NBML

Basics of EEG recording and signal processing in brain mapping

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Biomedical signal processing engineer and Data Acquisition specialist

Neuroimaging/Brain Imaging

- is the use of various techniques to either directly or indirectly image the structure, function, of the nervous system

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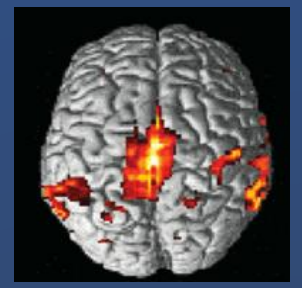
Brain imaging

fMRI



Structural

MRI

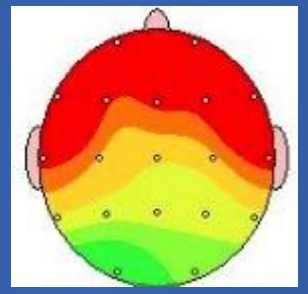
X-ray **CT**

Functional

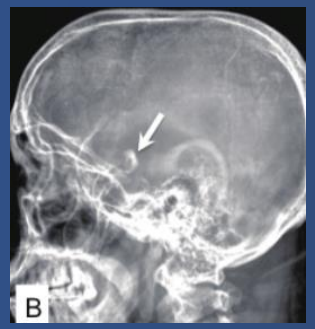
fMRI **SPECT**

PET

EEG **fNIRS**

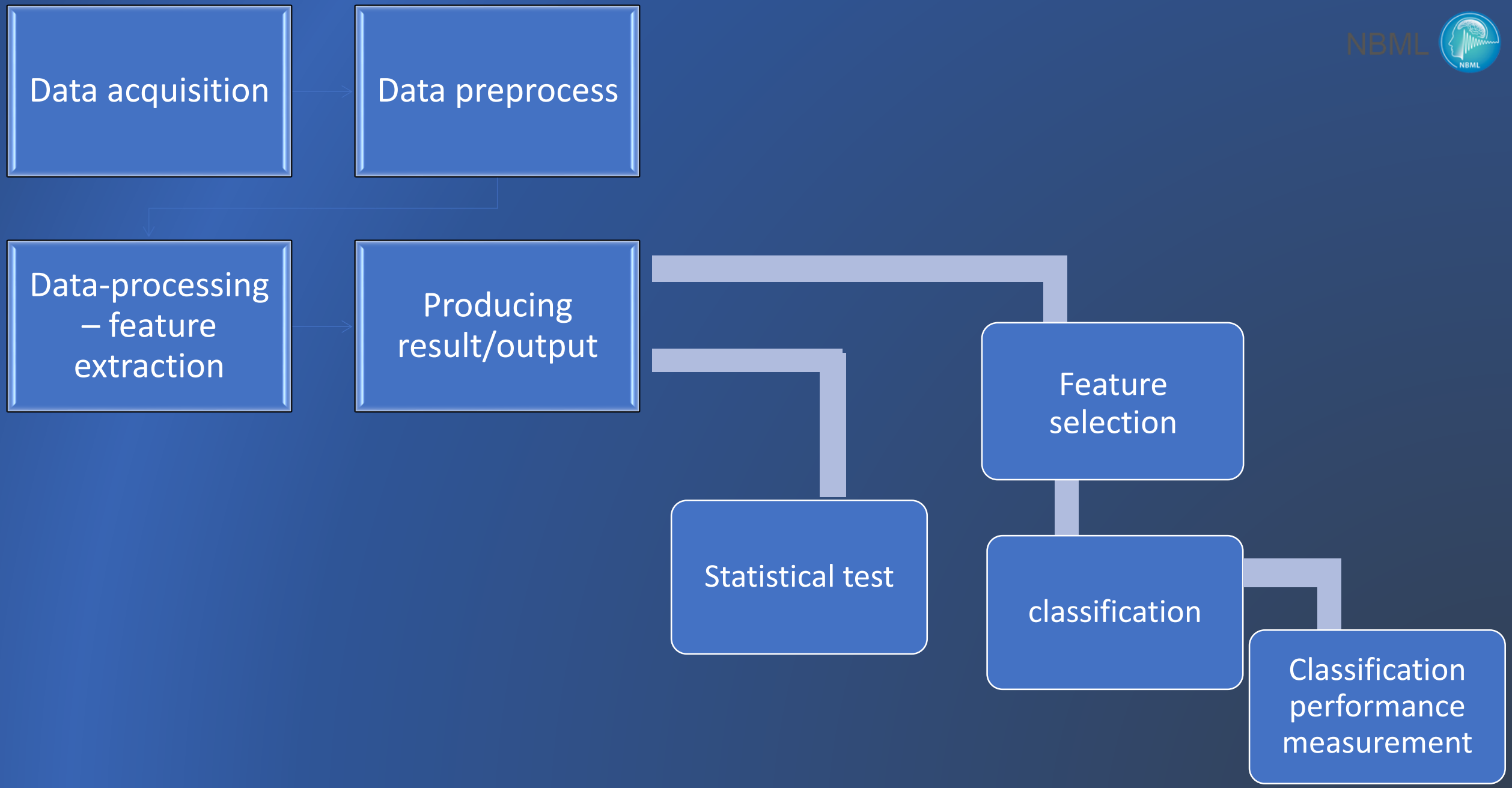


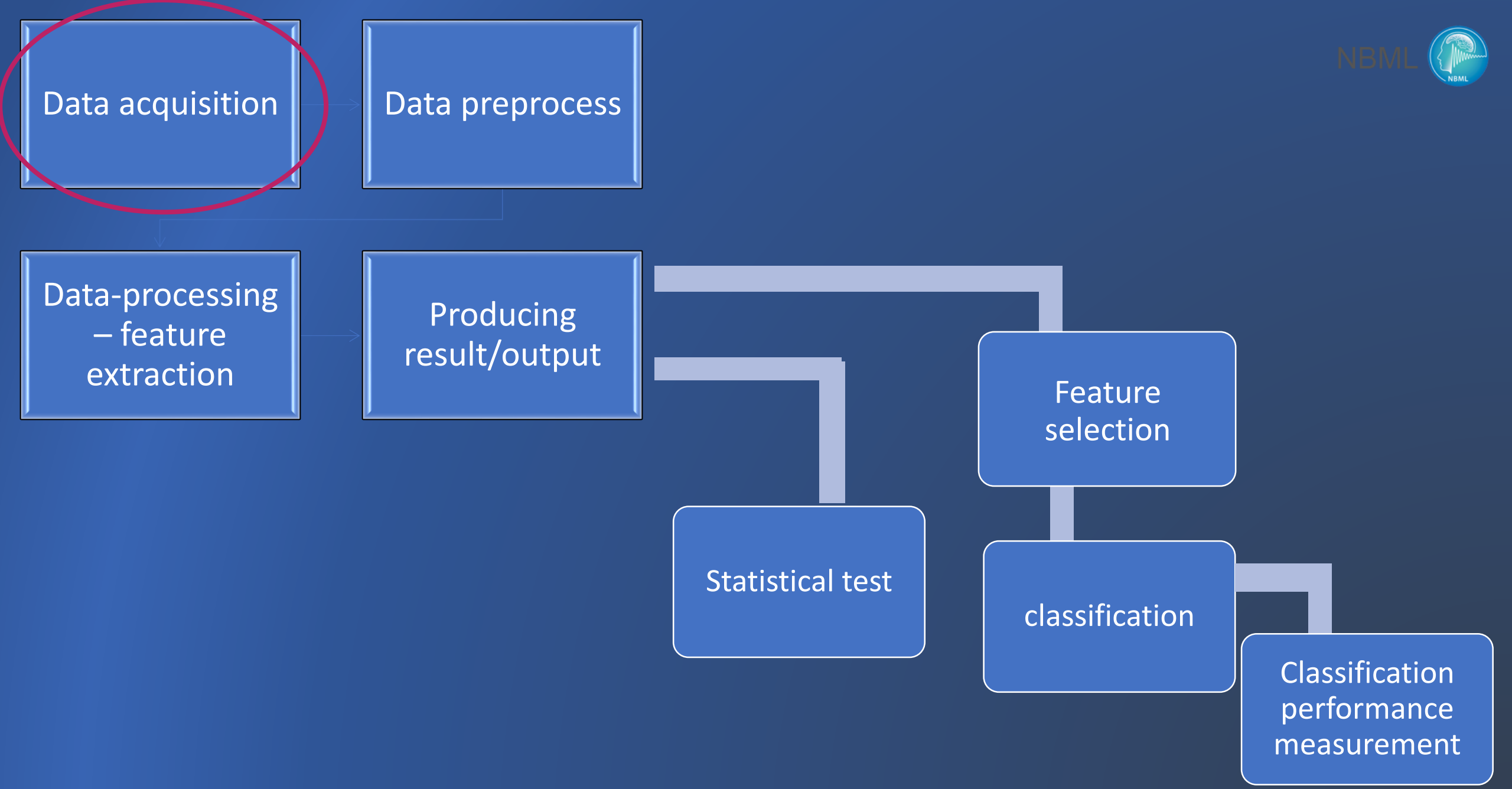
QEEG



X-ray

MRI


Data acquisition
Data preprocess
Data-processing – feature extraction
Producing result/output
Statistical test
Feature selection
classification
Classification performance measurement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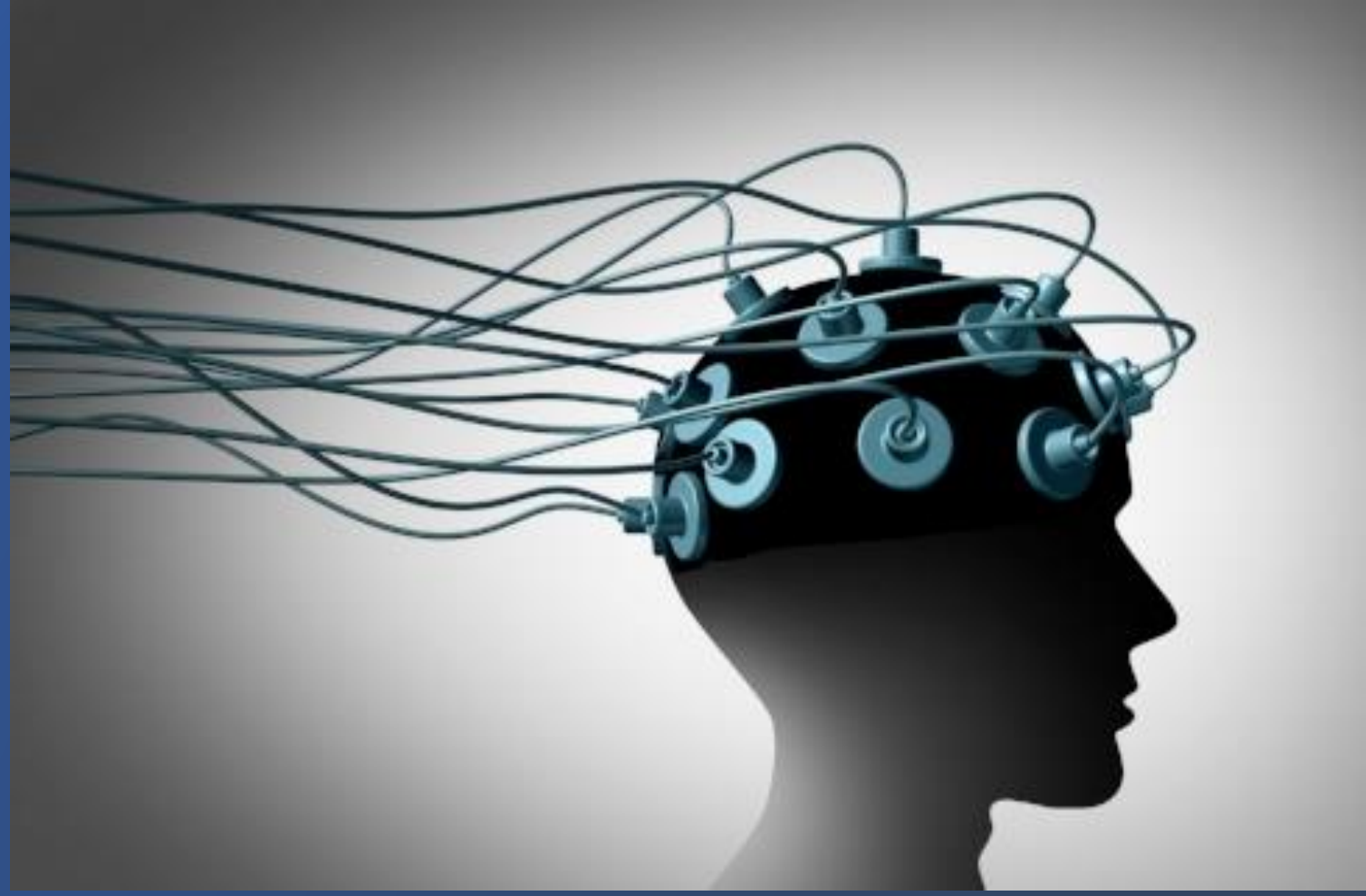


Stage 1 : Data acquisition

Outline

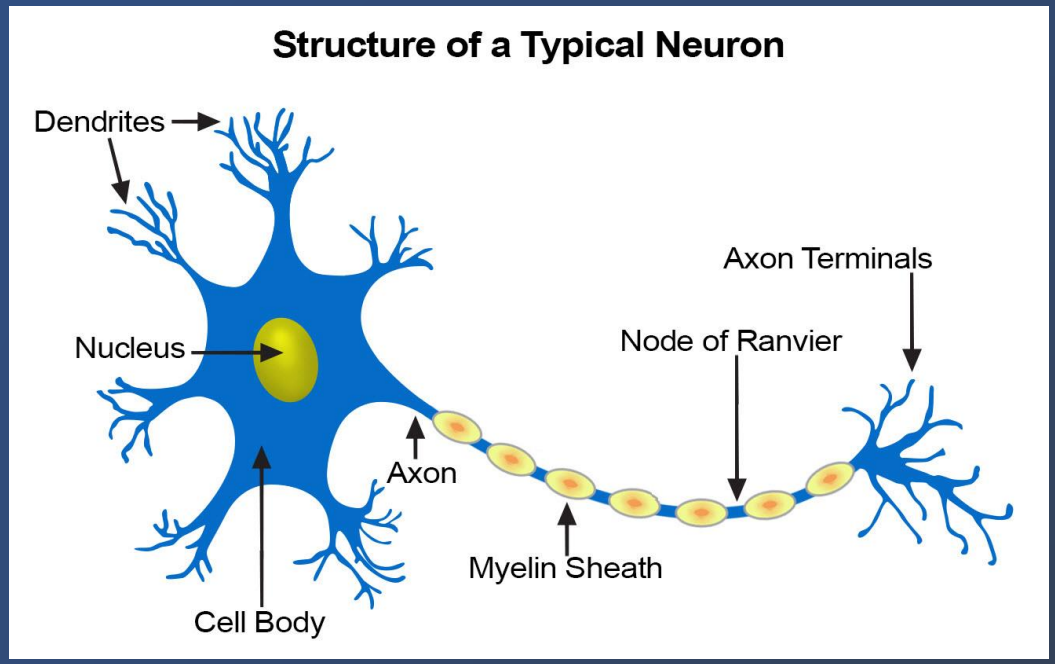
- Part 1:
  - Neural basis of the EEG
  - EEG recording setup
- Part 2:
  - Rest EEG vs Task based EEG
  - Task designing
- Part 3:
  - EEG Dataset

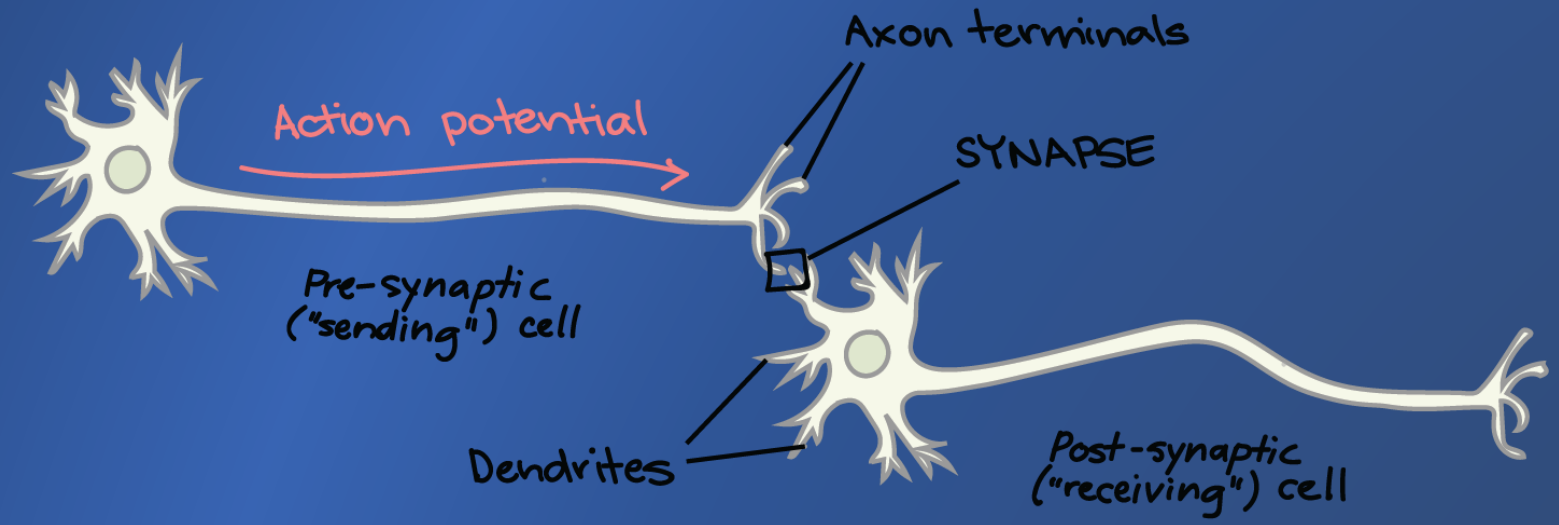
Neural basis of the EEG

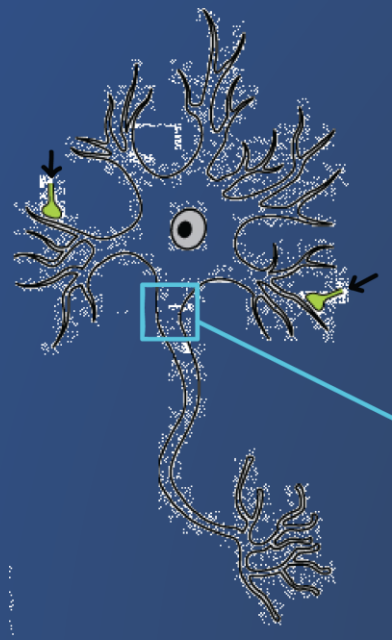
Part 1.1

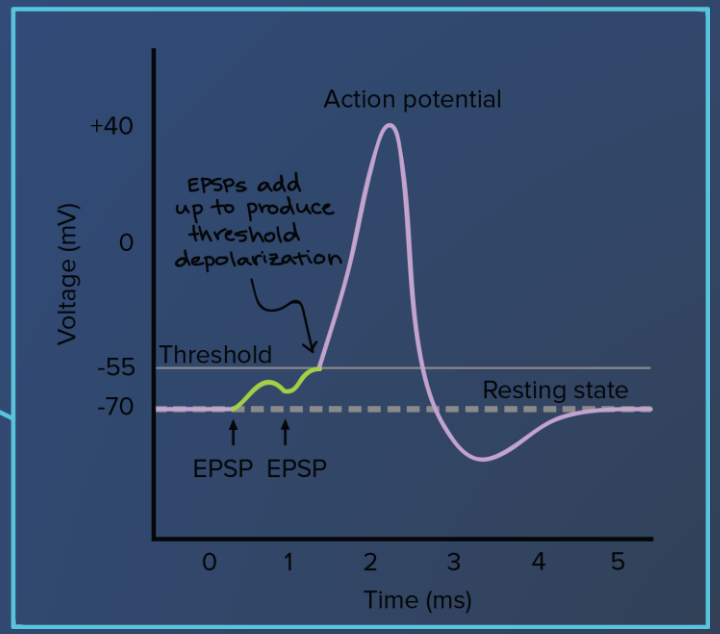
Neurons

- Neurons → Cells within the nervous system
- Electrically excitable cell
- Action potential




Axon terminals
Action potential
SYNAPSE
Pre-synaptic ("sending") cell
Dendrites
Post-synaptic ("receiving") cell




Action potential
+40
0
-55
-70
Voltage (mV)
EPSPs add up to produce threshold depolarization
Threshold
Resting state
EPSP
EPSP
0
1
2
3
4
5
Time (ms)

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EEG

- The EEG represents a set of field potentials from the summated activity of many neurons, recorded by multiple electrodes on the surface of the scalp.

- activity that occurs in the superficial layers of the cortex

Advantages

- Direct method
- Non invasive method
- High temporal resolution
- Less cost than nearly all other brain imaging devices
- Simple to use
- portable

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Advantages

- Safe and Painless → no real safety restrictions
- EEG does not aggravate claustrophobia
- EEG is silent
- Relatively tolerant of subject movement

Disadvantages

- Low spatial resolution
- Record electrical activity of cortex
- Low signal to noise ratio
- Hard to interpret (noise, artifacts)

Neuroimaging method	Activity measured	Direct/ Indirect Measurement	Temporal resolution	Spatial resolution	Risk	Portability
EEG	Electrical	Direct	~0.05 s	~10 mm	Non-invasive	Portable
MEG	Magnetic	Direct	~0.05 s	~5 mm	Non-invasive	Non-portable
ECoG	Electrical	Direct	~0.003 s	~1 mm	Invasive	Portable
Intracortical neuron recording	Electrical	Direct	~0.003 s	~0.5 mm (LFP) ~0.1 mm (MUA) ~0.05 mm (SUA)	Invasive	Portable
fMRI	Metabolic	Indirect	~1 s	~1 mm	Non-invasive	Non-portable
NIRS	Metabolic	Indirect	~1 s	~5 mm	Non-invasive	Portable

Applications of EEG

- study the brain
- clinical EEG
  - Diagnostic tests
    - mental illness/disorder
    - brain death
    - Epilepsy
    - Parkinson
    - Alzheimer's
  - evaluate the effect of medical and psychological treatment

Applications of EEG

- Brain Computer Interfaces (BCI):
- Sleep Study
- Alertness, Drowsiness Detection
- Sport study
- Neuromarketing

EEG recording setup

Part 1.2

EEG Recording setup

- Electrodes → Electrode cap

- Amplifier

- Recording software

Electrodes

- **Wet Electrodes :**

Saline-based electrode

Gel-based electrode

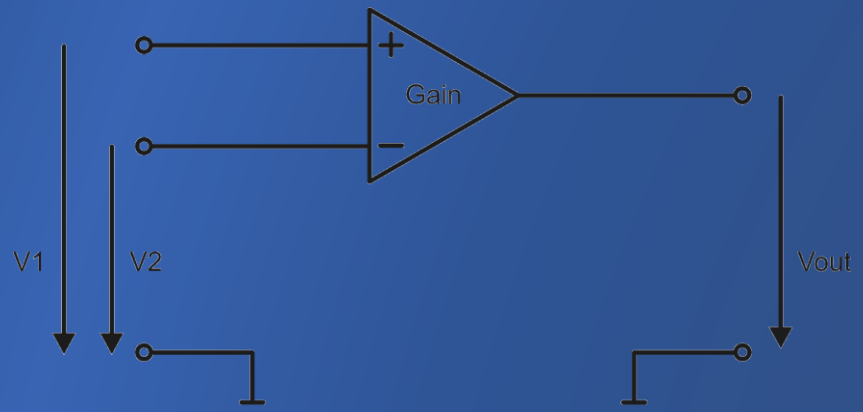
- **Dry Electrodes :**

Electrodes (cont.)

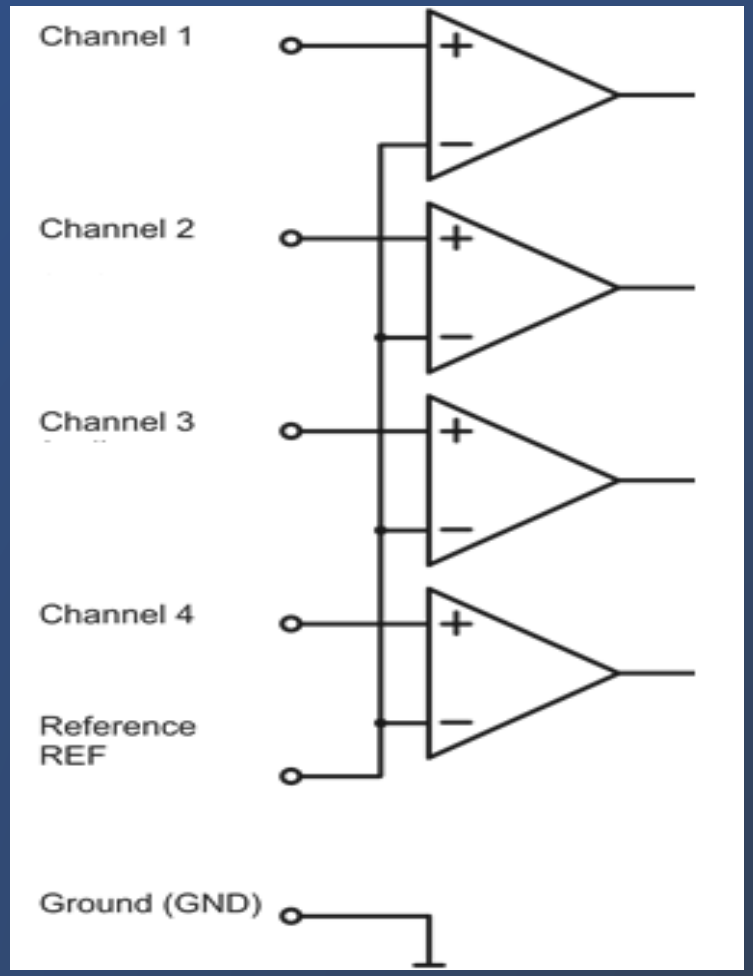
- **Passive Electrodes**

- **Active Electrodes**

Reference Electrode



Vout = (V1-V2) x Gain



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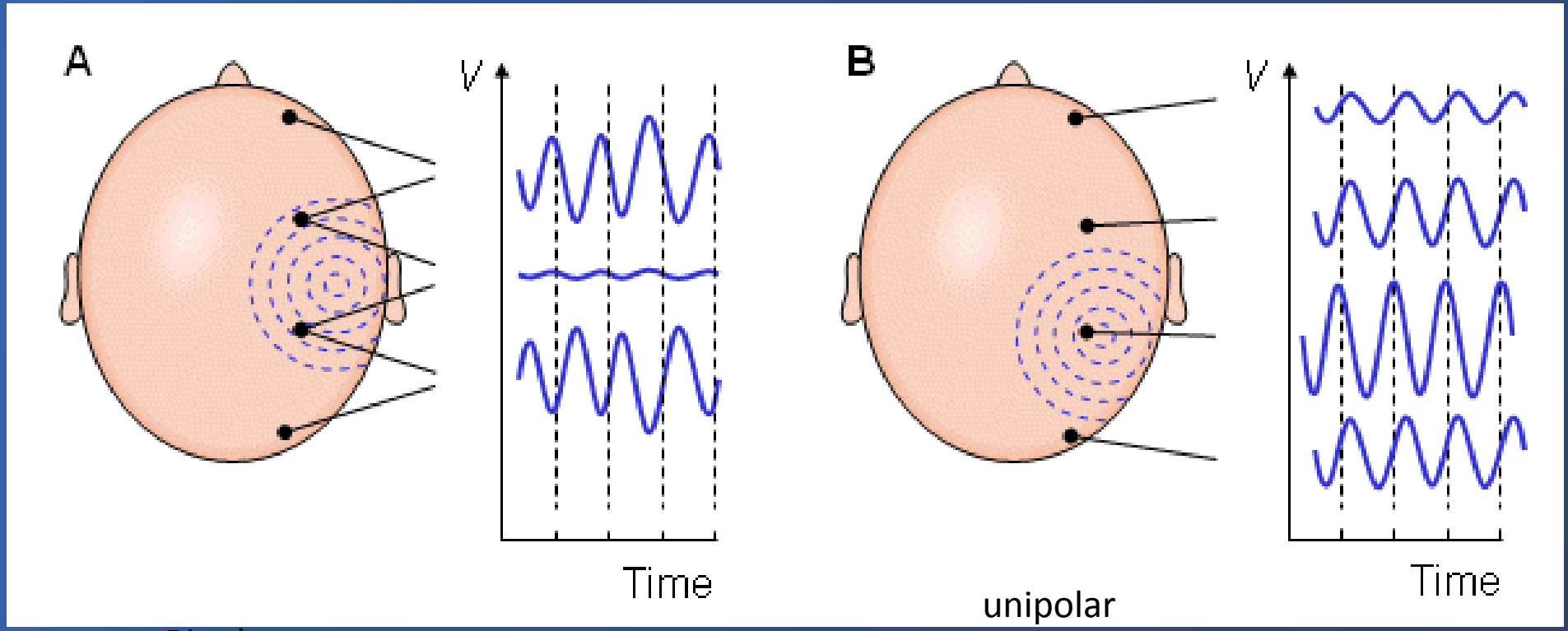
Bipolar and unipolar measurements



