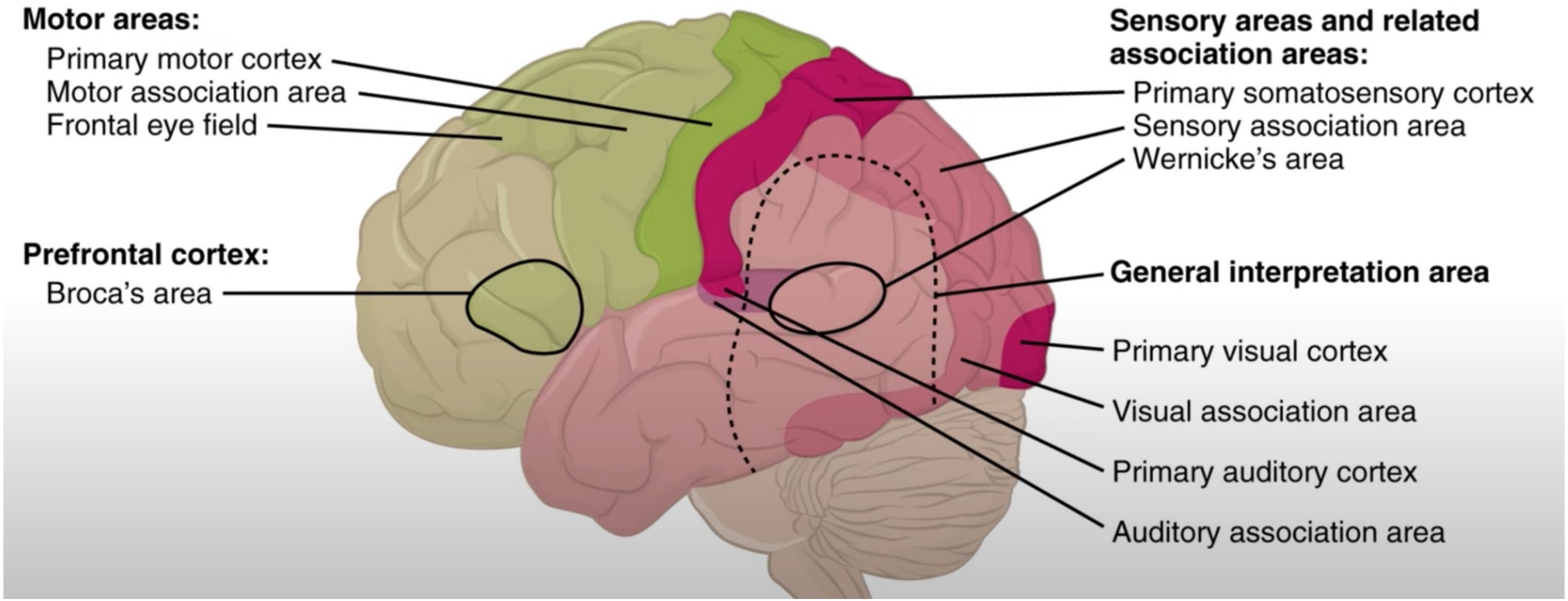
Week 2

Language and the brain


Motor areas:
Primary motor cortex
Motor association area
Frontal eye field
Prefrontal cortex:
Broca's area
Sensory areas and related association areas:
Primary somatosensory cortex
Sensory association area
Wernicke's area
General interpretation area
Primary visual cortex
Visual association area
Primary auditory cortex
Auditory association area

EEG vs. ERP

— From “where” to “when”

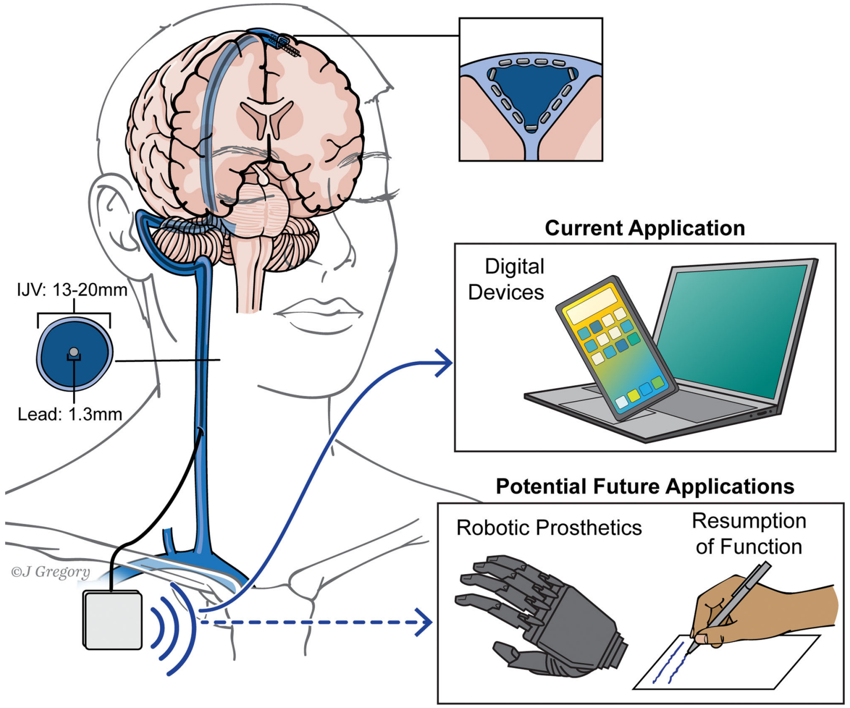
In which one of these pictures is an EEG measurement session taking place?

What biological property do we measure with EEG?

- A. difference in blood flow
- B. difference in electrical potential
- C. differences in the magnetic filed
- D. differences in temperature

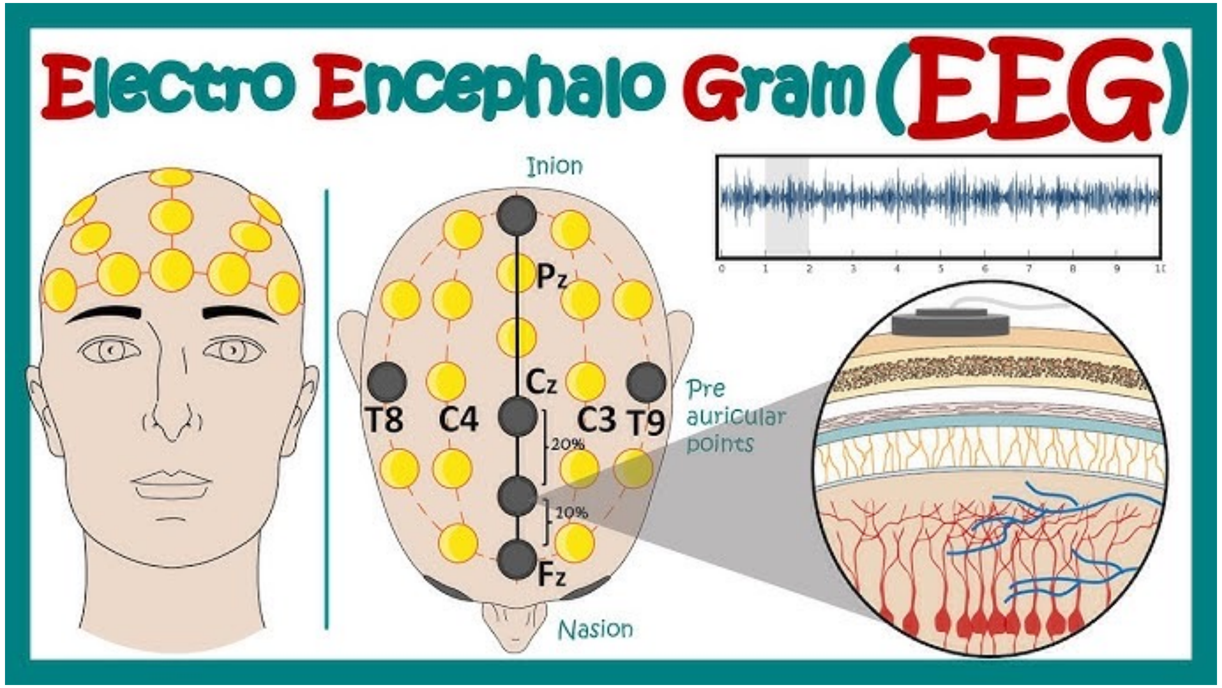
Can we read your thoughts using EEG?

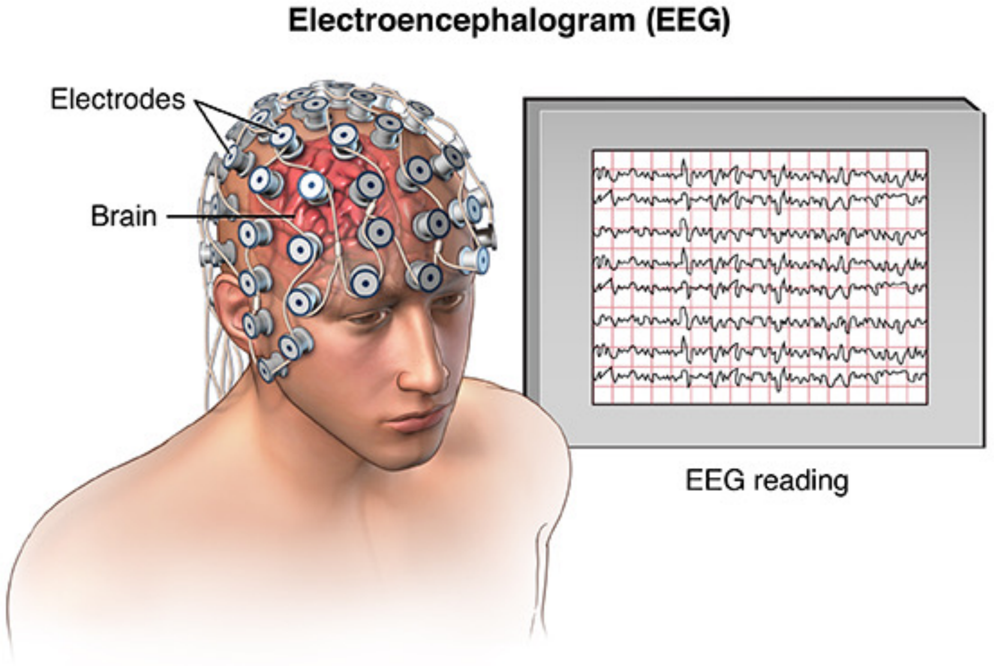
- A. yes
- B. no
- C. not yet, but we might in the future
- D. sort of, it depends.



Electro-encephalo-gram (EEG, 脑电图)

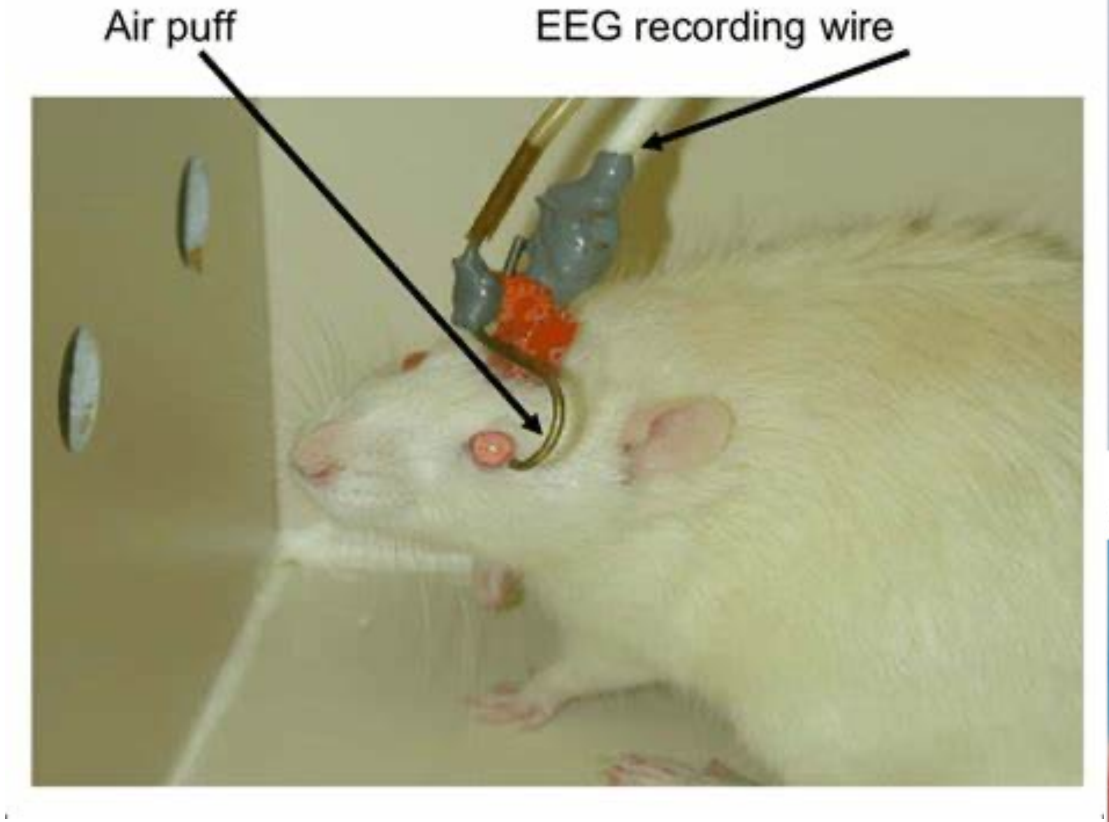
- EEG is a method to record the ***spontaneous electrical activity*** by placing electrodes on the scalp.
- EEG recordings represent the activity of the surface layer of the brain underneath the scalp.
- During the test, small sensors are attached to the scalp to pick up the electrical signals produced by the brain.

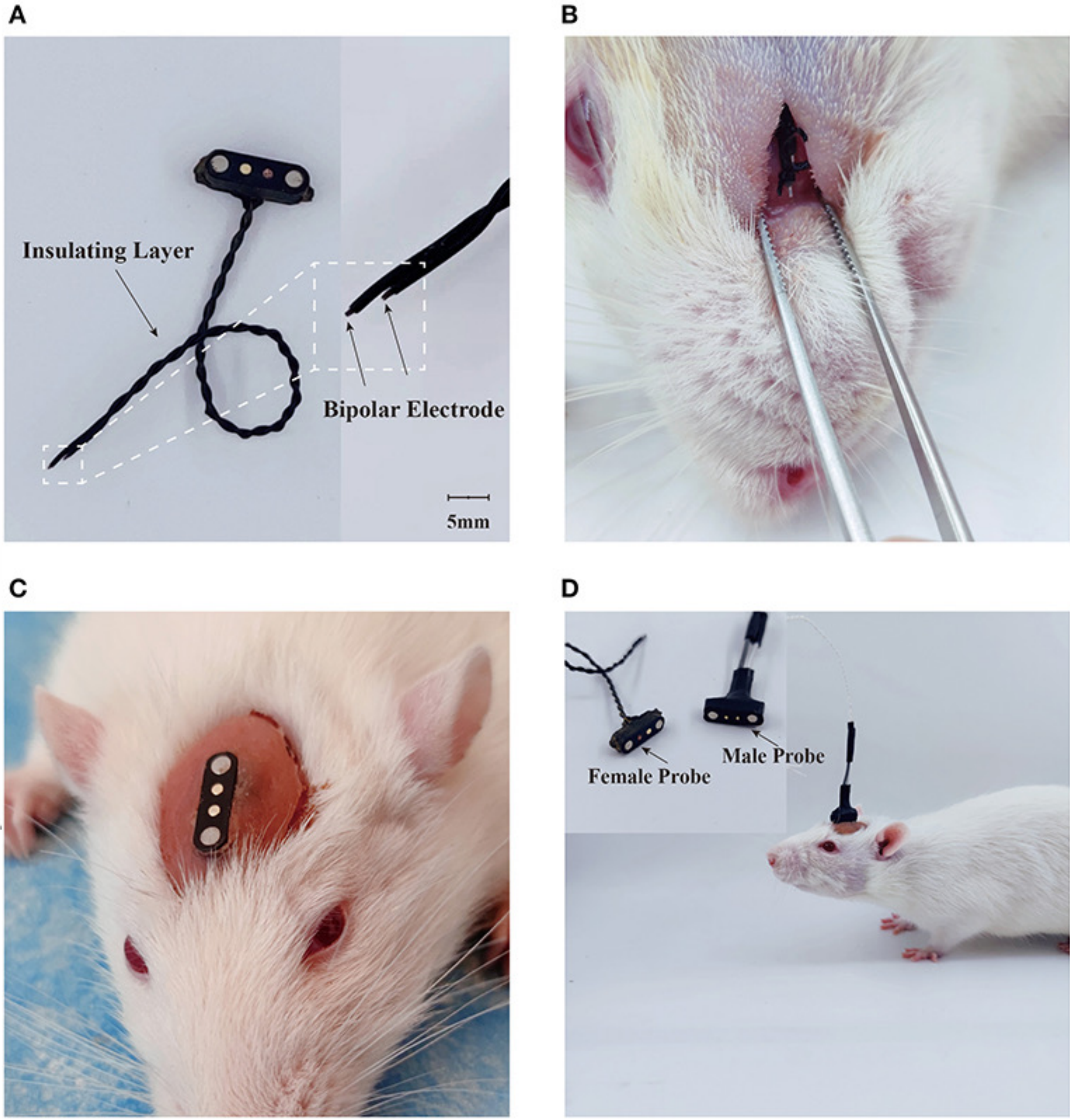




Your brain is on 24/7

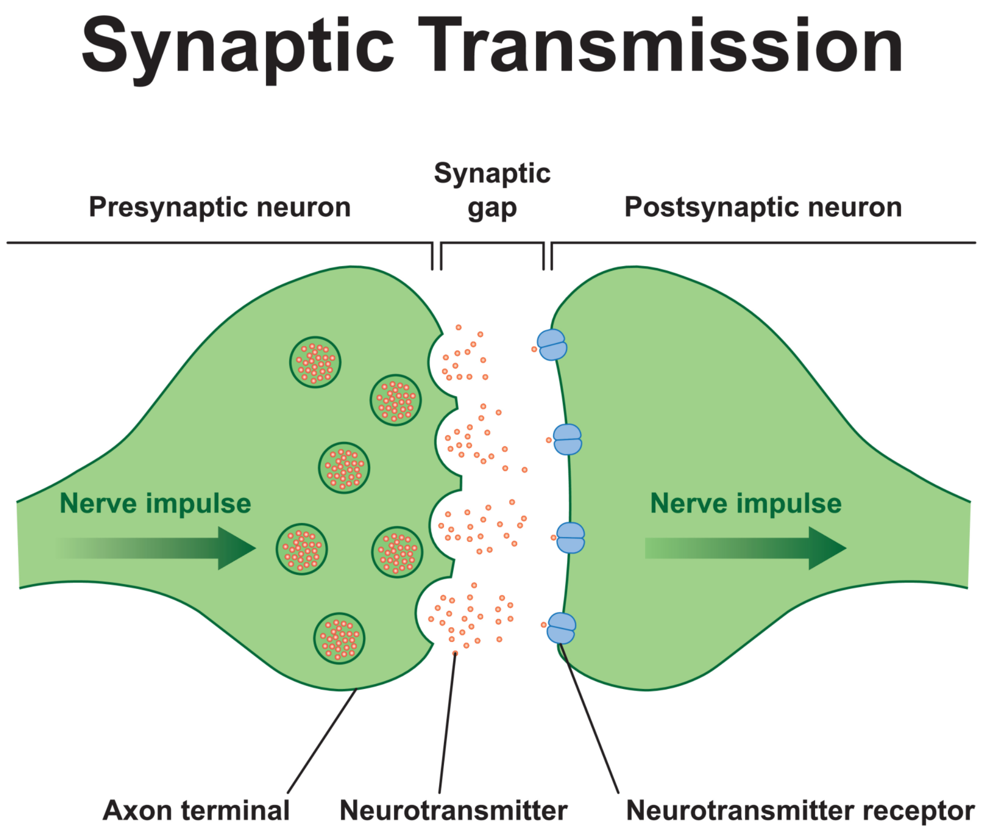
- No matter whether you’ re asleep or awake, preparing the assignment of quiz– as you think, dream, see and sense, your brain is constantly active.
- It absorbs all information, compacts and re-wires existing data, and integrates everything into a consistent experience, both of yourself and of your surroundings.
- Based on your thoughts, emotions, desires and experiences, your brain ultimately drives your behaviour. It even controls behavioural processes without you even noticing.


