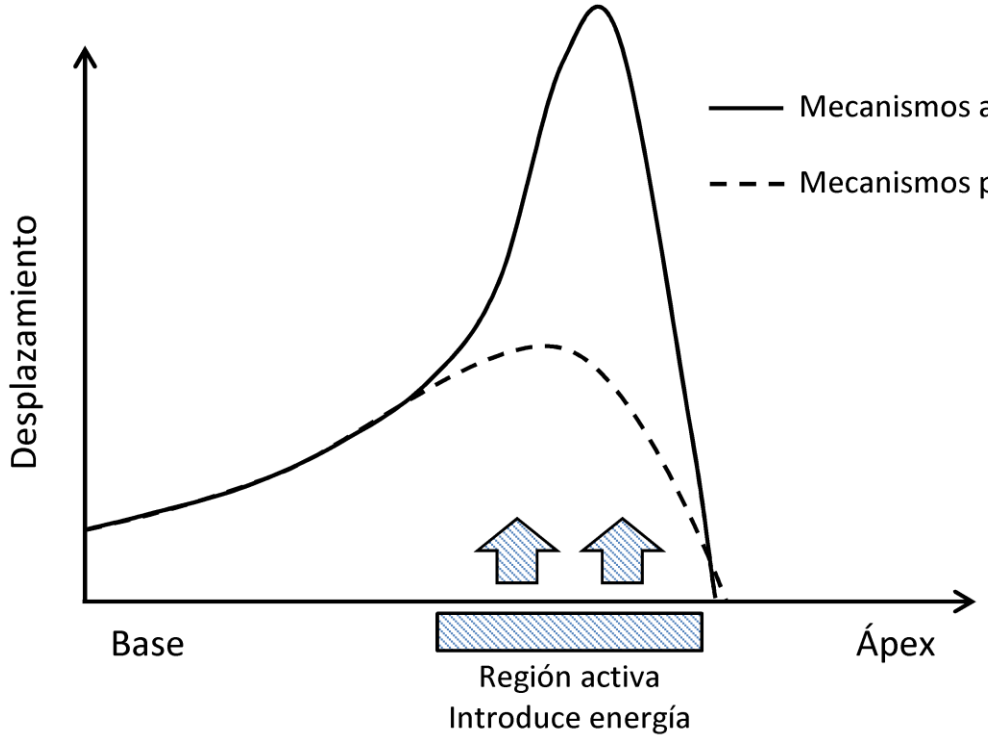


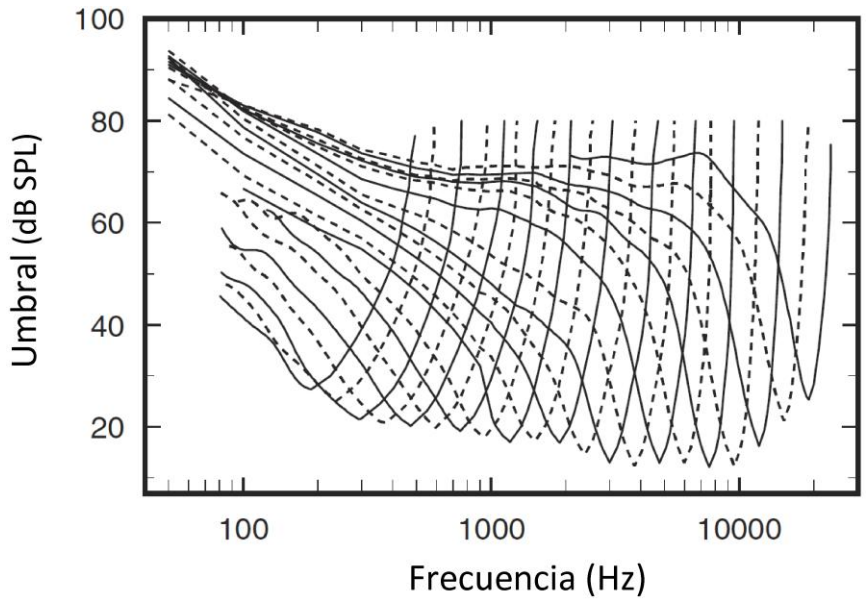


1.5. The outer hair cells (OHC)

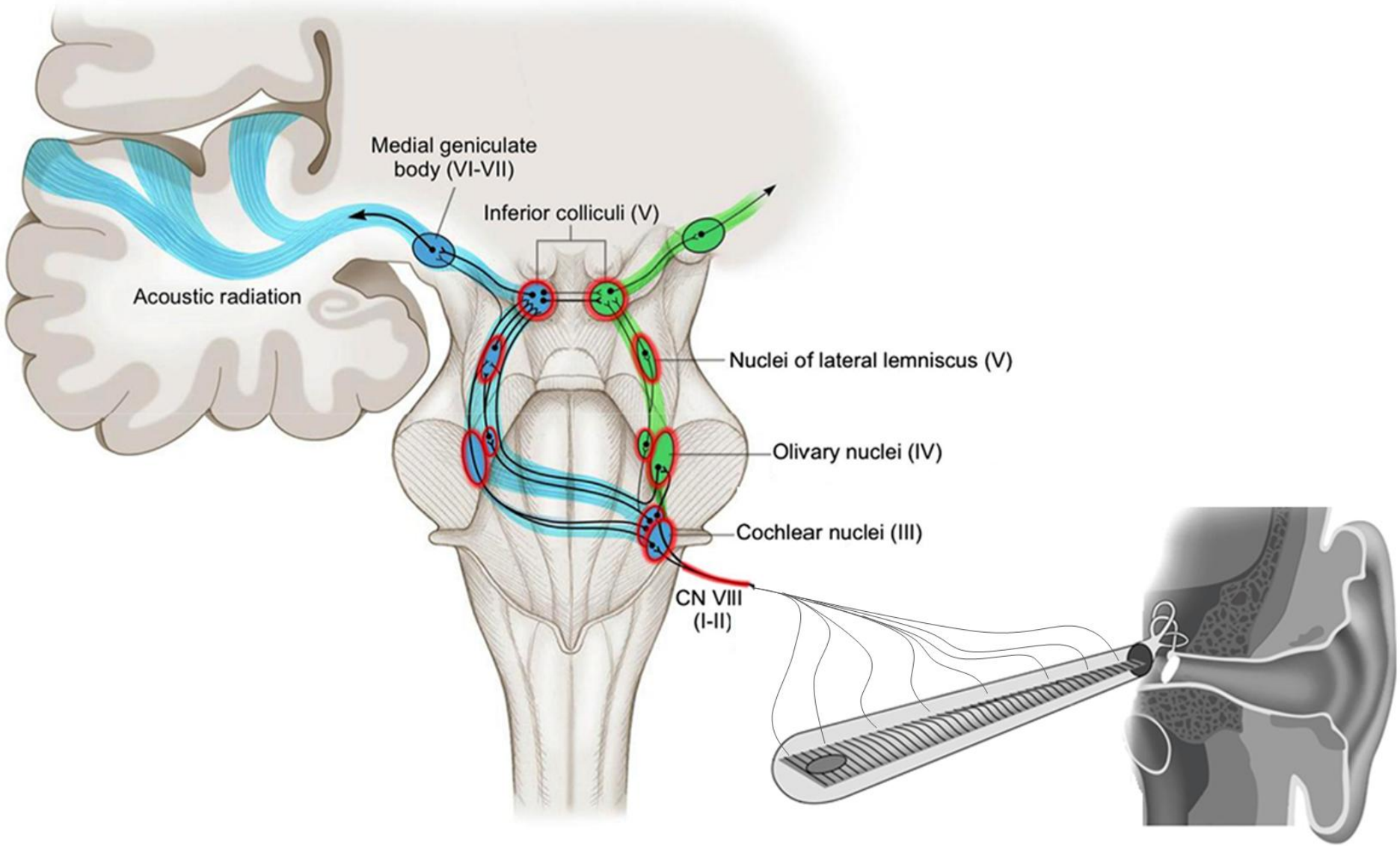




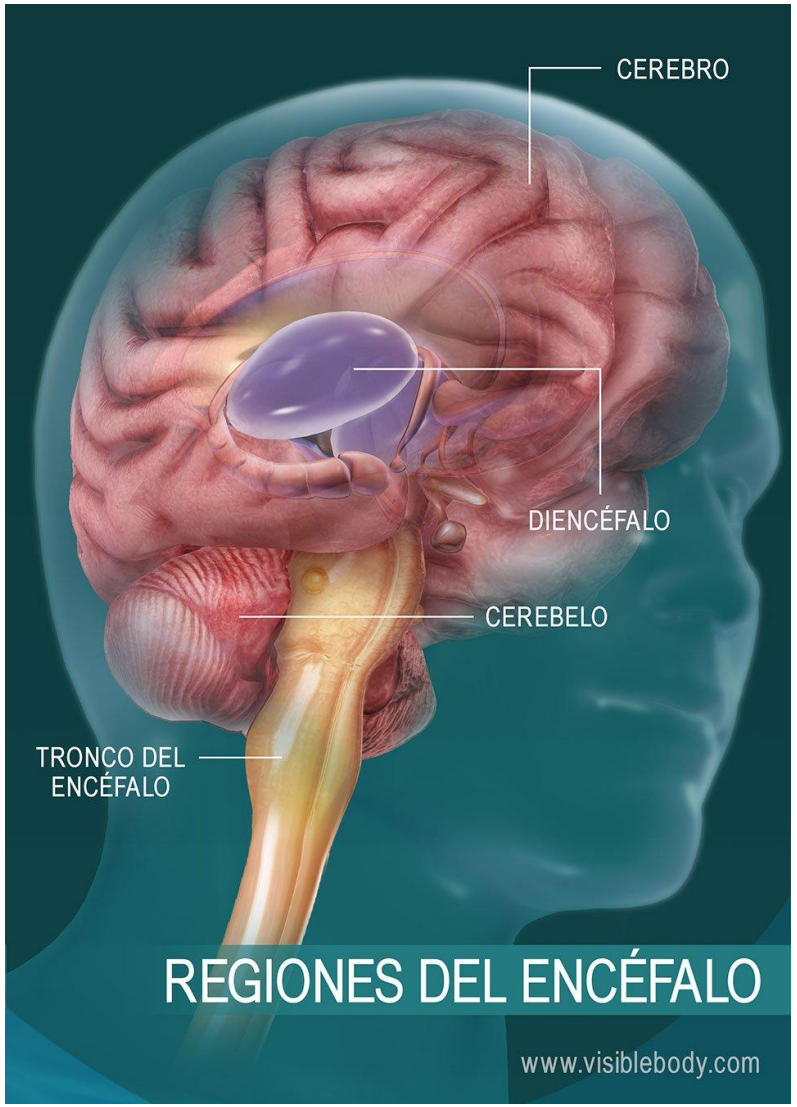




1.7. The auditory pathway

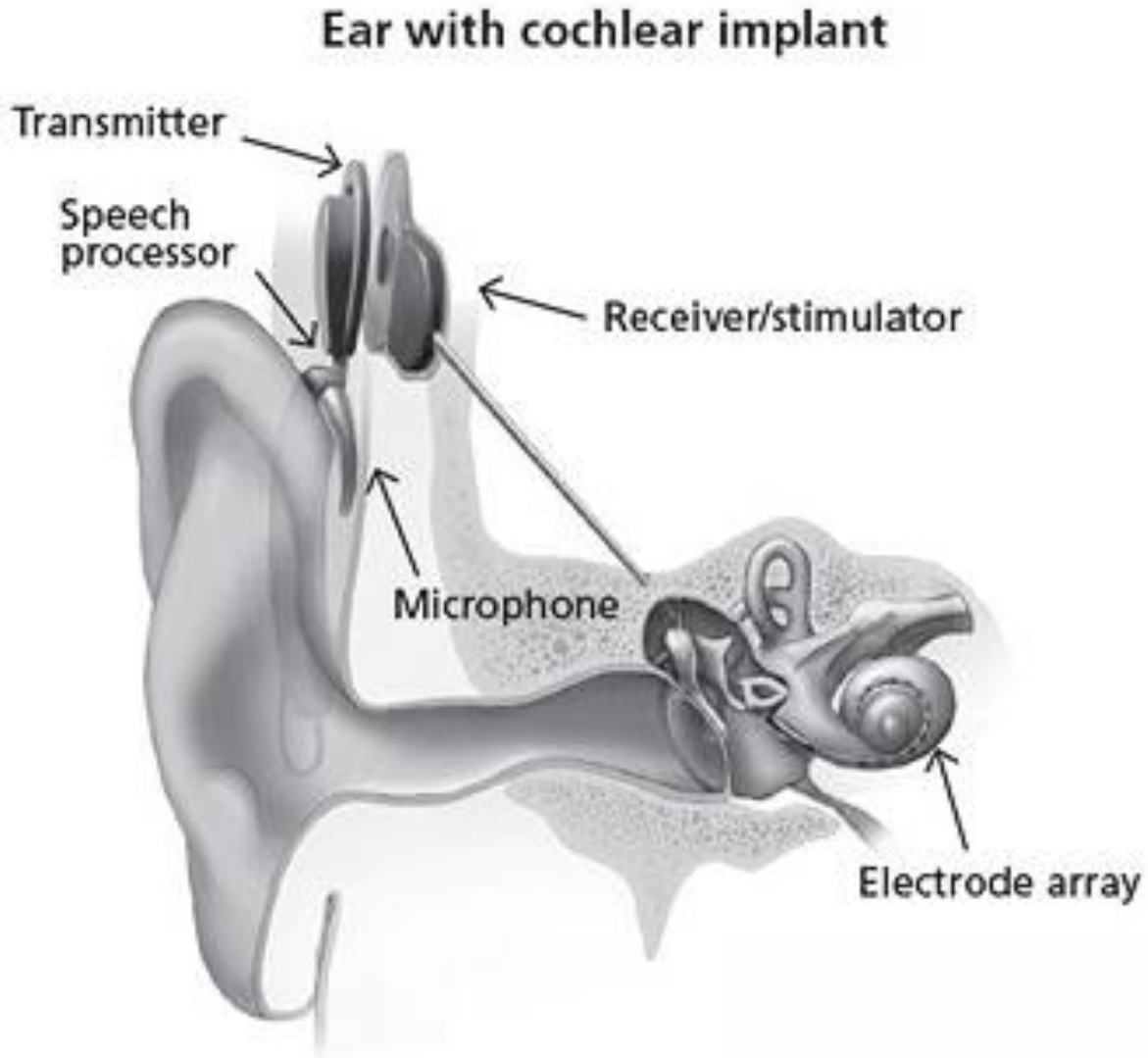


1.8. The brain



- The brain contains around 10^{11} neurons.
- Highly interconnected – 1 neuron → 1000—100.000 synapses.
  - Breathing, body temperature regulation, digestion, voluntary movements, thinking, creating, learning.
- **Grey matter** contains most of the bain's neuronal cell bodies.
- **White matter** is made up axons that connect different brain regions.
- **Left hemisphere** → speech comprehension, reading, writing, and logical thinking.
- **Right hemisphere** → artistic activities and creativity.
- **Frontal lobe** → voluntary control, planning, decision-making, reasoning, emotional regulation, and language—*higher cognitive functions*.
- **Parietal lobe** → Sense of touch, temperature perception, spatial orientation, audiovisual integration.
- **Occipital lobe** → Vision, colour perception, shape recognition, motion.
- **Temporal lobe** → Hearing, face and object recognition, memory, language, and speech comprehension.