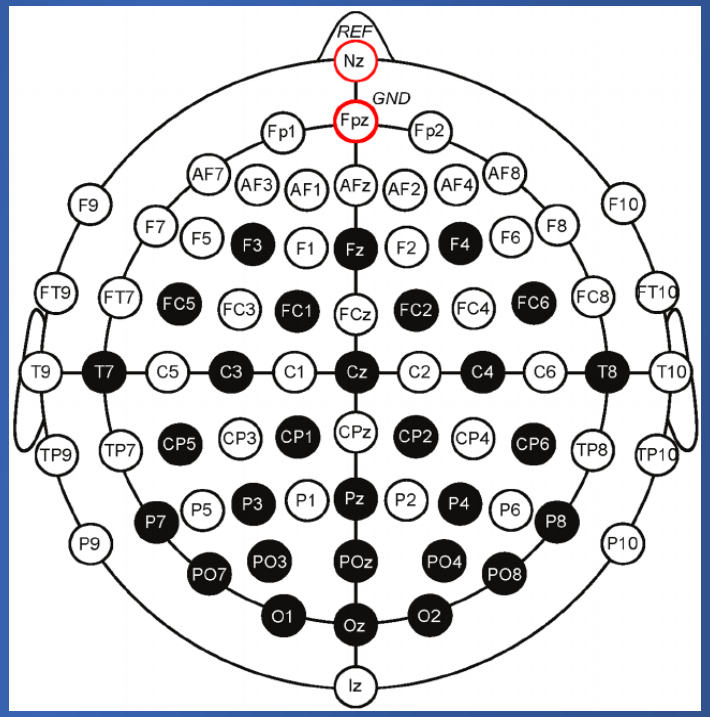
Bipolar

unipolar

EEG Electrode placement

- International system

is an internationally recognized method to describe and apply the location of scalp electrodes in the context of an EEG exam

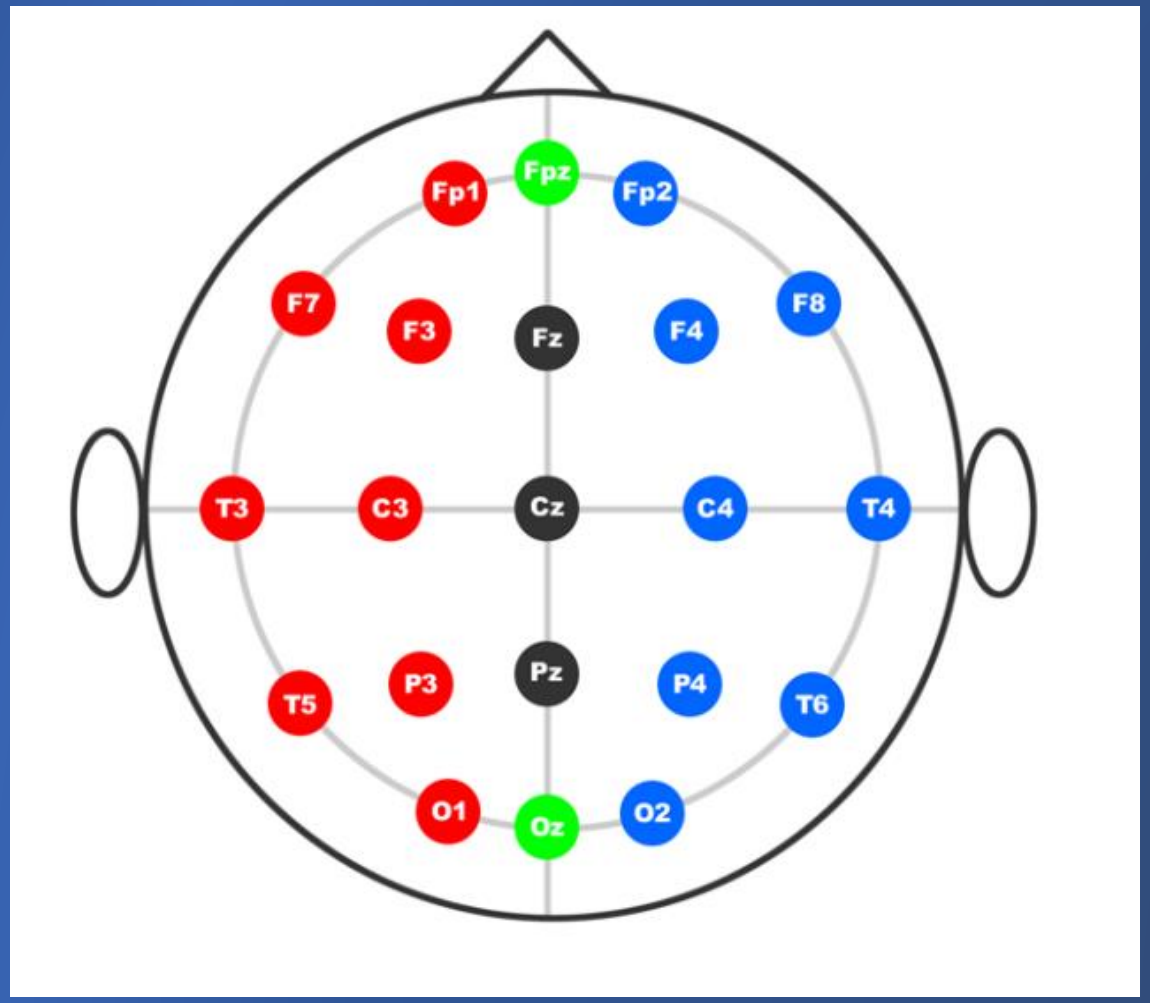


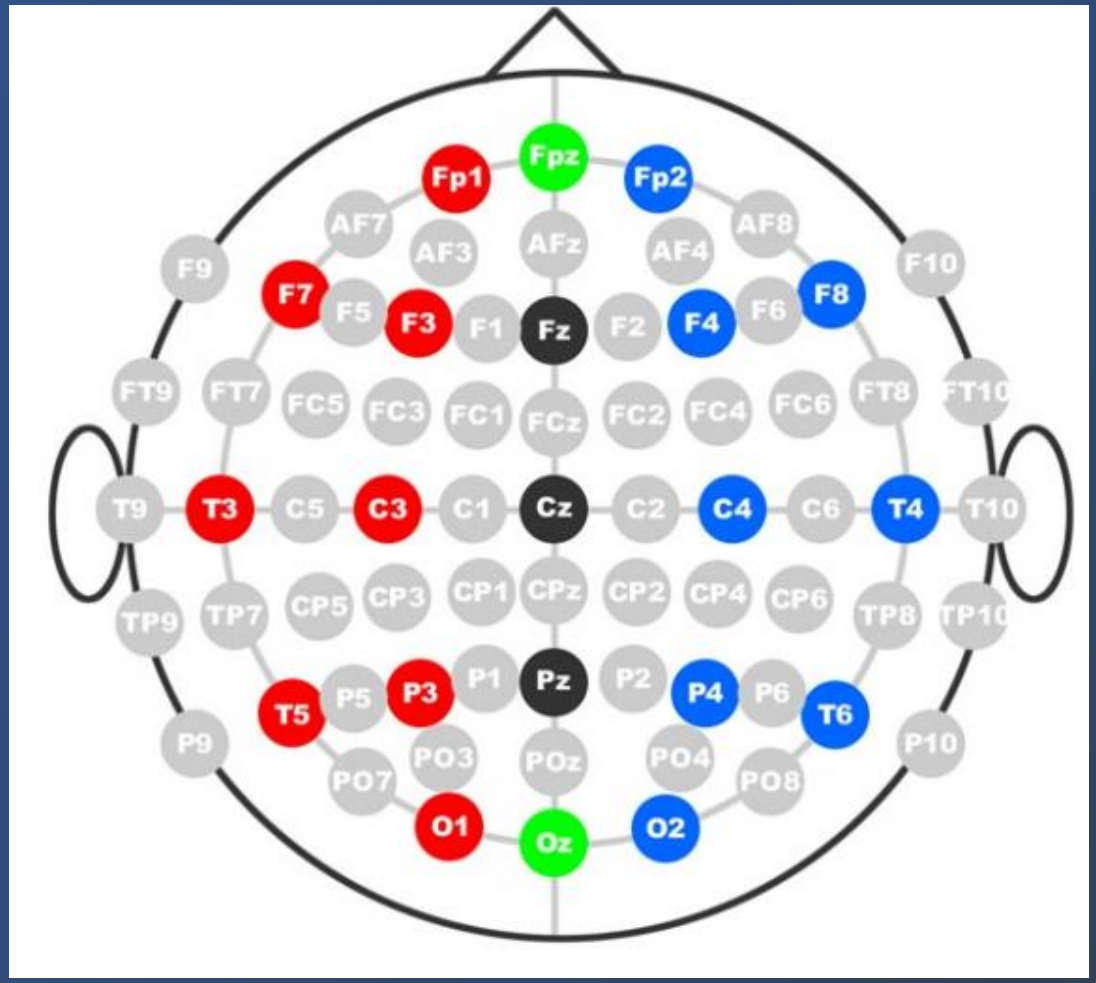
10–20 system or **International 10–20 system**

10-10 placement

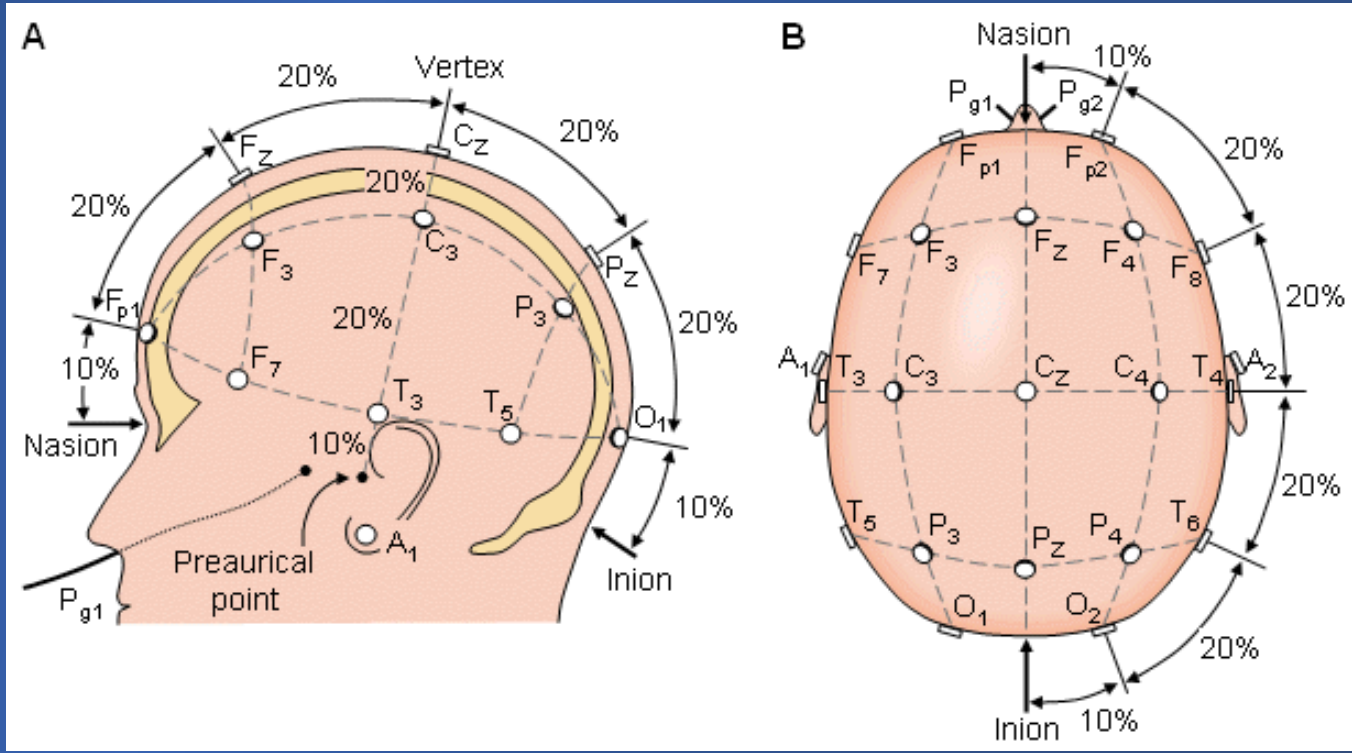
10 – 5 placement

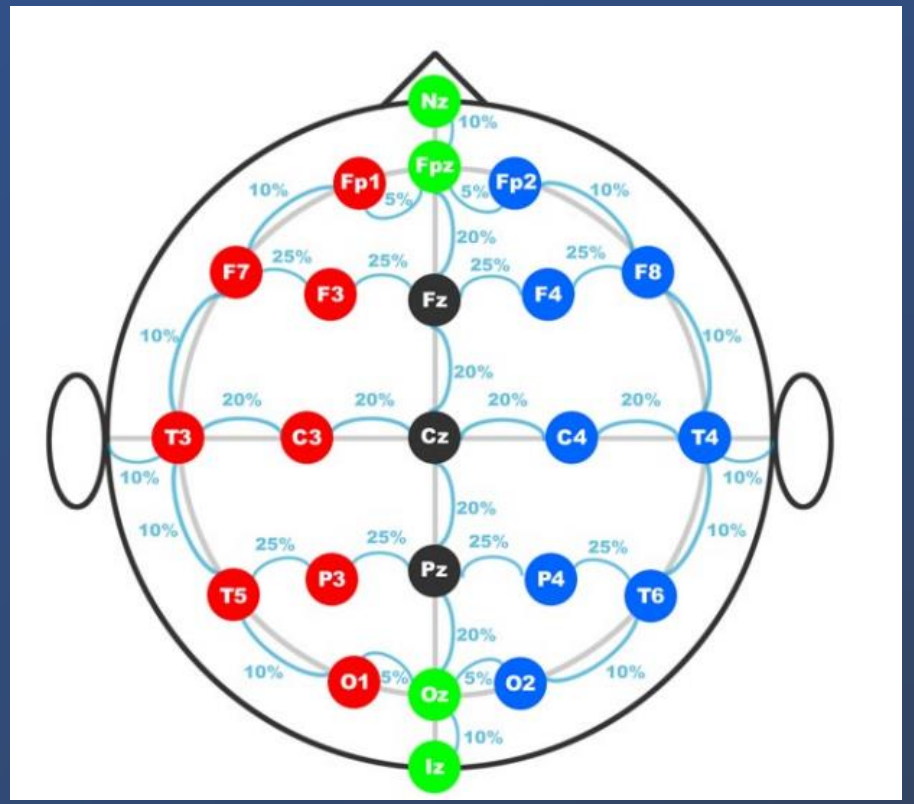
10–20 system vs 10–10 system

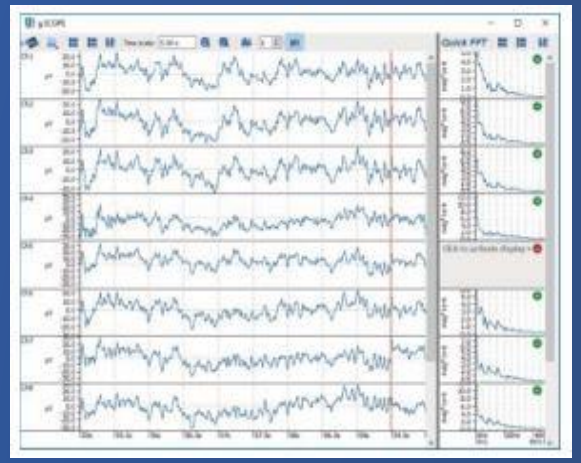


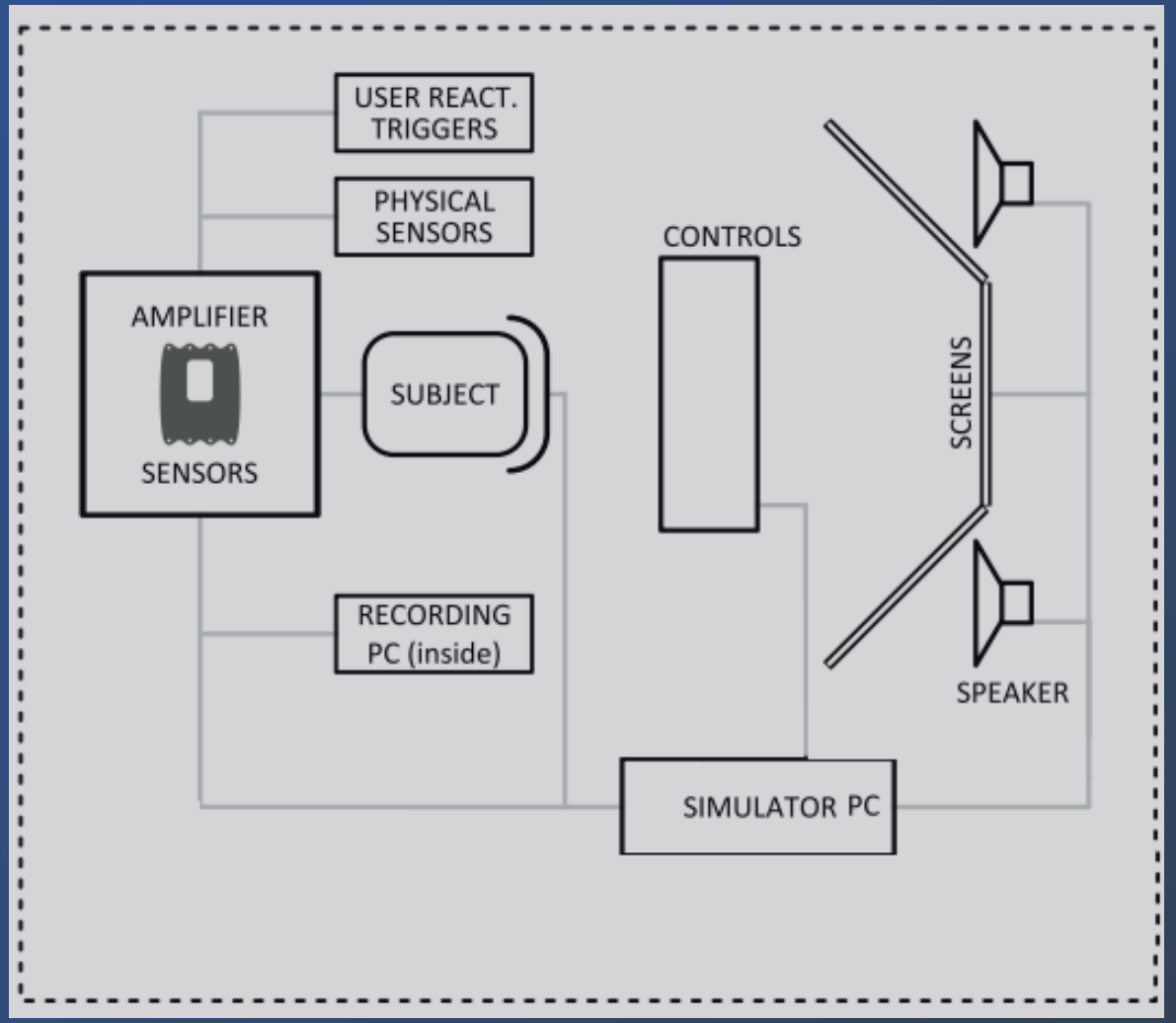


International 10–20 system







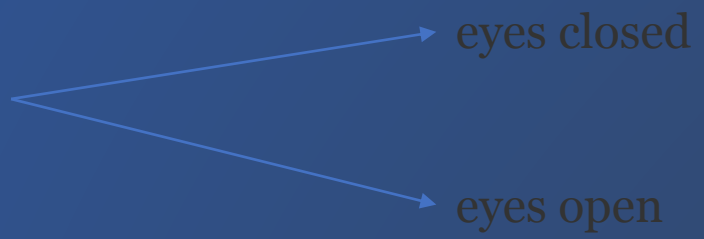

USER REACT. TRIGGERS
PHYSICAL SENSORS
AMPLIFIER
SENSORS
SUBJECT
CONTROLS
SCREENS
SPEAKER
RECORDING PC (inside)
SIMULATOR PC

Rest EEG vs Task based EEG

Part 2.1

Rest EEG vs Task based EEG

- Resting-state EEG



- Task based EEG

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Task designing

Part 2.2

Why we need task designing?

- We need to display different kind of stimulus
- In specific orders with specific timing

- We need to mark each event on our EEG or we want to have each event start time

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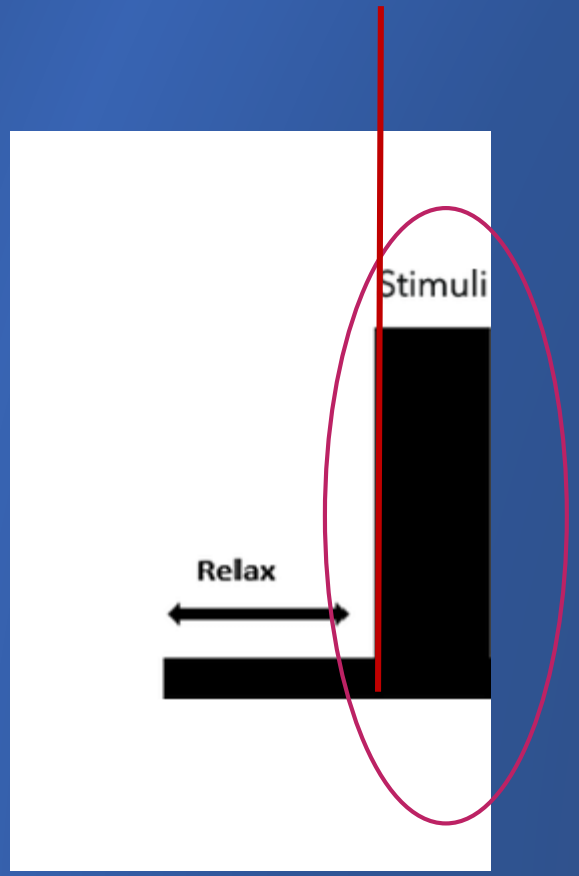
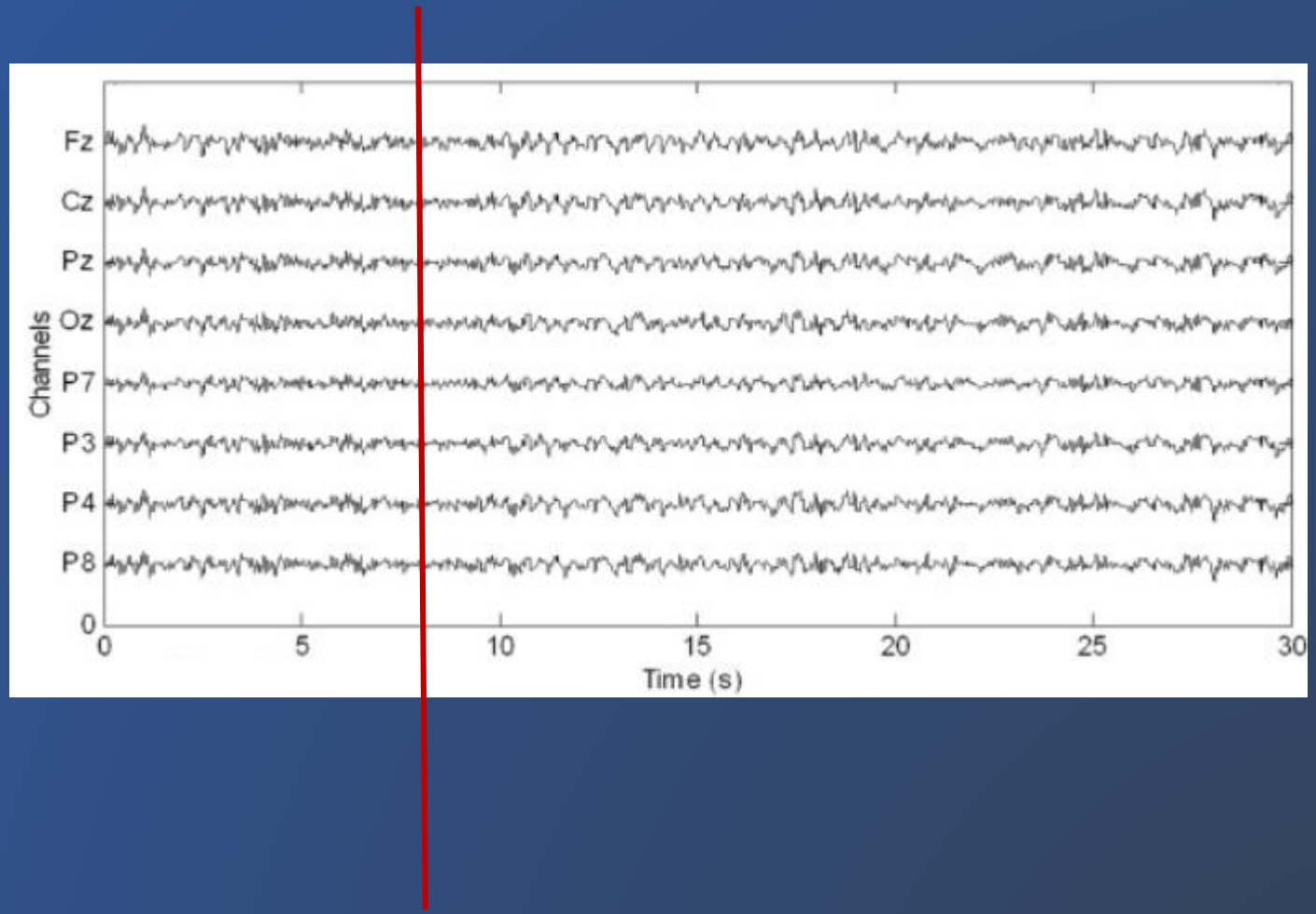
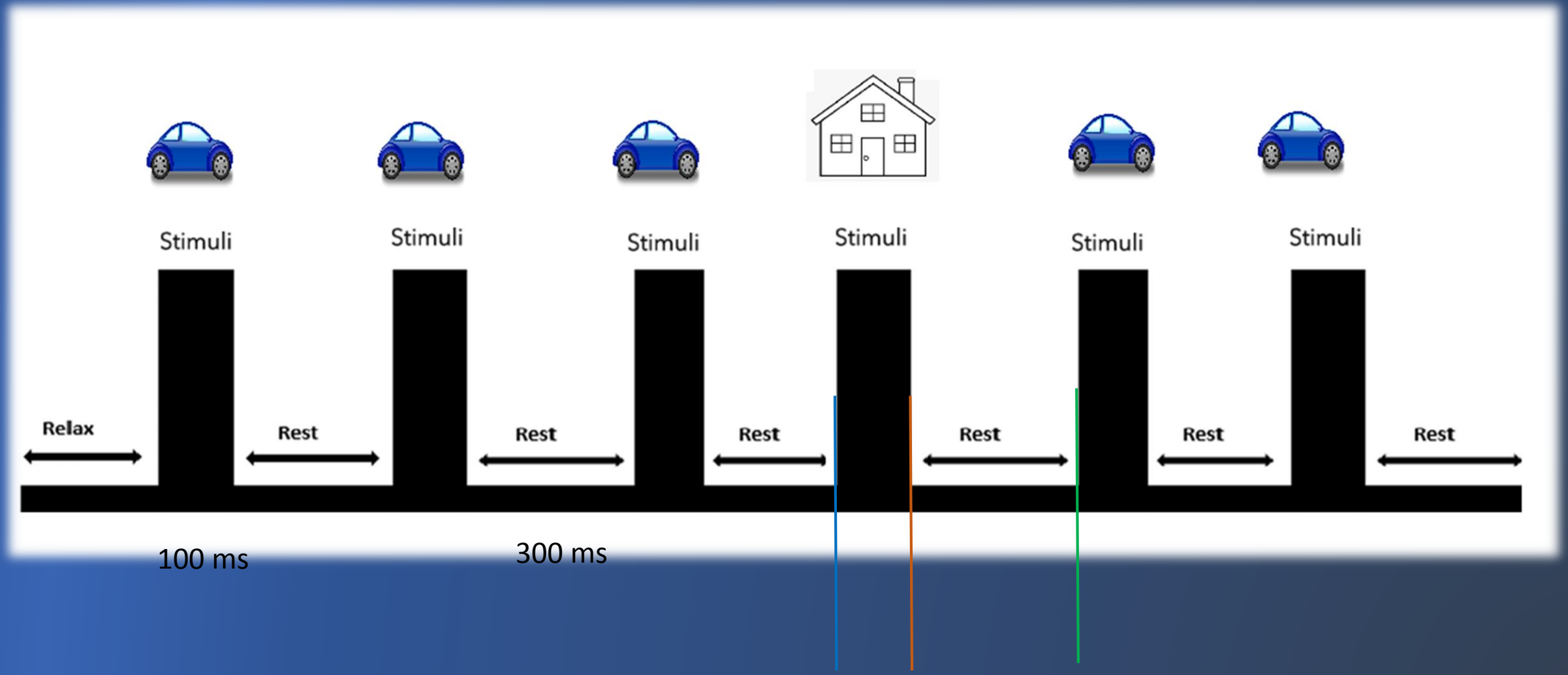

Stimuli
Relax


Fz
Cz
Pz
Oz
P7
P3
P4
P8
Channels
0
0
5
10
15
20
25
30
Time (s)


Stimuli
Stimuli
Stimuli
Stimuli
Stimuli
Stimuli
Relax
Rest
Rest
Rest
Rest
Rest
Rest
100 ms
300 ms

Task designing software/toolbox

- All coding language
- Psychtoolbox
- PsychoPy

Task designing software/toolbox (cont.)