Air puff
EEG recording wire


A
Insulating Layer
Bipolar Electrode
5mm
B
C
D
Female Probe
Male Probe

Excitatory vs. inhibitory neurons

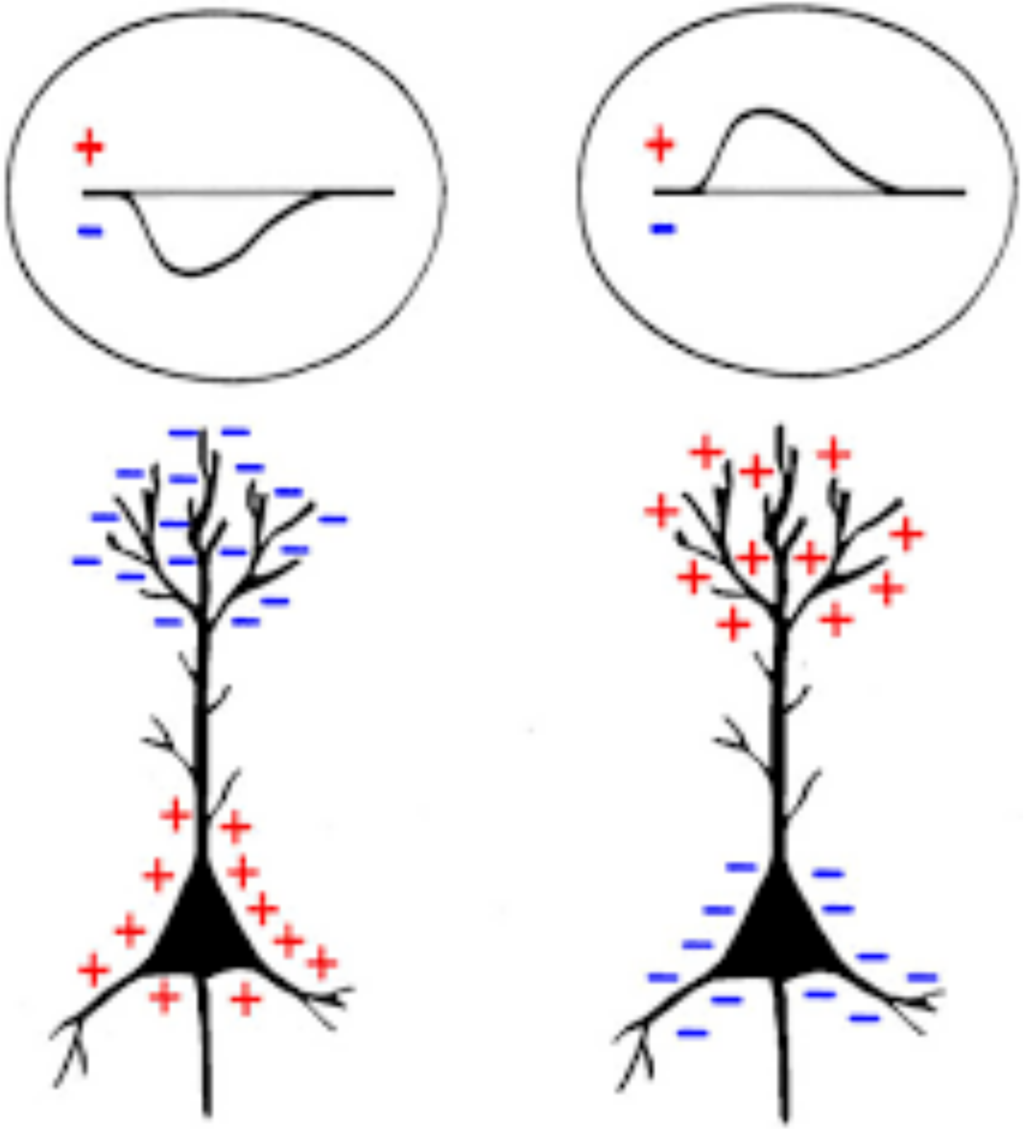
- If the neurotransmitter is excitatory, the post-synaptic neuron can fire action potentials (electrical impulses). If the neurotransmitter is inhibitory·, then the post-synaptic neuron may be unable to transmit signal.
- At the dendrites, the chemical message is converted back into an electrical impulse, and the transmission process occurs again.

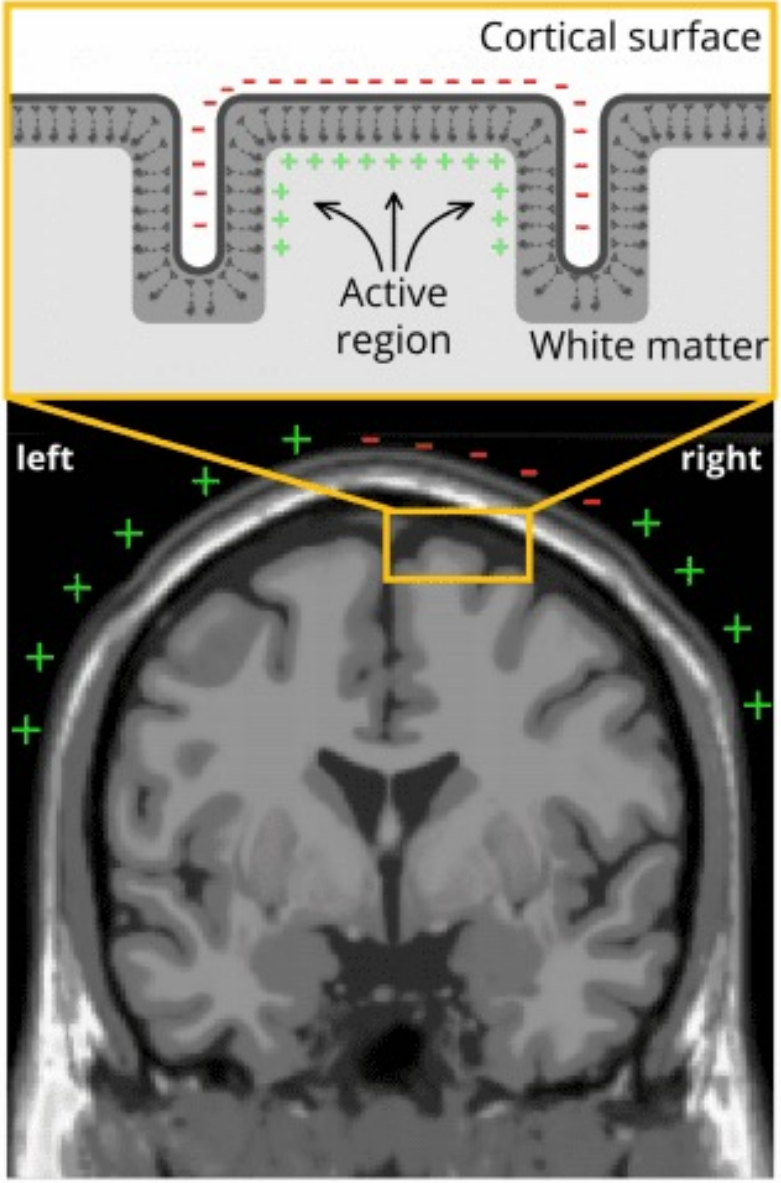


Excitatory vs. inhibitory neurons

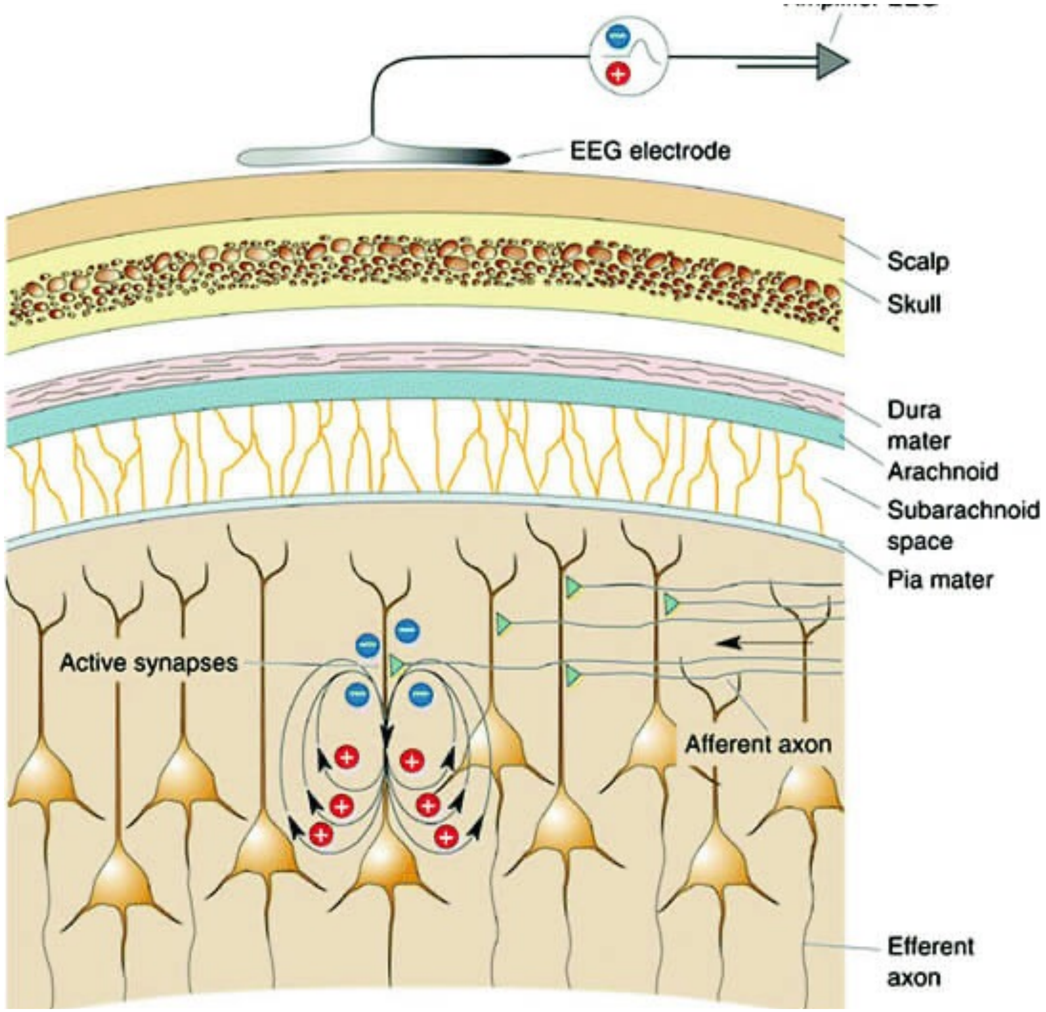
- In excitatory process, the electrochemical gradient drives sodium (钠离子) to rush into the cell. When sodium brings its positive charge into the cell, the cell’ s membrane potential （膜电位）becomes more positive, or depolarizes （去极化）.

- In inhibitory process, potassium （钾离子）go out of the cell, causing the potential of cell to become more negative. This change is called a hyperpolarization （超极化）.



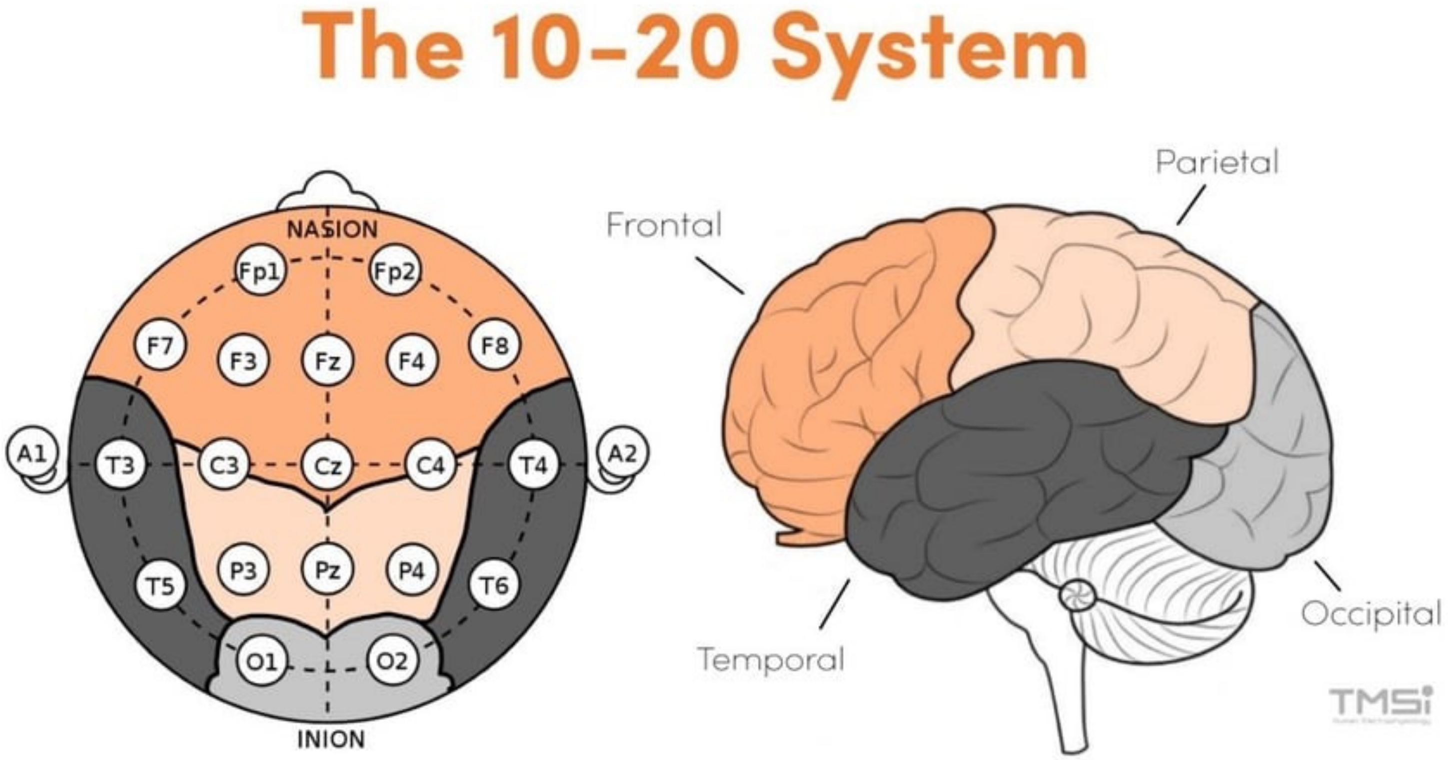


- Synaptic activity often generates a subtle electrical field, which is also called a postsynaptic potential (突触后电位), which typically last tens to hundreds of milliseconds.
- The postsynaptic potential of a single neuron is too tiny to even be noticed. However, whenever the voltage change associated with a postsynaptic potential occurs for a smaller group of neurons (about 1000 or more), the resulting electrical field becomes much stronger.
- Signal intensity is quite small, measured in microvolts (One millionth (10^{-6}) of a volt, abbreviated as µV)



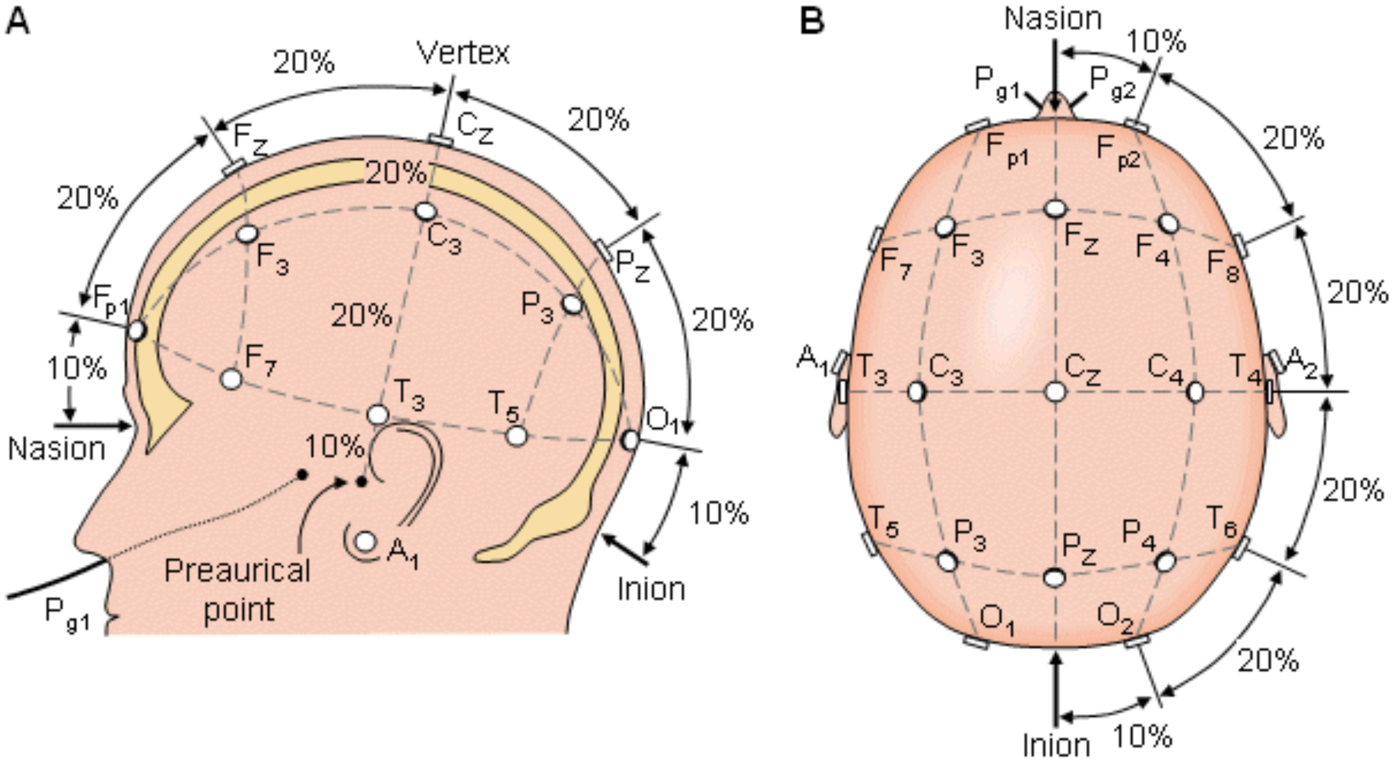
- Not all electrical fields generated by the brain are strong enough to spread all the way through tissue, bone and skull towards the scalp surface.
- Research indicates that it is primarily the synchronized activity of pyramidal (椎体细胞) neurons in cortical brain regions which can be measured from the outside (i.e. from EEG devices). Pyramidal neurons are organized in columns.
- Pyramidal cells can be found in all cortical areas (occipital, temporal, parietal, frontal cortices), where they are always oriented perpendicular(垂直的) to the cortical surface. The cell body is heading away from the surface (towards the grey matter), while their dendrite is heading towards the surface

Where are these electrodes placed?



Where are these electrodes placed?

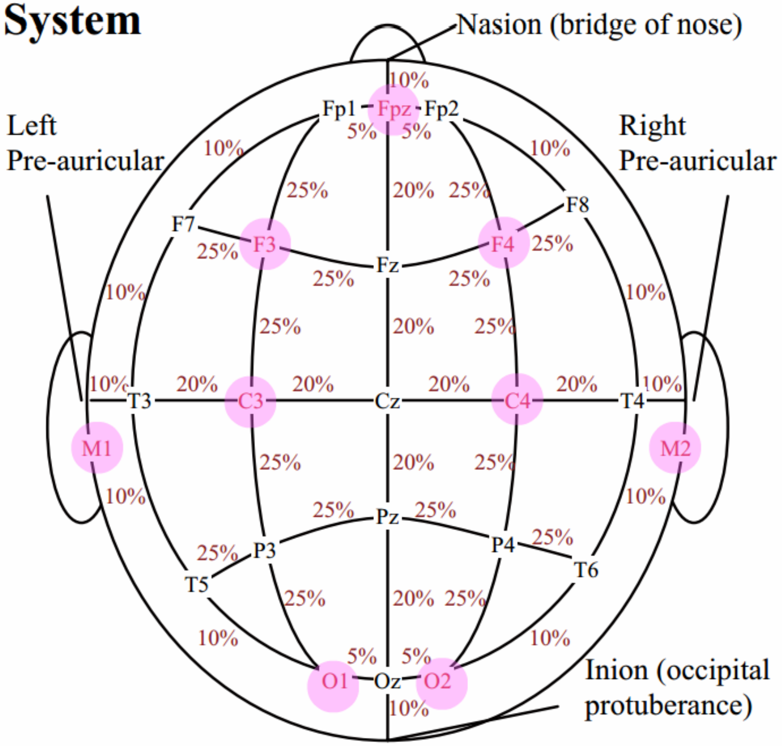
- **The 10-20 system** was presented to standardized method of EEG placement.
- The numbers "10" and "20" refer to the distances between adjacent electrodes, which are either 10% or 20% of the total distance (front-back or right-left) of the skull.
- The total distance is based on the anatomical locations on the scalp: nasion(鼻根) and inion(枕骨隆起) (front-back direction) and the two preauricular (耳前) points (right-left direction).