1.9. Hearing with a cochlear implant



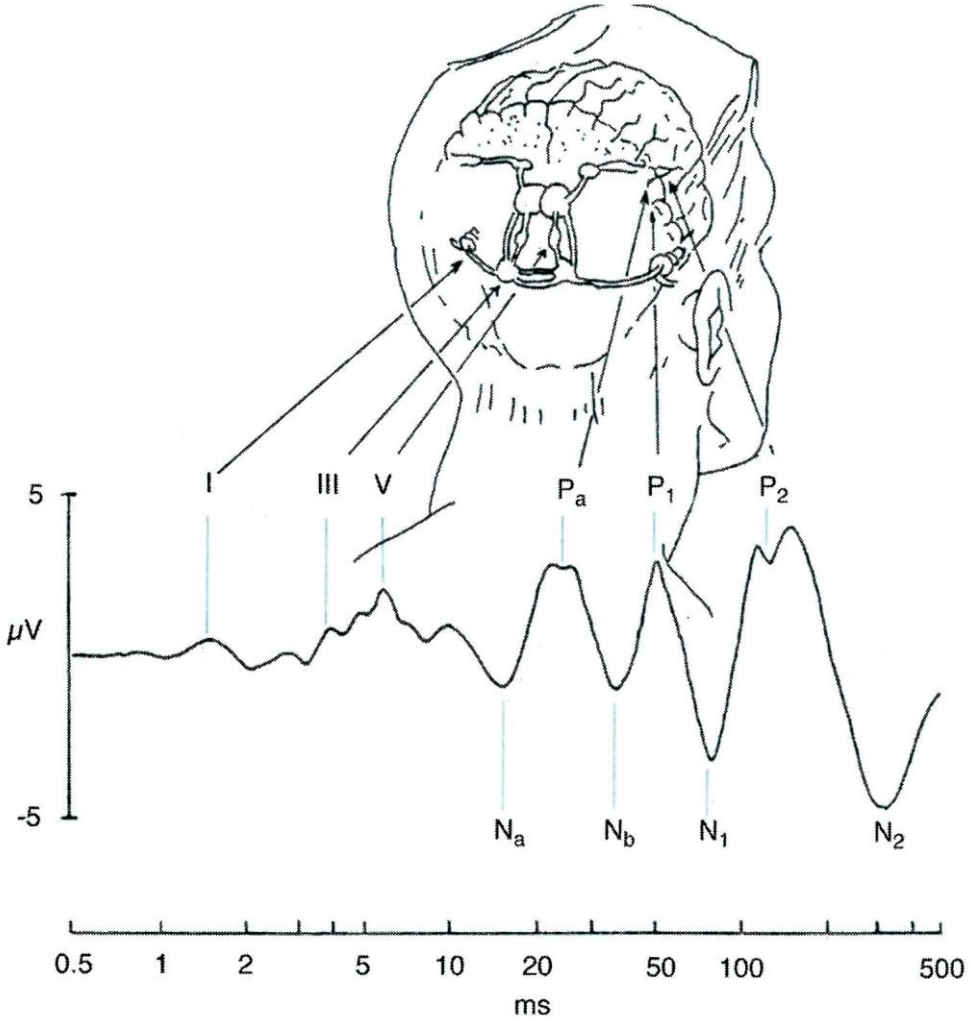
Normal hearing

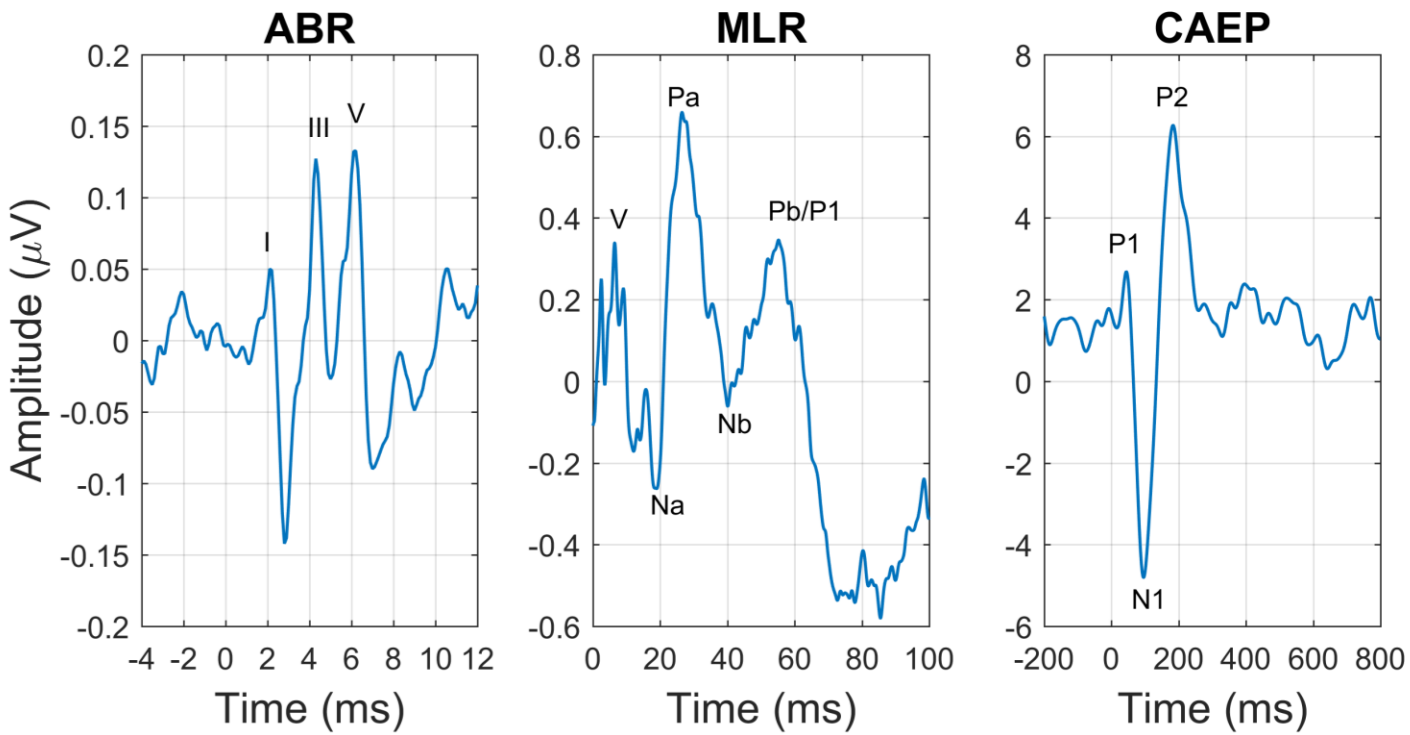
Cochlear implant

3. Hearing measures

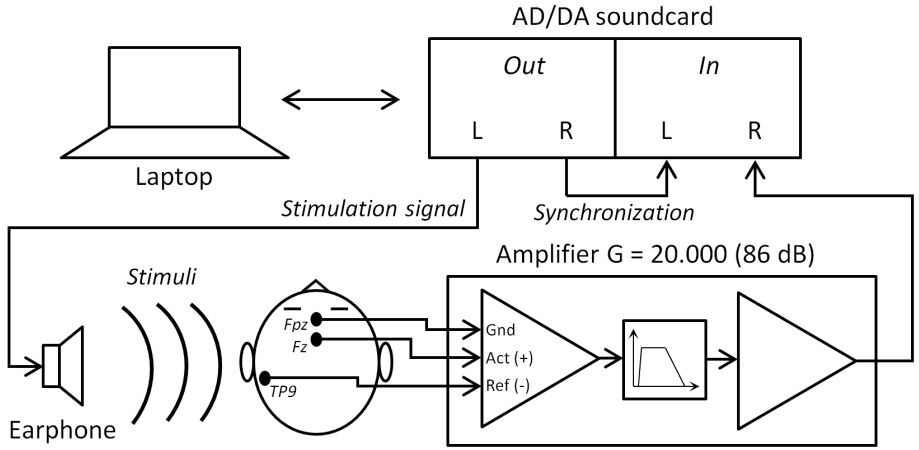
a. *Auditory evoked potentials (AEPs)*
b. *AEPs recording*
c. *Hearing threshold estimation*