Basic and Clinical NEUROSCIENCE

Spring 2011, Volume 2, Number 3

A Glance at Psychophysics Software Programs

Ali Yoonessi [1,2], Ahmad Yoonessi [3]

1. School of Advanced Medical Technologies, Tehran University of Medical Sciences, Tehran, Iran.
2. Iranian National Center for Addiction Studies, Tehran University of Medical Sciences, Tehran, Iran.
2. McGill Vision Research, McGill University, Canada

EEG Dataset

free EEG data database

physionet

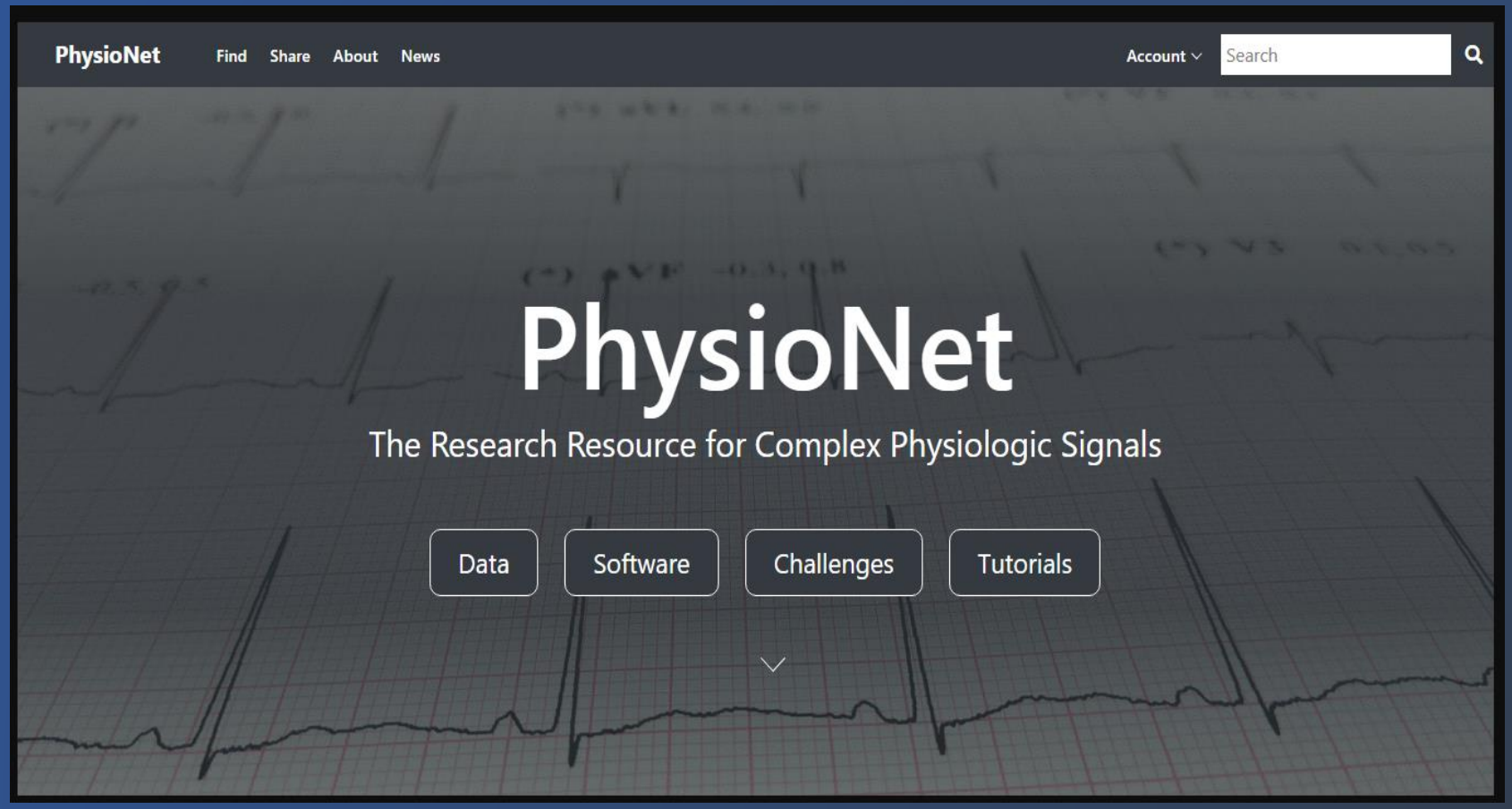
- https://www.physionet.org/

EEG Motor Movement/Imagery Dataset

Sleep-EDF Database

CHB-MIT Scalp EEG Database

MAMEM SSVEP Database



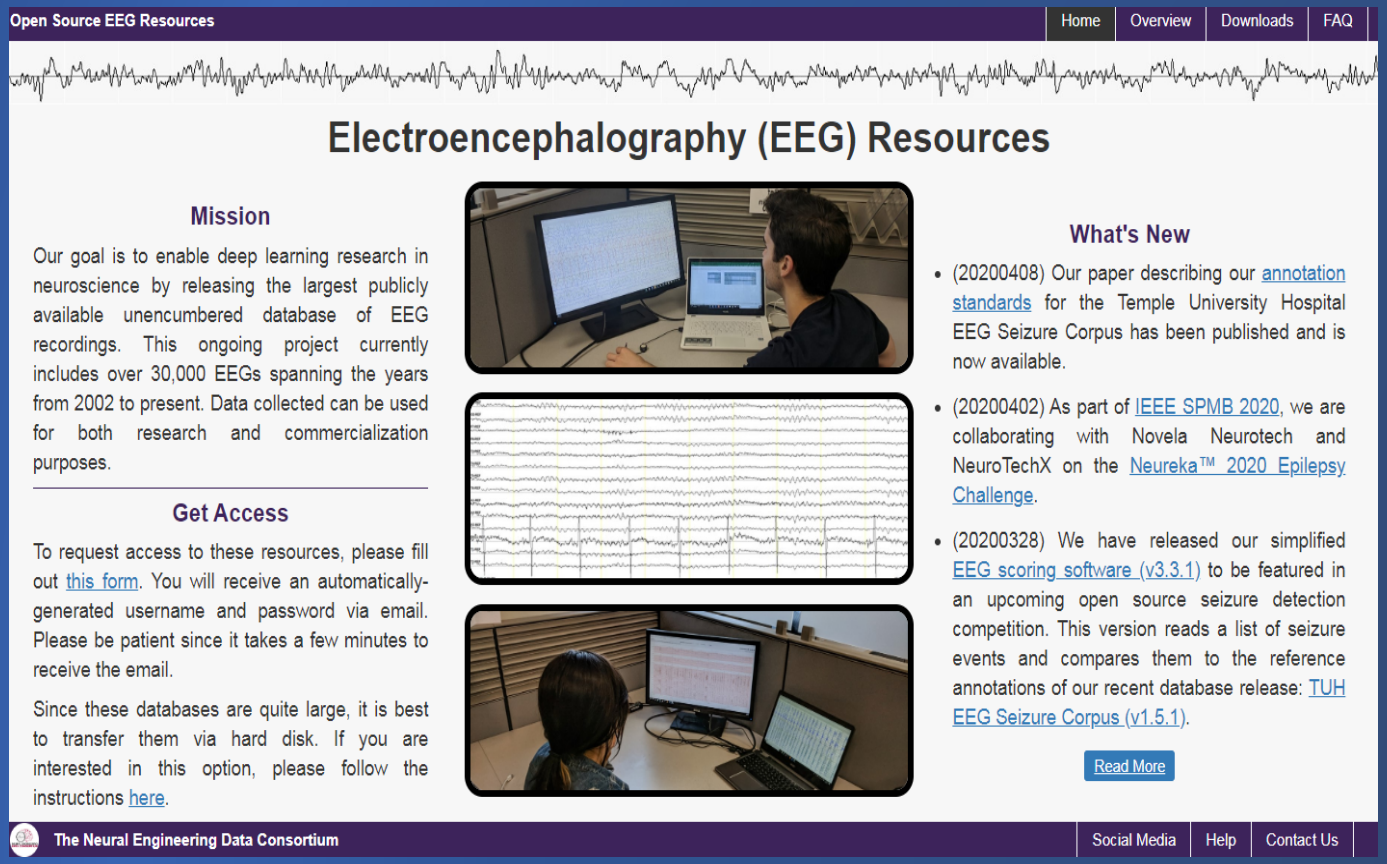
BCI Competitions

http://www.bbci.de/competition/

- BCI Competition I
- BCI Competition II (also called BCI Competition 2003)
- BCI Competition III
- BCI Competition IV

Temple University Hospital (TUH) Corpus

- A large collection of EEG recorded in clinical settings (hospital data).



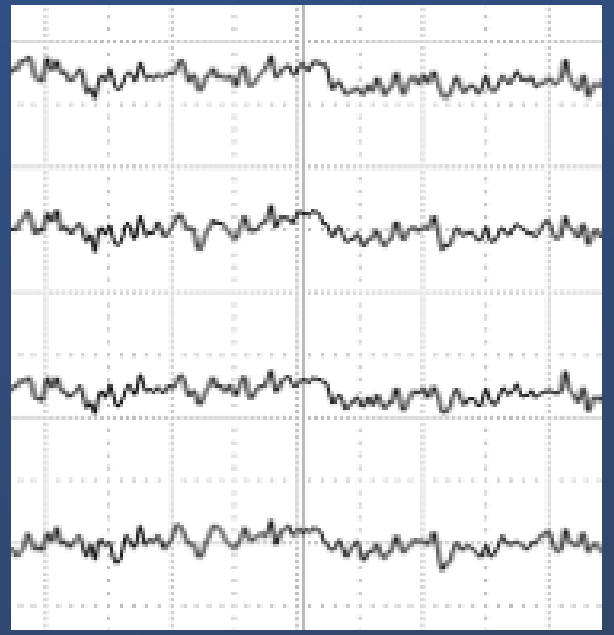
https://www.isip.piconepress.com/projects/tuh_eeg/

Data acquisition

Data preprocess

Data-processing – feature extraction

Producing result/output

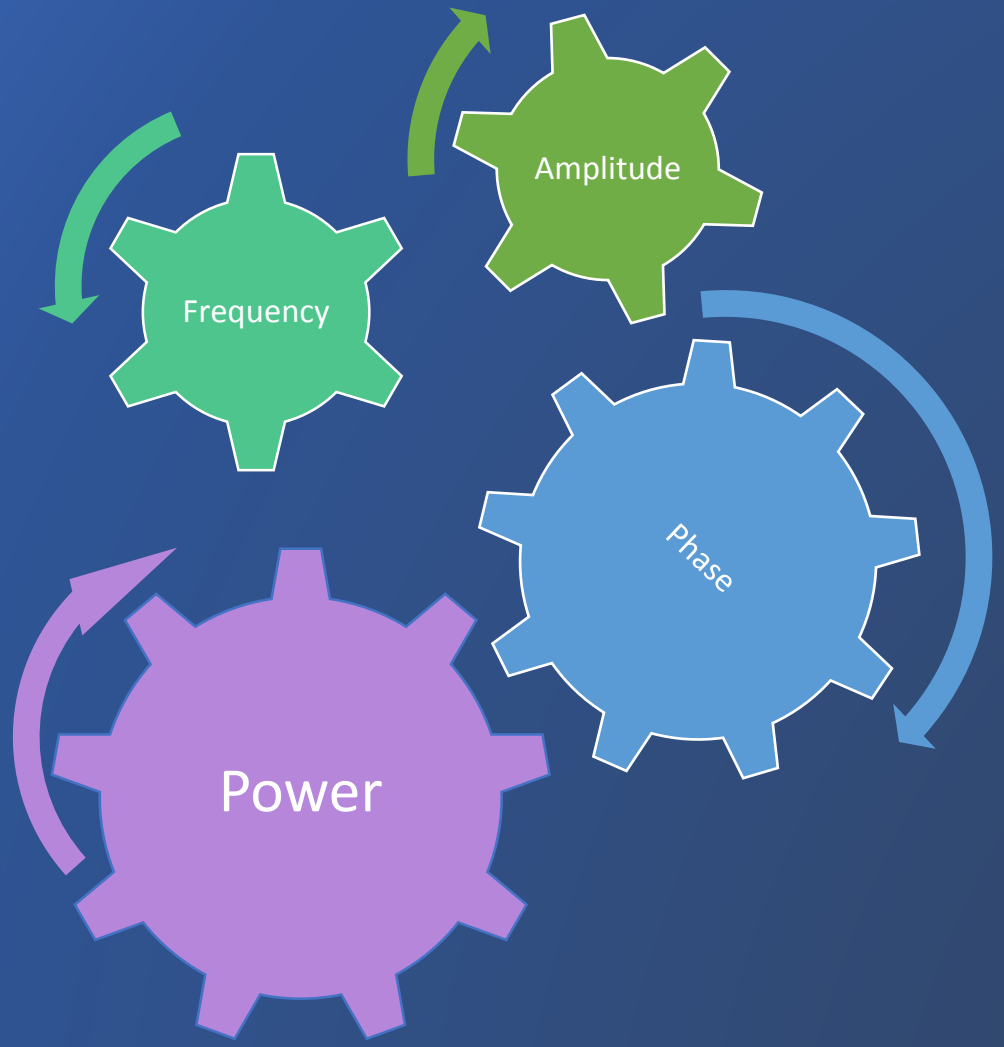


Frequency Is speed of an oscillation/ rhythm (number of oscillation per second)

Unit: HZ

0-100 HZ

0-45 HZ

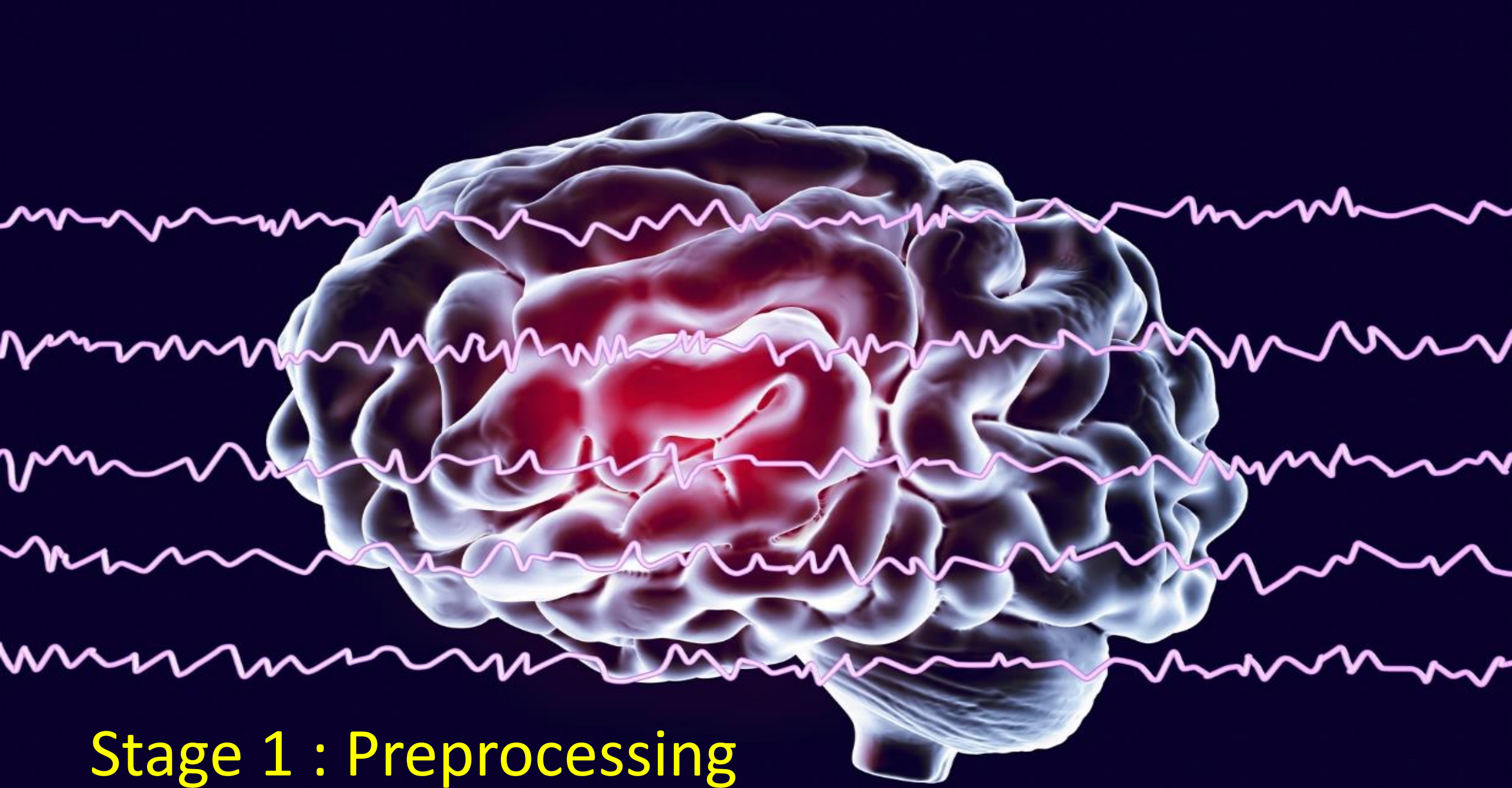


Amplitude in time

Power: amount of energy in each frequency band

Squared amplitude

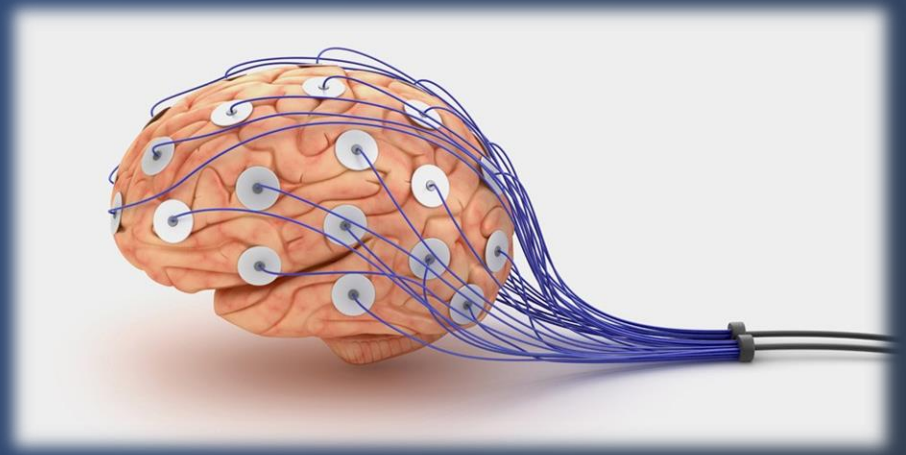
Amount of synchronization among neurons or



Stage 1 : Preprocessing

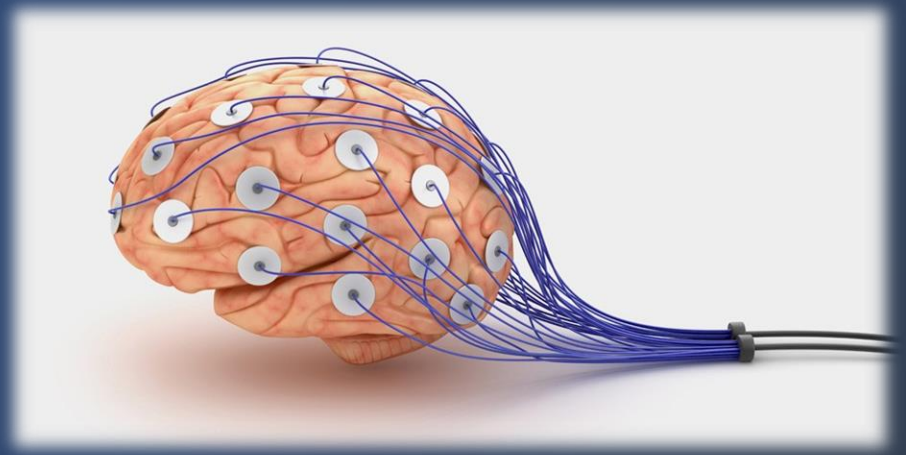
Outline

- Preprocessing
- EEG Artifact
- EEG Preprocessing method

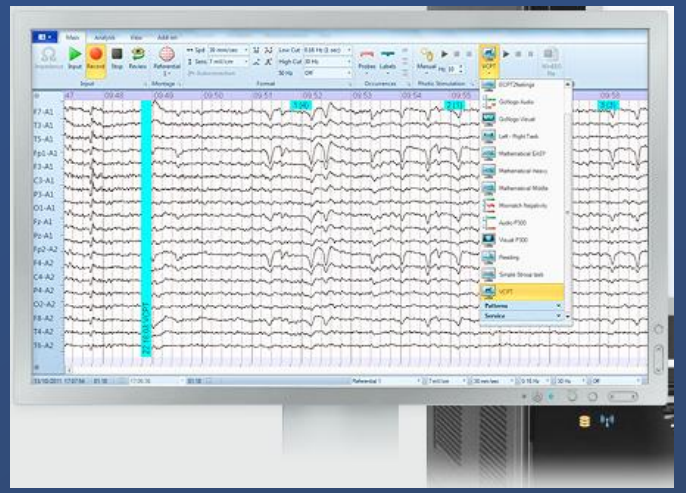


1st stage: Preprocessing

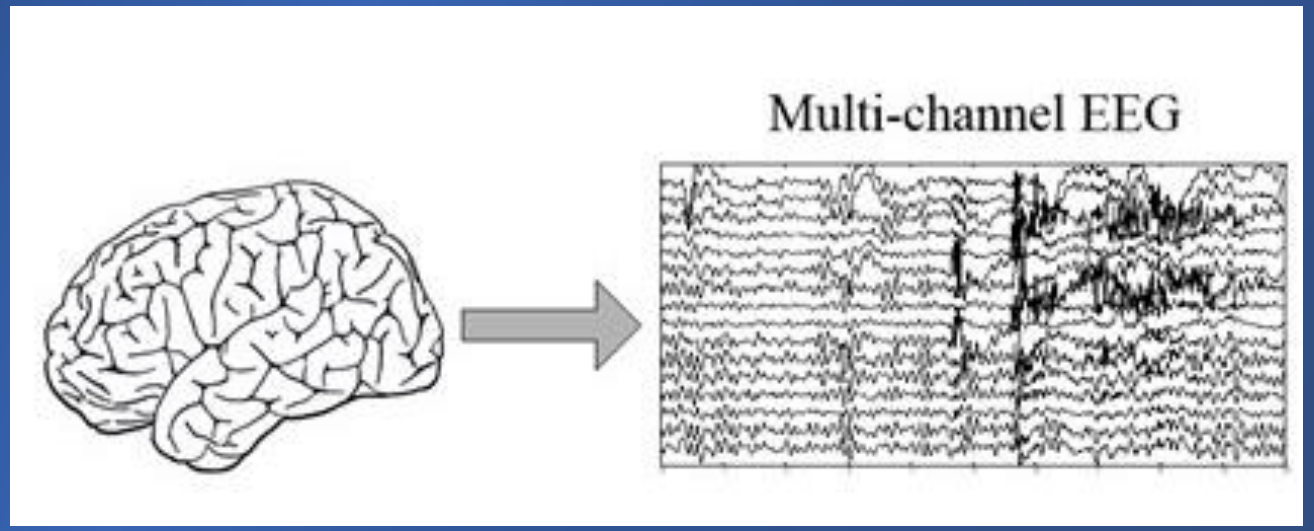
- Artifact rejection and noise removal
- Normalization
- Signal segmentation

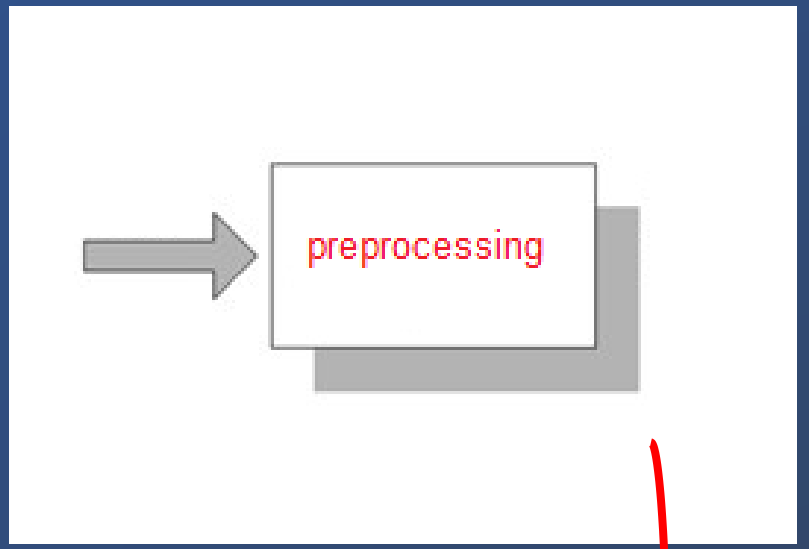


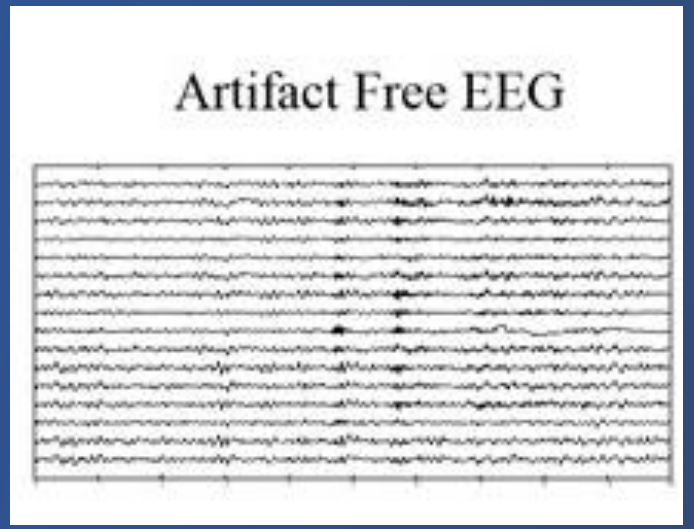
What is an artifact or noise in EEG?