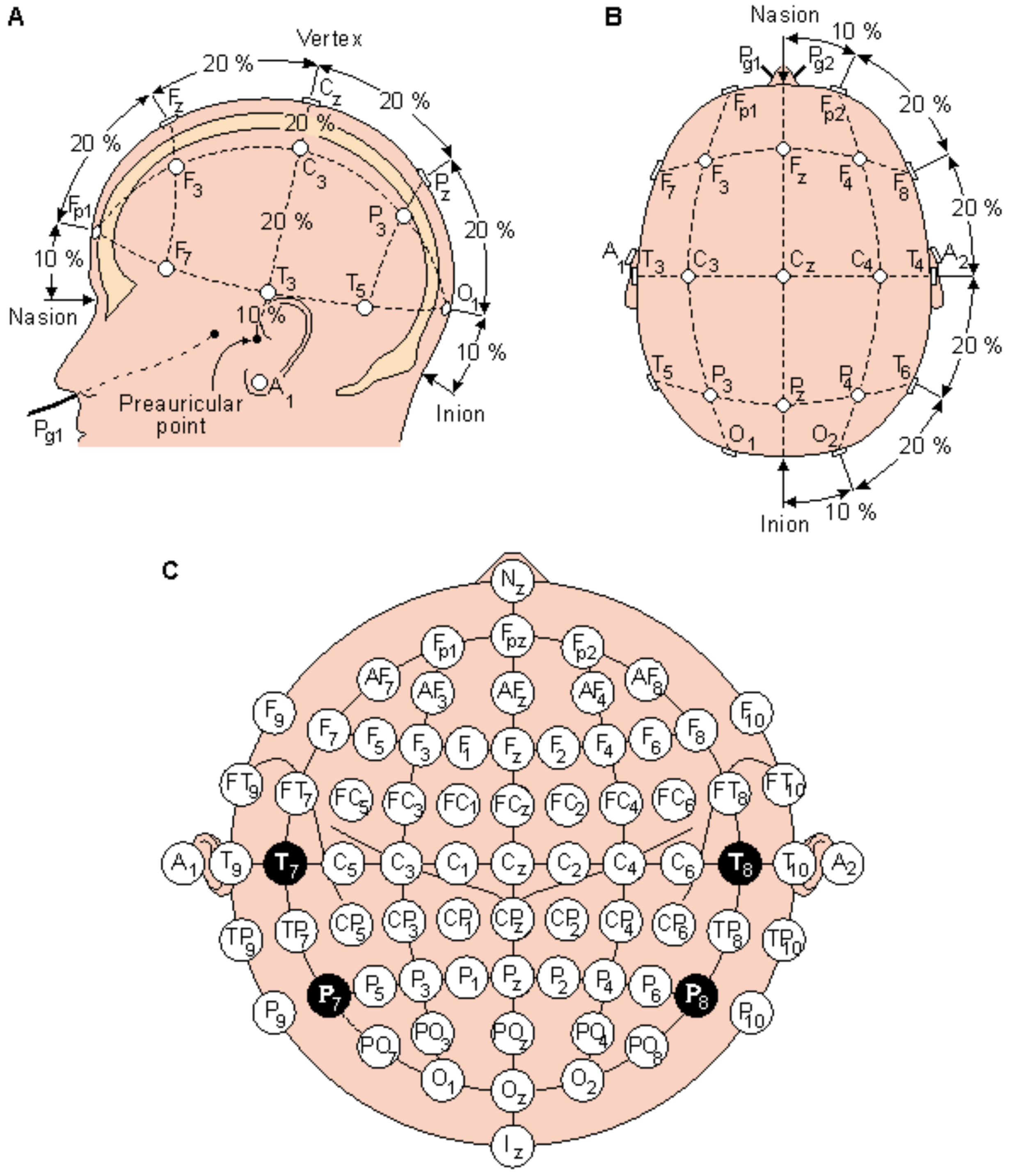


International 10/20 System

The following EEG electrode sites are used in a standard overnight sleep study:

- F3
- F4
- C3
- C4
- O1
- O2
- M1
- M2
- FpZ





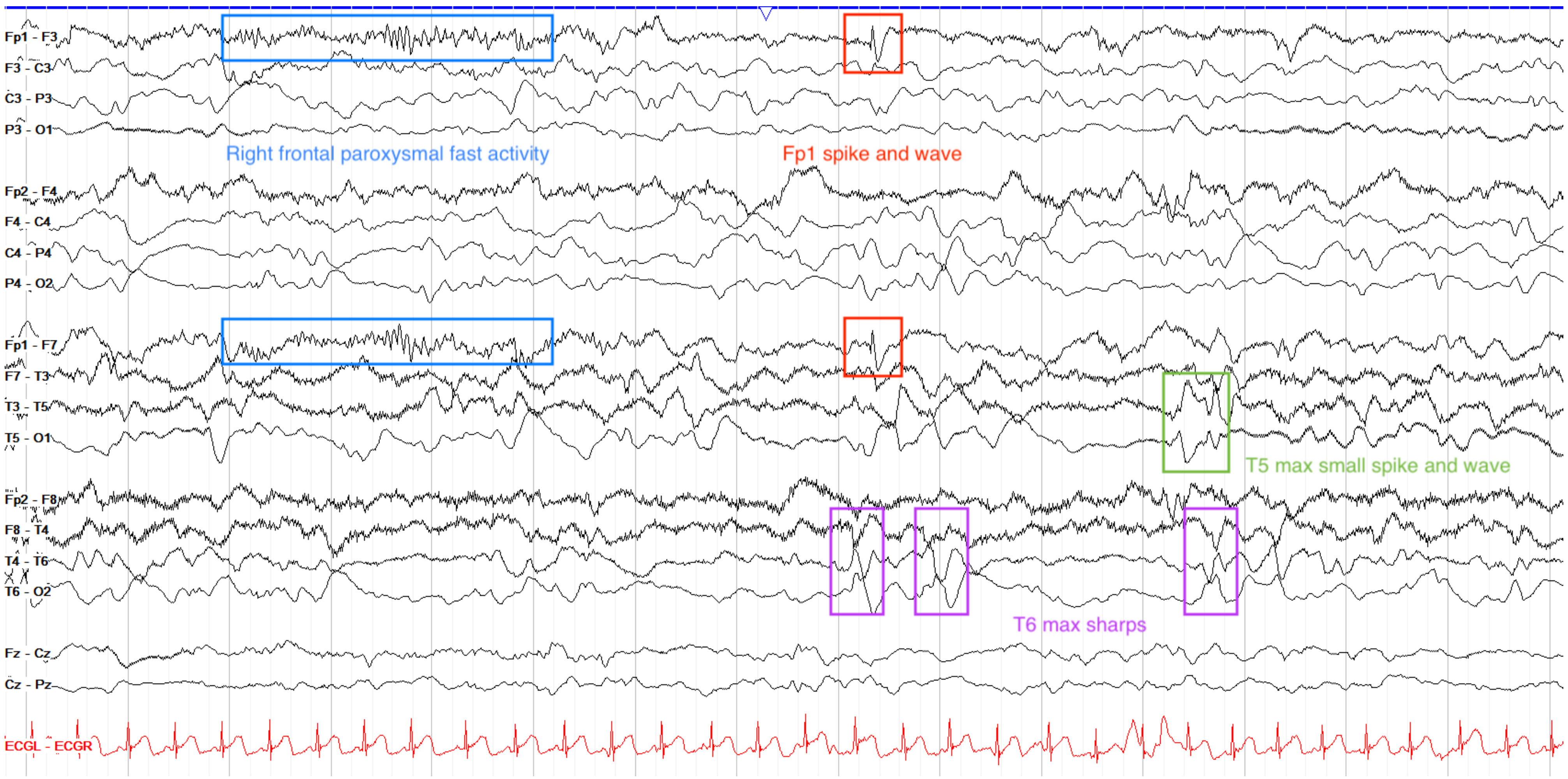
Why EEG?

- EEG has very high time resolution and captures cognitive processes in the time frame in which cognition occurs;
- EEG directly measures neural activity;
- EEG is inexpensive, lightweight, and portable;
- EEG monitors cognitive-affective processing in absence of behavioral responses.

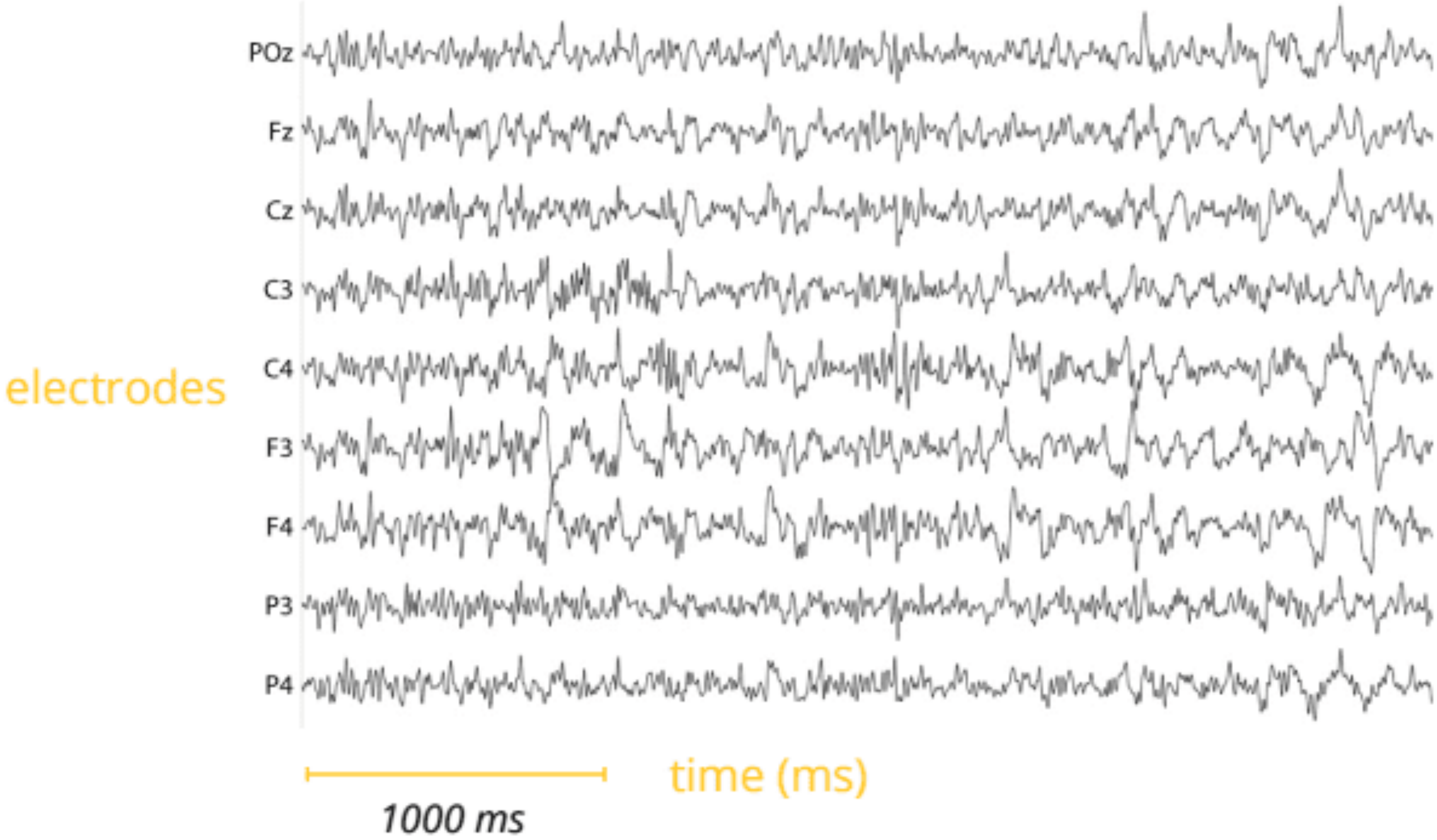
Compared to other brain imaging techniques:

- **Magnetoencephalography (MEG)** records the magnetic fields generated by neural activity. Like EEG, MEG has excellent time resolution and is often considered to capture deeper neural activity much better than EEG. MEG scanners are large and expensive. They require heavy technical maintenance and training resources.
- **Functional Magnetic Resonance Imaging (fMRI)** measures changes in blood flow which is associated with changes in neural activity. Increased neural firing requires oxygen, which is delivered by blood, and the magnetic properties of oxygenated blood are different from those of non-oxygenated blood. fMRI has excellent spatial resolution while at the same time lacking the time resolution of EEG.

- EEG is used to diagnose epilepsy, as well as to diagnose other medical conditions like sleep disorders or brain injuries, and to monitor brain activity during surgery or when a person is in a coma

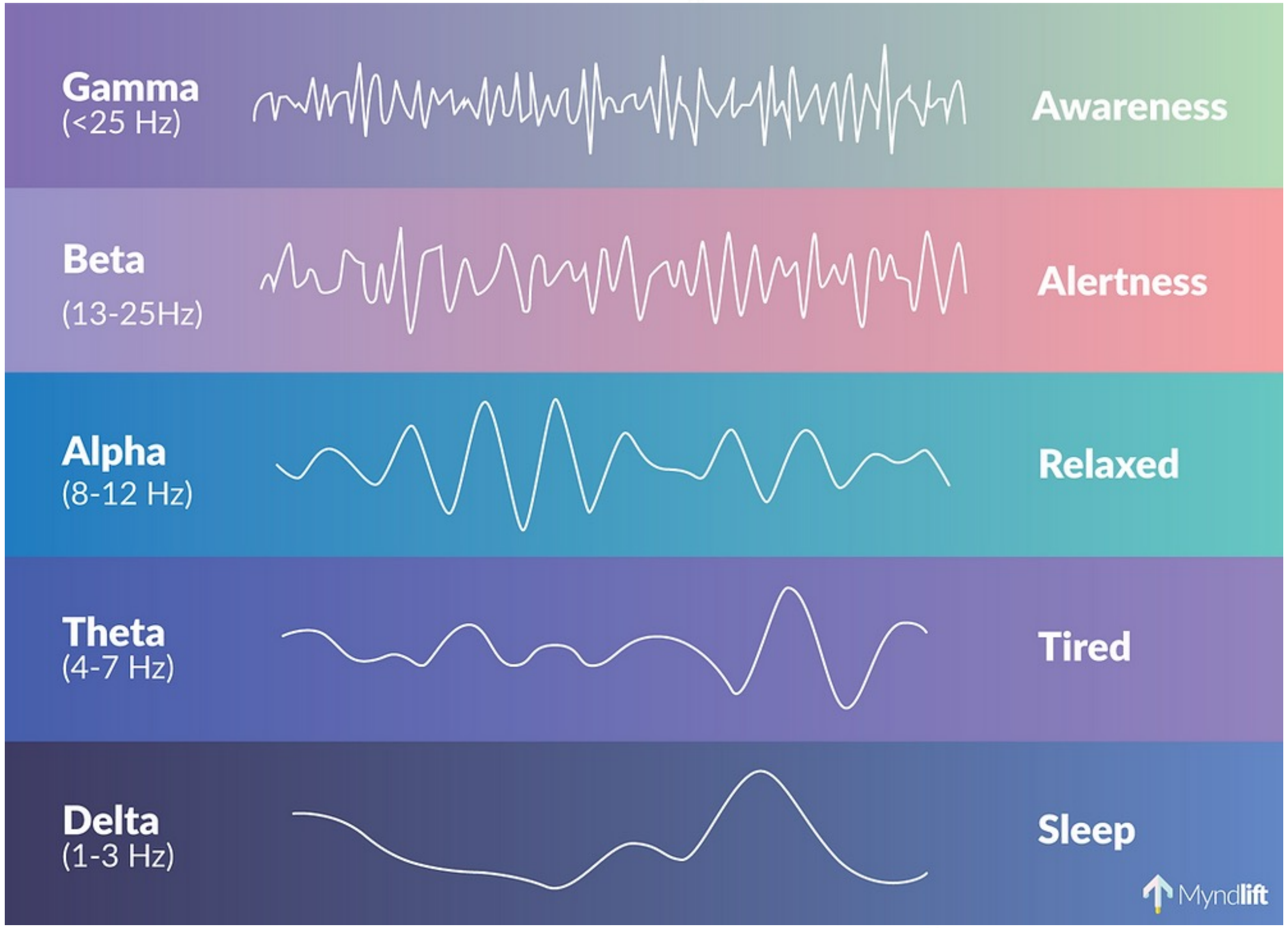


Two or three dimensional?

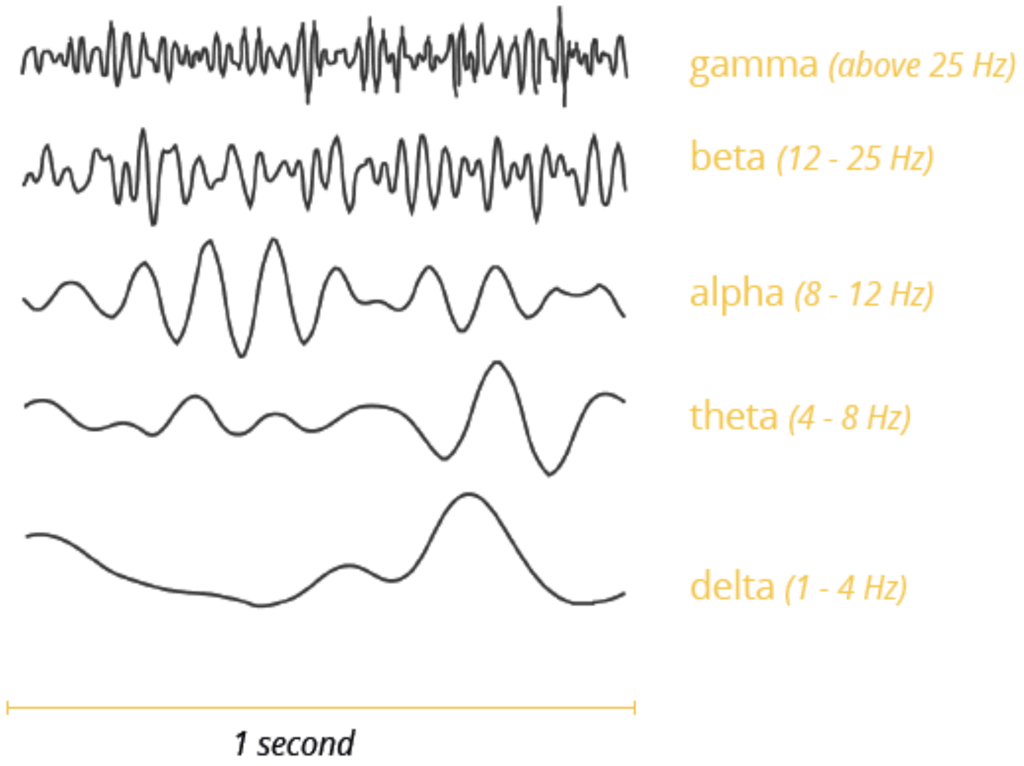


- EEG signals are a mixture of different frequencies, and Fourier Transform can reveal peaks at specific frequencies.

- Neural oscillation, synchronized rhythmic patterns of electrical activity produced by neurons in the brain. In the brain, oscillations typically reflect excitation and inhibition.

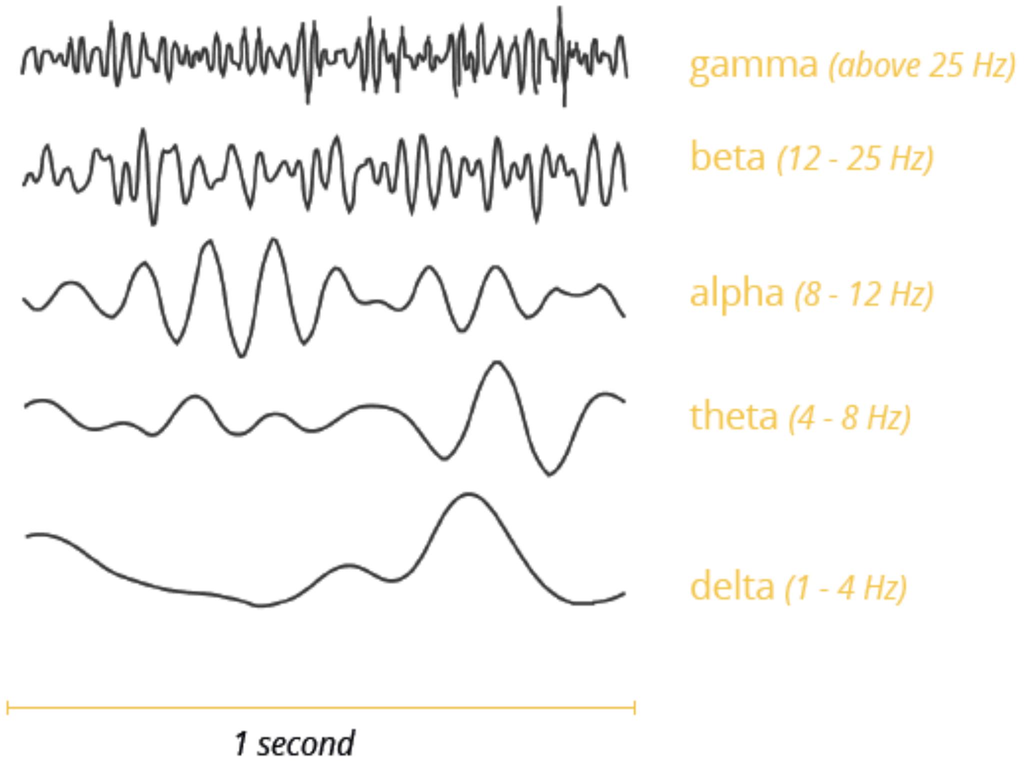


Frequency Bands



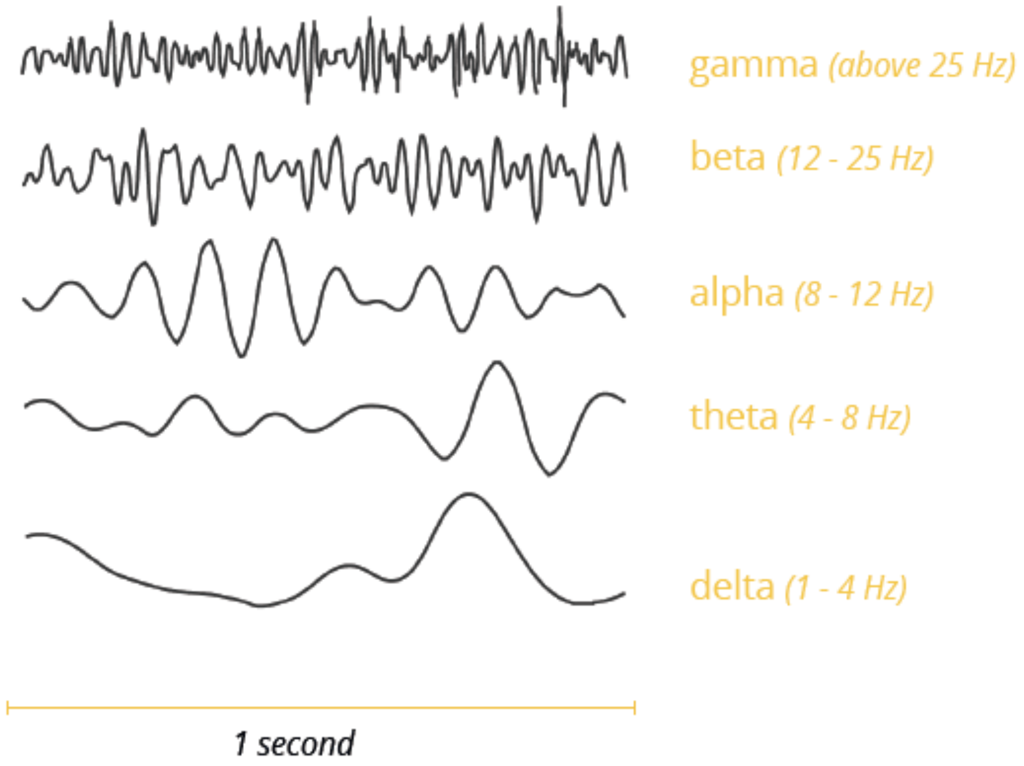
- **Delta band (1 – 4 Hz)**
  - Being the slowest and highest amplitude brainwaves, oscillations in the 1 – 4 Hz range are characterized as delta waves.
  - Delta waves are usually only present during deep non-REM sleep.
  - Delta band power is examined to assess the depth of sleep. The stronger the delta rhythm, the deeper the sleep.
  - Since sleep is associated with memory consolidation, delta frequencies play a core role in the formation and internal arrangement of memory as well as acquired skills and learned information.