3.1. Auditory evoked potentials





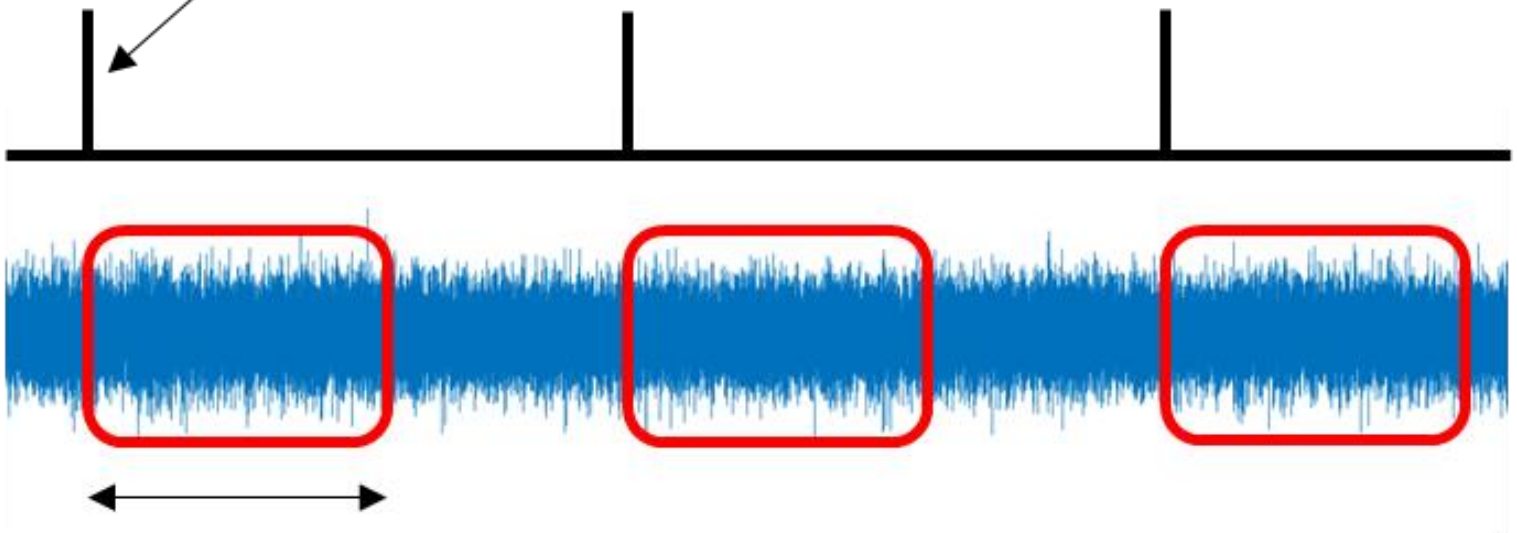
3.2. AEPs recording



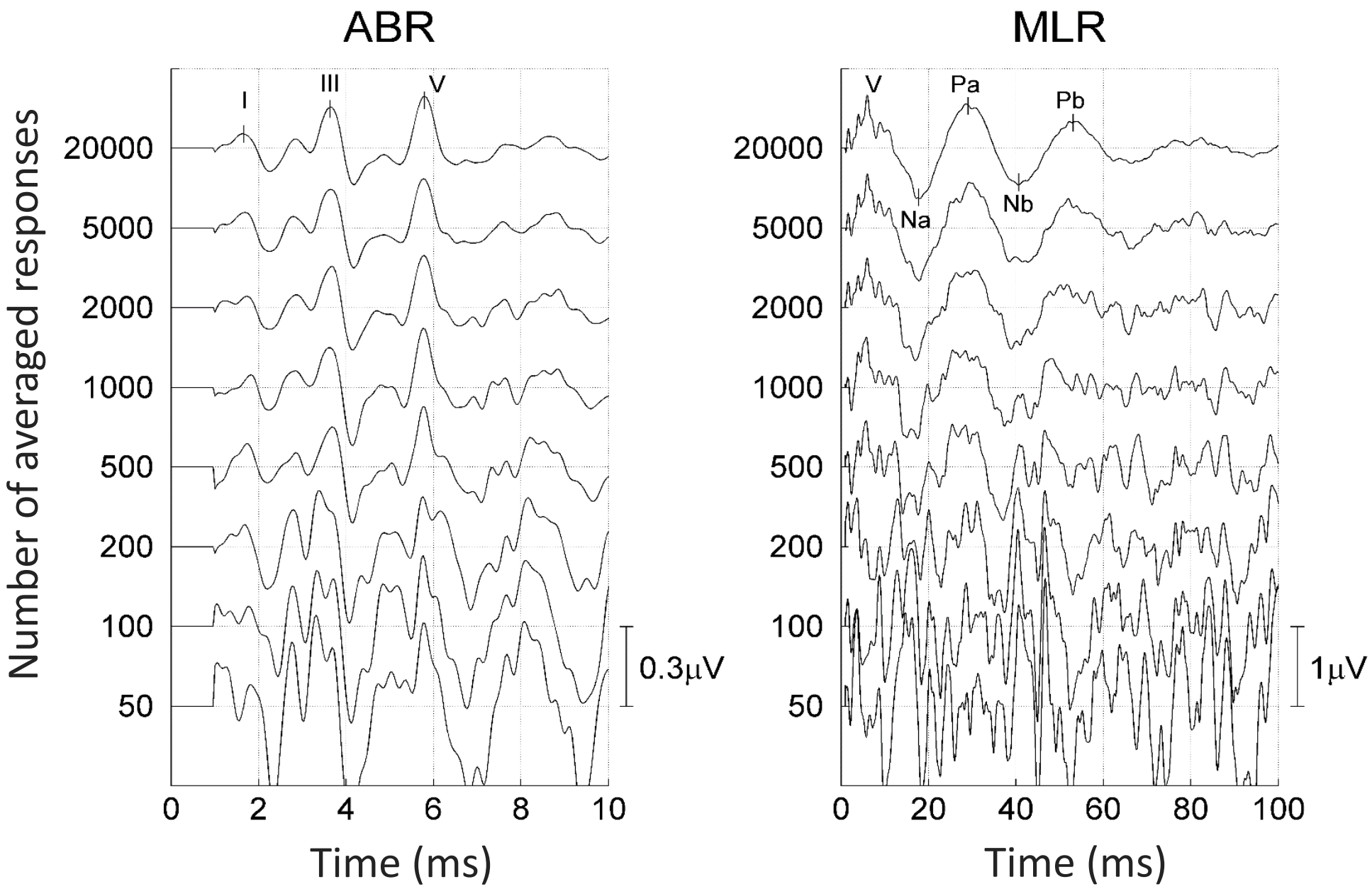
Stimulus onset

Channel L - Synchronisation

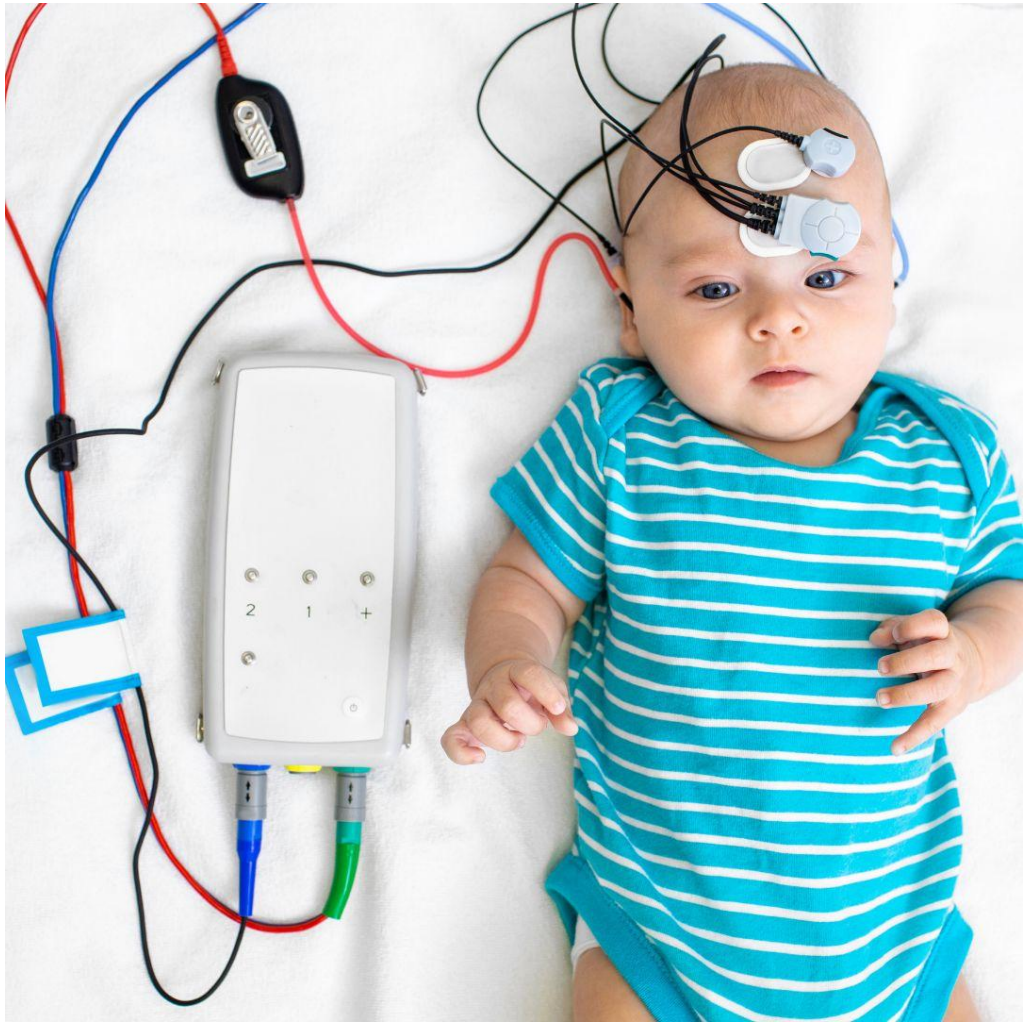