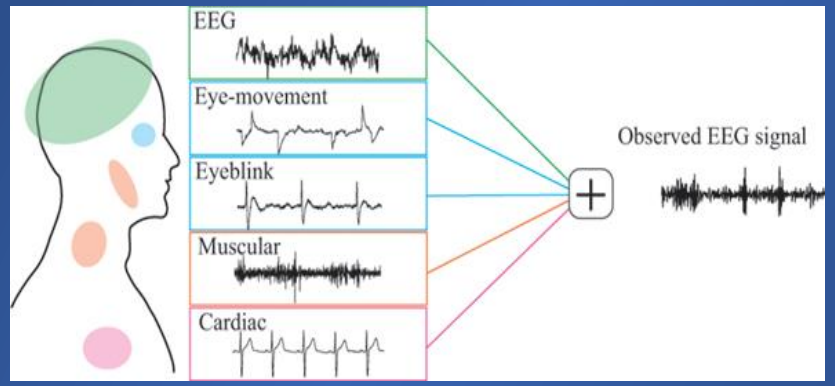


- Any **unwanted** signal that appears with your signal(data) and prevent you to see or analysis the main signal(data)

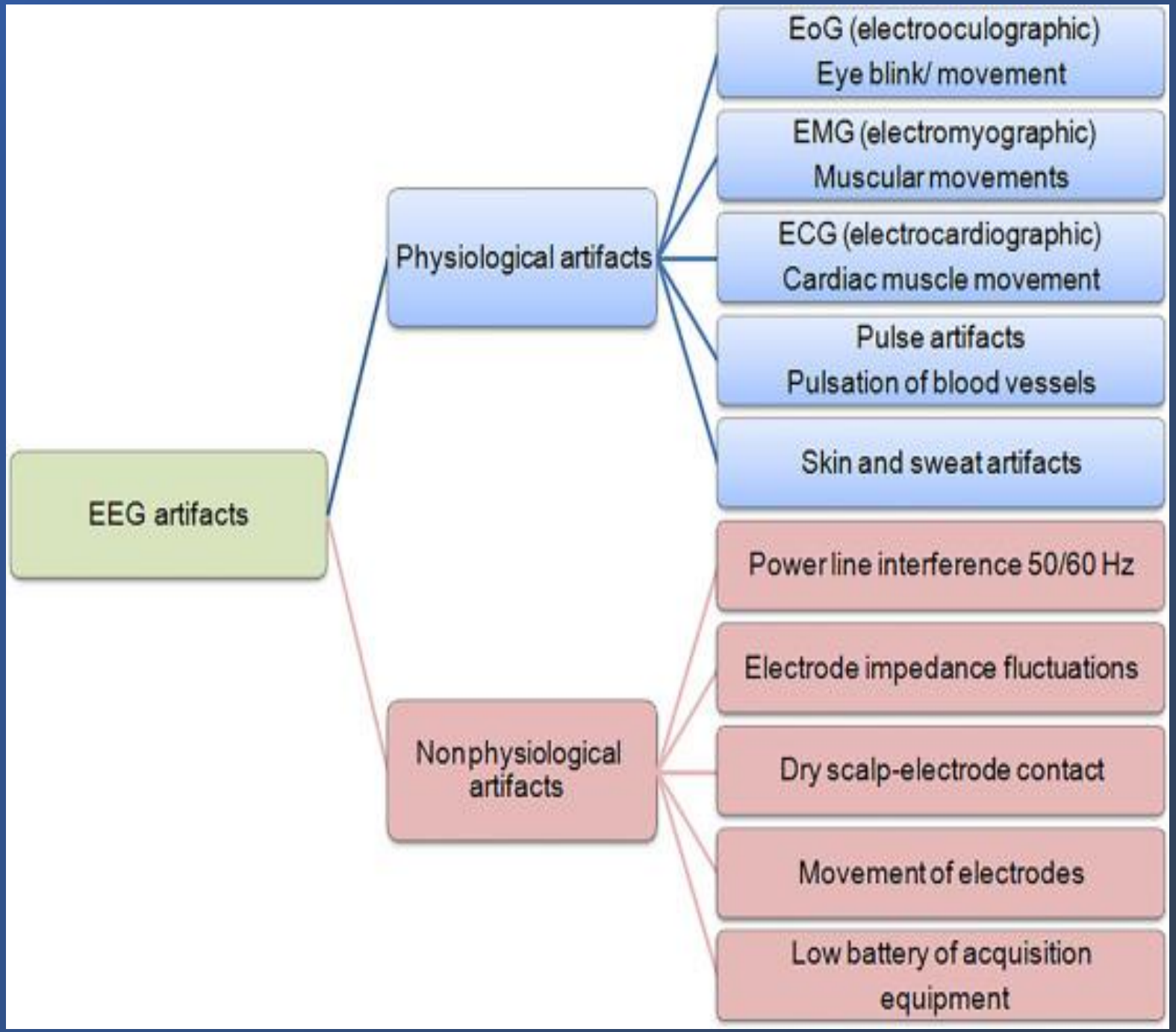

Multi-channel EEG


preprocessing


Artifact Free EEG



EEG Artifact



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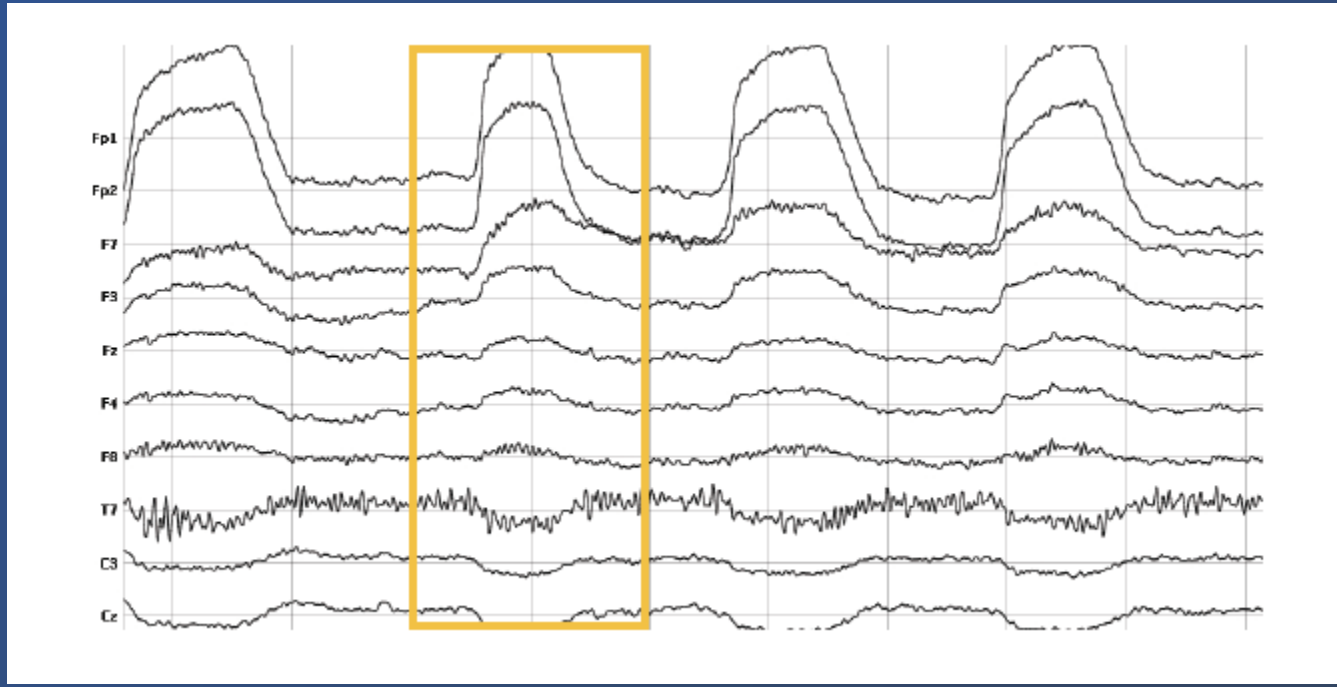
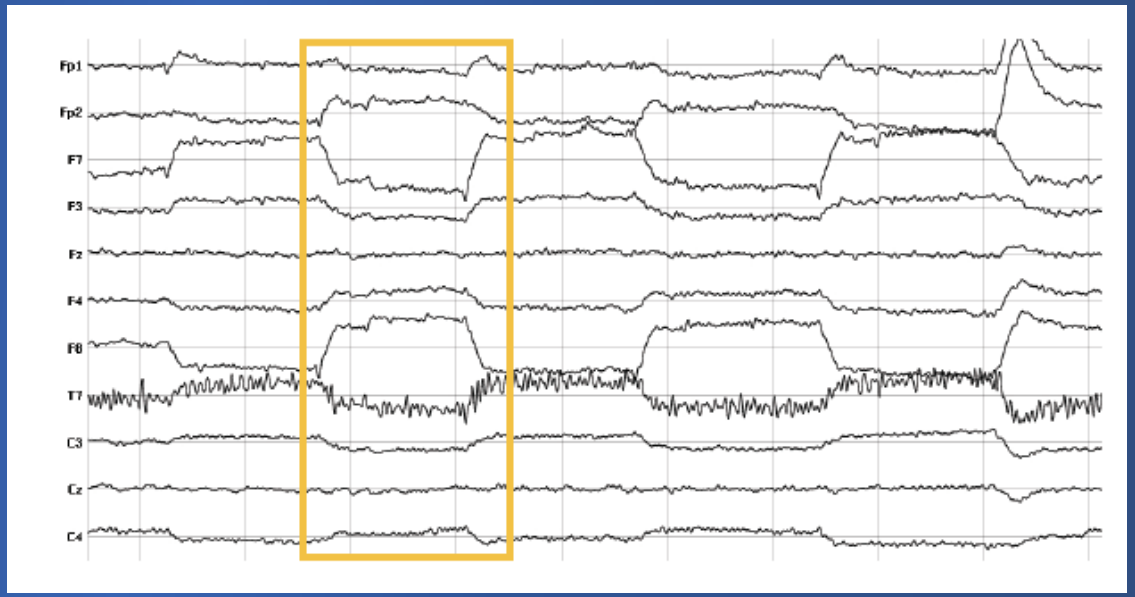
What we could do?

- Prevent it :
  - Take control step so we have as MINIMUM as possible unwanted signal

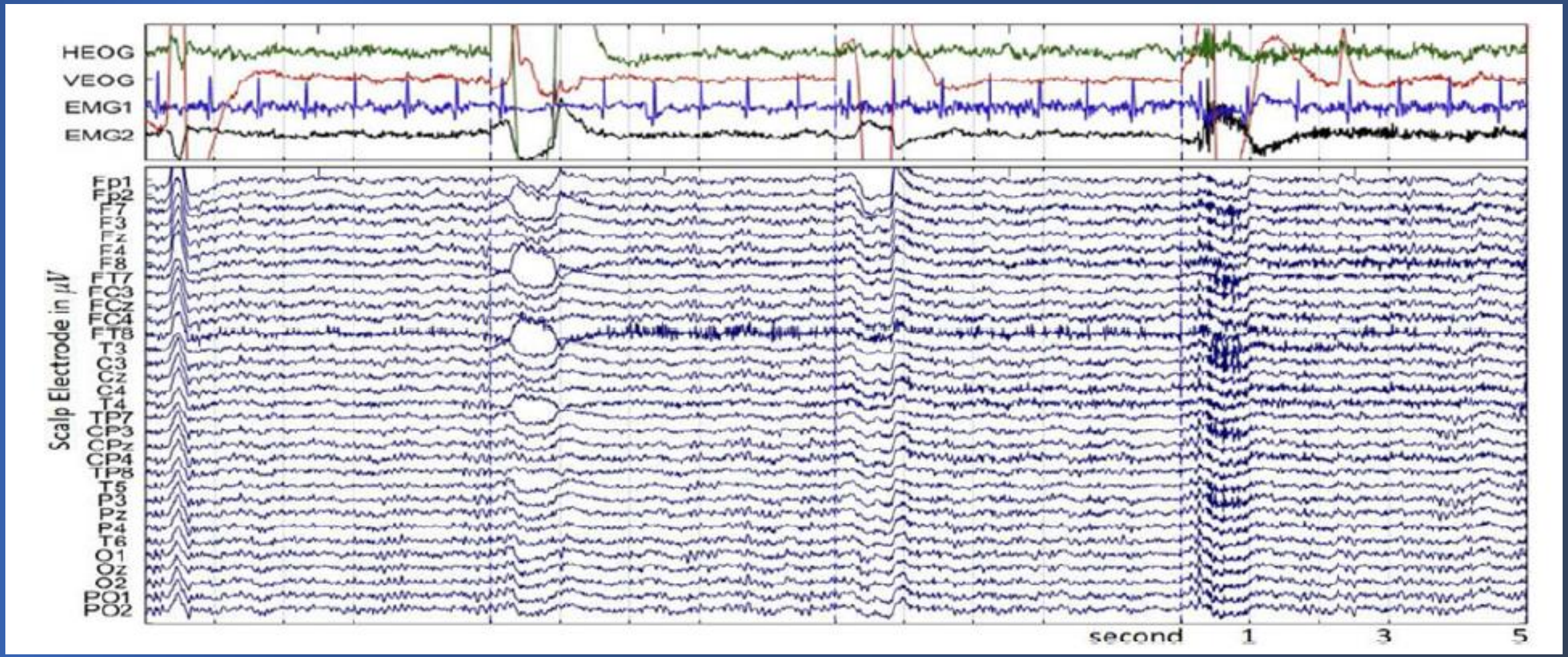
- Clean it and try to remove it :
  - Artifact removal method in preprocessing stage

Physiological artifacts: Eye movement (EOG)





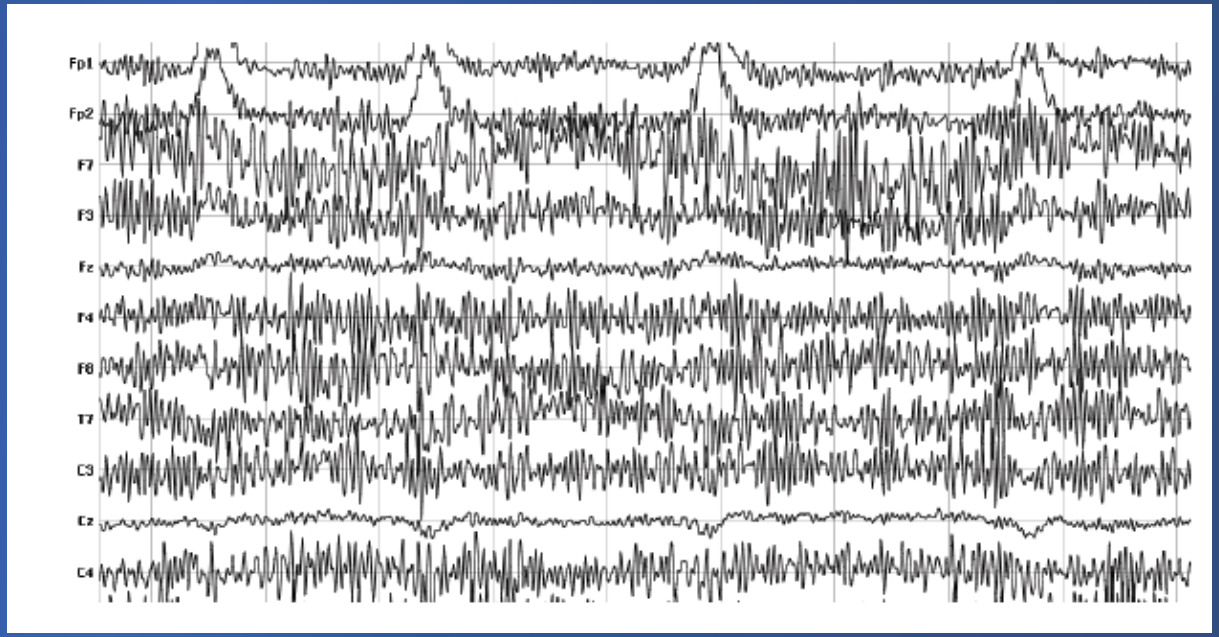
Physiological artifacts: Eye movement (EOG)



Eye blink (EB), horizontal eye movement (HEM), vertical eye movement (VEM) .

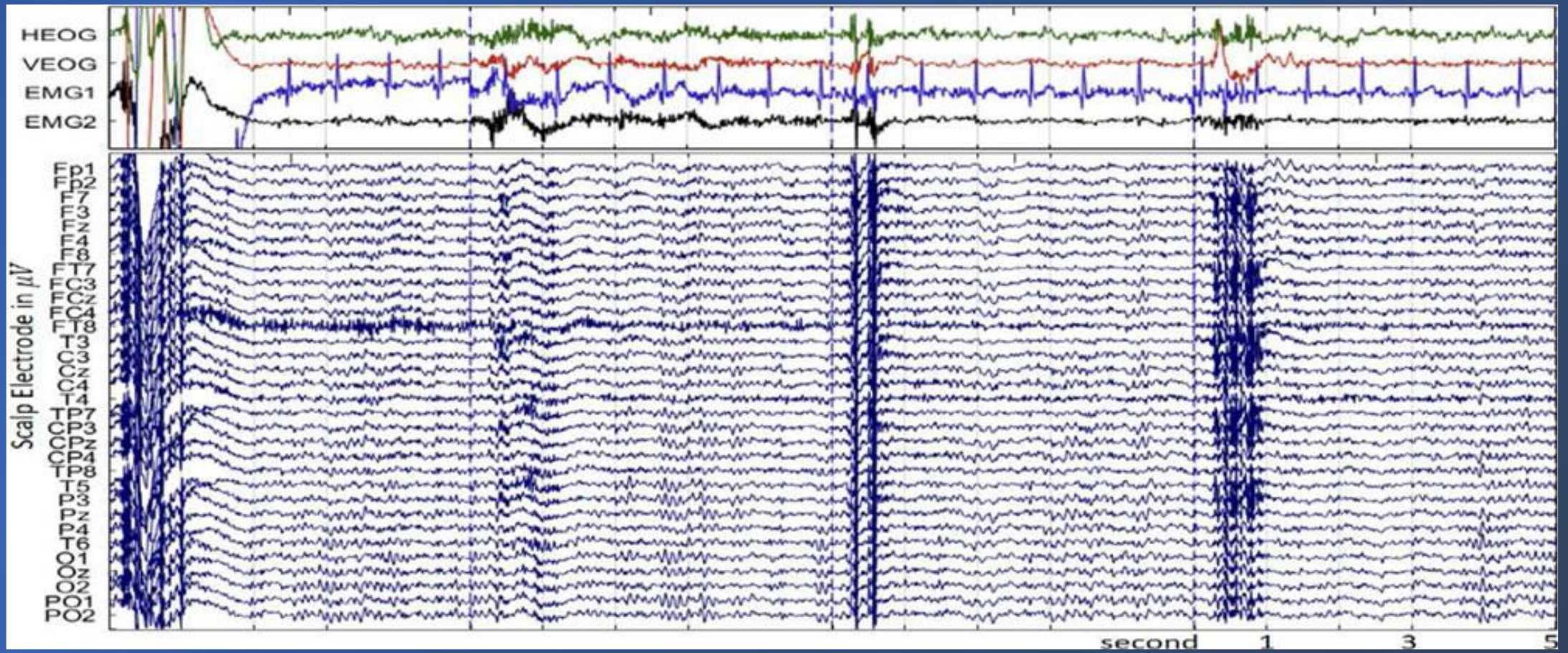
Physiological artifacts: Muscle activity (EMG)

- **Muscle Artefact (EMG) artifact starts as low as 12 Hz and ranges to 300 Hz.**
- **Most of the spectrum lies between 30-150 Hz.**



- **The duration of EMG artifact varies according to the duration of the muscle activity; thus, it ranges from less than a second to an entire EEG record.**

Physiological artifacts: Muscle activity (EMG)

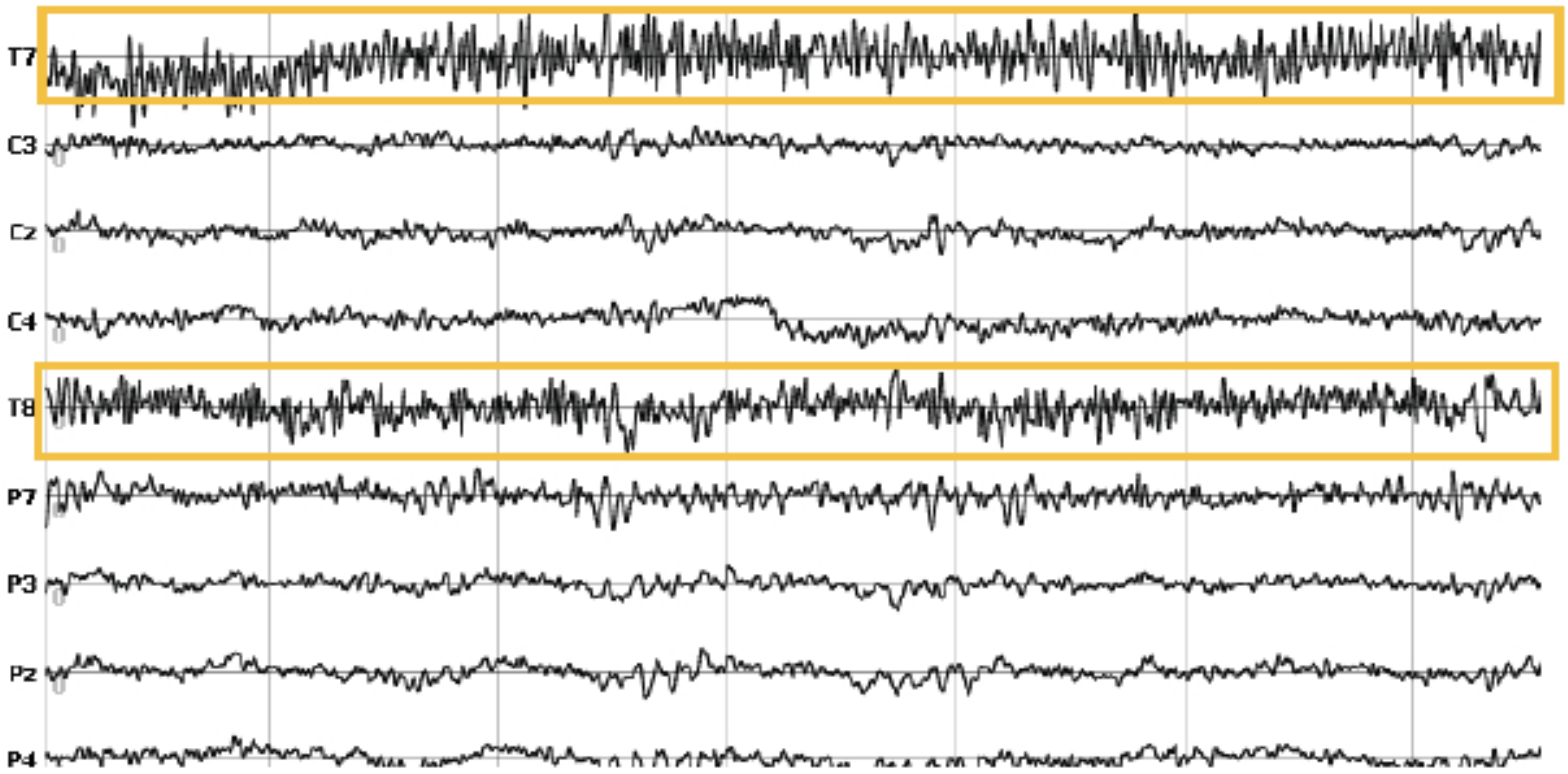


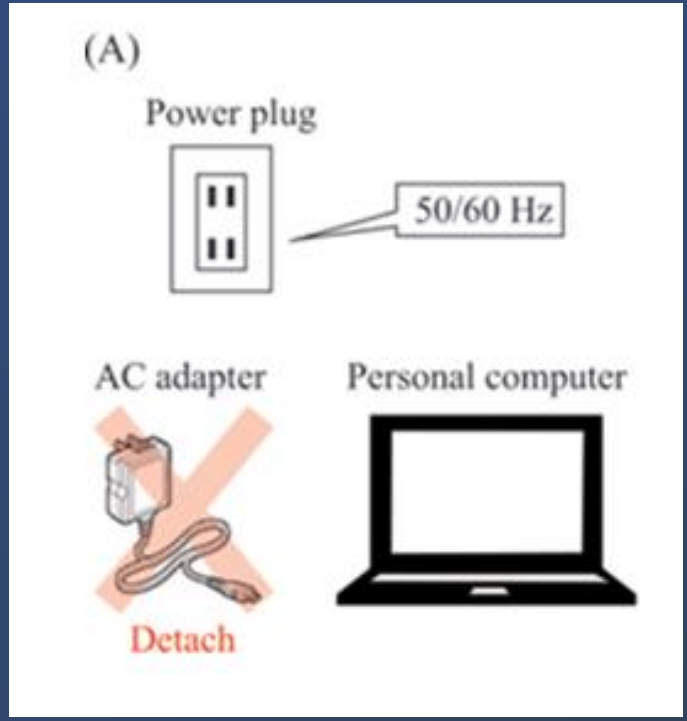
Head shaking movement (HSM), swallowing, teeth tapping (TT) and grinding teeth (GT).

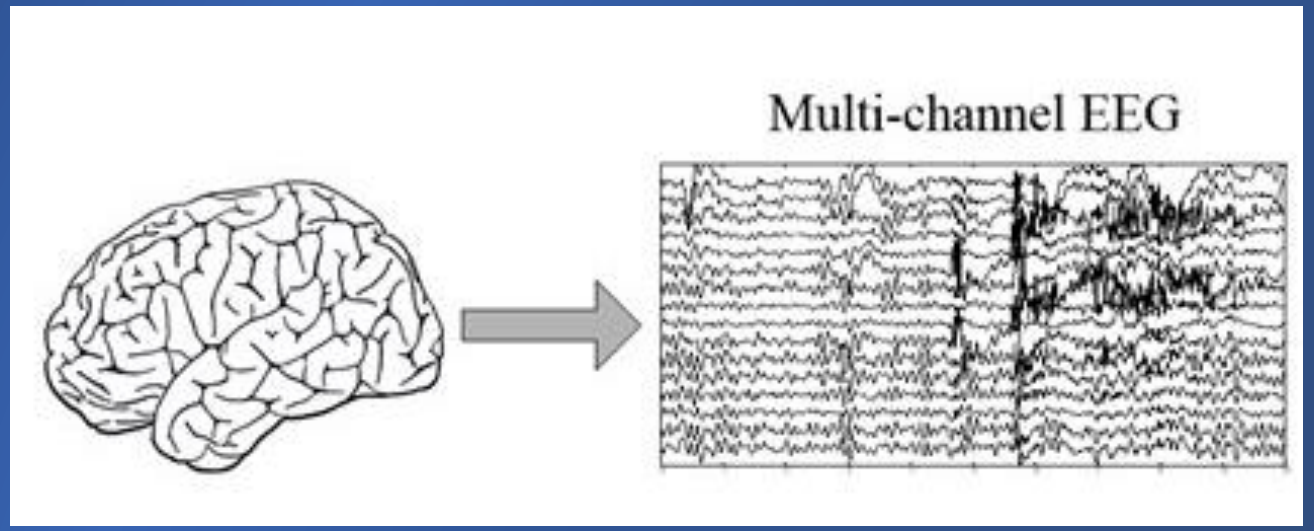
Physiological artifacts: Heart activity (ECG)

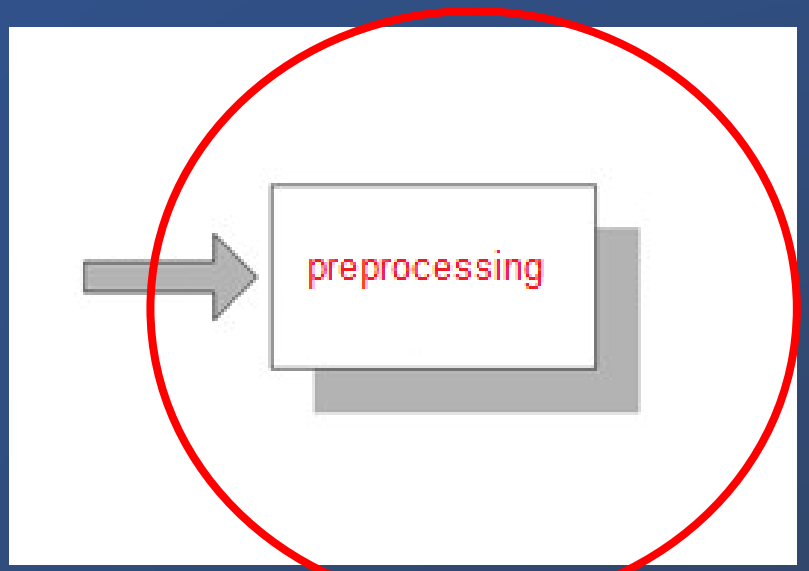
- **time locked to cardiac contractions**
- **most easily identified by their synchronization with complexes in the ECG channel**

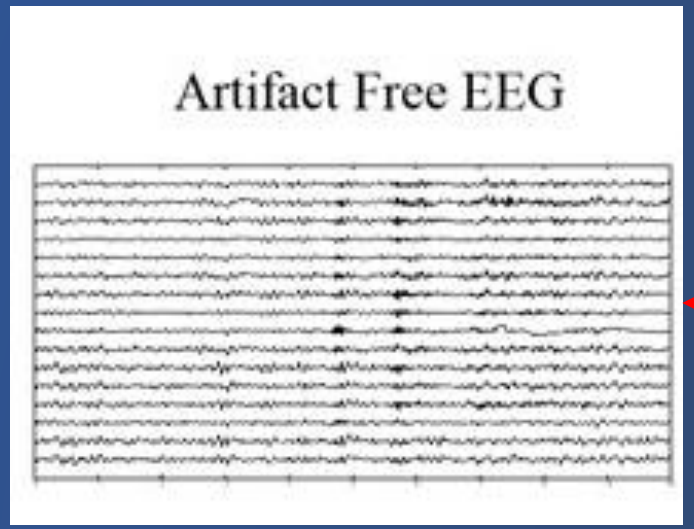
NON - Physiological artifacts : line artifact (50/60 HZ)