Frequency Bands



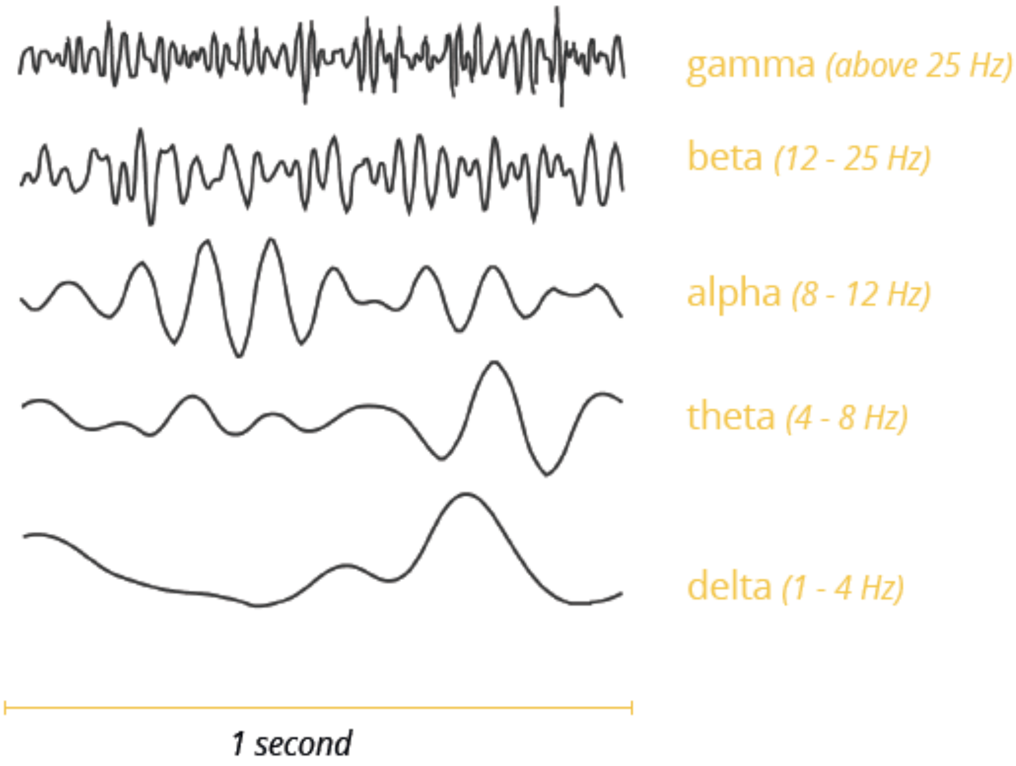
- **Theta band (4 – 8 Hz)**
  - ➢ Studies consistently report frontal theta activity to correlate with the difficulty of mental operations, for example during focused attention and information processing or during memory recall.
  - ➢ Theta frequencies become more prominent with increasing task difficulty. This is why theta is generally associated with brain processes underlying mental workload or working memory.

Frequency Bands



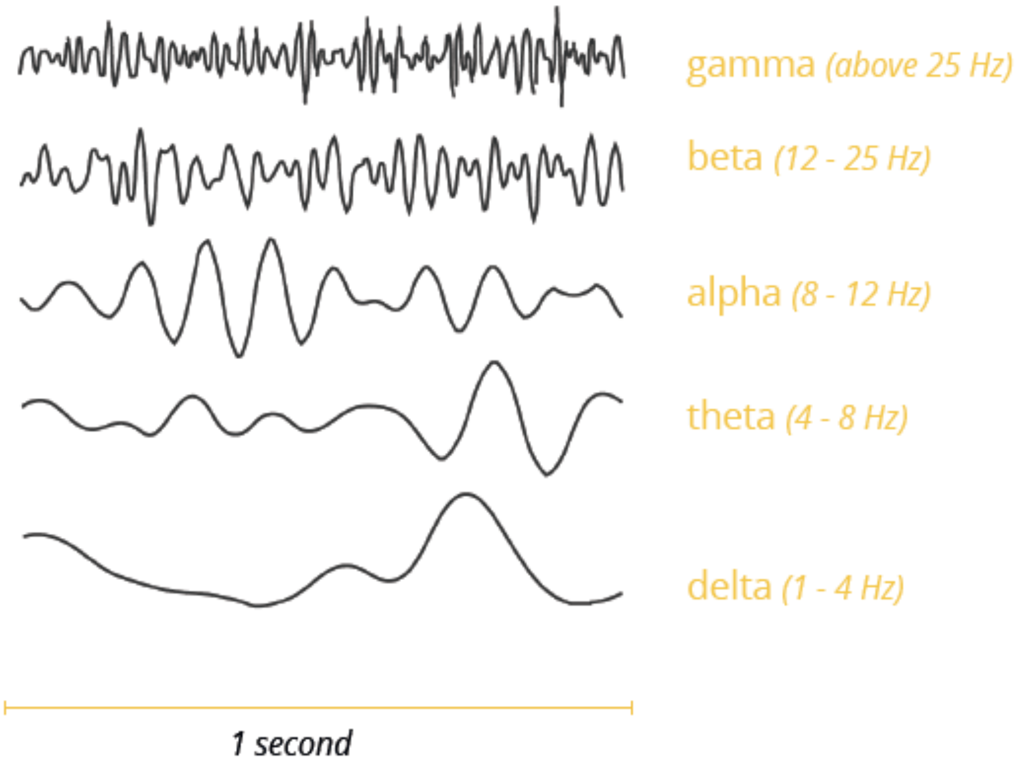
- **Alpha band (8 – 12 Hz)**
  - Alpha waves have several functional correlates reflecting sensory, motor and memory functions. You can see increased levels of alpha band power during mental and physical relaxation with eyes closed.
  - By contrast, alpha power is reduced, or suppressed, during mental or bodily activity with eyes open.

Frequency Bands

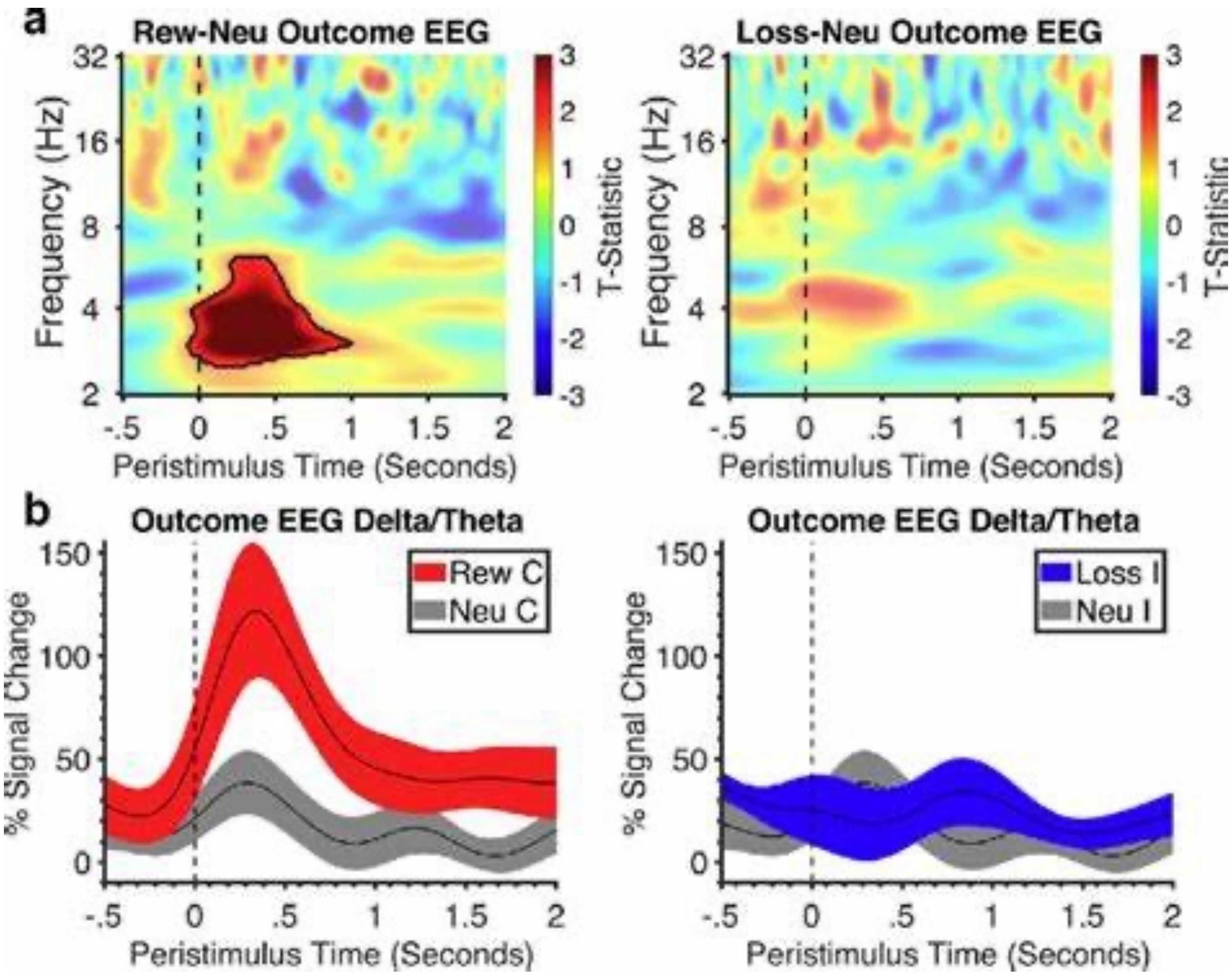


- **Beta band (12 – 25 Hz)**
  - Active, busy or anxious thinking and active concentration are generally known to correlate with higher beta power.
  - Over central cortex (along the motor strip), beta power becomes stronger as we plan or execute movements, particularly when reaching or grasping requires fine finger movements and focused attention.

Frequency Bands

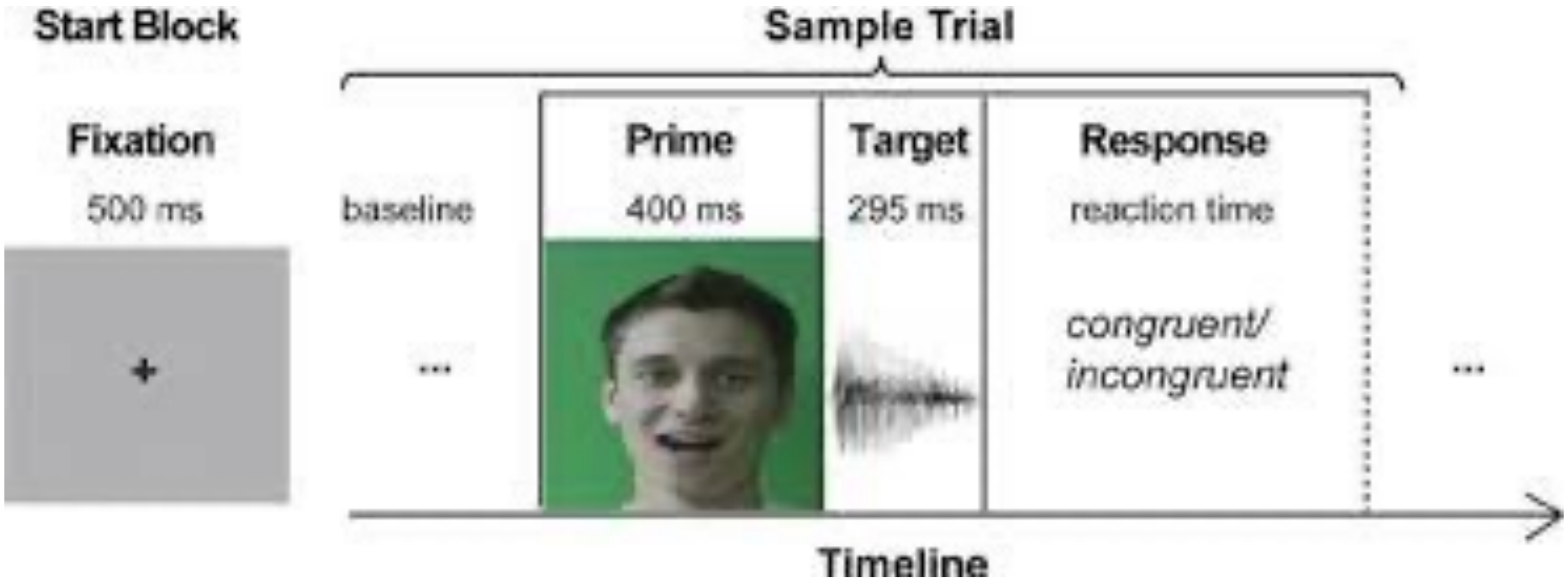


- **Gamma band (above 25 Hz)**
  - gamma frequencies are the black holes of EEG research as it is still unclear where exactly in the brain gamma frequencies are generated and what these oscillations reflect.
  - Some researchers argue that gamma, similar to theta, reflecting an attentional process.
  - Others argue that gamma frequency is a by-product of other neural processes such as eye-movements, and therefore do not reflect cognitive processing at all.


a
Rew-Neu Outcome EEG
Loss-Neu Outcome EEG
Frequency (Hz)
32
16
8
4
2
T-Statistic
3
2
1
0
-1
-2
-3
-.5
0
.5
1
1.5
2
Peristimulus Time (Seconds)
b
Outcome EEG Delta/Theta
% Signal Change
150
100
50
0
Rew C
Neu C
Loss I
Neu I

Event-related Potentials (ERP)

- An ERP is the measured brain response that is the direct result of a specific sensory, cognitive, or motor event.



EEG vs. ERP

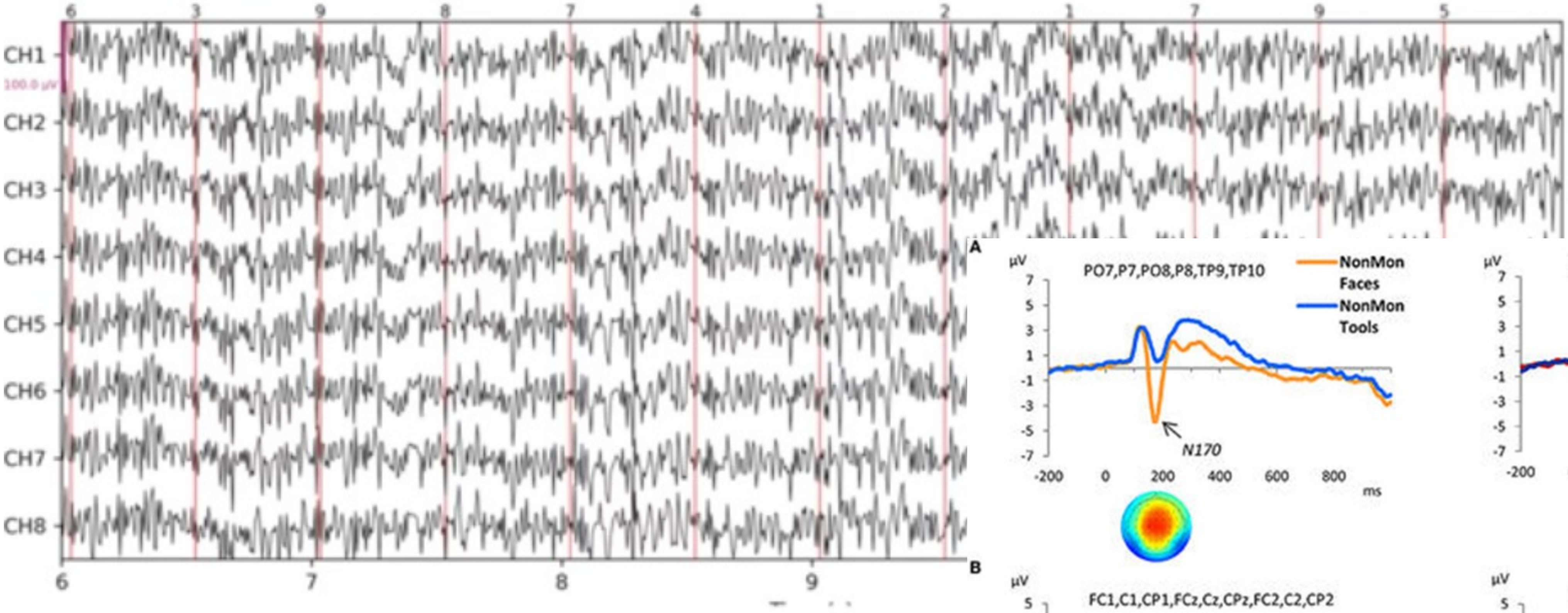
- There is continuous and **ongoing EEG activity** as well as random noise completely unrelated to the onset of a stimulus continually occurring. This is your “default activity“ (your ongoing thoughts and mental states). When you present a stimulus, you trigger **stimulus-related EEG activity**.
- In order to uncover the stimulus-related EEG data from the unrelated ongoing data, the stimulus is shown several times – 50 times or more, for example. At the end of the data collection, you will have 50 trials, which are data portions time- locked to stimulus-onset and typically range from about 200ms prior to stimulus onset to 1000 ms after stimulus onset. Each trial is a time-course of data at each electrode.

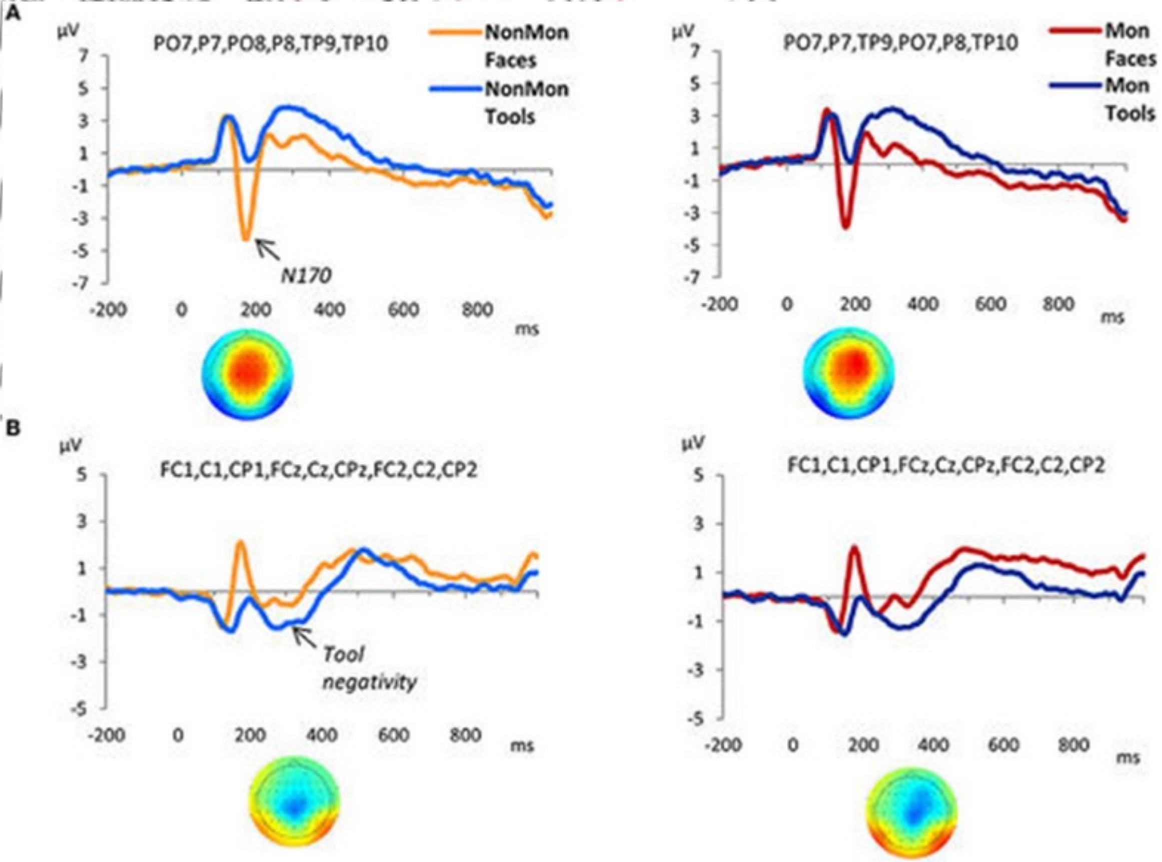
How to Perform an EEG Experiment

Dan Acheson

Neurobiology of Language Department
Max Planck Institute for Psycholinguistics
Donders Institute for Brain, Cognition and Behaviour
Nijmegen, The Netherlands

Can you spot a peak?