Channel R - EEG

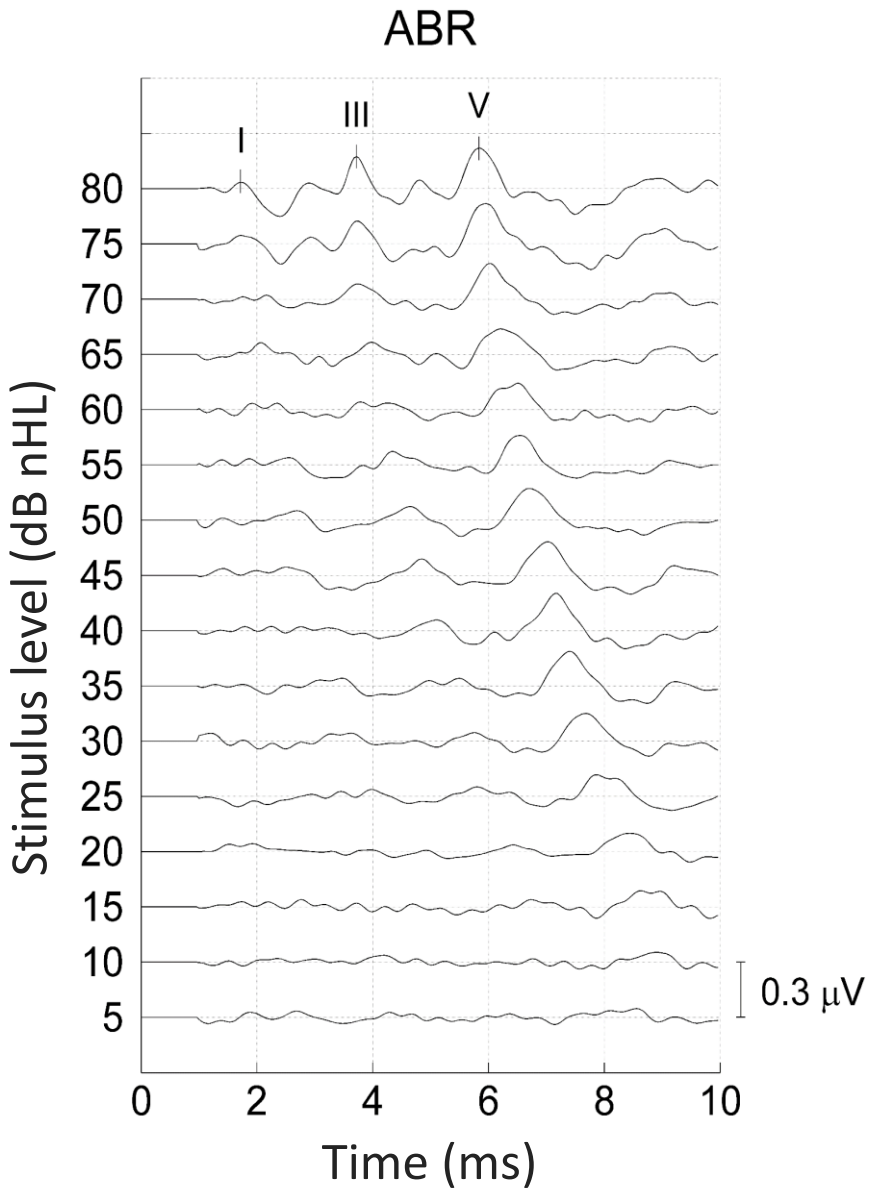


Averaging window


ABR
MLR
Number of averaged responses
20000
5000
2000
1000
500
200
100
50
I
III
V
0.3μV
0
2
4
6
8
10
Time (ms)
V
Pa
Pb
Na
Nb
1μV
0
20
40
60
80
100
Time (ms)