Multi-channel EEG

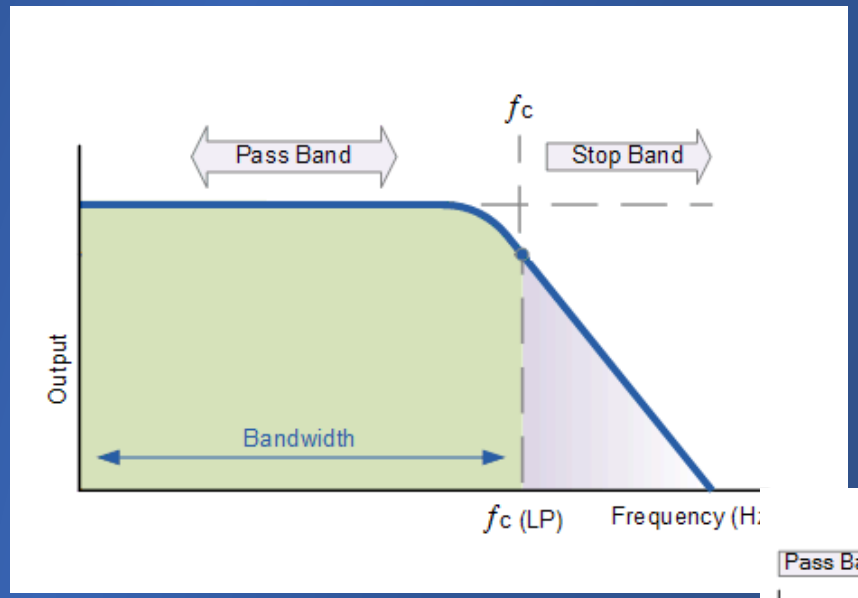

preprocessing

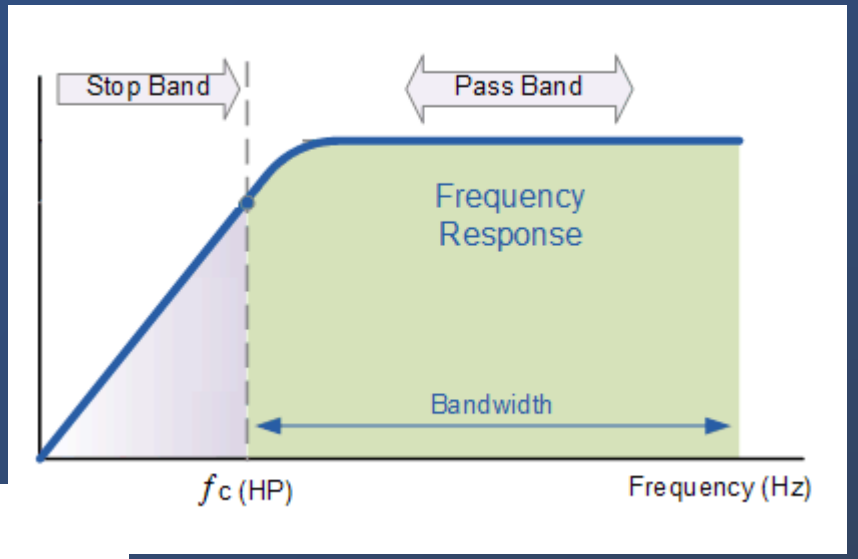

Artifact Free EEG

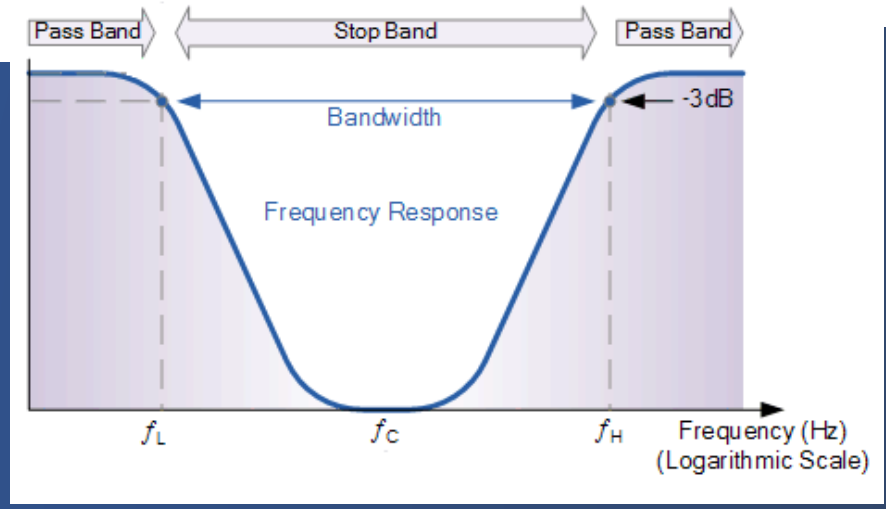
Preprocessing method

- Filtering (high-pass filter- low-pass filter- notch filter(Band-stop filter))
- Baseline removal
- Re-reference
- Channel rejection
- Data rejection
- ICA
- Interpolate all the removed channels

Applying Filter





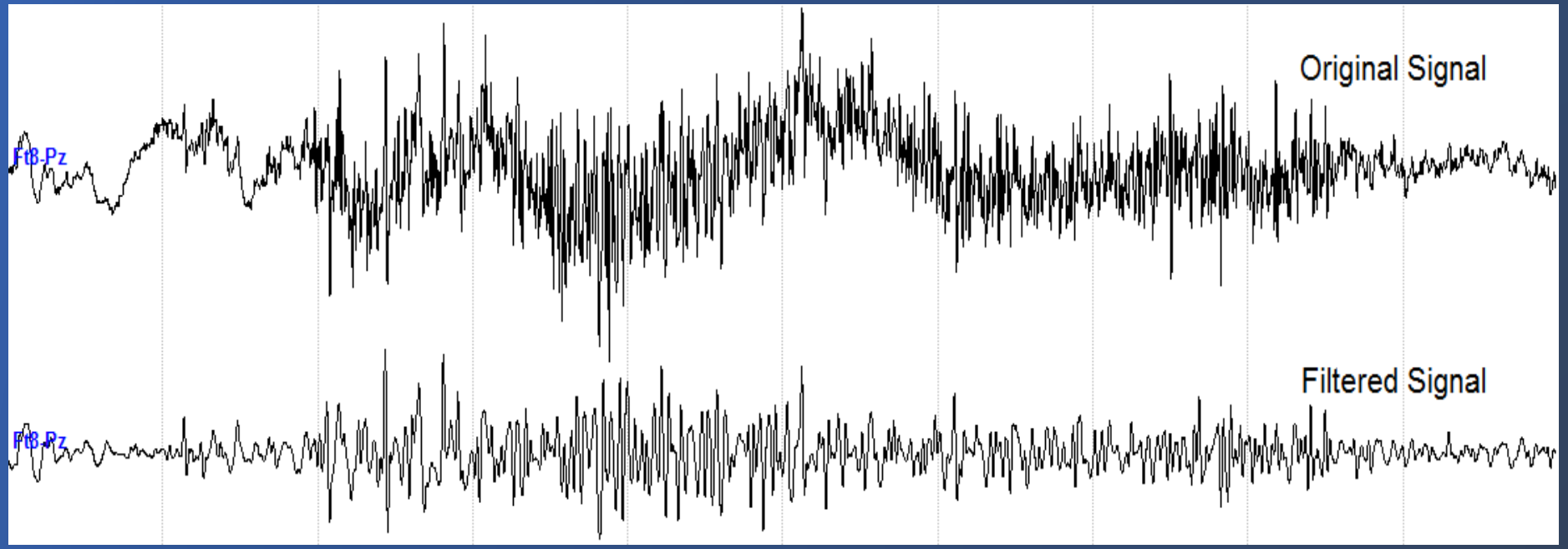


- The frequency range of signal
- The range for signal analysis
- Processing method
- The goal of analysis