2.2.4. Recording and analysis

Continuous electroencephalographic (EEG) signals were recorded from the EGI 128 electrode Hydro Cel Geodesic Sensor Net with a sampling rate of 1000 Hz. During the recordings, the impedances were all kept below 50kΩ before each block. After the recordings, the EEG data were analyzed off-line using Net Station 4.5.6 software and the data were filtered with a 0.1–30 Hz band-pass. The filtered data were then segmented into 600 ms epochs with a 100 ms of pre-stimulus interval and a 500 ms of post-stimulus interval. The first 10 standard trials and the standard trials presented immediately after deviants were all excluded for further analysis. An artifact detection criterion of ±27.5μV was used to detect eye movements and ±70μV was used to detect eye blinks at all scalp sites. Channels were considered bad in each segment if the voltage variation was larger than ±100μV in at least one of the channels. Meanwhile, channels were considered bad in recording if more than 20% of the segments met the abovementioned criteria. Additionally, segments with more than 10 bad channels, with an eye blink or with an eye movement were all discarded. Bad channels were replaced using the average value obtained from surrounding channels and the ERP segments were then averaged for each participant. All waveforms were referenced to the average of all 128 electrodes and a 100 ms pre-stimuli baseline correction was applied. A minimum of 70 deviant trials was required for each subject to be included in the final analyses. The number of valid trails was not significantly different between the two groups under different conditions (*ps* > 0.05) (Table 1).

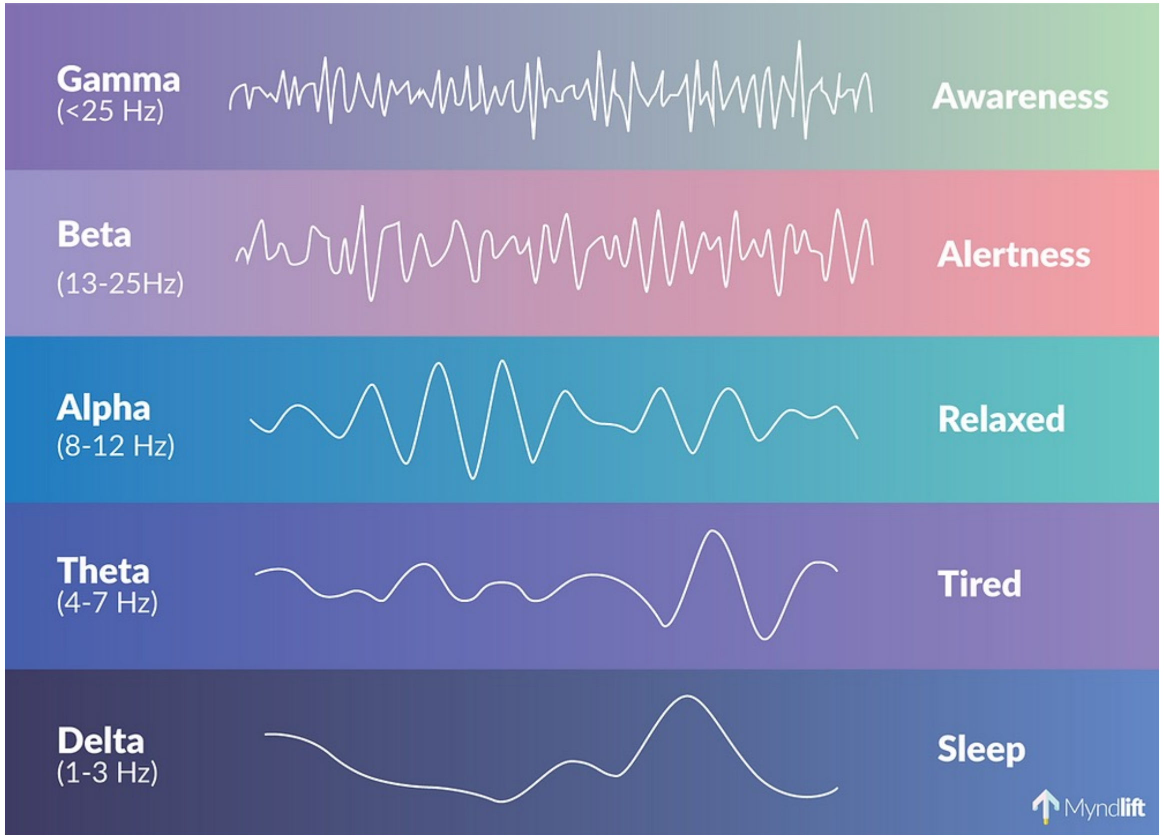
- Impedance
- Filtering
- Segmentation
- Artificial detection
- Re-reference
- Baseline correction

Electrode impedance

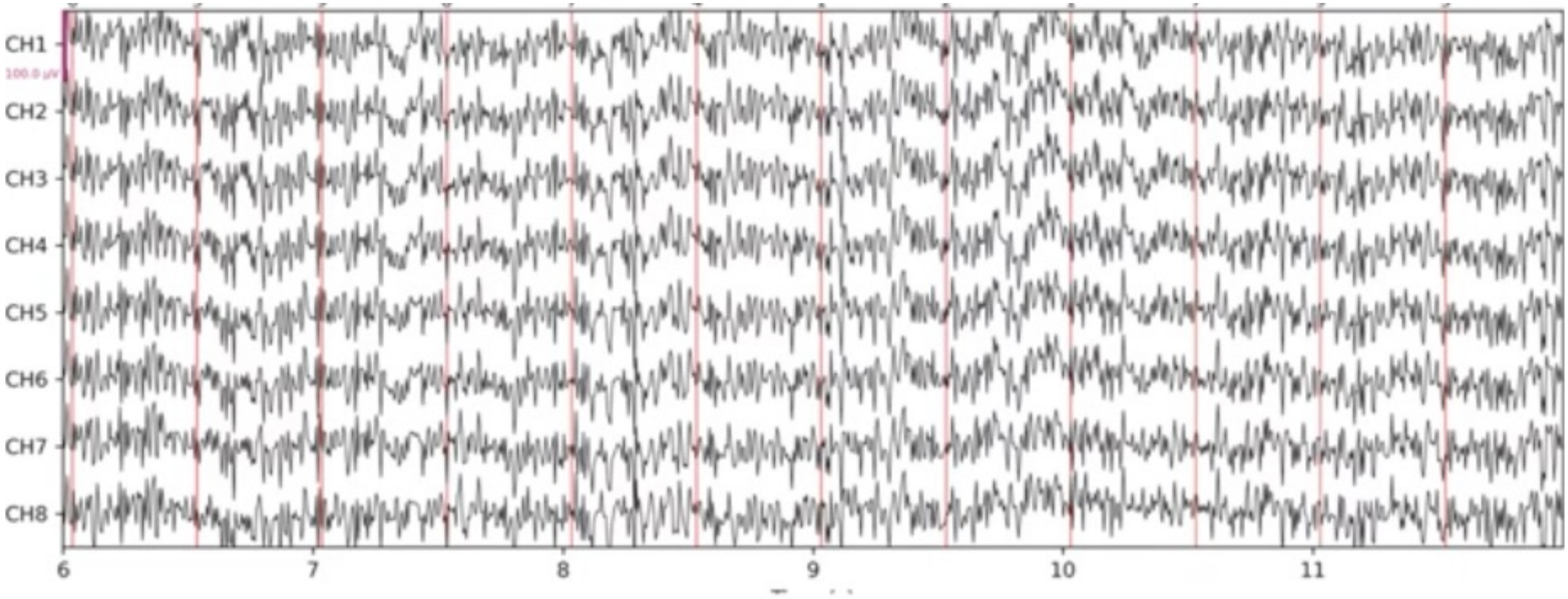
- A stable electrical connection between electrode and scalp is key to recording clean EEG signals. However, dead skin cells, oily skin, and sweat accumulate on the scalp and constitute a wall of electrical resistance as they do not propagate electrical activity well.
  - ➢Instruct respondents to come to the experimental session with washed and dried hair;
  - ➢Clean all electrode sites;
  - ➢Apply electrode gel/conductive paste

Filtering

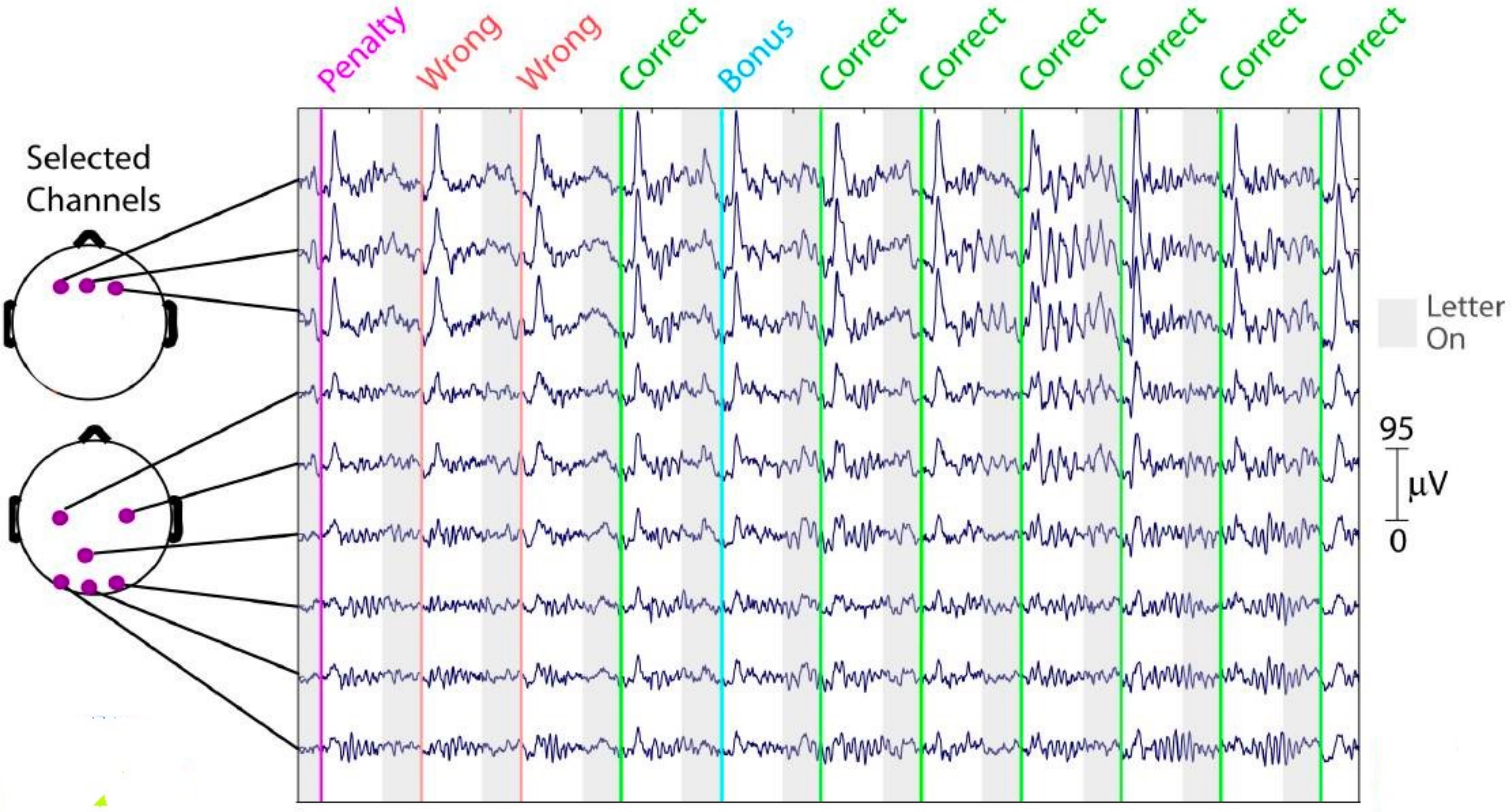
- Aims to remove high and low frequency signals by filtering out frequencies above and below certain cutoff frequencies
  - The low pass filter allows the low frequencies to pass
  - The high pass filter allows the high-frequency parts to pass.



After a **band-pass** filter



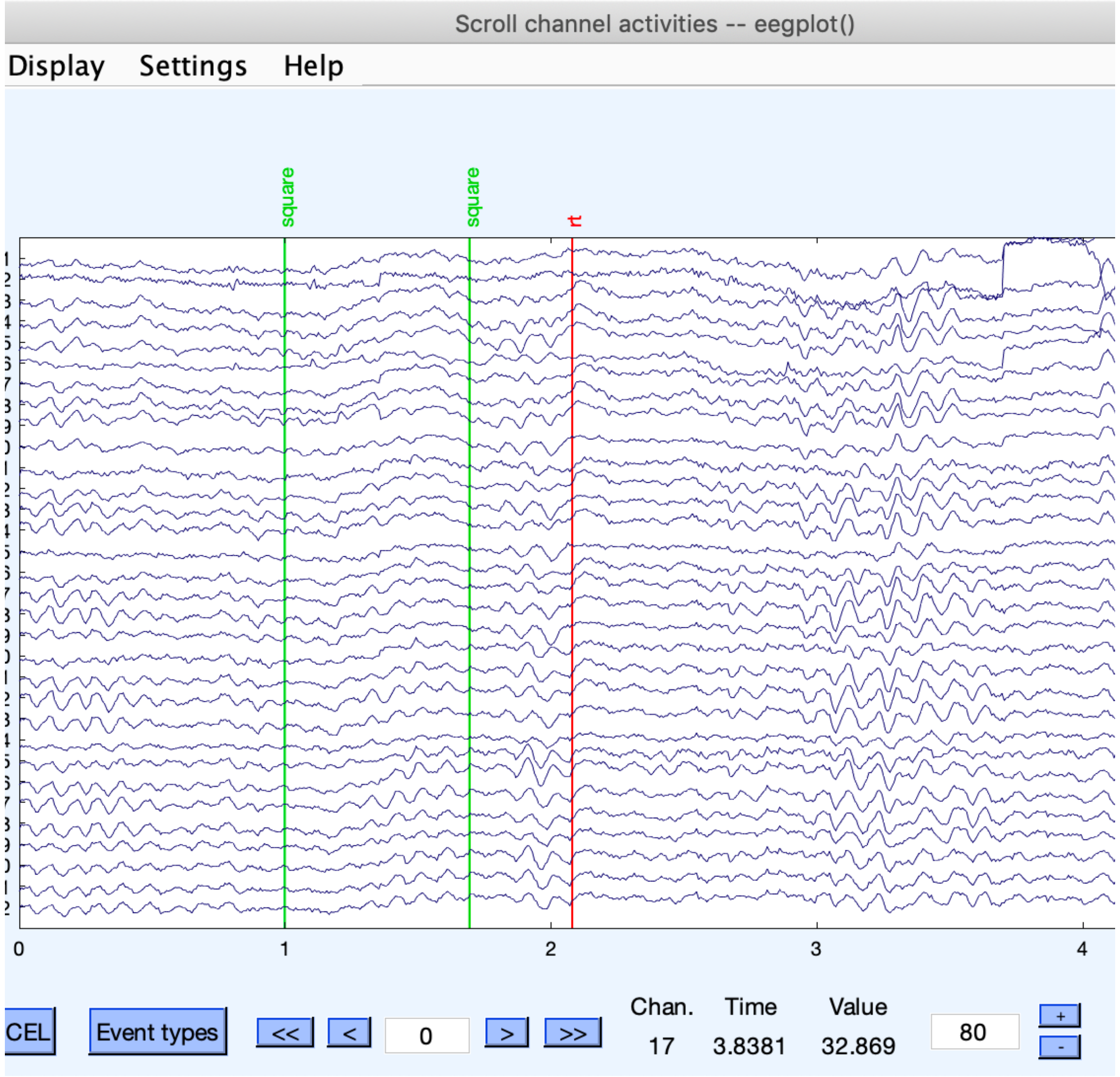
The onset of stimuli?



Penalty
Wrong
Wrong
Correct
Bonus
Correct
Correct
Correct
Correct
Correct
Correct
Selected Channels
Letter On
95
μV
0

Segmentation

- Aims to take continuous signal and break into segments of interest (e.g., around an 'event') by extracting time window of interest using the event codes



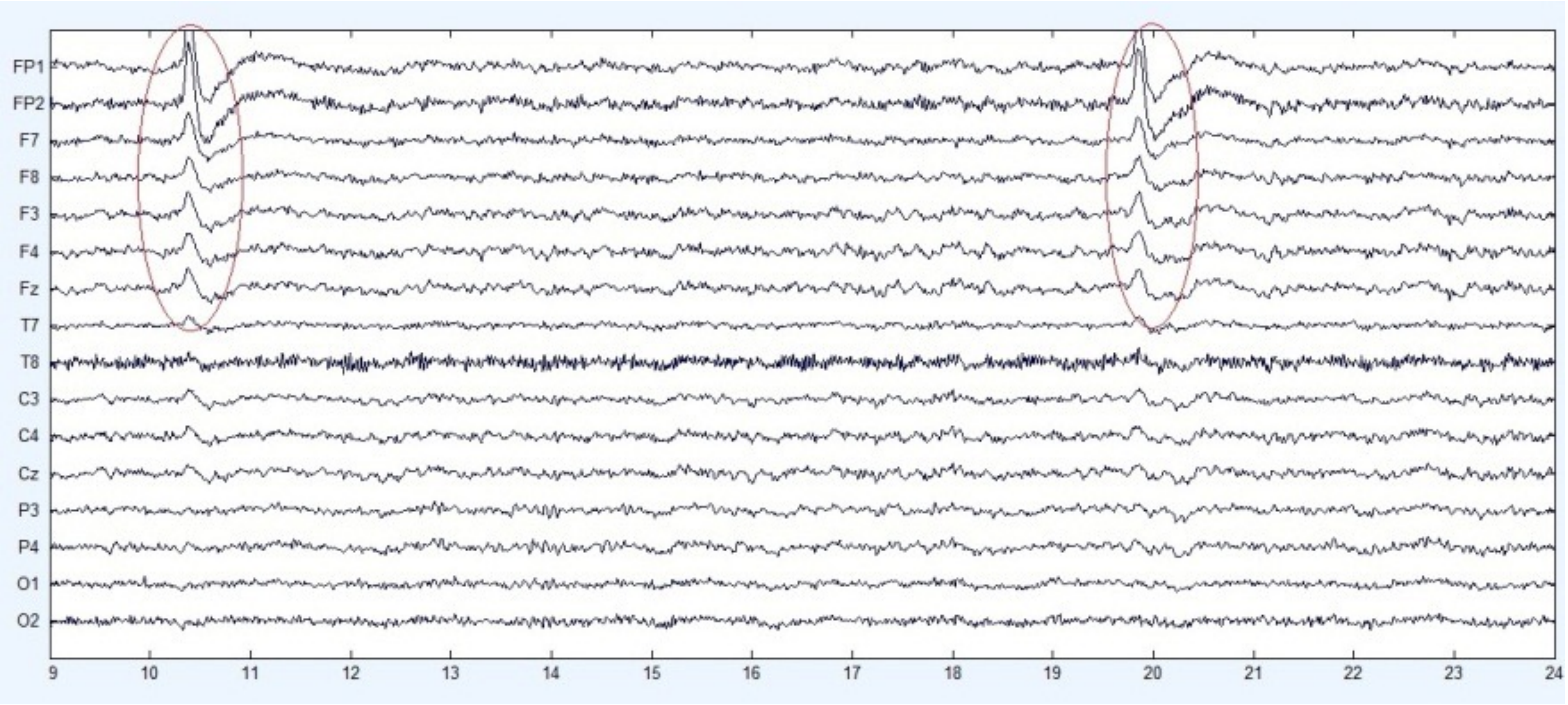
Artificial detection

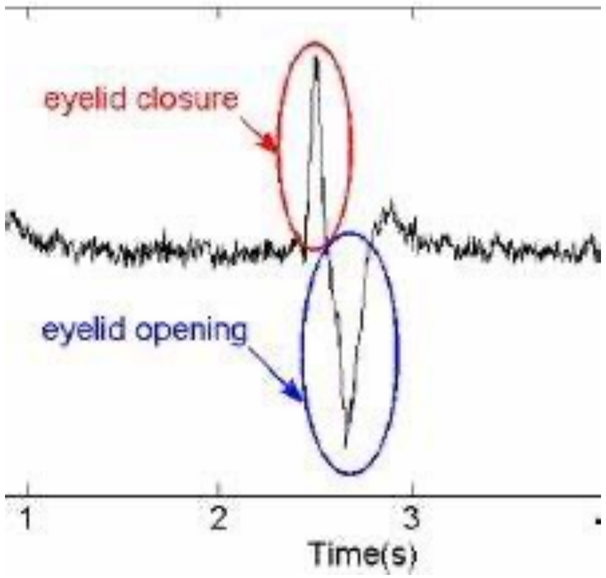
- Aims to get rid of eye-movement and eye-blink artifacts by calculating eye channels to detect blinks and eye-movements