3.3. Hearing threshold estimation

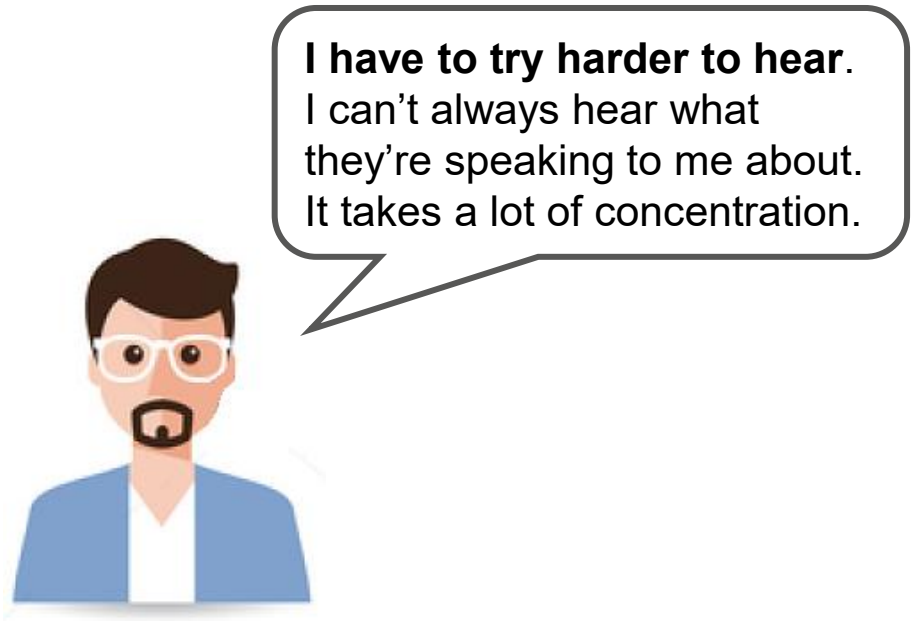




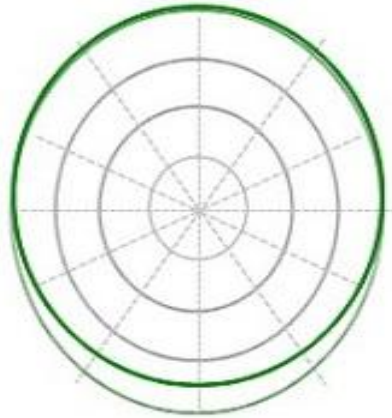
4. Cognitive measures

a. *Listening effort*
b. *Selective attention*
c. *Emotions recognition*

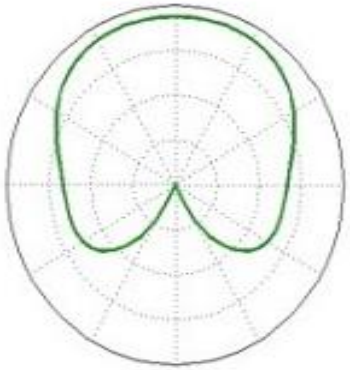
4.1. Listening effort



Hearing aid microphones



[OD] Quasi Omnidirectional



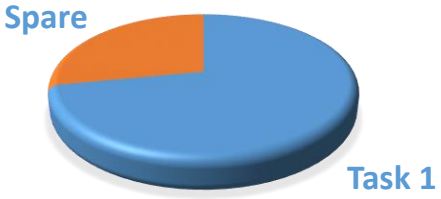
[BB] Binaural Beamforming

Dual-task

- Task 1. Speech-in-noise task
- Task 2. Behavioural task

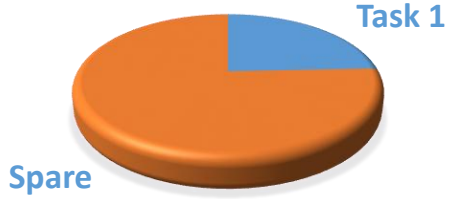
Reaction time

OD



Small amount of spare cognitive resources (long reaction time)

BB



Large amount of spare cognitive resources (short reaction time)

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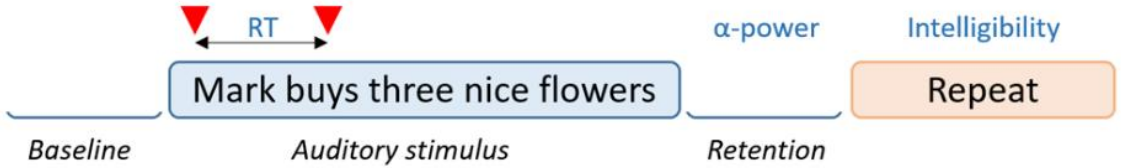
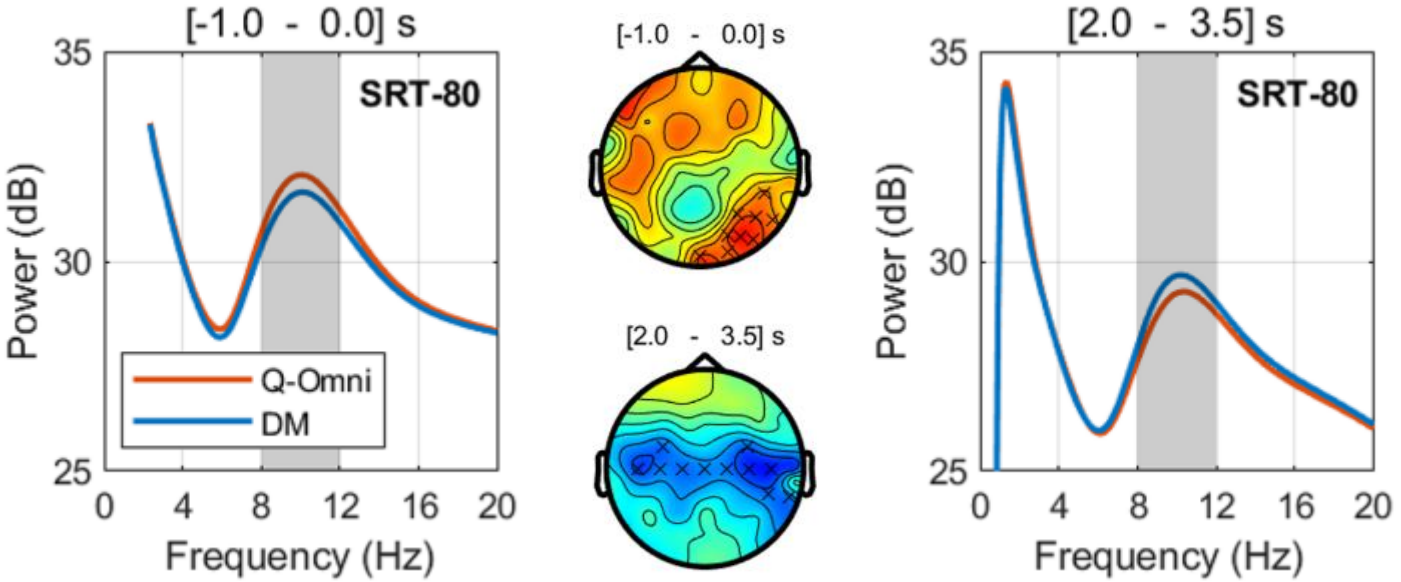
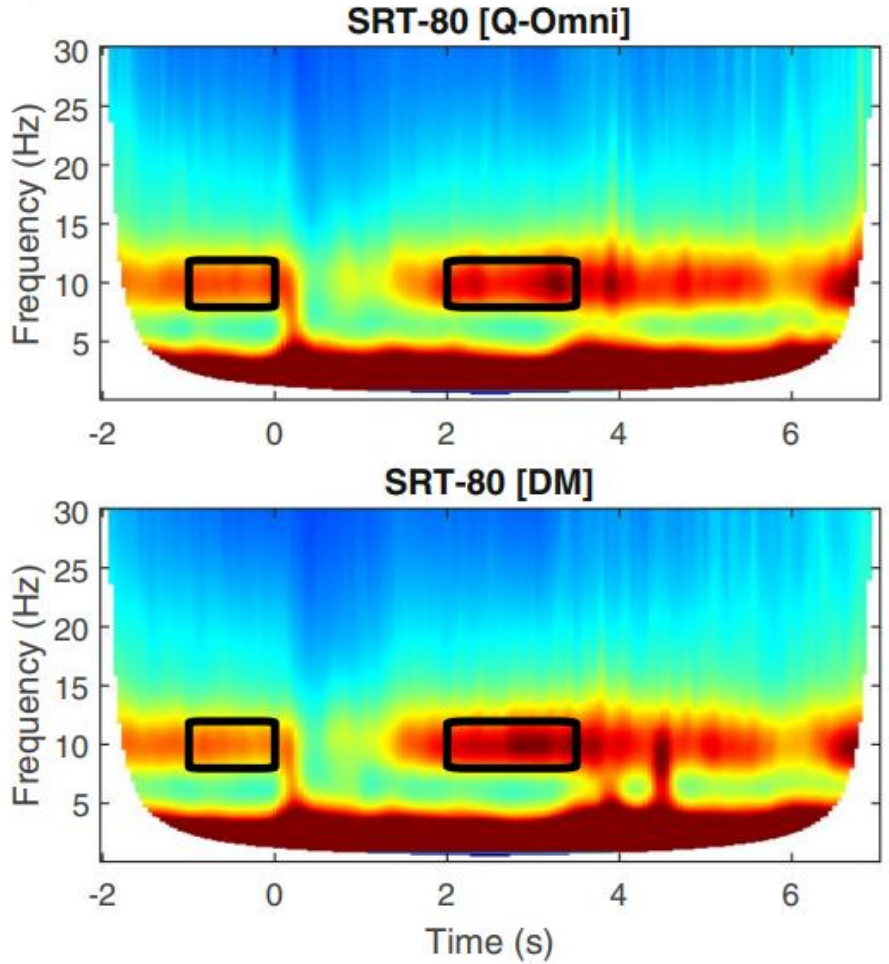
Reduced listening effort with adaptive binaural beamforming in realistic noisy environments

Joaquin T. Valderrama[1,2,3,4]✉, Jorge Mejia[3,5], Angela Wong[3], Nicholas C. Herbert[6] & Brent Edwards[3,4]