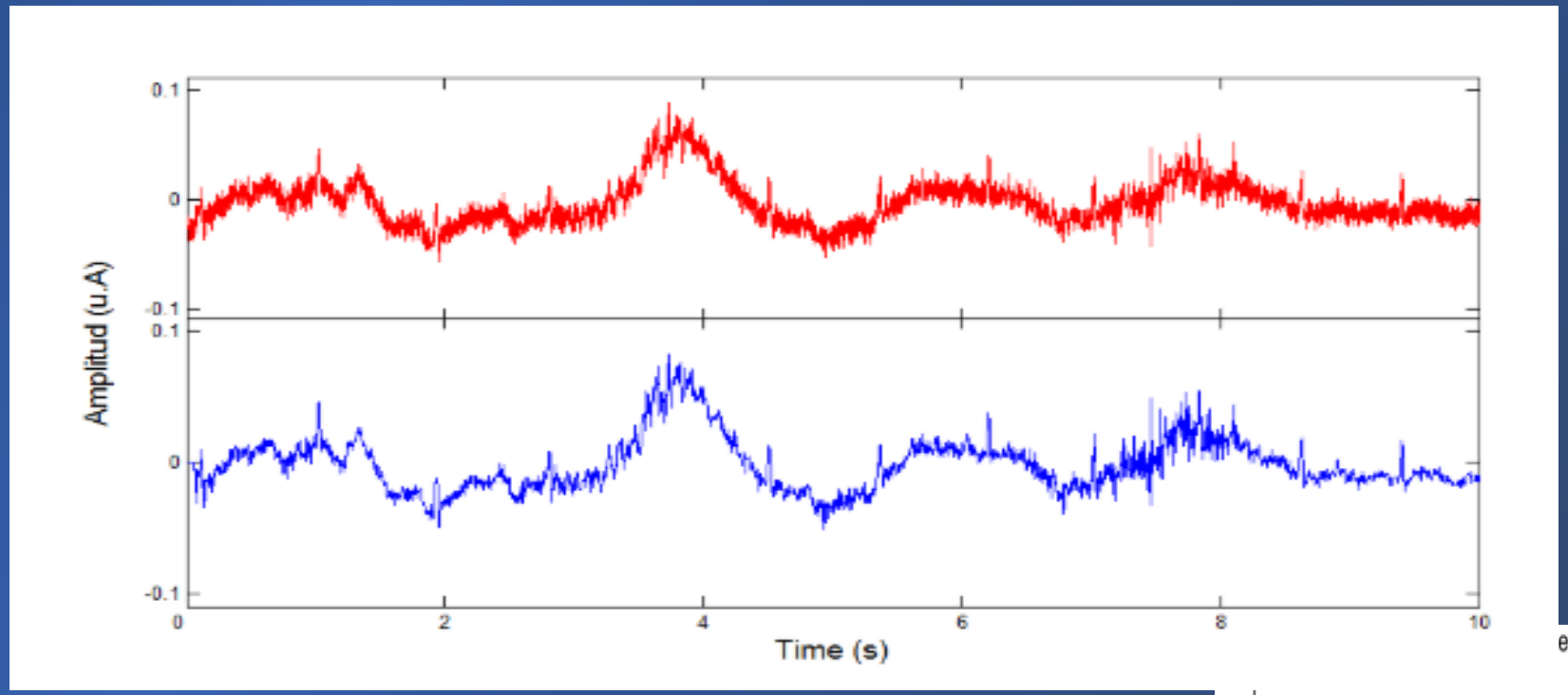
Sampling frequency

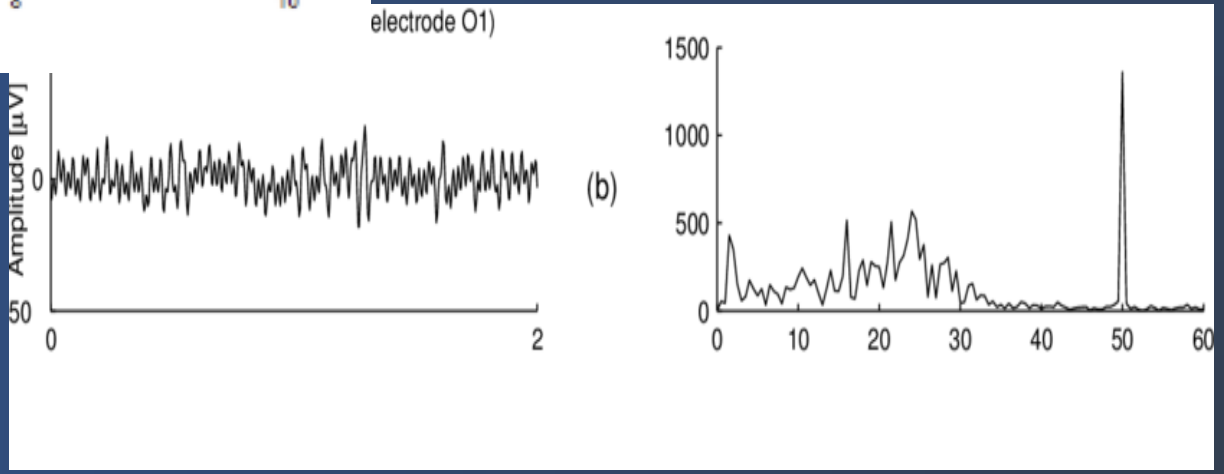
$$f_s \geq 2f_m$$

EEG with Muscle artifact: before and after filtering

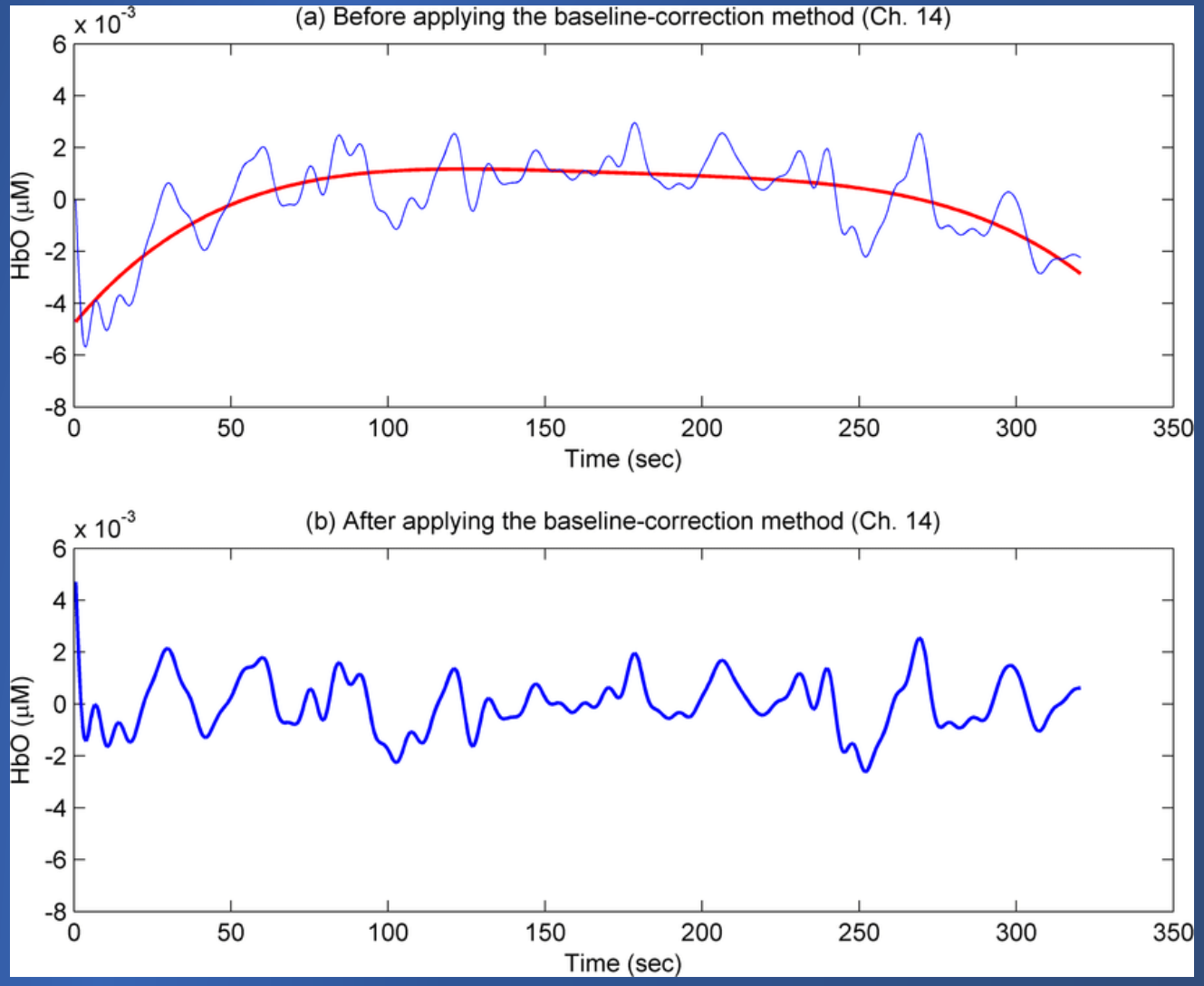


50 HZ noise removal by applying notch filter





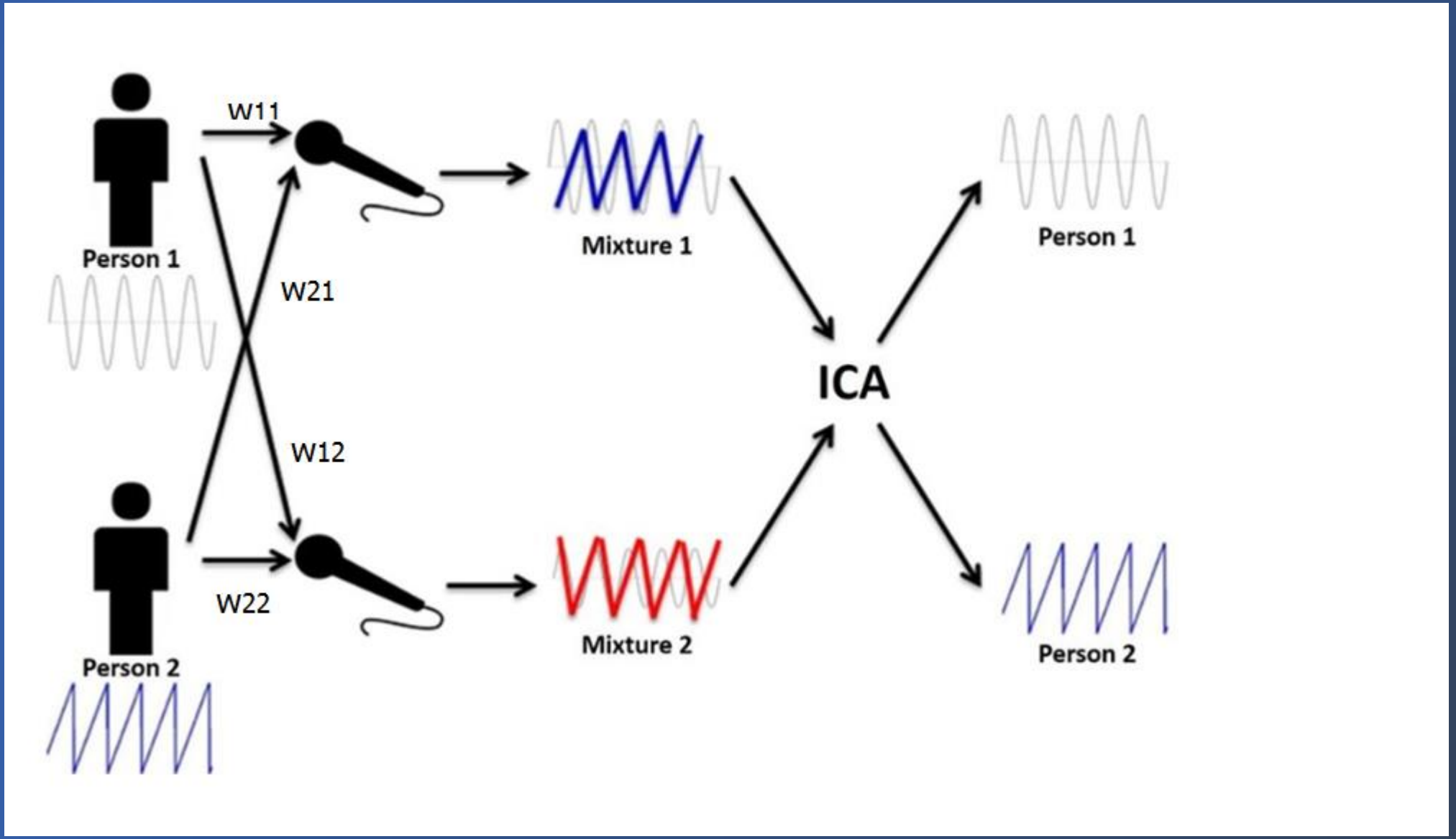
Baseline correction



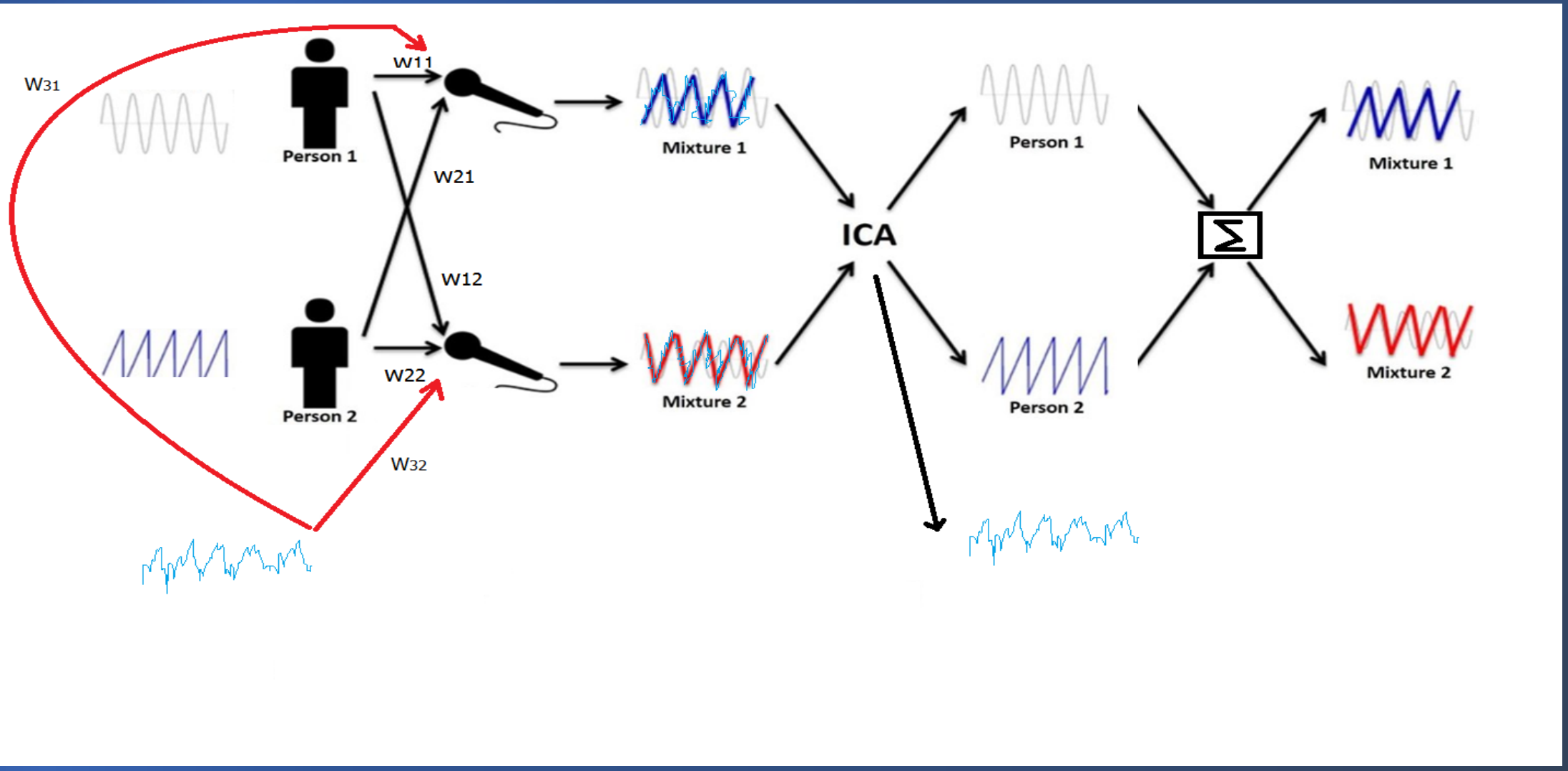
Filtering → High pass filter

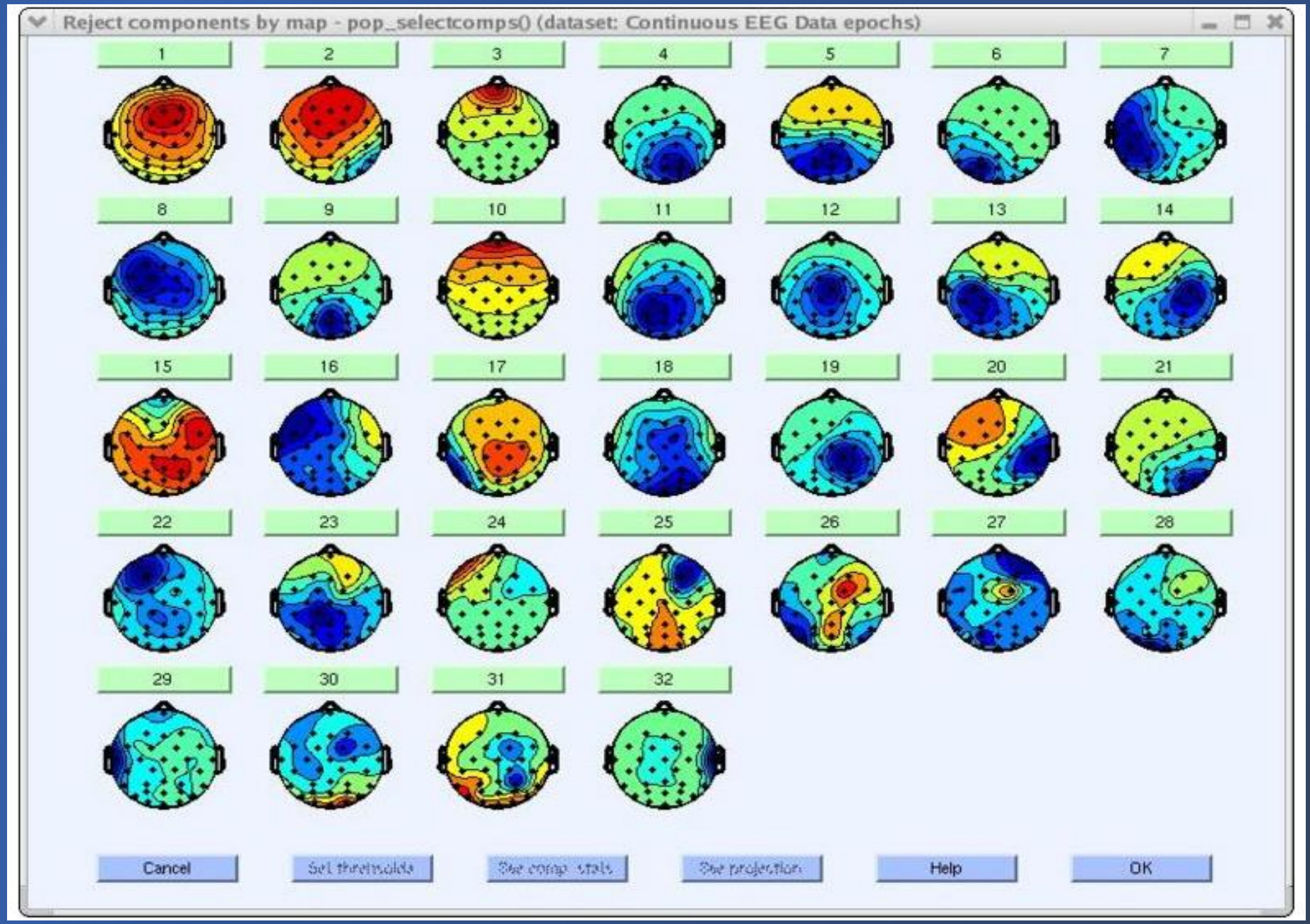
detrend

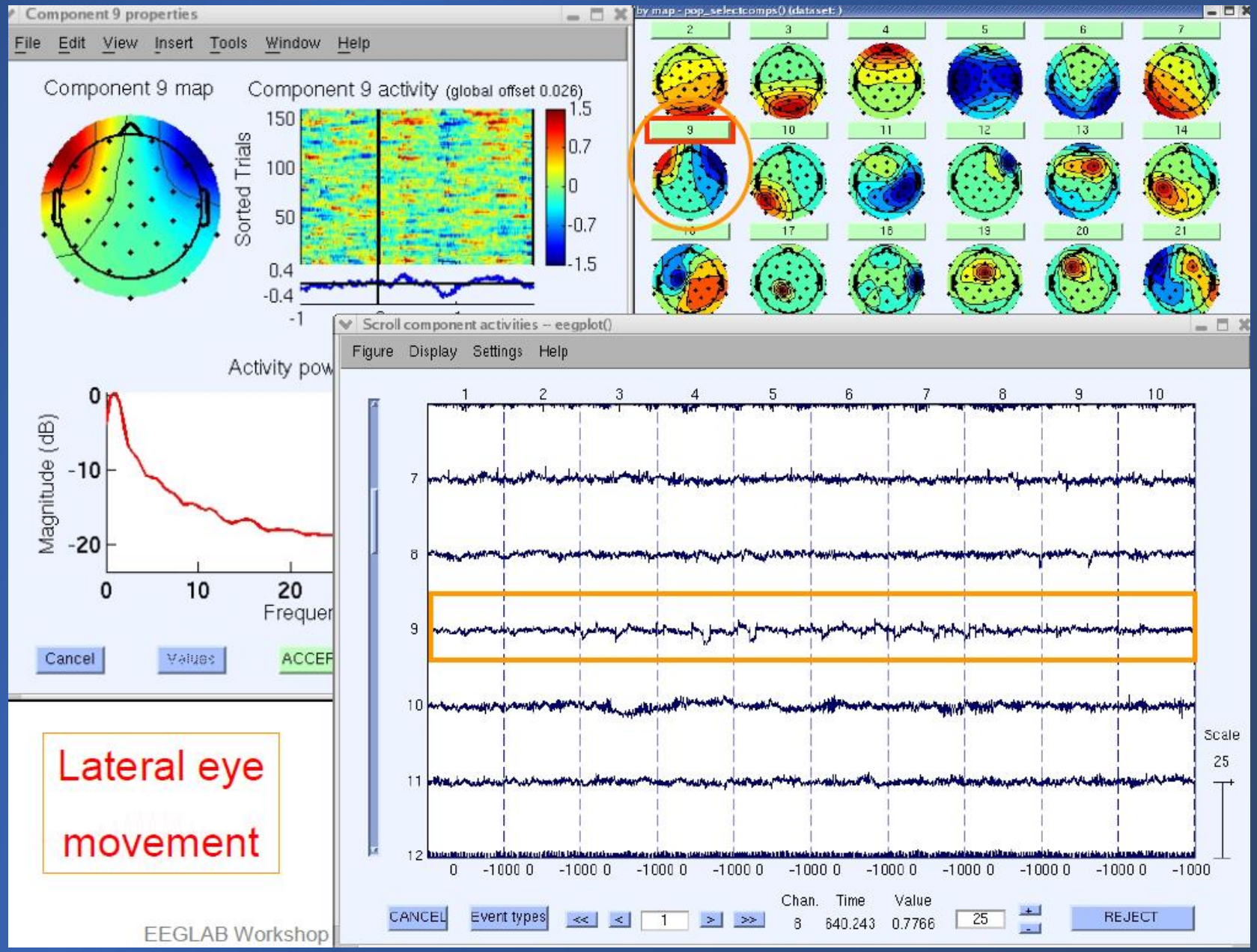
ICA


W11
Person 1
W21
W12
W22
Person 2
Mixture 1
Mixture 2
ICA
Person 1
Person 2

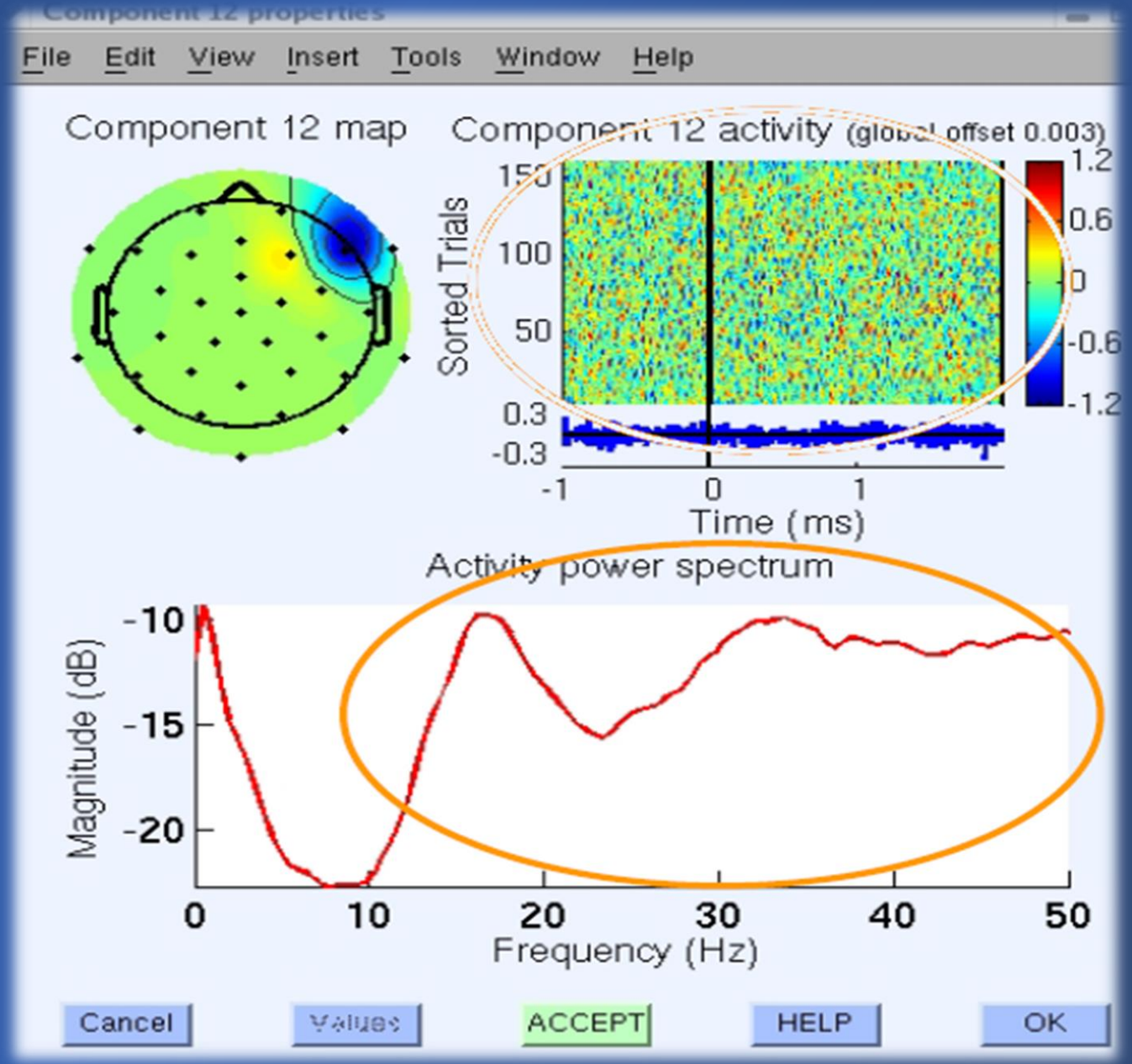
ICA for denoising



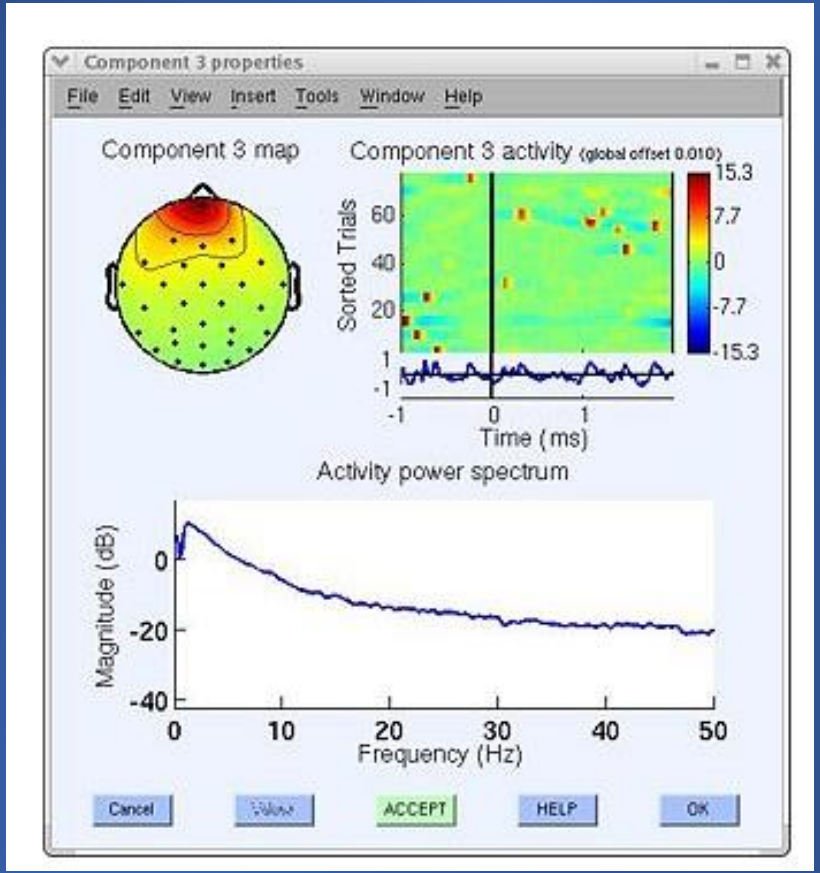

Reject components by map - pop_selectcomps() (dataset: Continuous EEG Data epochs)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Cancel
Help
OK

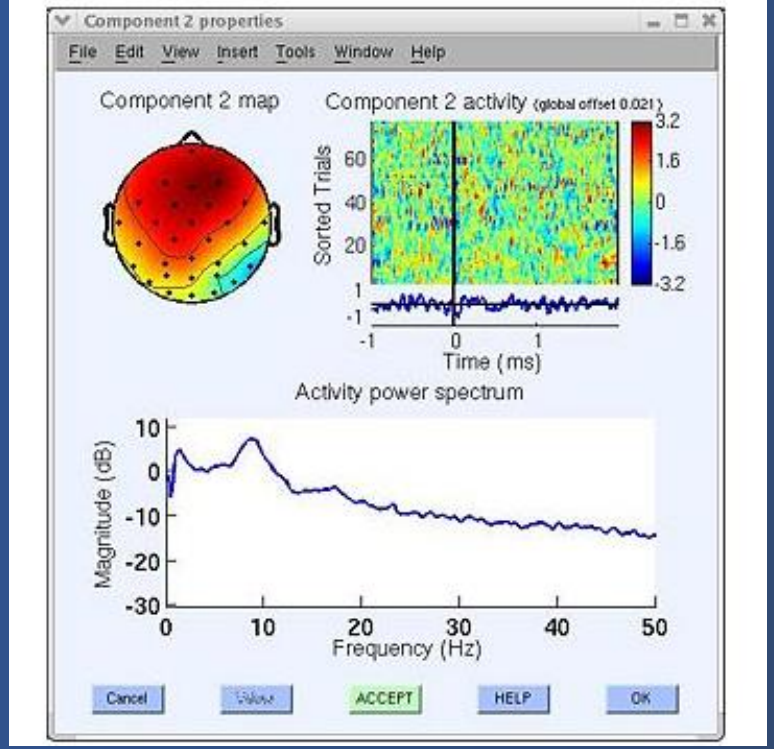


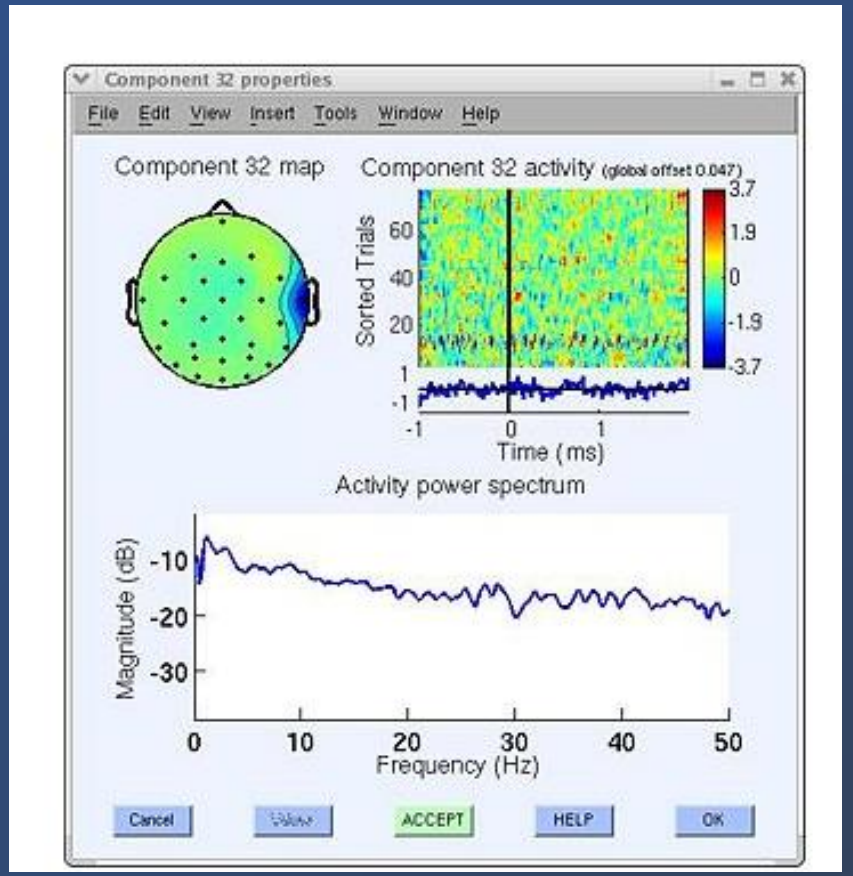
Lateral eye movement


File Edit View Insert Tools Window Help
Component 12 map
Component 12 activity (global offset 0.003)
Sorted Trials
150
100
50
0.3
-0.3
1.2
0.6
0
-0.6
-1.2
-1
0
1
Time (ms)
Activity power spectrum
Magnitude (dB)
-10
-15
-20
0
10
20
30
40
50
Frequency (Hz)
Cancel
Values
ACCEPT
HELP
OK

Muscle


Component 3 properties
File Edit View Insert Tools Window Help
Component 3 map
Component 3 activity (global offset 0.010)
Sorted Trials
Time (ms)
Activity power spectrum
Magnitude (dB)
Frequency (Hz)
Cancel
ACCEPT
HELP
OK


Component 2 properties
File Edit View Insert Tools Window Help
Component 2 map
Component 2 activity (global offset 0.021)
Sorted Trials
Time (ms)
Activity power spectrum
Magnitude (dB)
Frequency (Hz)
Cancel
ACCEPT
HELP
OK


Component 32 properties
File Edit View Insert Tools Window Help
Component 32 map
Component 32 activity (global offset 0.047)
Sorted Trials
Time (ms)
Activity power spectrum
Magnitude (dB)
Frequency (Hz)
Cancel
ACCEPT
HELP
OK

Automatic ICA component removal(cont.)

- Visual inspection
- Toolbox and plugins

ADJUST

ICLabel

MARA

Automatic ICA component removal(cont.)

www.ncbi.nlm.nih.gov › pubmed

ADJUST: An automatic EEG artifact detector based on the joint ...

by A Mognon - 2011 - Cited by 695 - Related articles

doi: 10.1111/j.1469-8986.2010.01061.x. **ADJUST: An automatic EEG artifact detector based on the joint use of spatial and temporal features**. Mognon ...

www.ncbi.nlm.nih.gov › pubmed

Automatic classification of artifactual ICA-components ... - NCBI

by I Winkler - 2011 - Cited by 282 - Related articles

Aug 2, 2011 - **Automatic classification of artifactual ICA-components for artifact removal in EEG signals**. ... (1)Machine Learning Laboratory, Berlin Institute of Technology, Franklinstr, 28/29, 10587 Berlin, Germany. **irene.winkler**@tu-berlin.de.

Psychophysiology, *48* (2011), 229–240. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2010.01061.x

ADJUST: An automatic EEG artifact detector based on the joint use of spatial and temporal features

ANDREA MOGNON,[a,b] JORGE JOVICICH,[a] LORENZO BRUZZONE,[c] AND MARCO BUIATTI[a,d,e,f]

[a]Functional NeuroImaging Laboratory, Center for Mind/Brain Sciences, Department of Cognitive and Education Sciences, University of Trento, Trento, Italy
[b]NILab, Neuroinformatics Laboratory, Fondazione Bruno Kessler, Trento, Italy
[c]Department of Information Engineering and Computer Science, University of Trento, Trento, Italy
[d]INSERM, U992, Cognitive Neuroimaging Unit, Gif/Yvette, France
[e]CEA, DSV/I2BM, NeuroSpin Center, Gif/Yvette, France
[f]Université Paris-Sud, Cognitive Neuroimaging Unit, Gif/Yvette, France

Winkler *et al. Behavioral and Brain Functions* 2011, **7**:30
http://www.behavioralandbrainfunctions.com/content/7/1/30

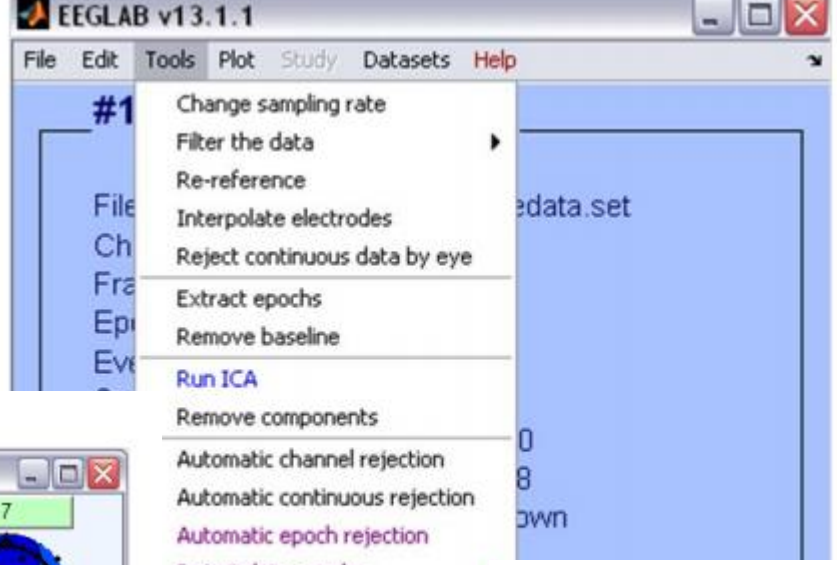
BBF BEHAVIORAL AND BRAIN FUNCTIONS

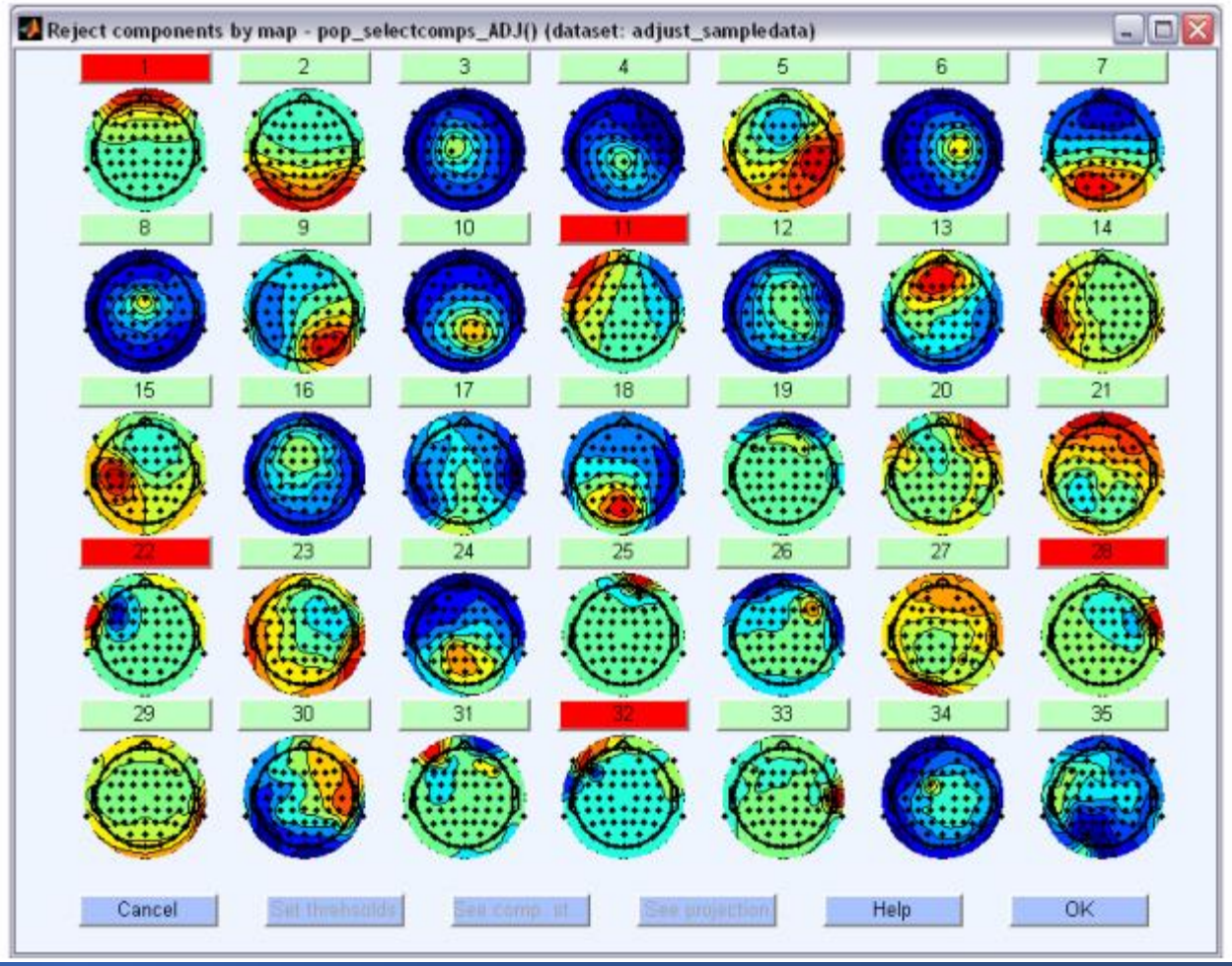
METHODOLOGY **Open Access**

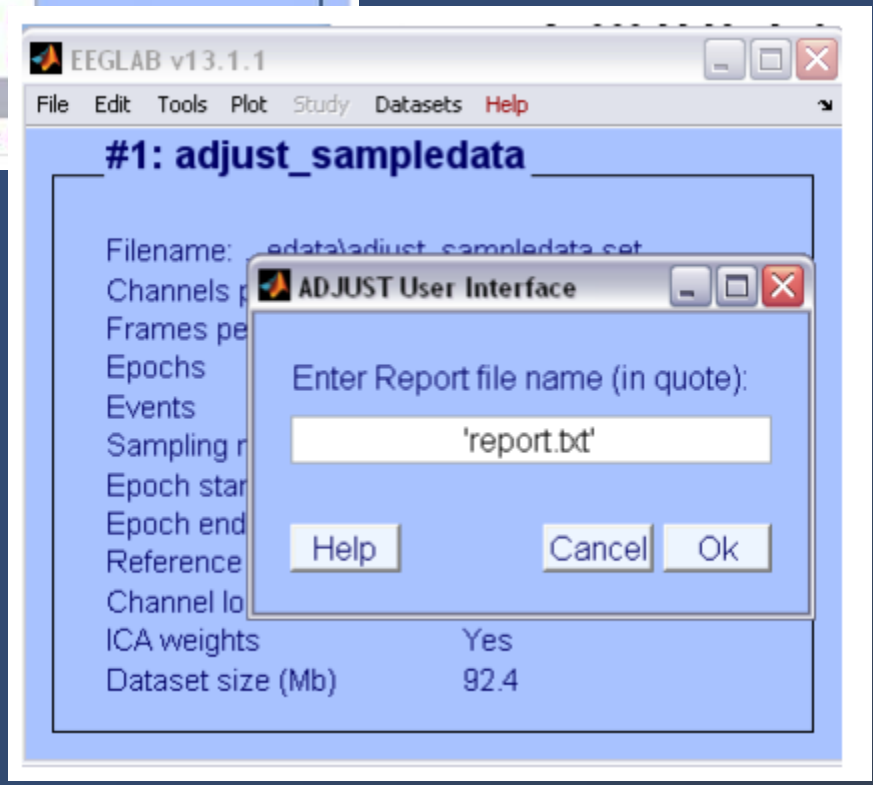
Automatic Classification of Artifactual ICA-Components for Artifact Removal in EEG Signals

Irene Winkler*, Stefan Haufe and Michael Tangermann

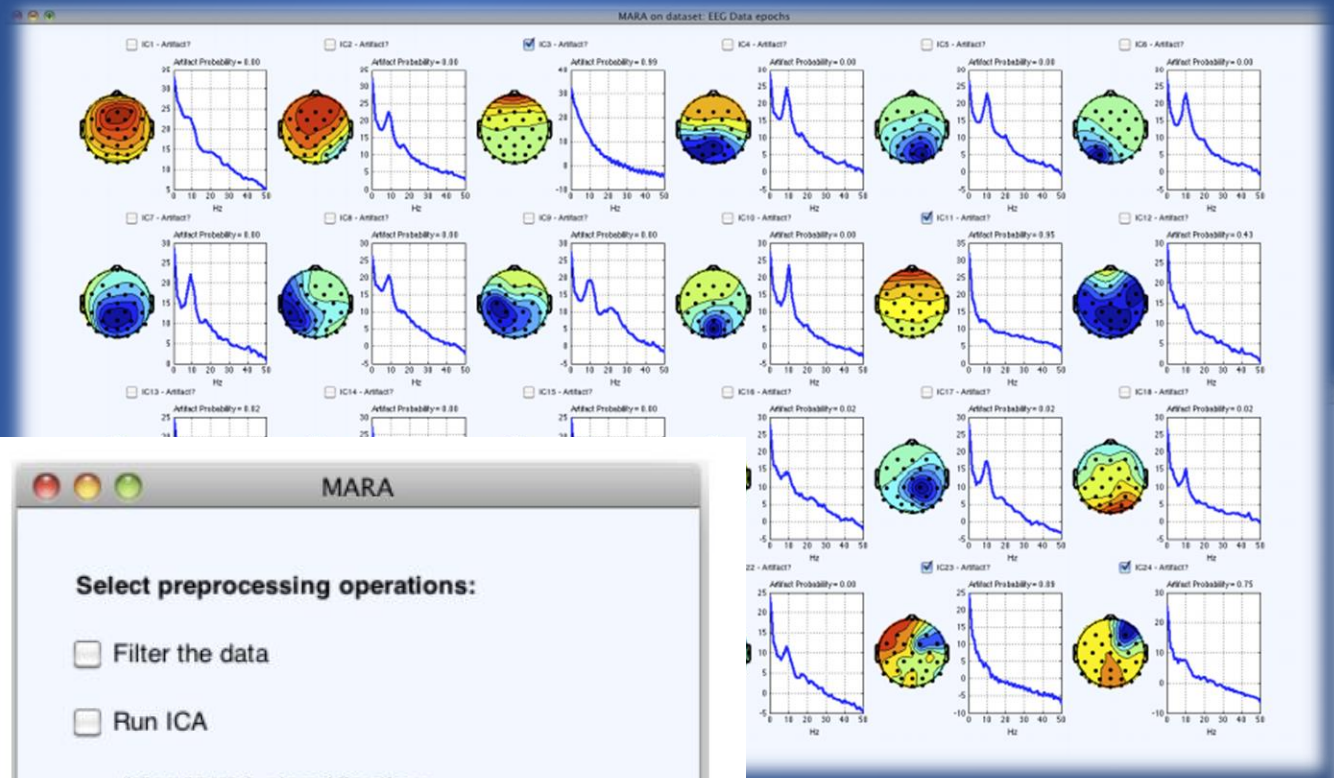
ADJUST

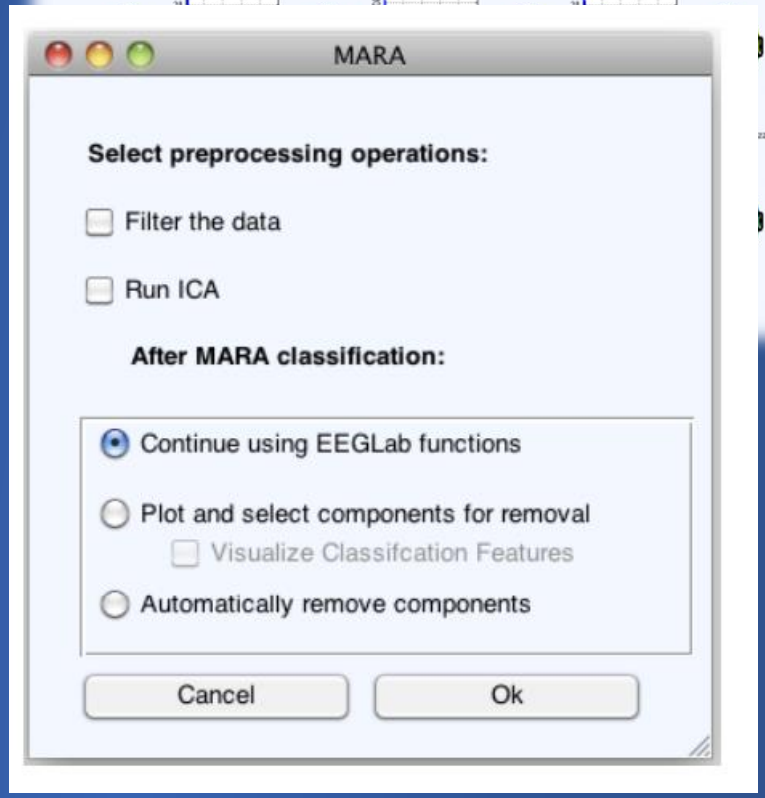

EEGLAB v13.1.1
File Edit Tools Plot Study Datasets Help
Change sampling rate
Filter the data
Re-reference
Interpolate electrodes
Reject continuous data by eye
Extract epochs
Remove baseline
Run ICA
Remove components
Automatic channel rejection
Automatic continuous rejection
Automatic epoch rejection
Reject data epochs
Reject data using ICA
ADJUST1.1
Locate dipoles using DIPFIT 2.x