2.2.4. Recording and analysis

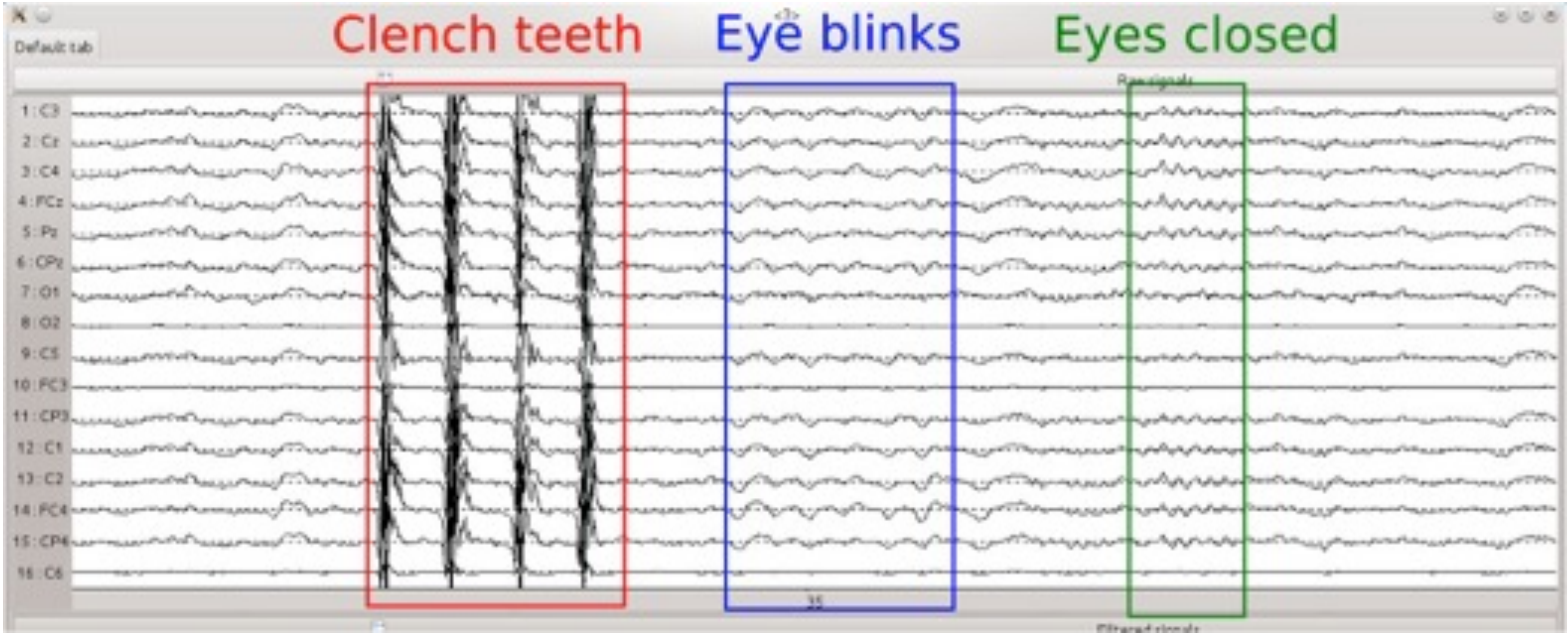
Continuous electroencephalographic (EEG) signals were recorded from the EGI 128 electrode Hydro Cel Geodesic Sensor Net with a sampling rate of 1000 Hz. During the recordings, the impedances were all kept below 50kΩ before each block. After the recordings, the EEG data were analyzed off-line using Net Station 4.5.6 software and the data were filtered with a 0.1–30 Hz band-pass. The filtered data were then segmented into 600 ms epochs with a 100 ms of pre-stimulus interval and a 500 ms of post-stimulus interval. The first 10 standard trials and the standard trials presented immediately after deviants were all excluded for further analysis. An artifact detection criterion of ±27.5μV was used to detect eye movements and ±70μV was used to detect eye blinks at all scalp sites. Channels were considered bad in each segment if the voltage variation was larger than ±100μV in at least one of the channels. Meanwhile, channels were considered bad in recording if more than 20% of the segments met the abovementioned criteria. Additionally, segments with more than 10 bad channels, with an eye blink or with an eye movement were all discarded. Bad channels were replaced using the average value obtained from surrounding channels and the ERP segments were then averaged for each participant. All waveforms were referenced to the average of all 128 electrodes and a 100 ms pre-stimuli baseline correction was applied. A minimum of 70 deviant trials was required for each subject to be included in the final analyses. The number of valid trails was not significantly different between the two groups under different conditions ($ps > 0.05$) (Table 1).

Eye blink

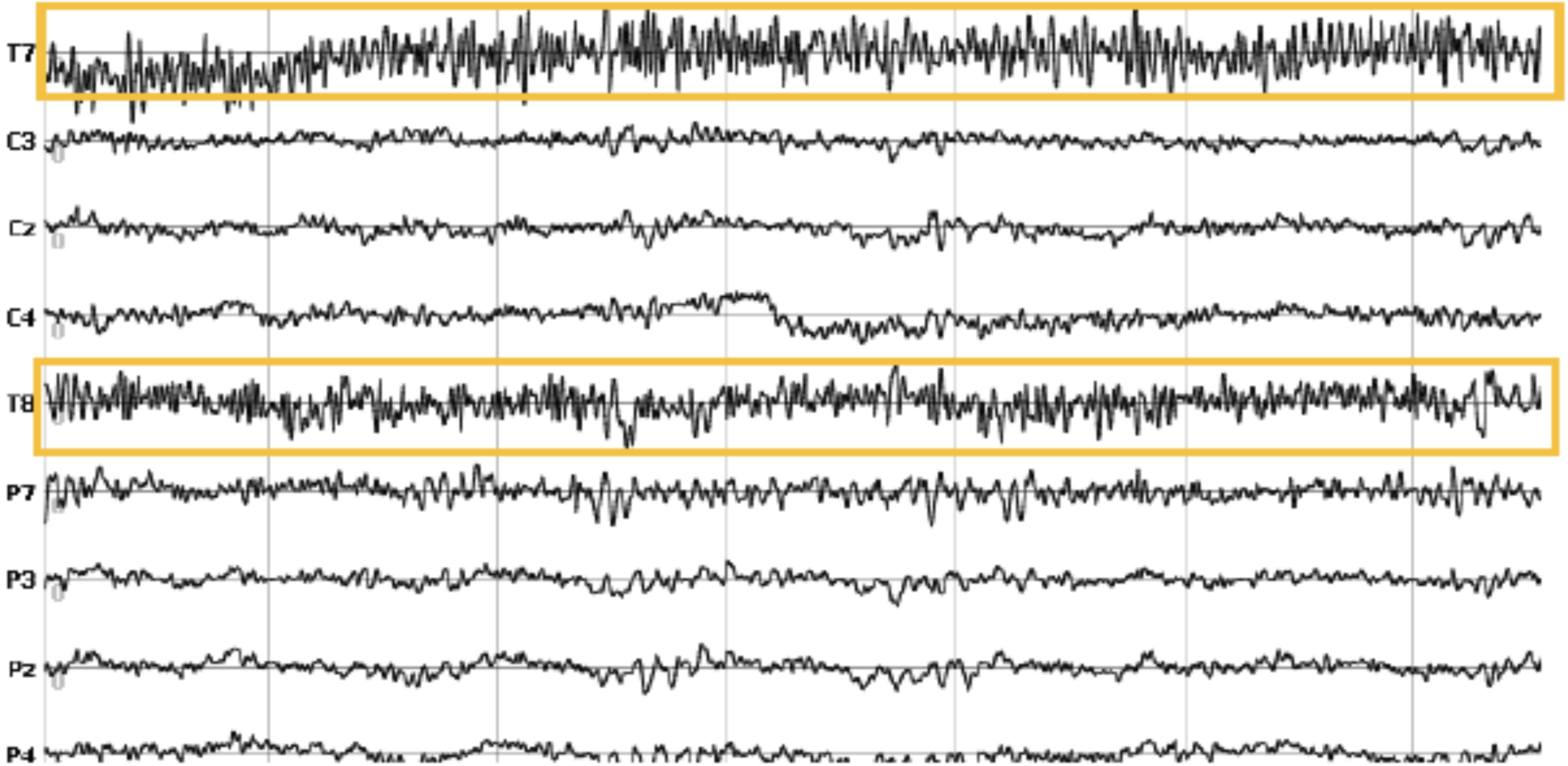

FP1
FP2
F7
F8
F3
F4
Fz
T7
T8
C3
C4
Cz
P3
P4
O1
O2
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


eyelid closure
eyelid opening
1 2 3
Time(s)

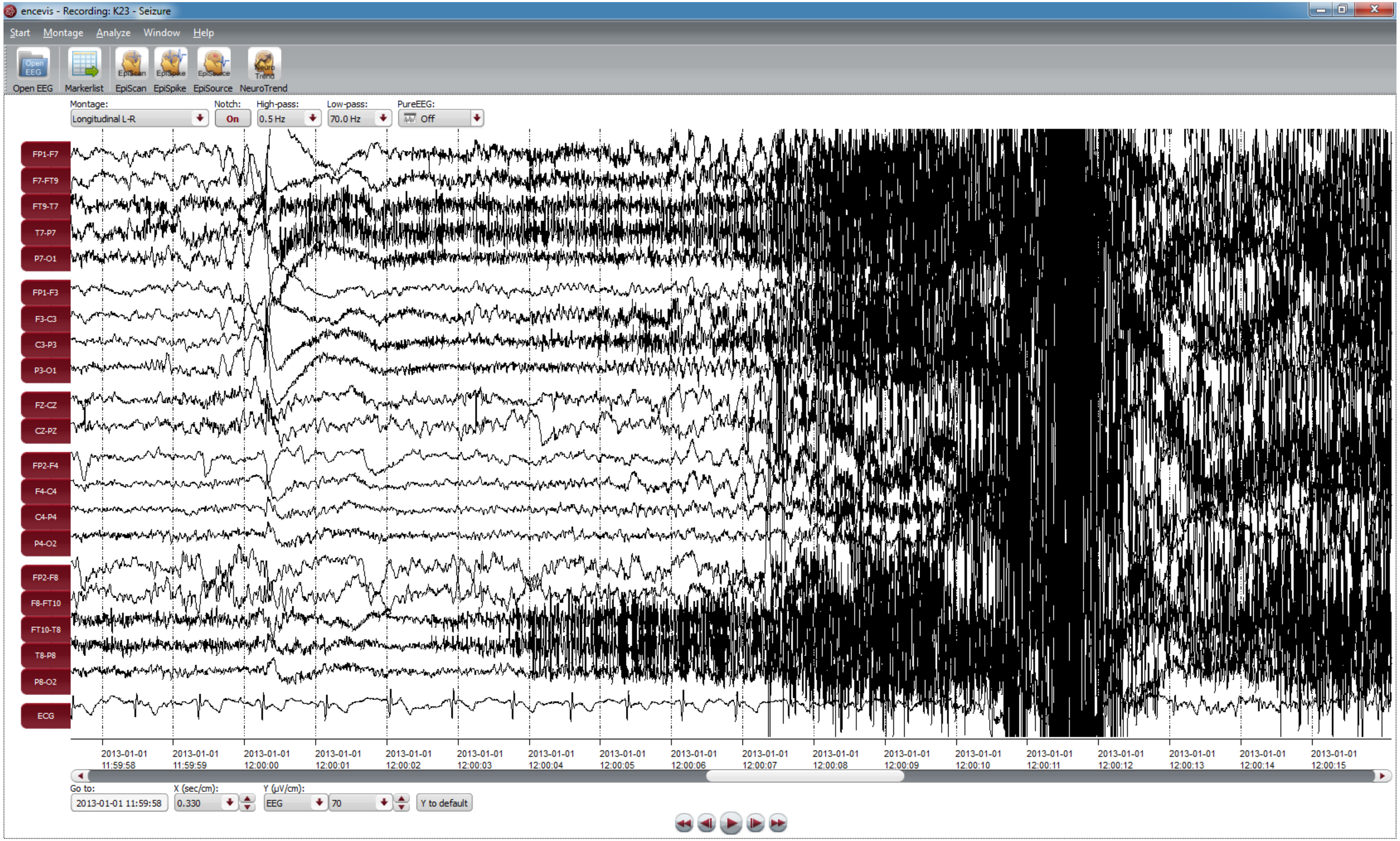
Noises

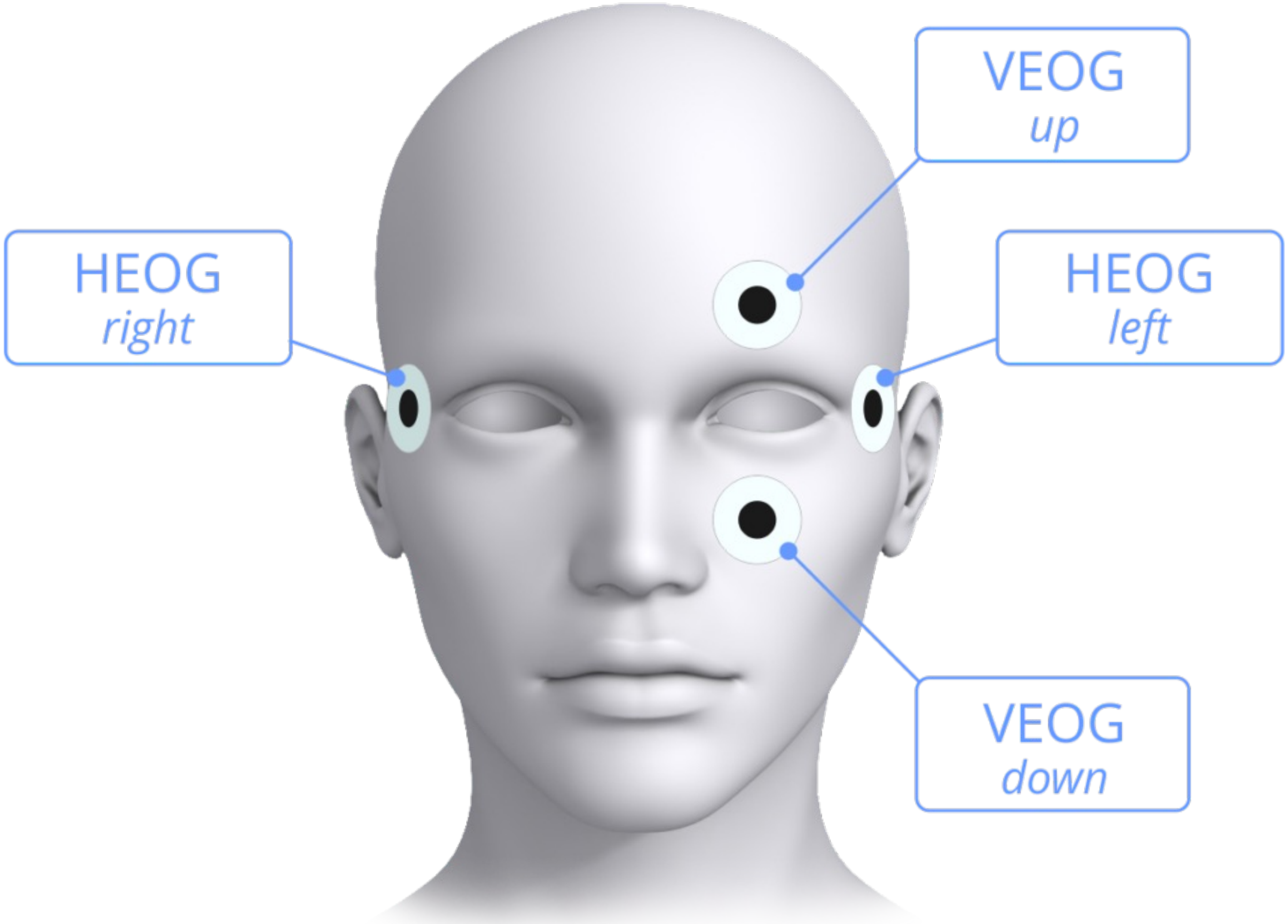

Clench teeth
Eye blinks
Eyes closed
Default tab
1 : C3
2 : Cz
3 : C4
4 : FCz
5 : Pz
6 : CPz
7 : O1
8 : O2
9 : C5
10 : FC3
11 : CP3
12 : C1
13 : C2
14 : FC4
15 : CP4
16 : C6