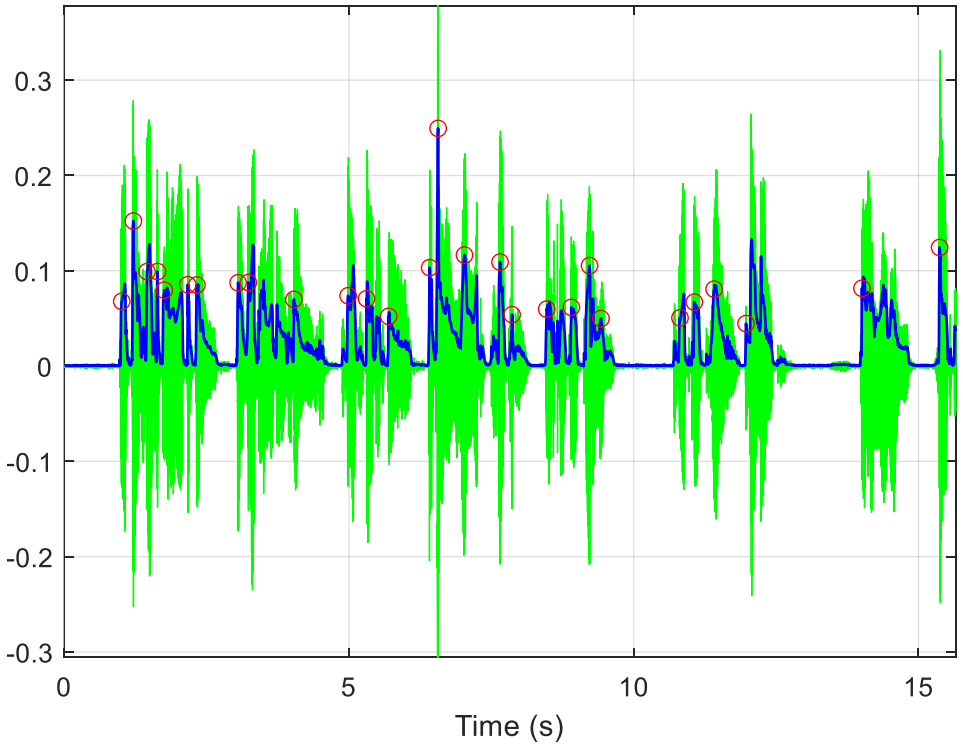


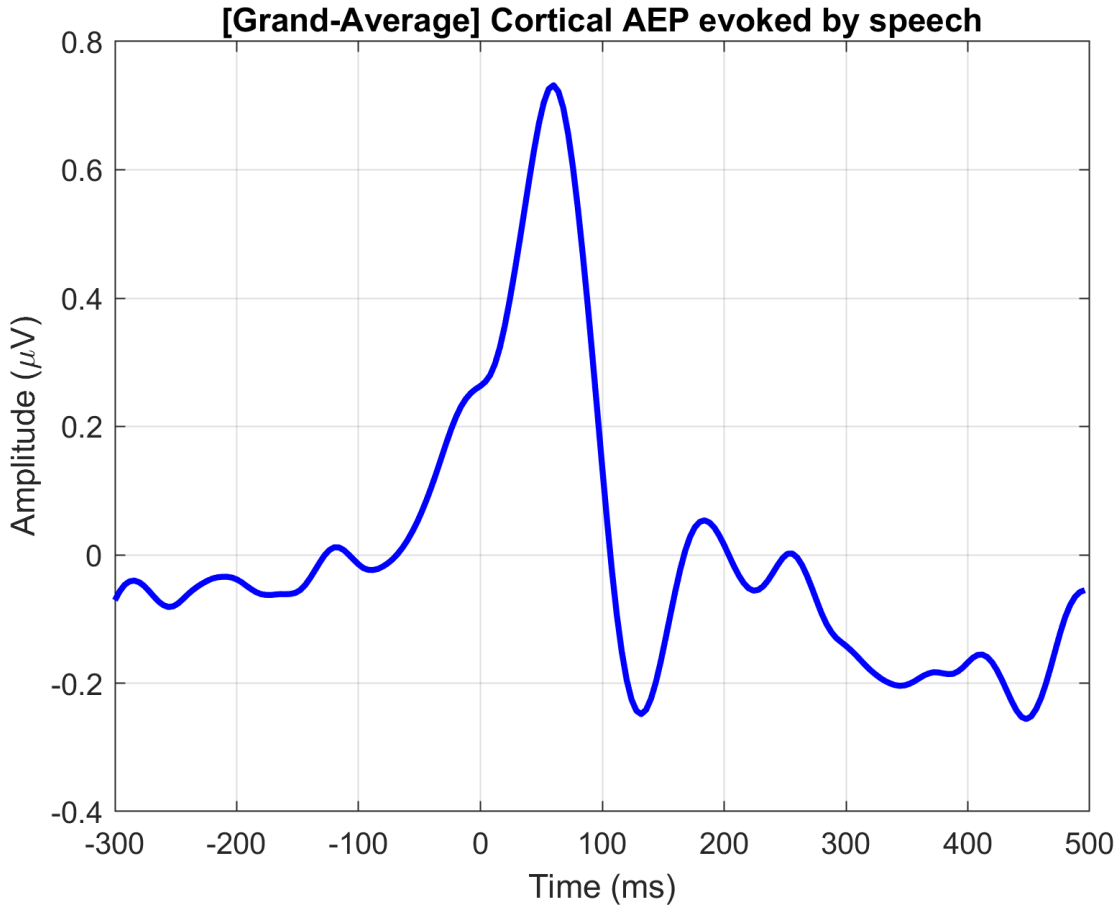




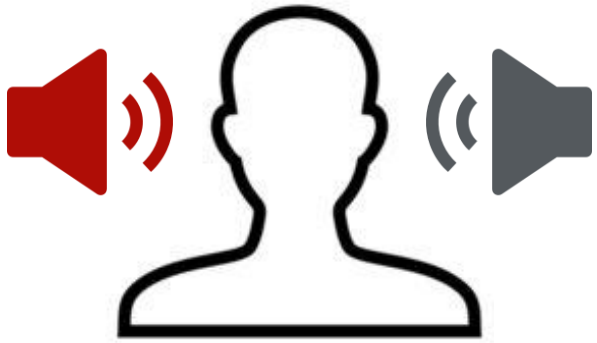
4.2. Selective attention

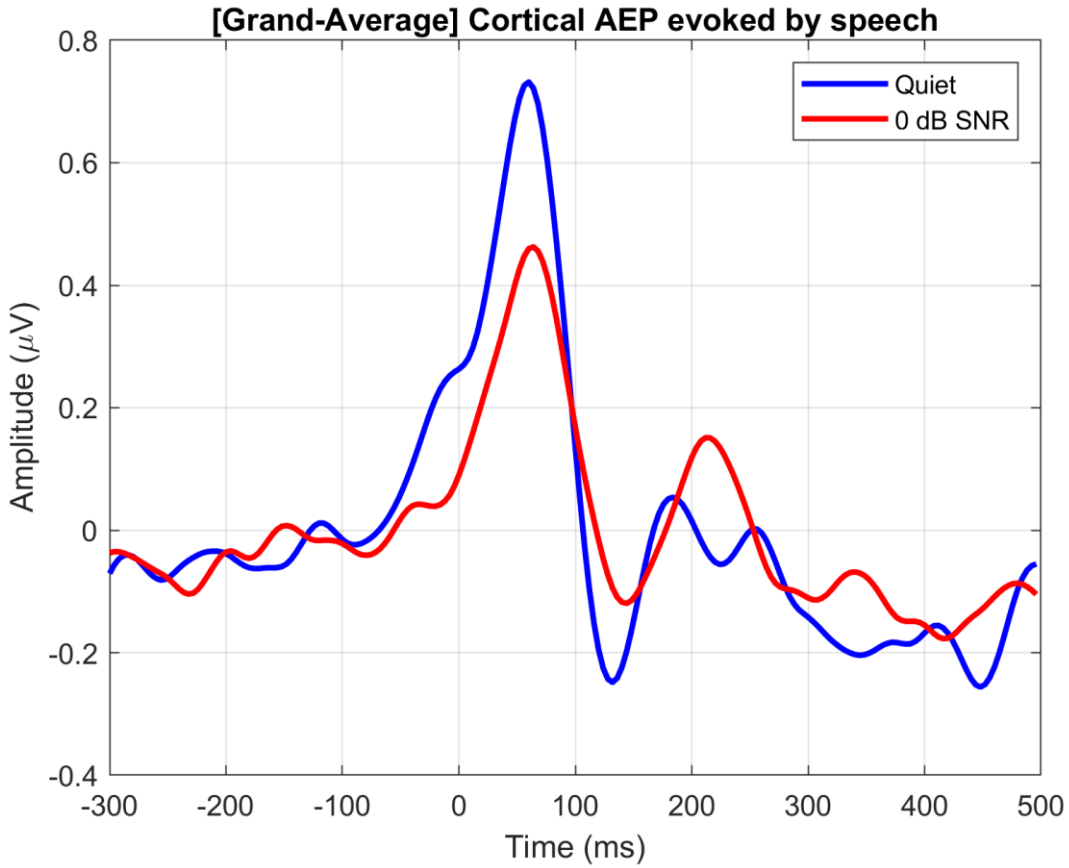
Audiobook 1

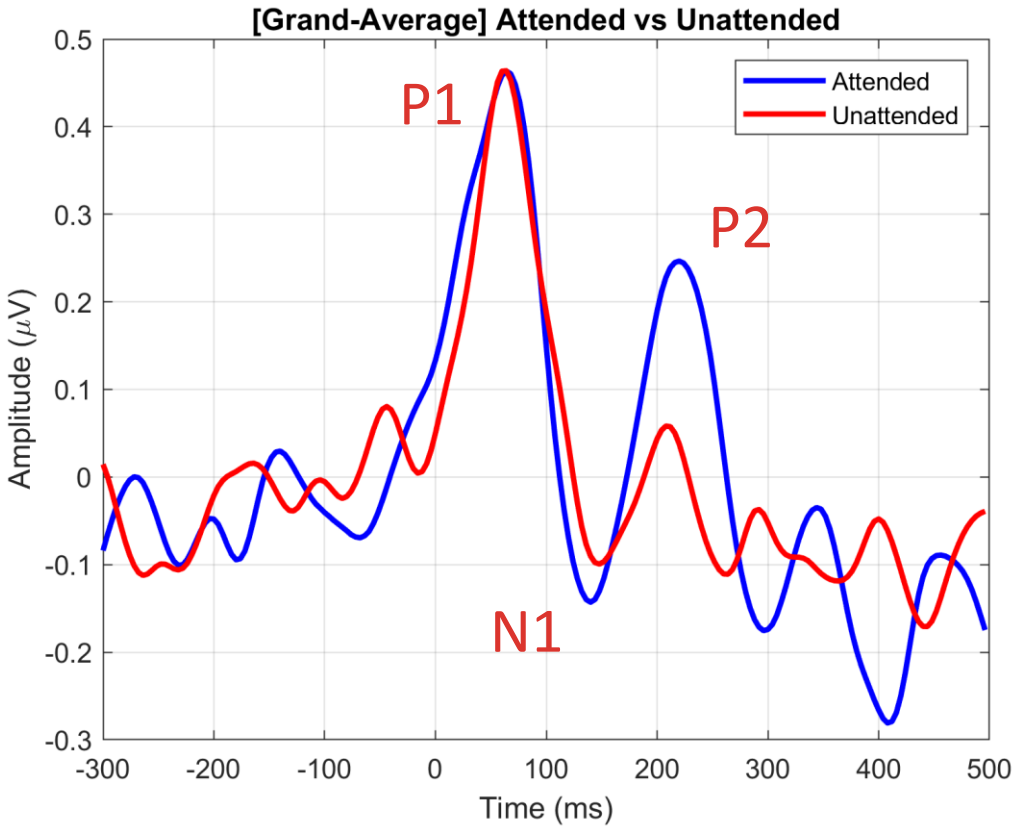


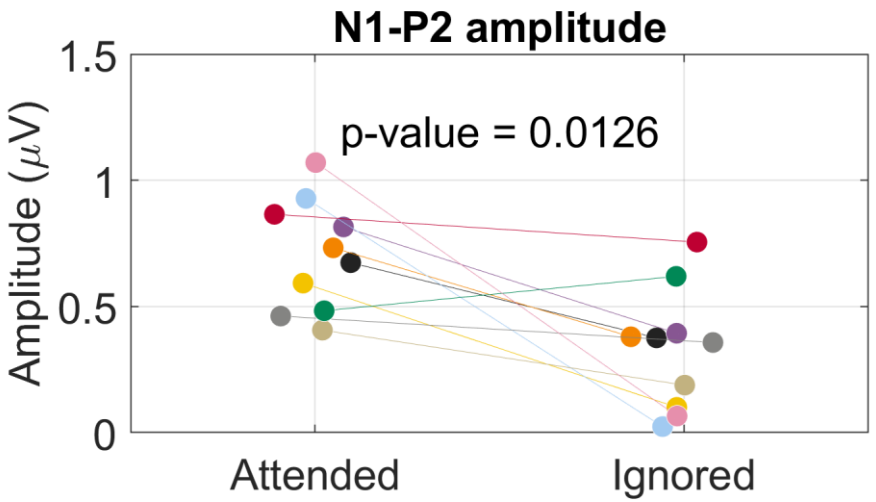


Audiobook 1 Audiobook 2

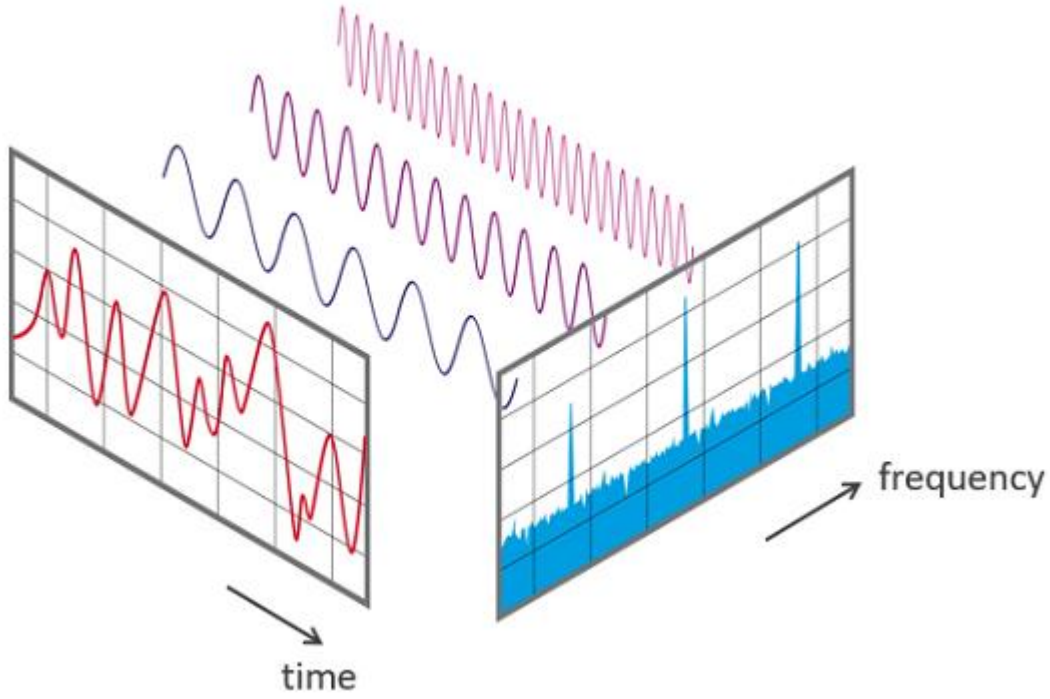








4.3. Emotions recognition



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Key takeaways

- EEG signals offer a safe and simple way to assess how we process surrounding sounds.
- These techniques are widely used in clinical settings for objective hearing assessment.
- They also help investigate cognitive processes such as attention and cognitive load.
- EEG holds potential for identifying emotional states.

SLIDES & NOTES

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