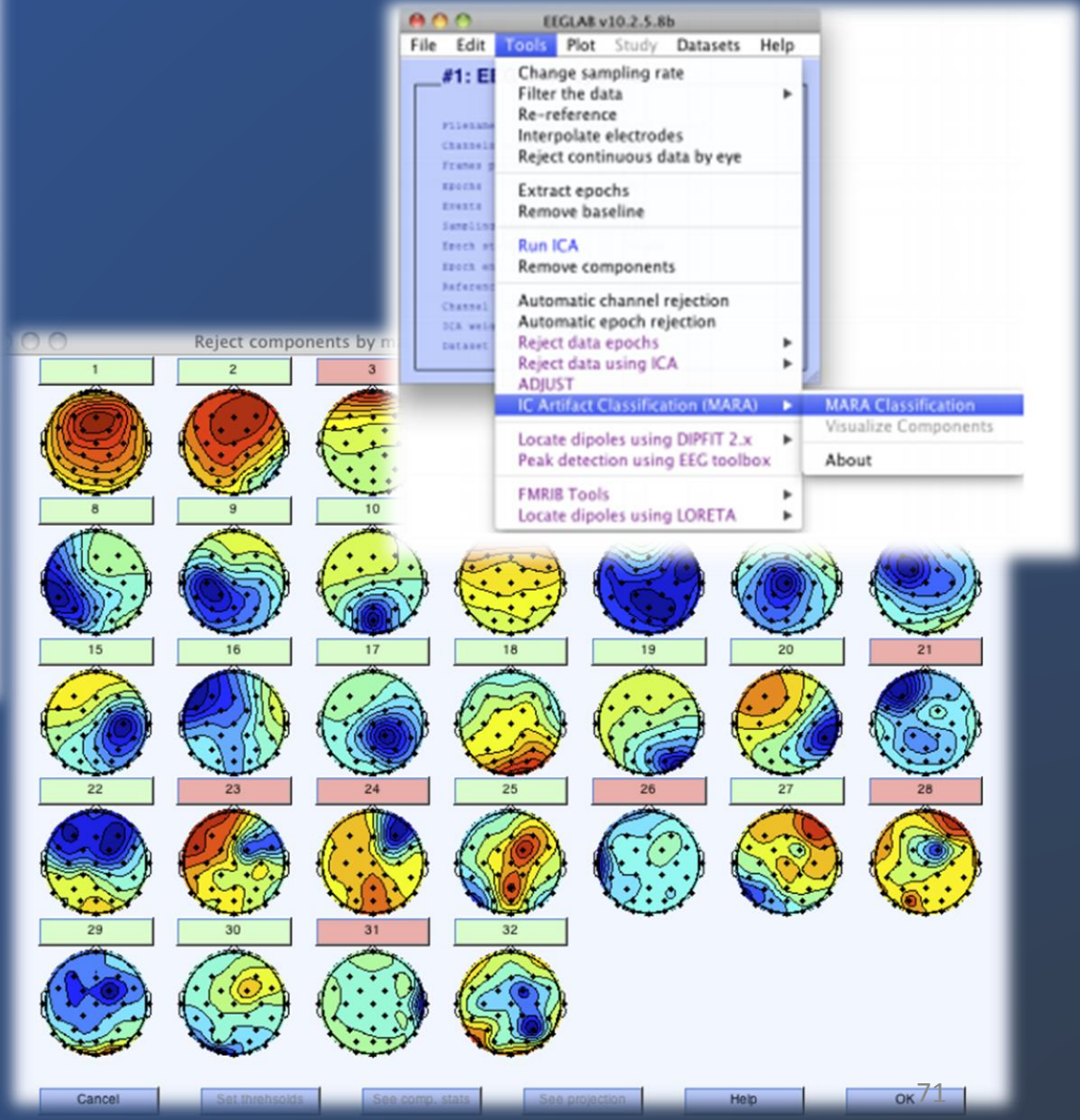

Reject components by map - pop_selectcomps_ADJ() (dataset: adjust_sampledata)
Cancel
Help
OK


EEGLAB v13.1.1
File Edit Tools Plot Study Datasets Help
#1: adjust_sampledata
Filename:
Epochs
Events
Epoch end
Reference
ICA weights Yes
Dataset size (Mb) 92.4
ADJUST User Interface
Enter Report file name (in quote):
'report.txt'
Help
Cancel
Ok

MARA (Multiple Artifact Rejection Algorithm)

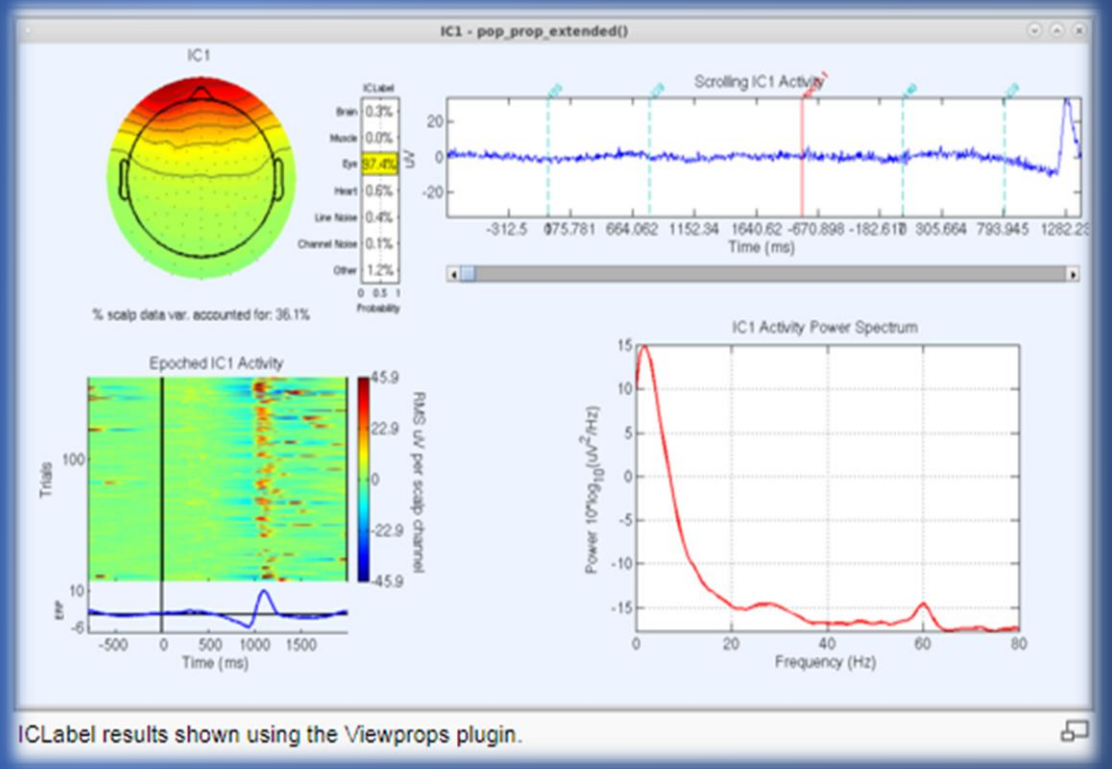






ICLabel

- EEGLAB plug-in for automatic independent component (IC) classification.

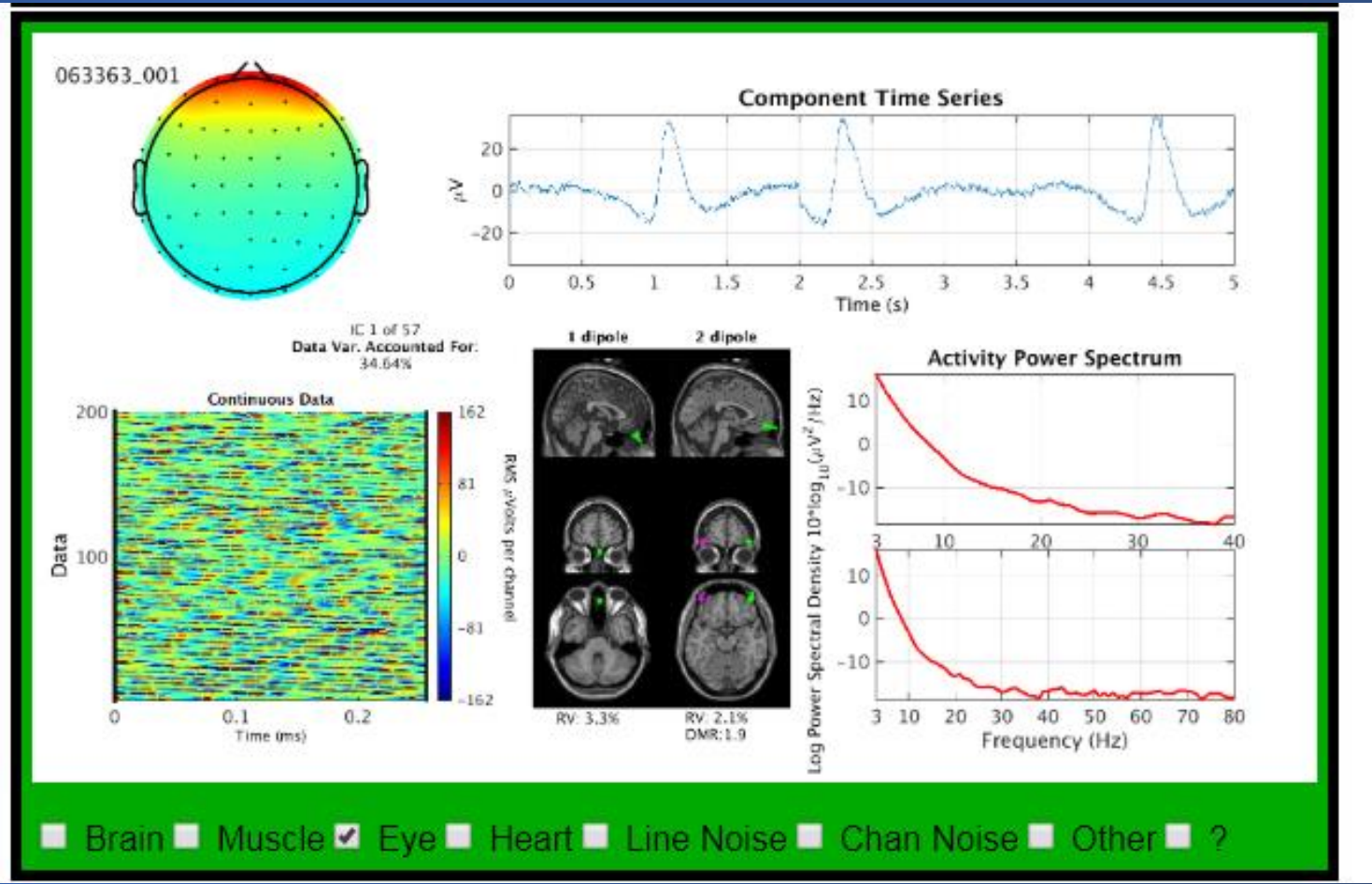


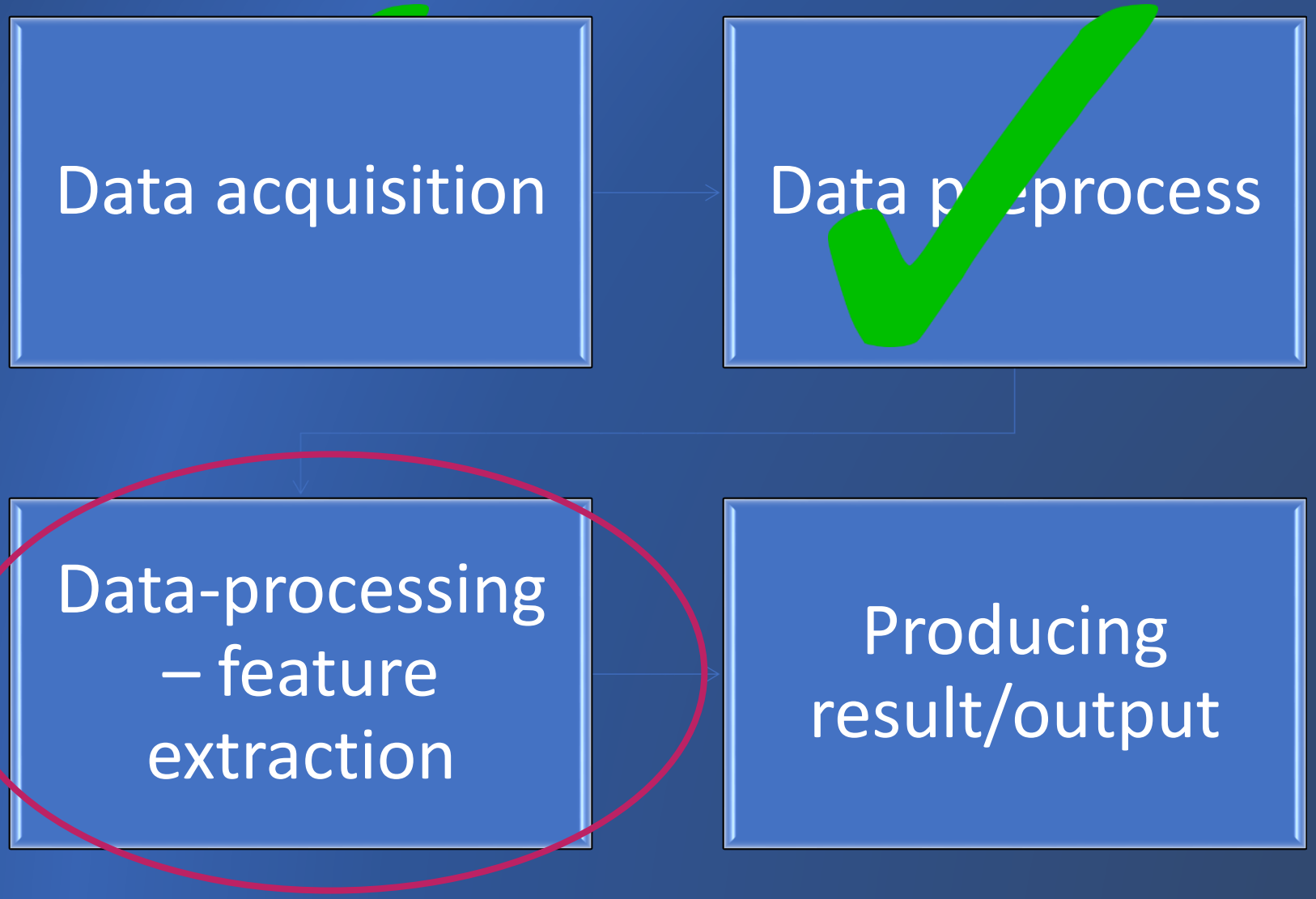
ICLabel results shown using the Viewprops plugin.

trained on thousands of labeled ICs and hundreds of thousands of unlabeled ICs.

Practice

https://labeling.ucsd.edu/tutorial/practice



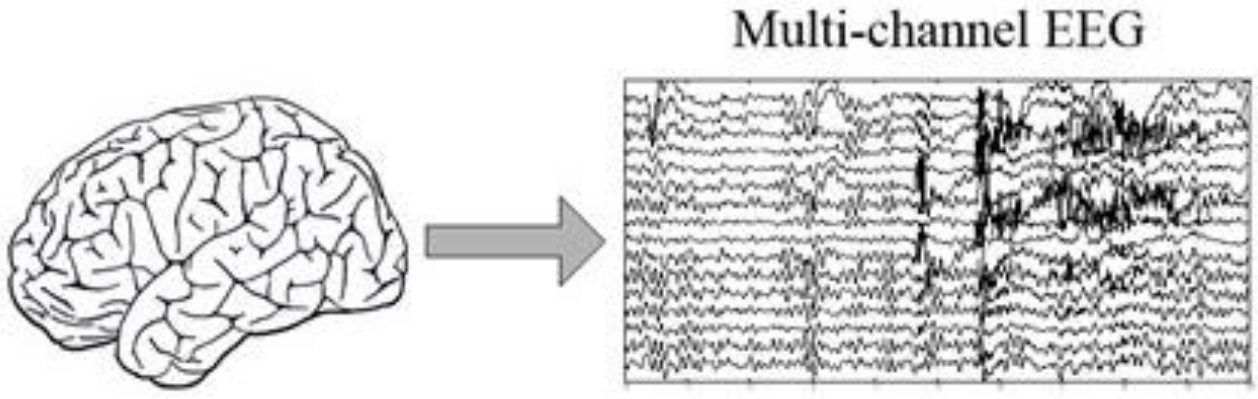

Data acquisition
Data preprocess
Data-processing – feature extraction
Producing result/output


Feature extraction

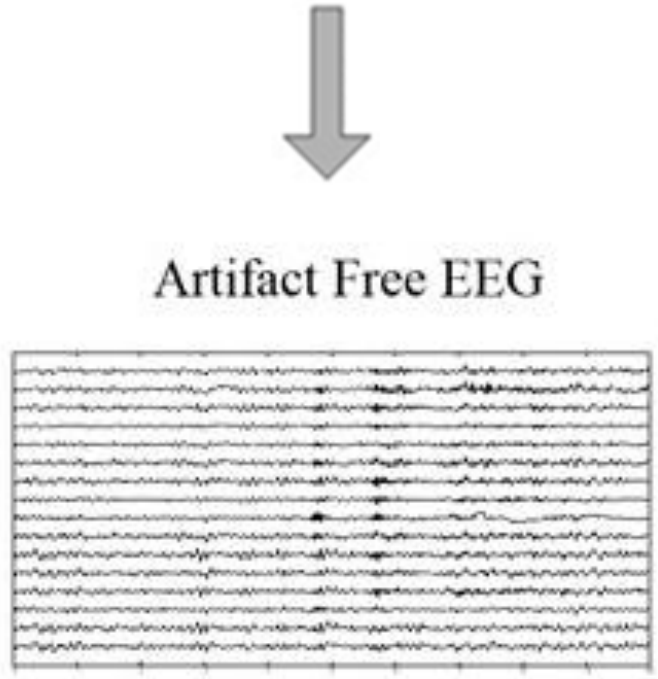
Stage 2 : Processing (Feature Extraction)

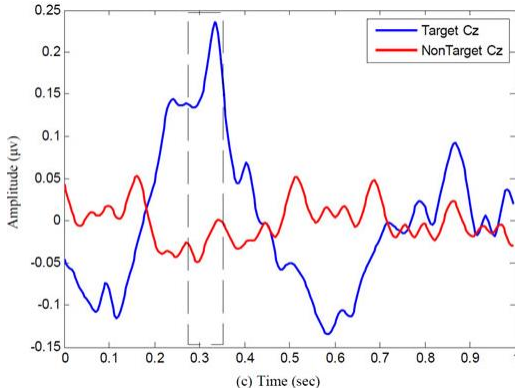
Why we need feature extraction?

NBML


Multi-channel EEG


preprocessing


Artifact Free EEG

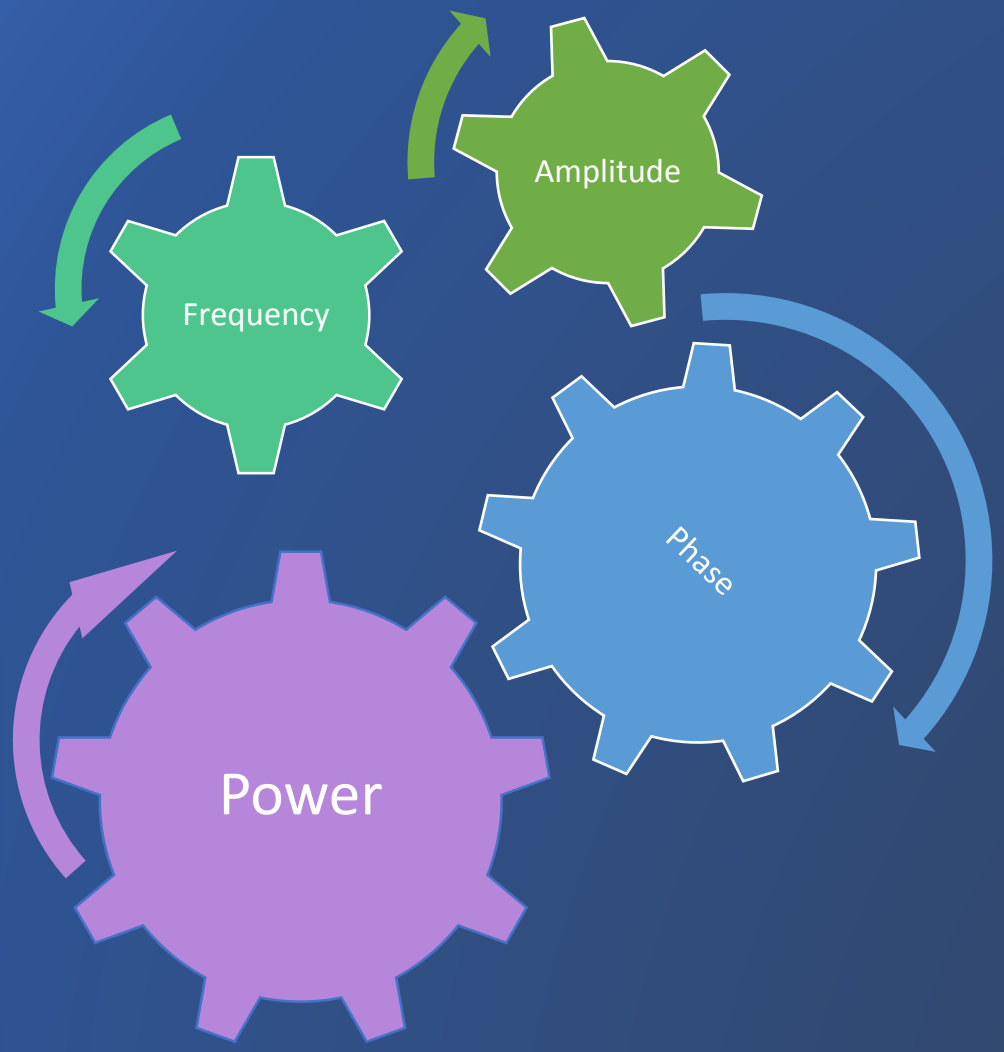

Target Cz
NonTarget Cz
Amplitude (μv)
(c) Time (sec)

Frequency Is speed of an oscillation/ rhythm (number of oscillation per second)

Unit: HZ

0-100 HZ

0-45 HZ



Amplitude in time

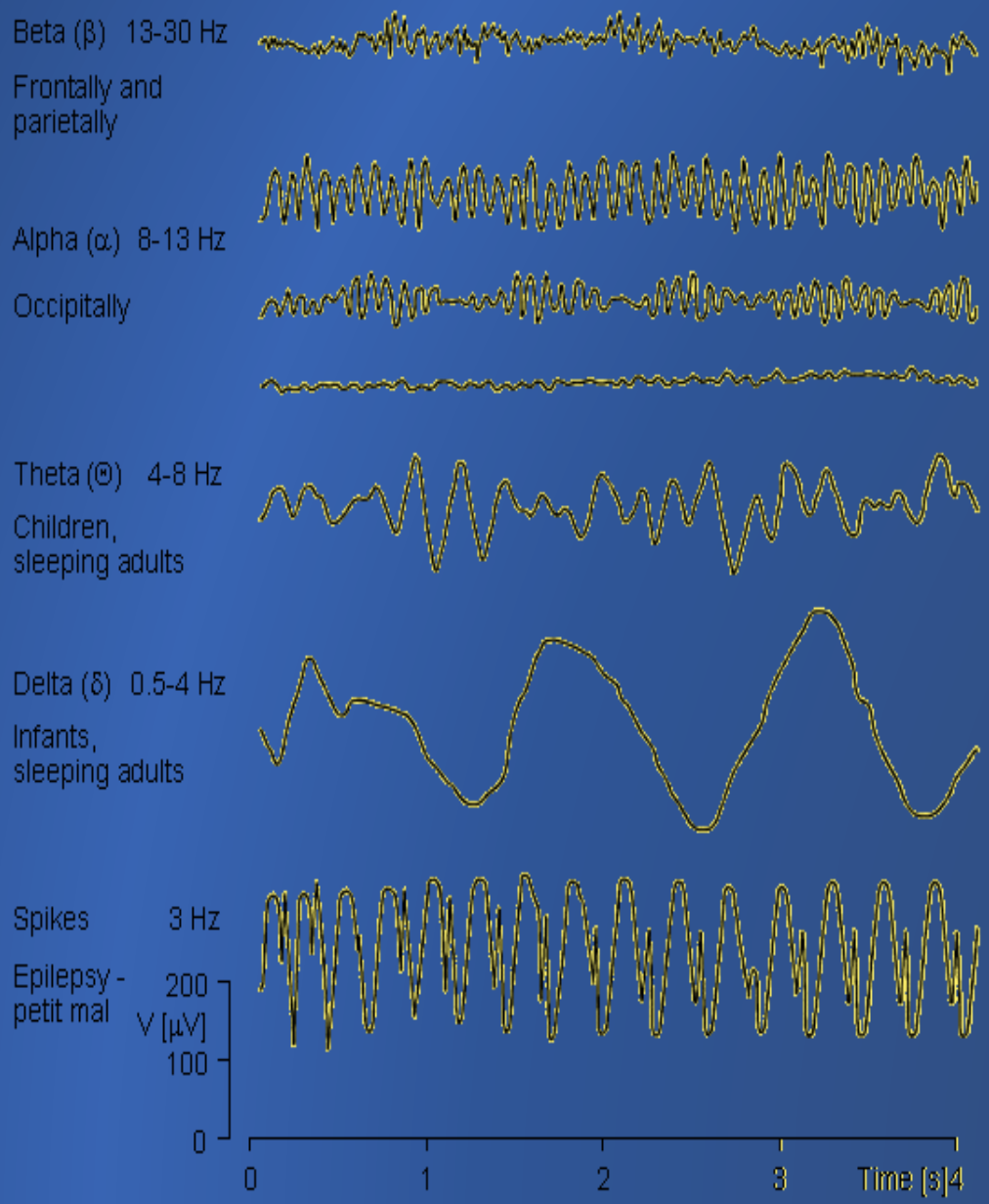
Power: amount of energy in each frequency band

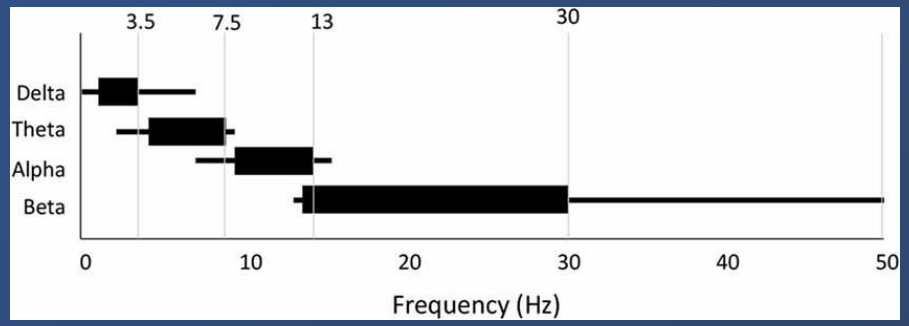
Squared amplitude

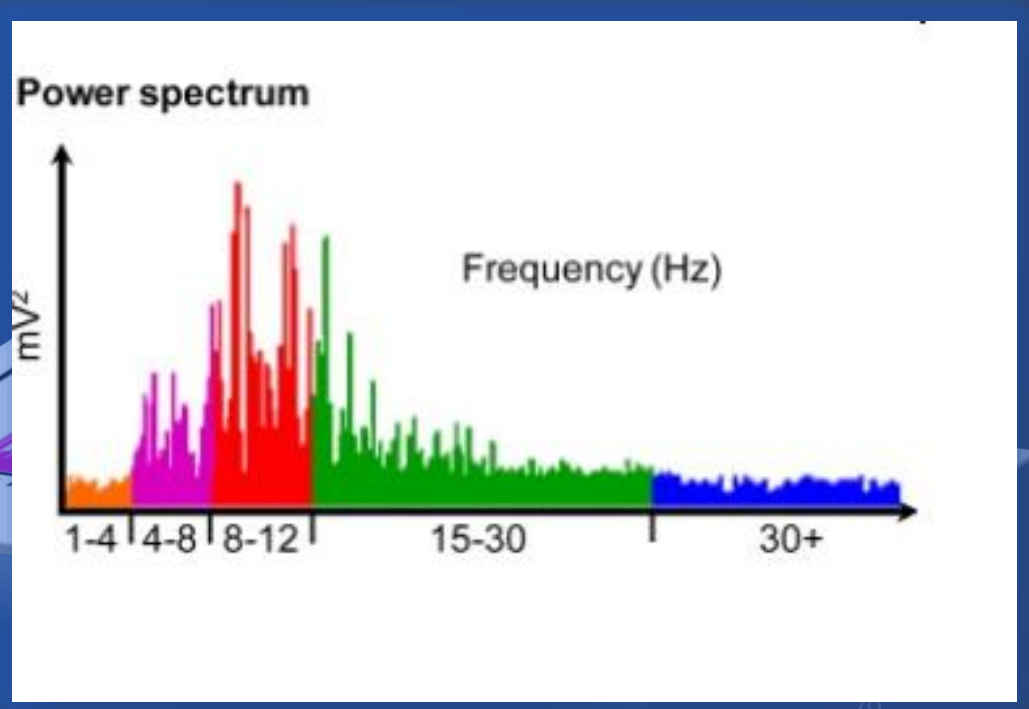
Amount of synchronization among neurons or