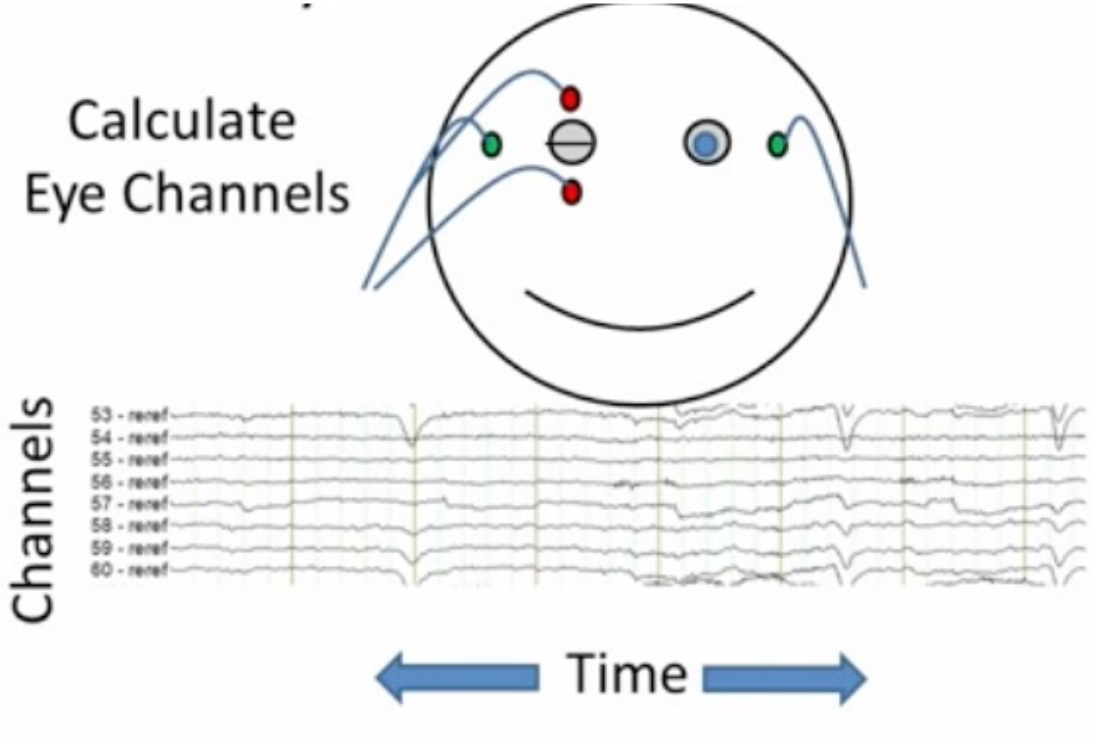
Line noises

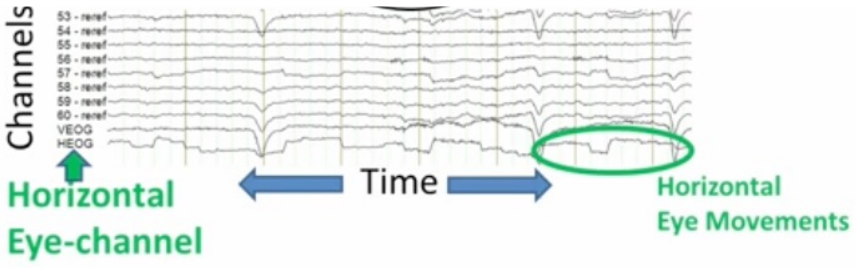


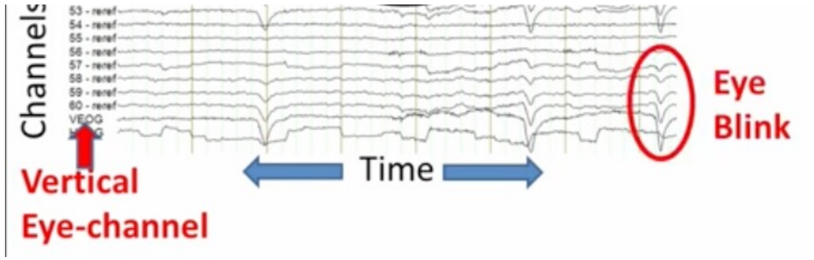
Muscle noise

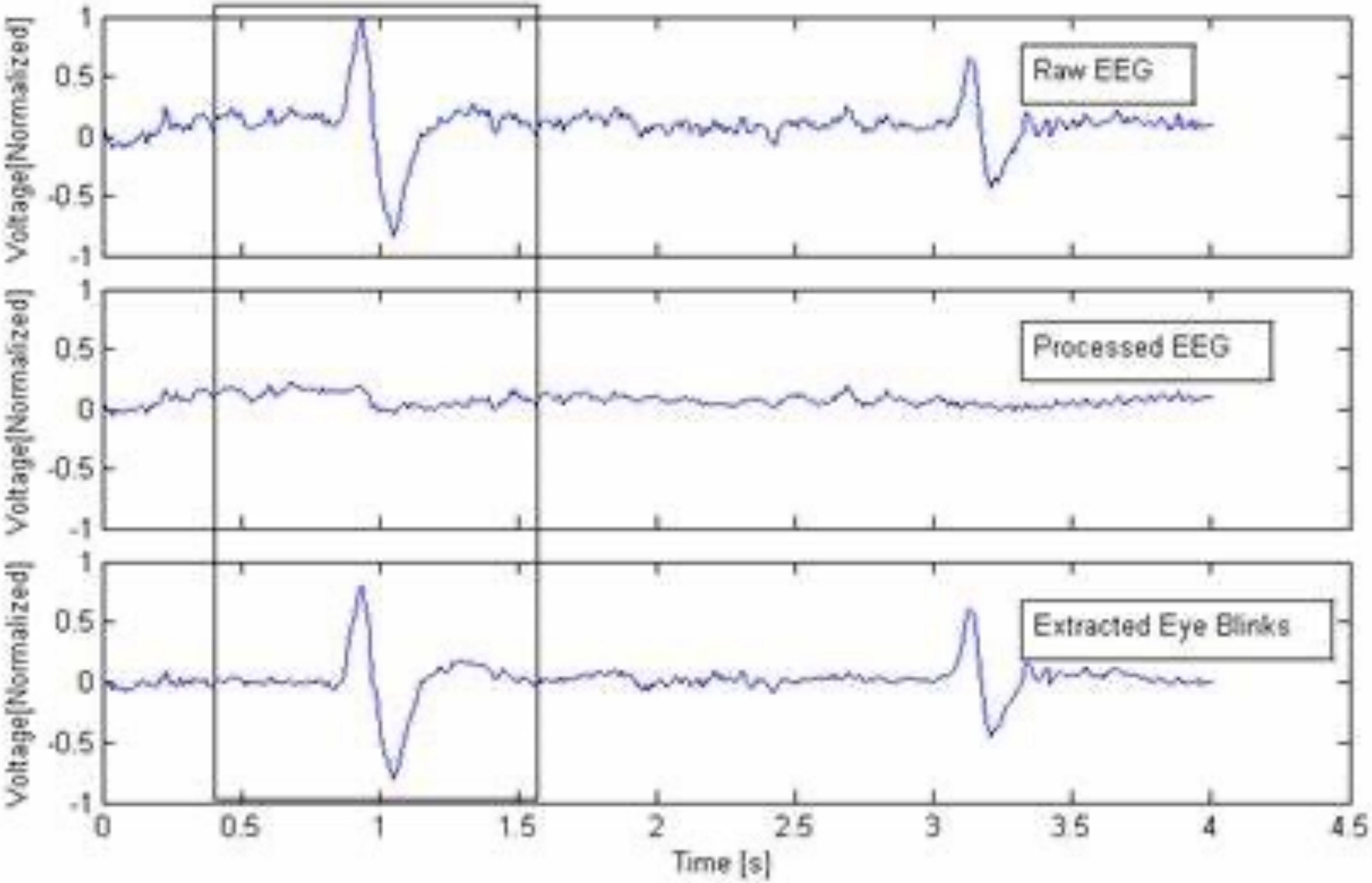



VEOG
up
HEOG
right
HEOG
left
VEOG
down


Calculate
Eye Channels
Channels
53 - reref
54 - reref
55 - reref
56 - reref
57 - reref
58 - reref
59 - reref
60 - reref
Time


Channels
VEOG
HEOG
Horizontal
Eye-channel
Time
Horizontal
Eye Movements

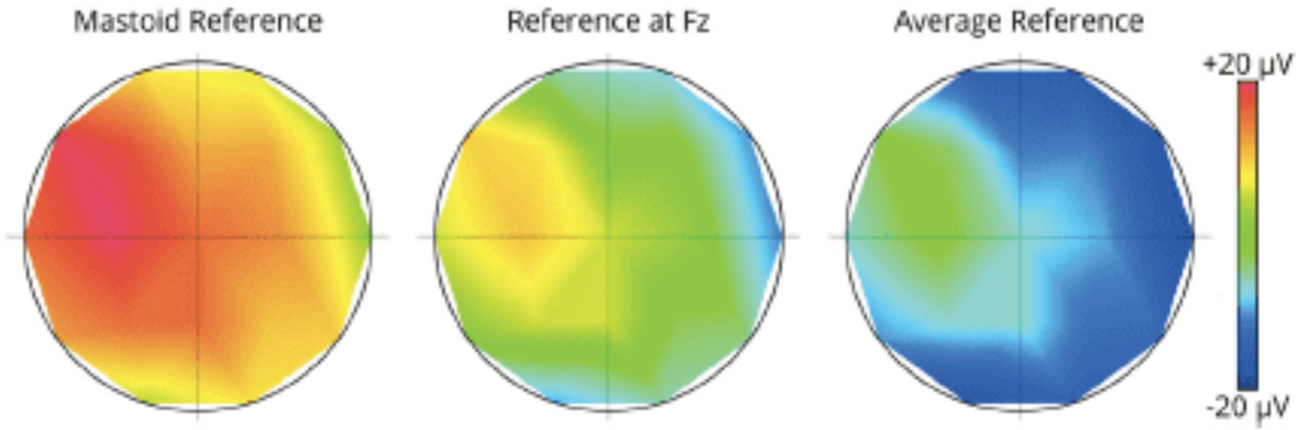

Channels
Vertical
Eye-channel
Time
Eye
Blink



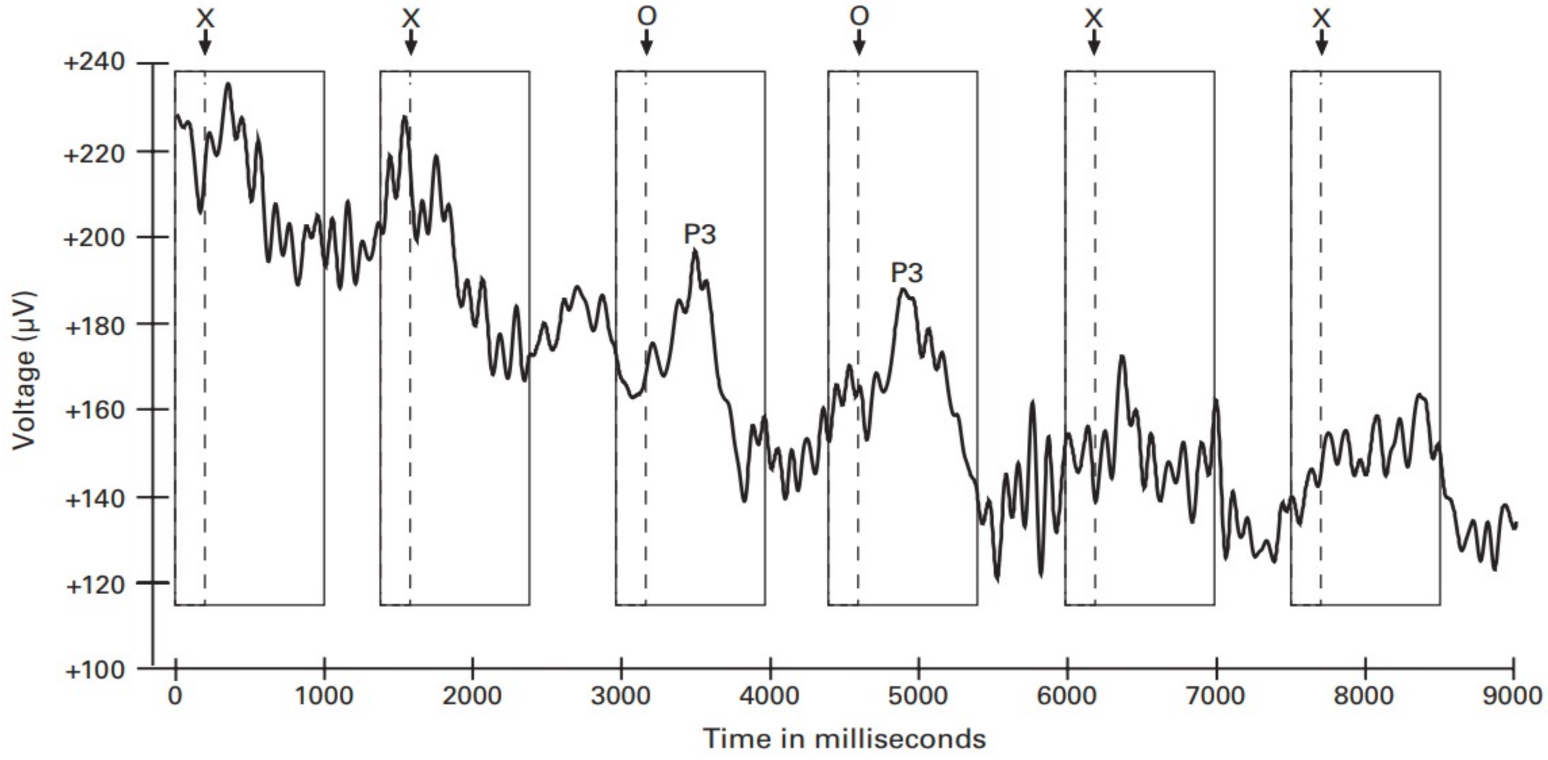
Raw EEG
Processed EEG
Extracted Eye Blinks
Voltage[Normalized]
Voltage[Normalized]
Voltage[Normalized]
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time [s]

Re-reference

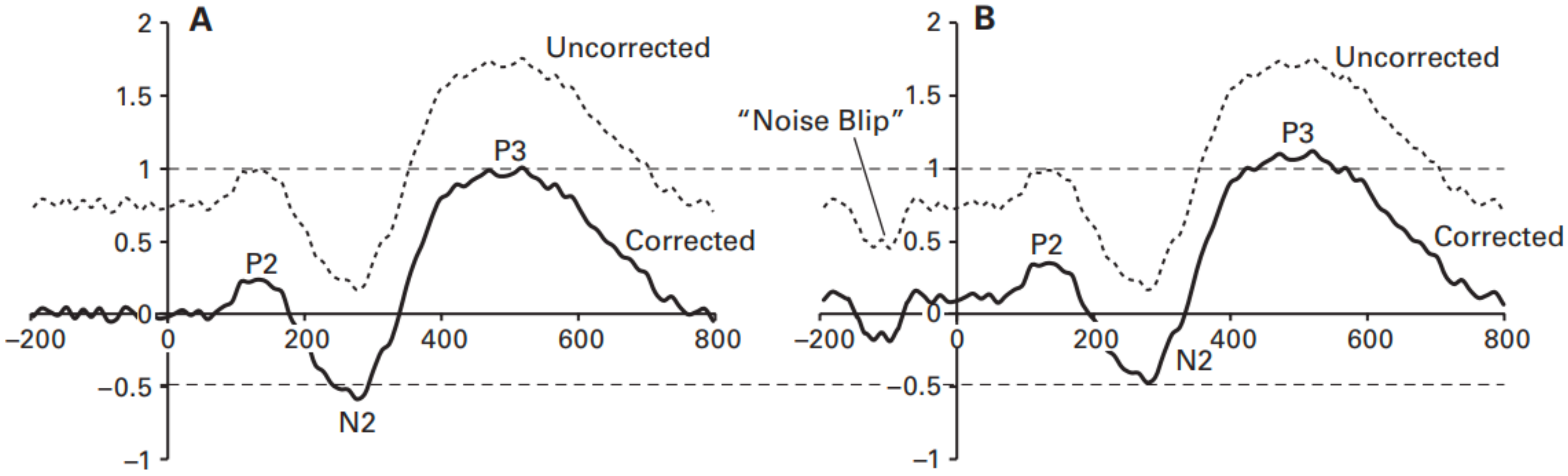
- The choice of the reference only affects the absolute electrode voltage across all electrodes while the relative voltages remain completely unchanged.
- This means that changing the site of the reference may make the scalp voltage look quite different, even though the relative distribution is completely identical.
- Imagine a landscape with mountains and valleys. Changing the reference electrode is similar to flooding the landscape with water. While the sea level changes, the absolute shape of the landscape is completely unchanged.

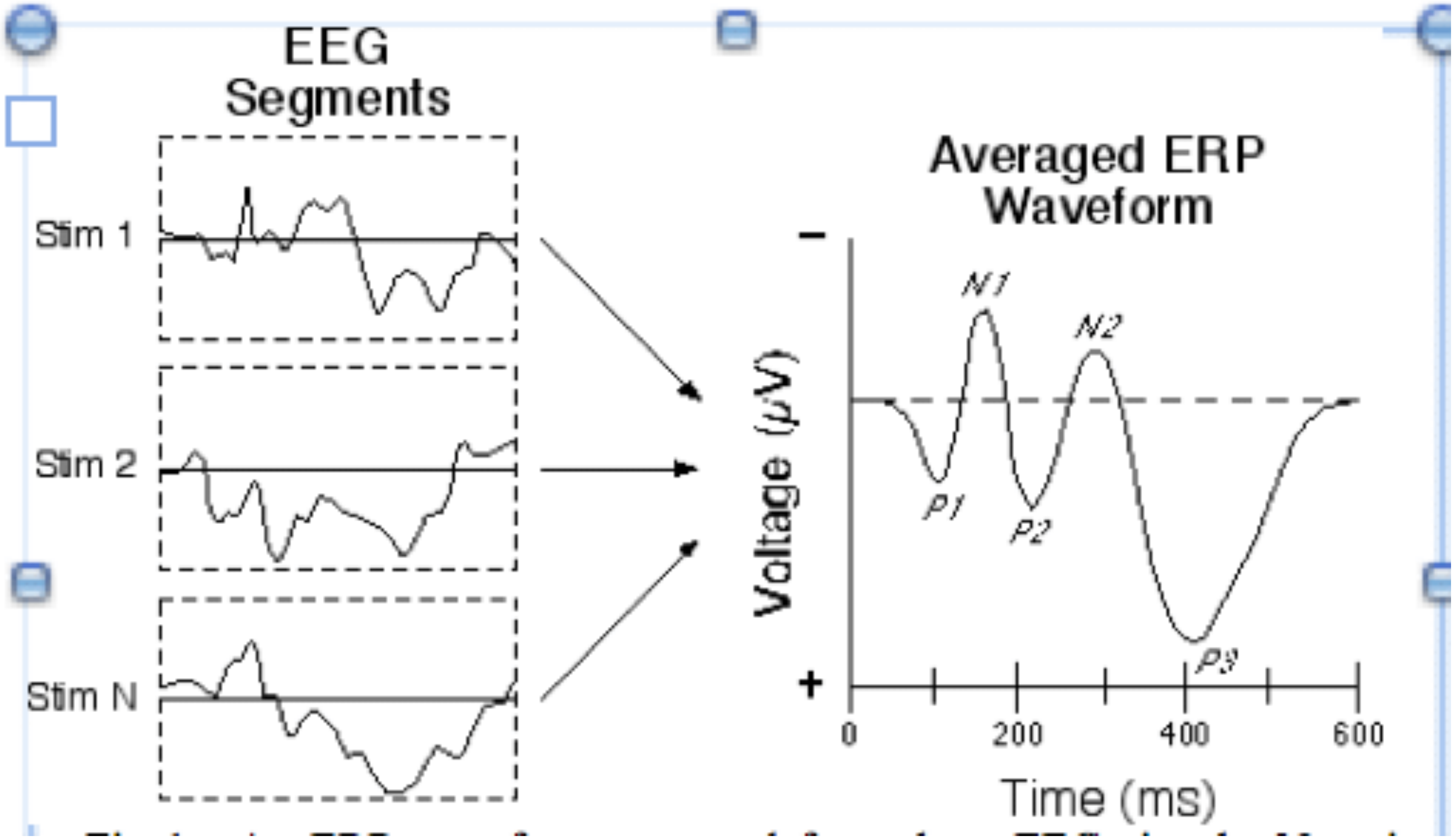


Baseline correction



- Aims to put all segments onto the same scale by subtracting average signal for some amount of time before the stimulus begins (i.e., the baseline period)
- This is necessary because factors such as skin hydration and static charge in the electrodes may cause an overall vertical offset in the EEG

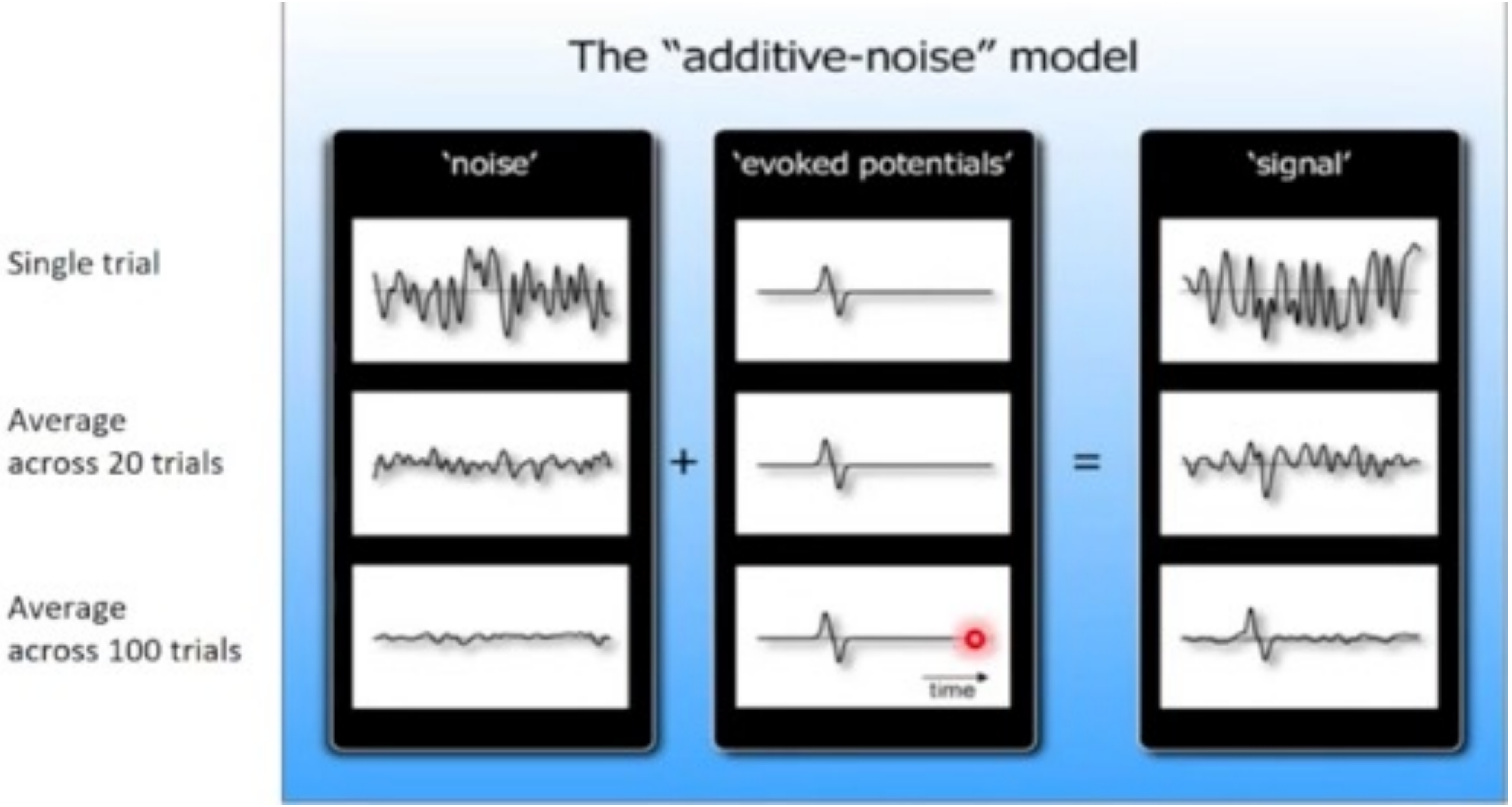

A
B
Uncorrected
Corrected
"Noise Blip"
P2
N2
P3
2
1.5
1
0.5
0
–0.5
–1
–200
0
200
400
600
800