NBML

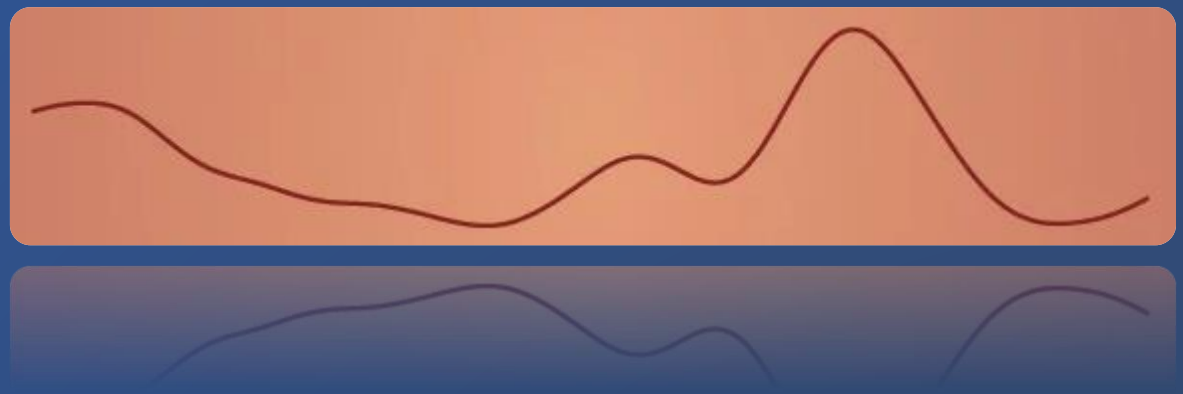
EEG Frequency Band



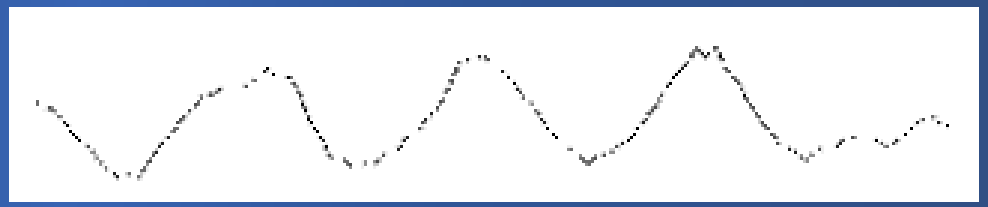




Delta wave

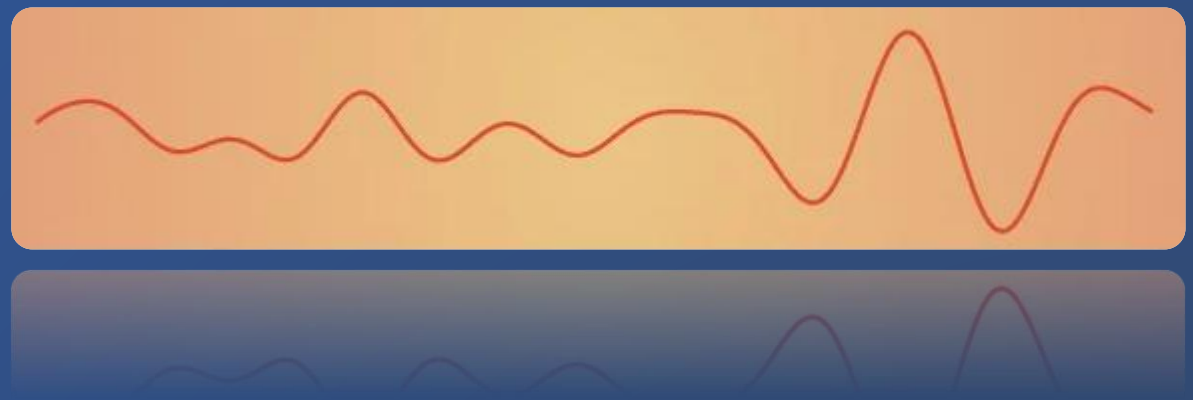


- slow, < 3.5 Hz
- in adults
- normal sleep rhythm (stages III & IV)



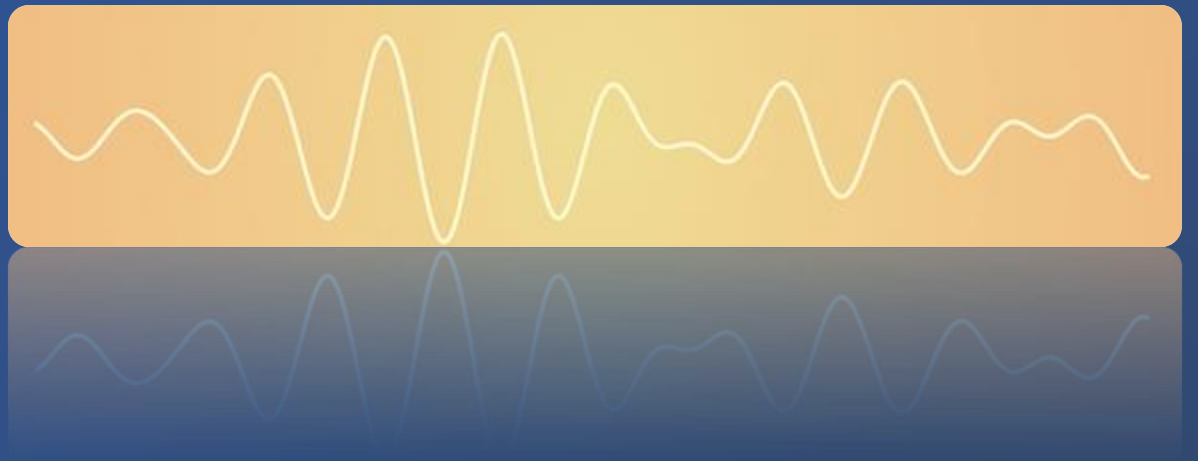
NBML

Theta wave



- rhythmic, 4-7 Hz
- Drowsy, sleep (stage I)

NBML

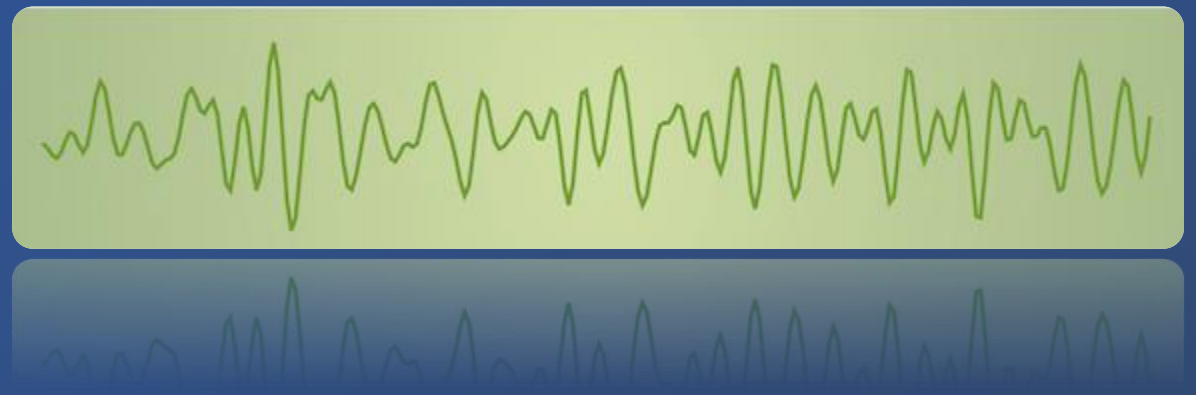


Alpha wave

- rhythmic, 8-13 Hz
- mostly on occipital lobe
- 20-200 μ V
- Normal
- Physically and mentally relaxed
- relaxed awake rhythm with eyes closed

NBML

Beta wave



- irregular, 14-30 Hz
- mostly on temporal and frontal lobe
- mental activity, sensory-motory recovery
- excitement

NBML

Gamma wave

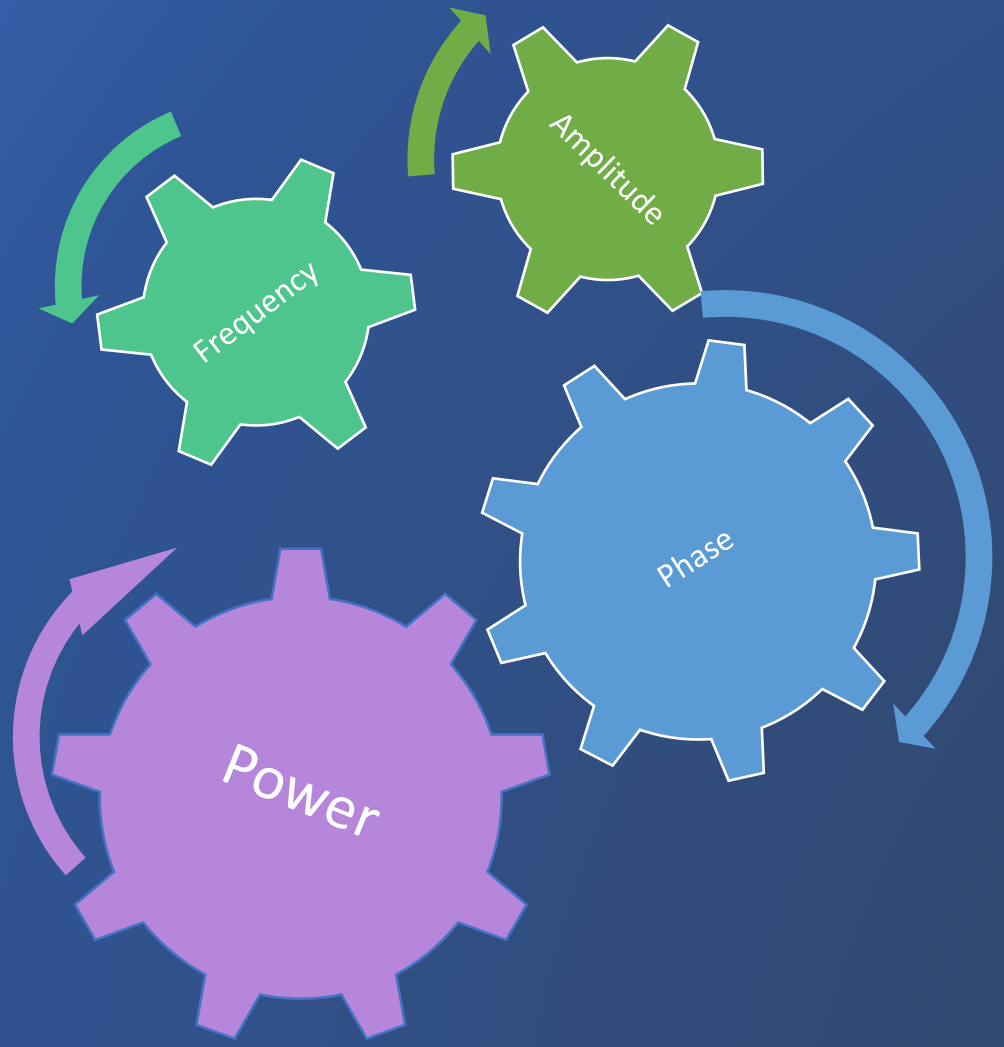
- >30 Hz
- frontal and central lobes
- inspiration, focus, higher learning

Frequency Is speed of an oscillation/ rhythm (number of oscillation per second)

Unit: HZ

0-100 HZ

0-45 HZ

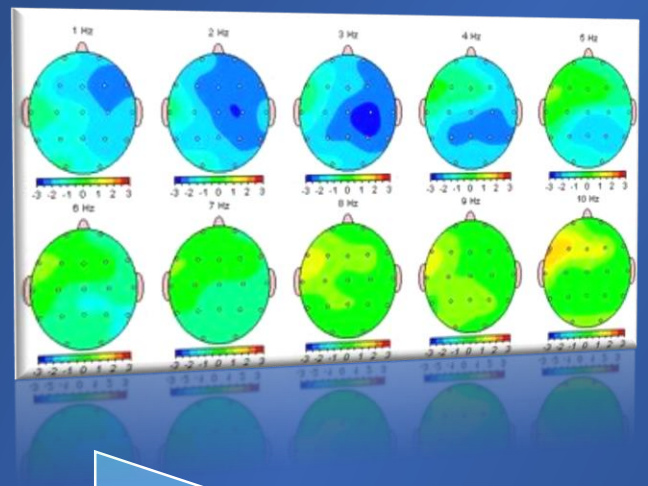


Amplitude in time

Power: amount of energy in each frequency band

Squared amplitude

Amount of synchronization among neurons or



Time-Domain analysis

- Maximum and Minimum
- Mean
- Variance
- Skewness
- kurtosis

Frequency-Domain analysis

- Absolute Power
- Relative Power
- Mean frequency

Time-Frequency analysis

- Wavelet Transform
- Hilbert–Huang transform
- STFT

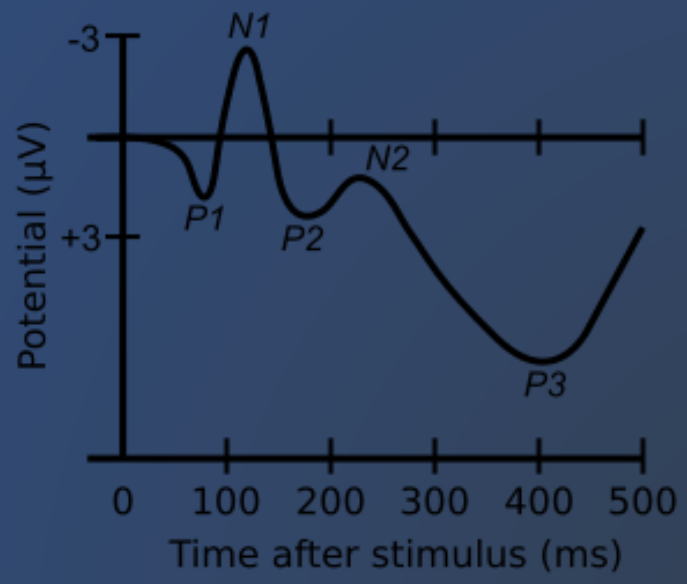
Non-Linear analysis

- Approximate entropy
- Correlation dimension

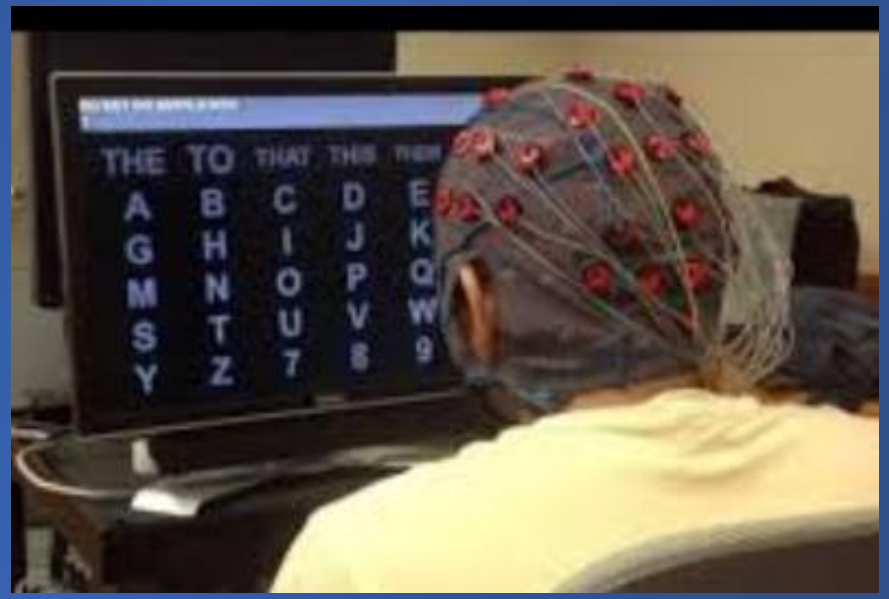
ERP

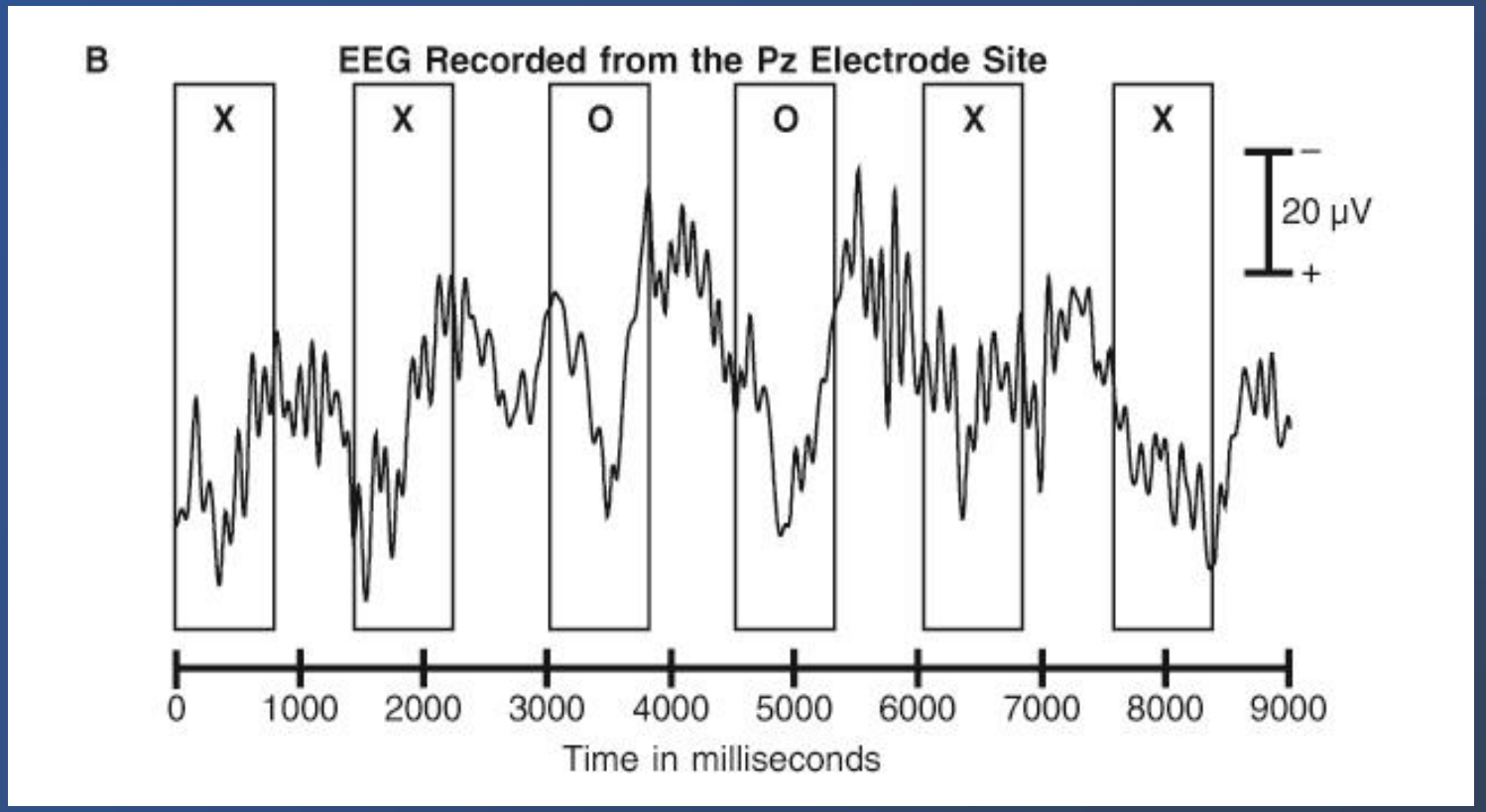
- Event-related potentials (ERPs) are very small voltages generated in the brain structures in response to specific events or stimuli (Blackwood and Muir, 1990).

- Stimulus-locked



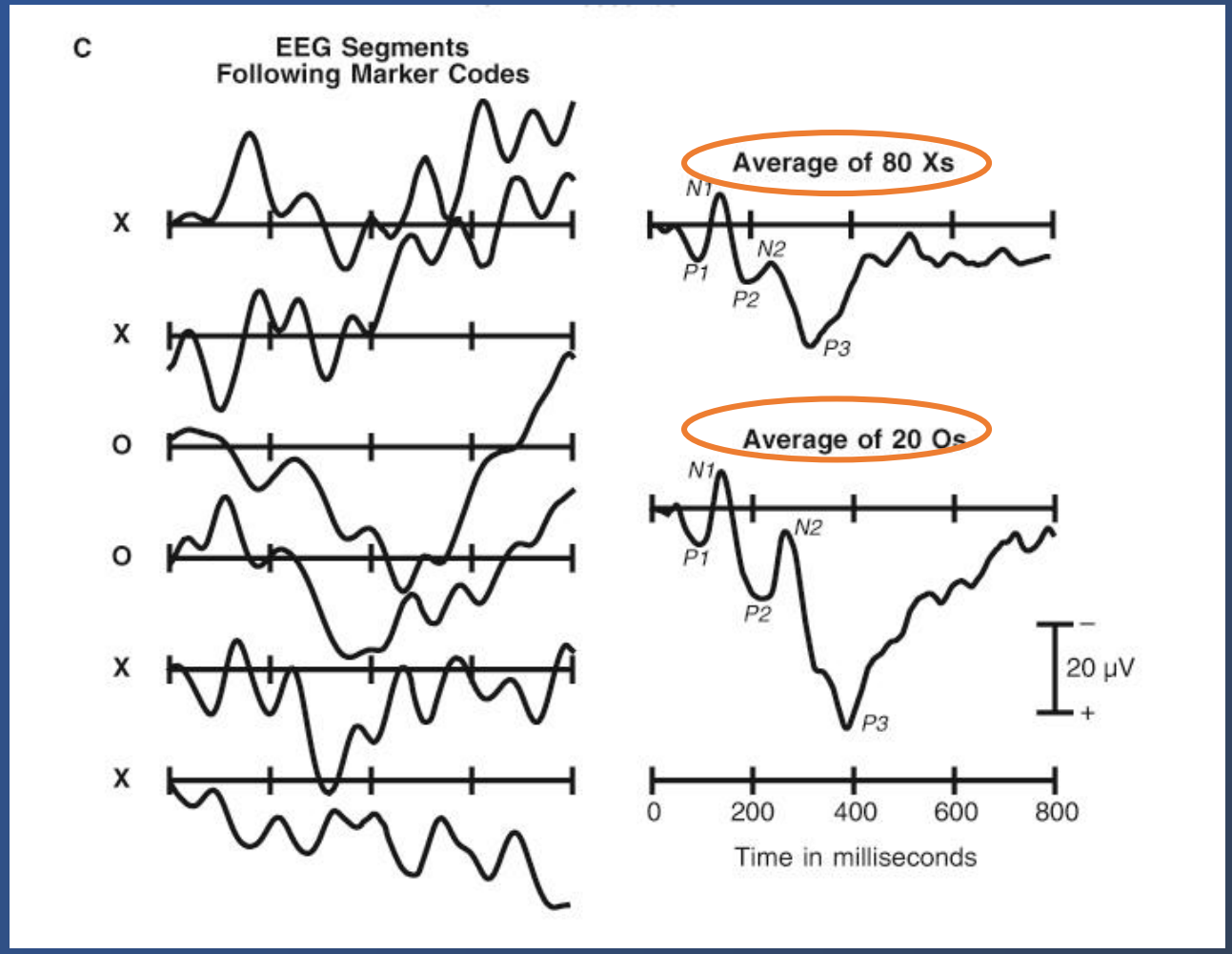
ERP (cont.)

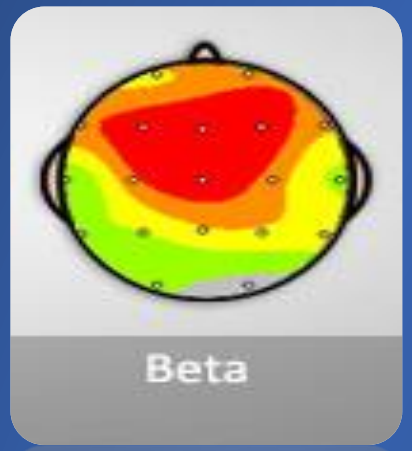

THE TO THAT THIS
A B C D E
G H I J K
M N O P Q
S T U V W
Y Z 7 8 9

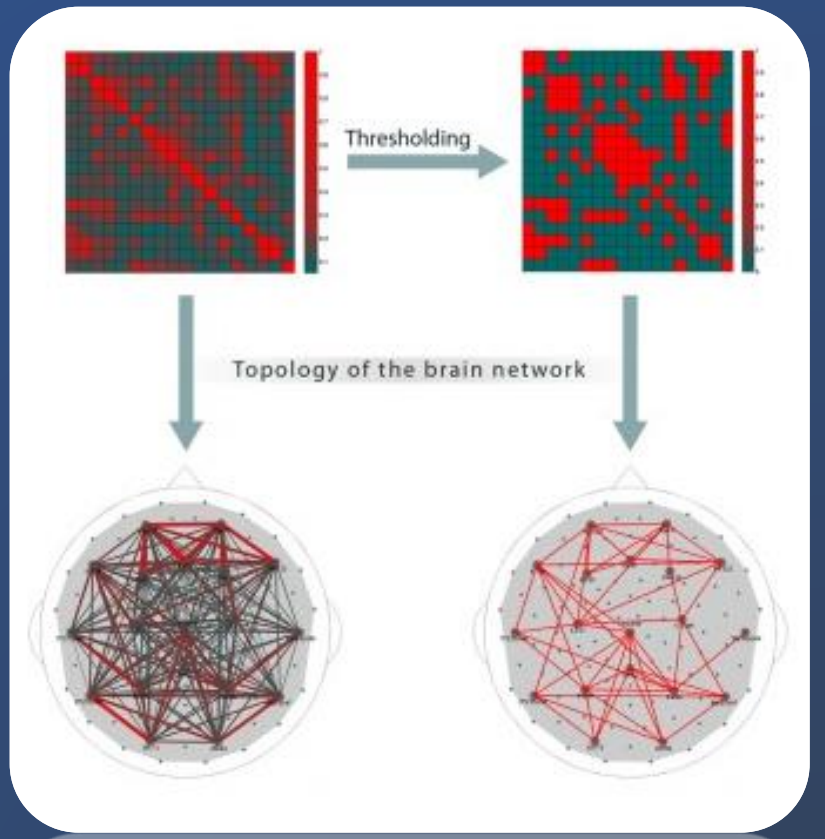

B
EEG Recorded from the Pz Electrode Site
X
X
O
O
X
X
20 μV
−
+
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Time in milliseconds

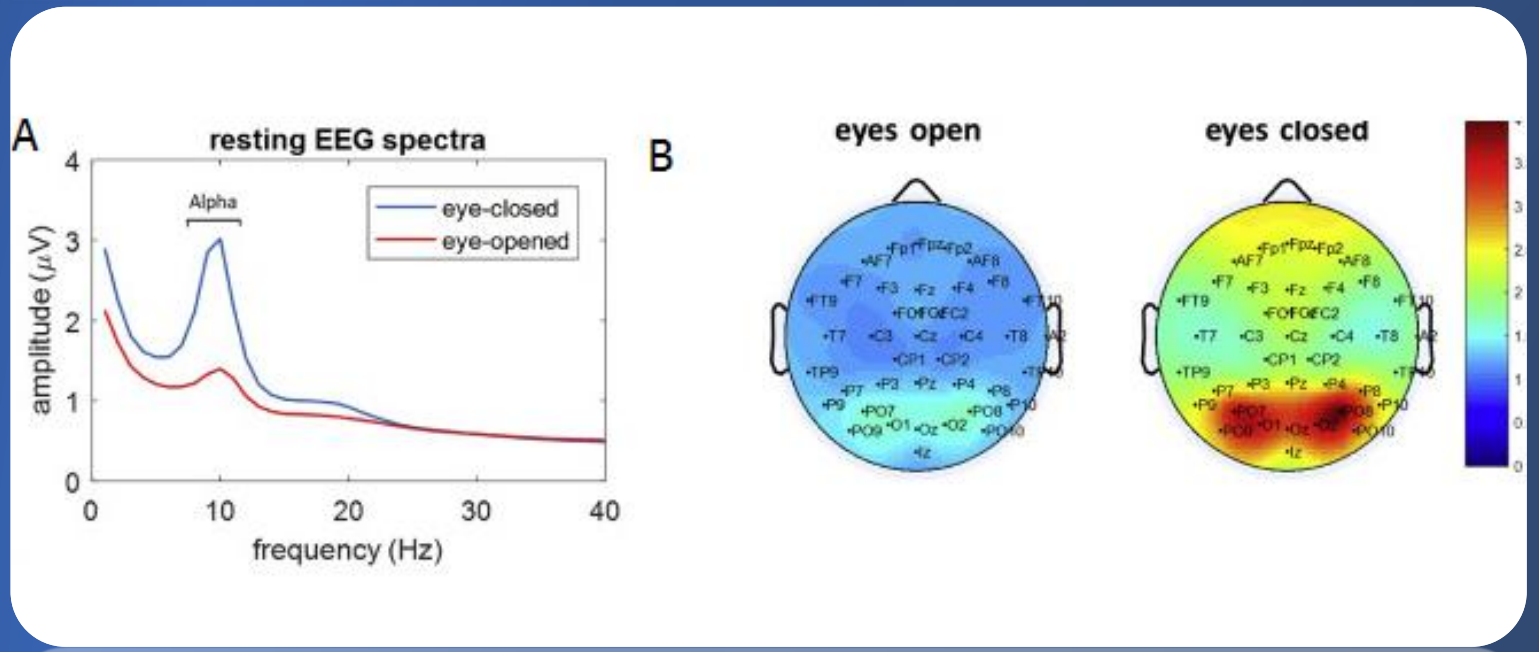
ERP (cont.)

- **Occurrence**
- **Amplitude**
- **Latency**




Beta


Thresholding
Topology of the brain network


A
resting EEG spectra
Alpha
eye-closed
eye-opened
amplitude (μV)
frequency (Hz)
B
eyes open
eyes closed

NBML

Thank you for your attention