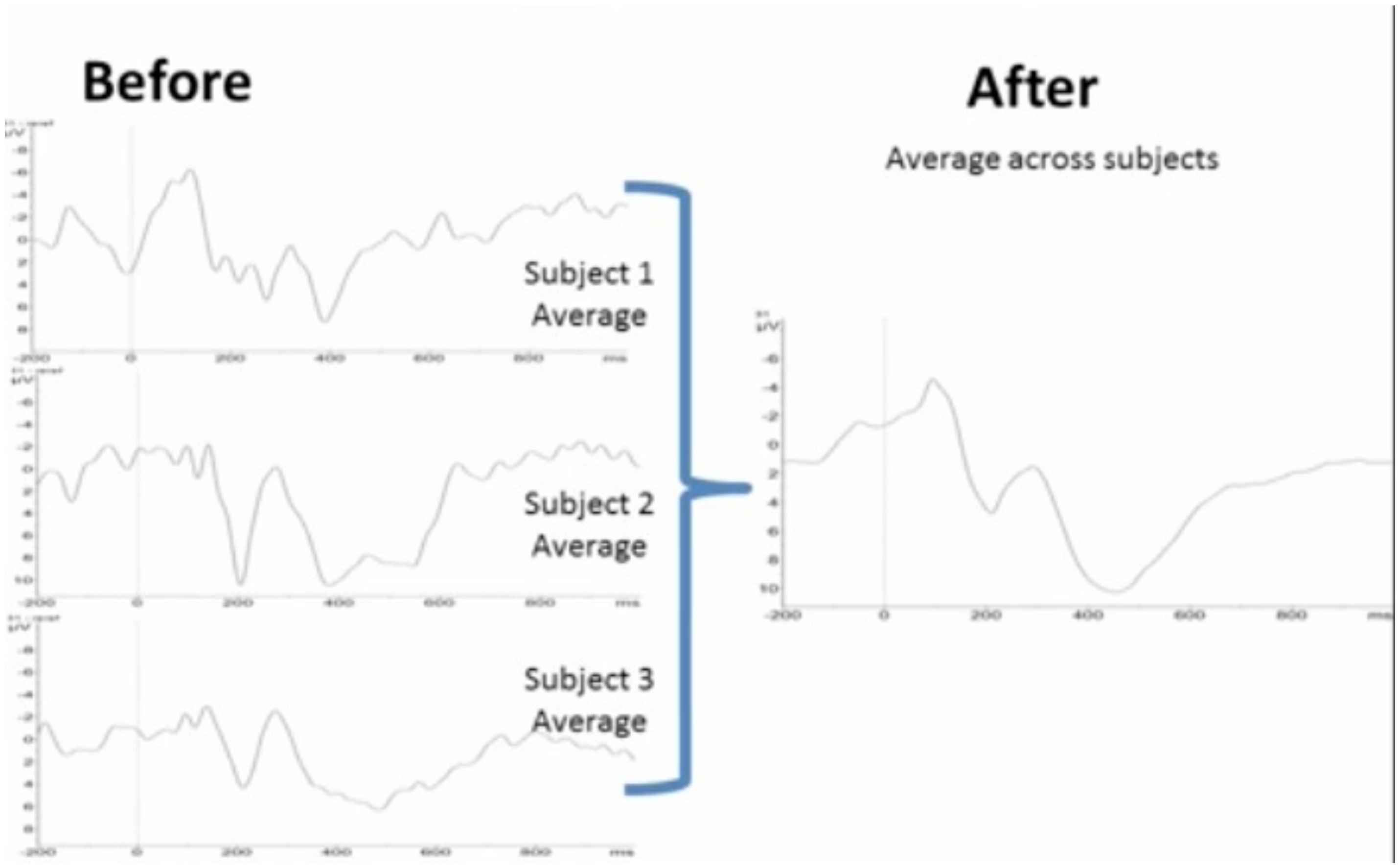


Averaging within subject

- Aims to get better signal for a given condition to extract data for statistics by averaging all trials of a given condition

Why do we need hundreds of trials?





Averaging across subjects

- Aims to combine all subject data together for plotting average effects by averaging all subject averages together

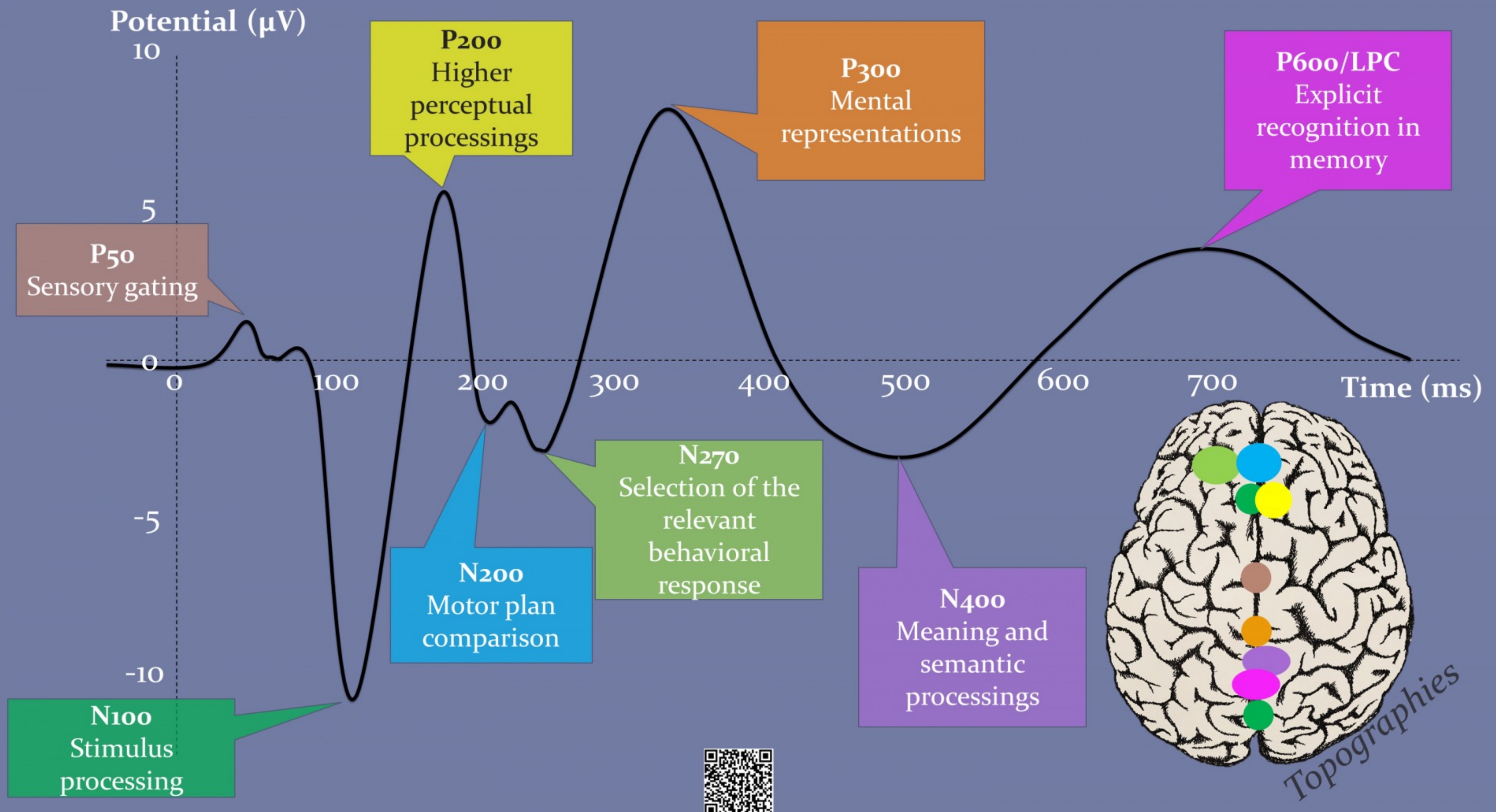
ERPs are classified according to the nature of the stimulus: visual, somato-sensory, and auditory; they can also be classified according to the latency at which their components occur after stimulus presentation

The shorter latency components are generated during the sensory stimulus processing stages (外源性 exogenous components). The longer latency components represent the cortical processing stages, which are less determined by the physical features of the stimulus (内源性 endogenous components).

Exogenous potentials	Endogenous potentials
- Depend on physical features of the sensory stimulus.	- Do not depend on physical features of sensory stimulus. They can be evoked, just with stimulus expectancy, even in the absence of stimulus.
- Do not depend on the subjects' level of consciousness.	- Can change depending on the level of attention, its relevancy during the task and resources required for stimulus processing.
- Are not influenced by cognition processes.	- Related to cognition processing.

*An **E**vent **R**elated **P**otential (ERP) is a direct measure of the brain electrophysiological response to an exogenous (sensory input) stimulus or an endogenous (cognitive/motor) activity.*

Due to the weak SNR, ERPs are only visible after averaging several stimuli or response-locked identical trials.

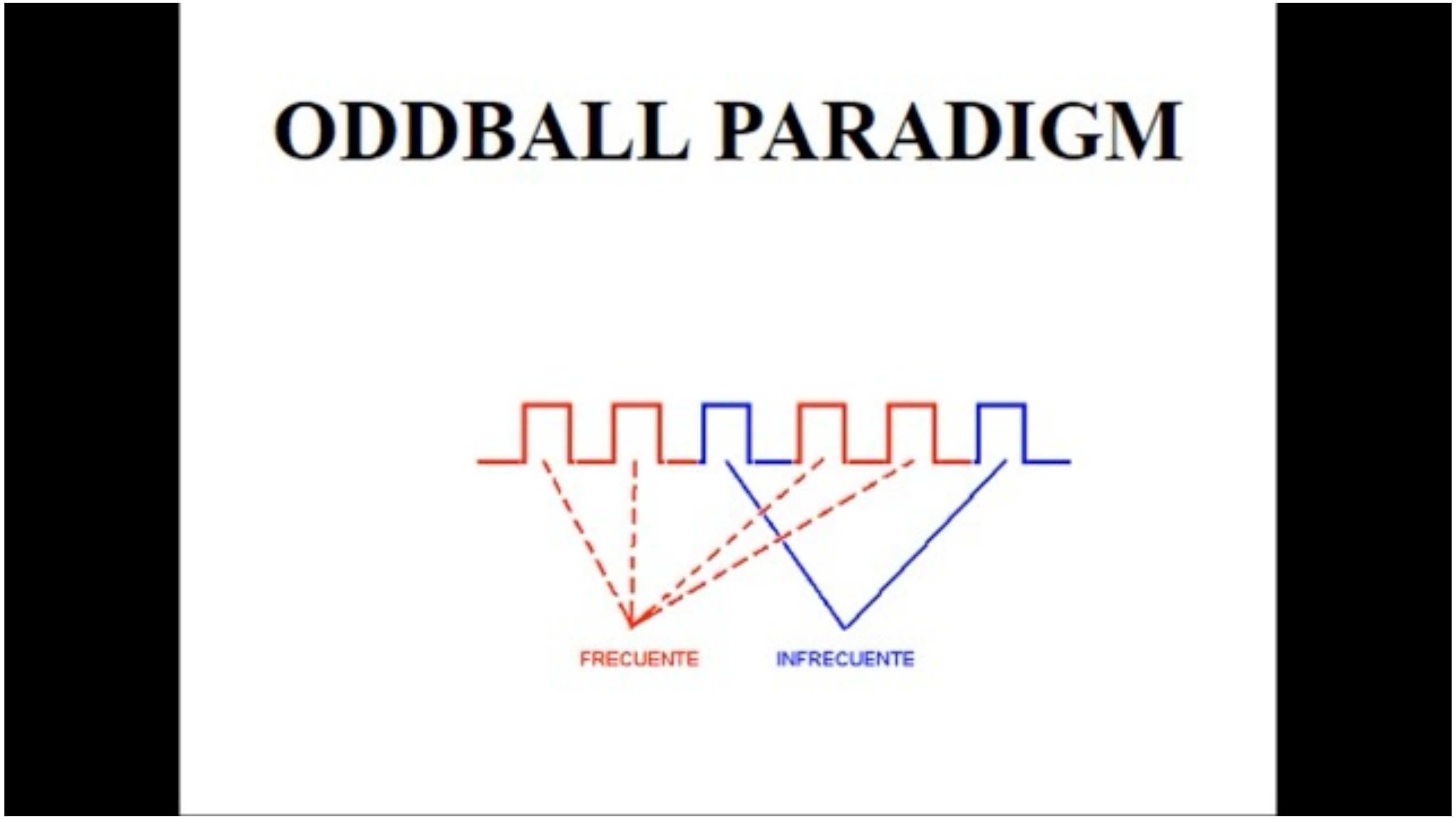


Scan me for more ERP component descriptions
www.quickscience.e-monsite.com

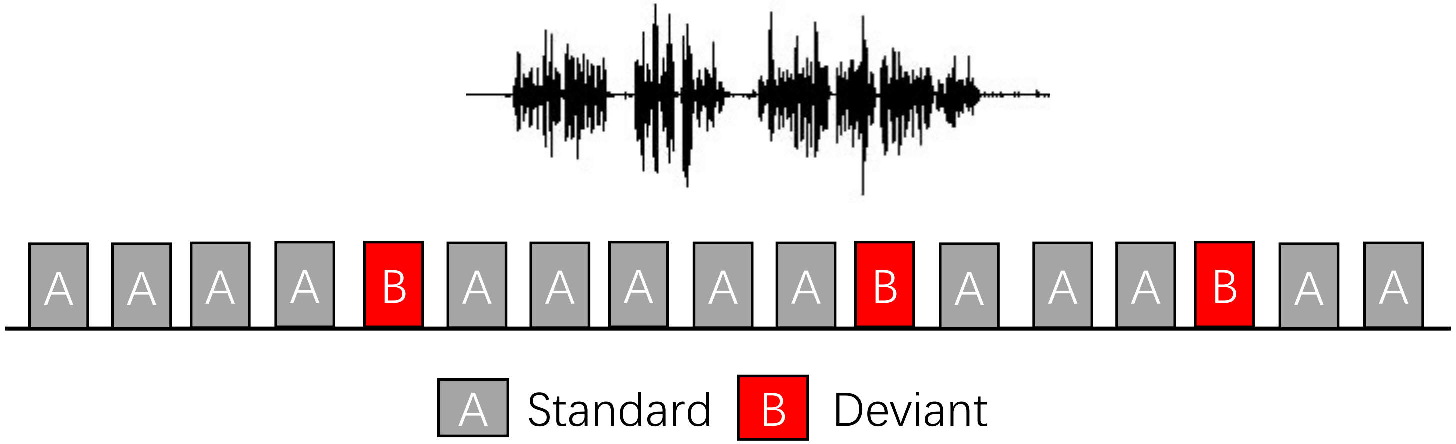
DCAS, Neuroergonomics lab
s.scannella@isae-supaero.fr

Oddball paradigm

- The oddball paradigm relies on the brain's sensitivity to rare deviant stimuli presented pseudo-randomly in a series of repeated standard stimuli.
- The oddball paradigm has a wide selection of stimulus types, including stimuli such as sound duration, frequency, intensity, phonetic features, complex music, or speech sequences. The reaction of the participant to this "oddball" stimulus is recorded.

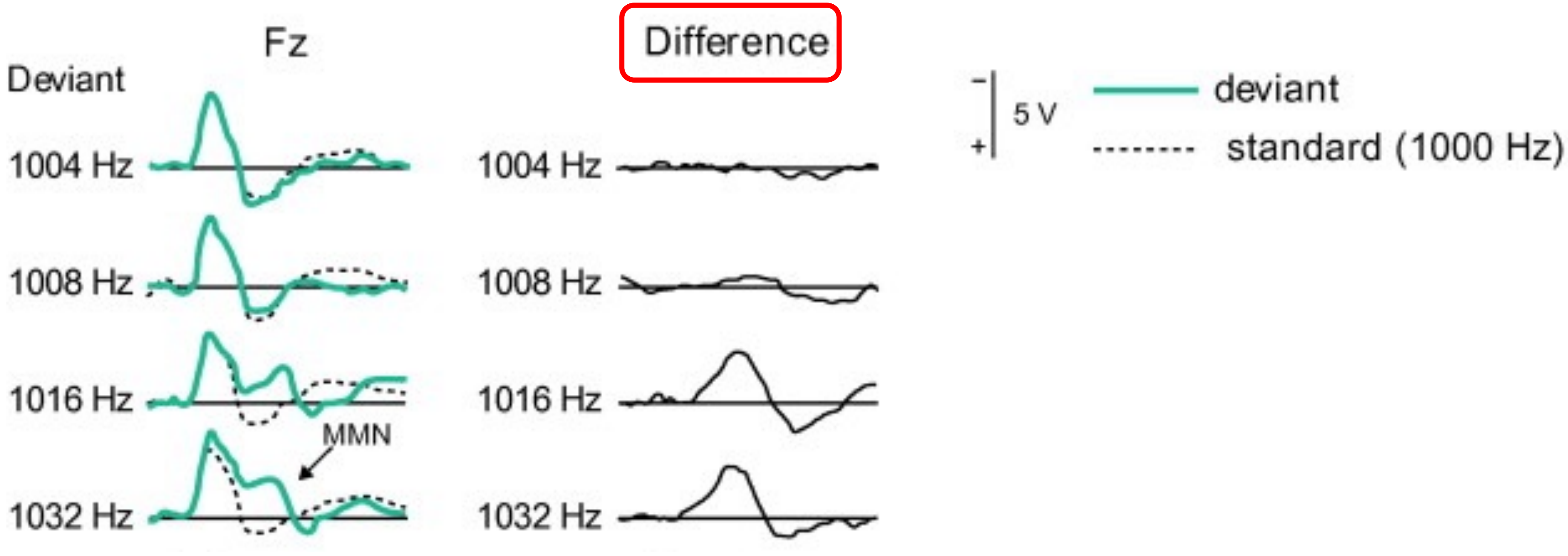


➢ MMN



brain activation

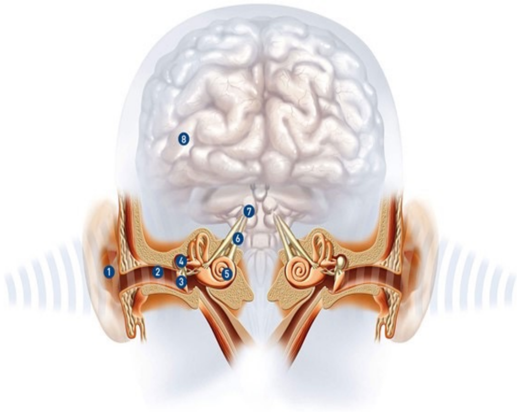
- Mismatch negativity (MMN) component = Deviant - Standard



MMN is an event-related potential that is generated when a stimulus feature deviates from the regularity of previous auditory stimuli. This deviance can be a simple physical characteristic, such as tone duration, intensity, frequency or location; or more abstract characteristics, such as lexical tone or phoneme.

MMN generation relies on the creation of an auditory memory trace for the preceding tones, in order to identify the subsequent deviance. MMN is thought to be an automatic, pre-attentional process and functions as an index of auditory discrimination and memory integrity.

- Ternary mapping algorithm



Match

[m], [LABIAL] → [m], [LABIAL]

Mismatch

[g], [DORSAL]

No-mismatch

[m]
greenbag
[LABIAL]

→

[n]
green
[—]

- Semantic violations elicited a negativity response around 400ms.
- The N400 wave is an event-related brain potential (ERP) measured using EEG. N400 refers to a negativity peaking at about 400 milliseconds after stimulus onset. It has been used to investigate semantic processing.
- Meaningful items, including spoken, written, and signed words, and word-like items such as pronounceable pseudowords, elicit N400 activity.
-

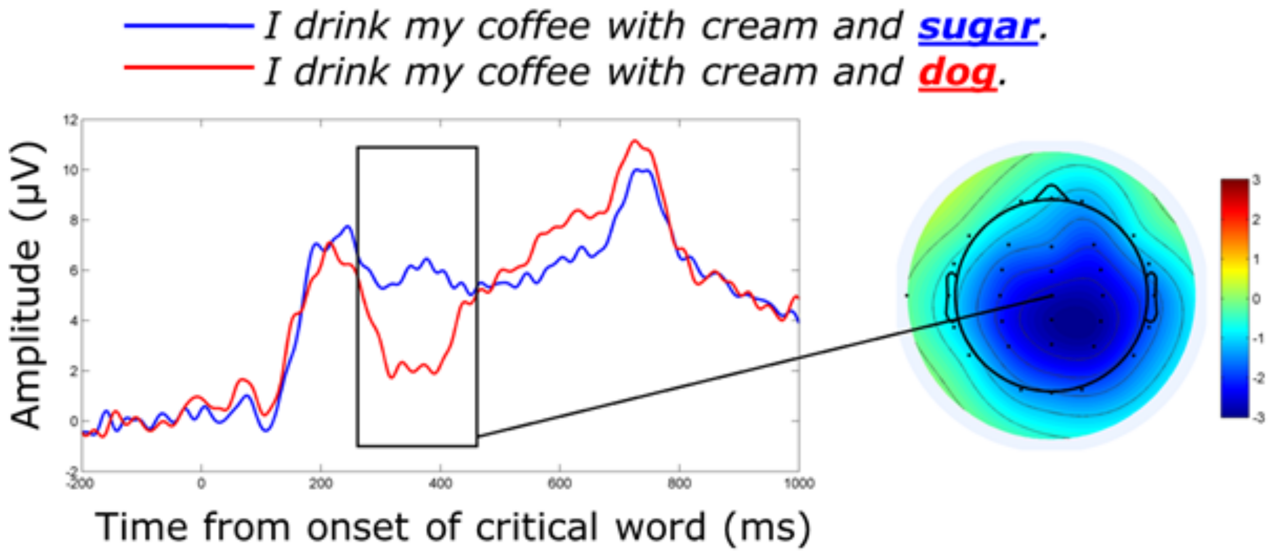


Figure adapted from Hunt, Politzer-Ahles, Gibson, Minai, & Fiorentino (2013)