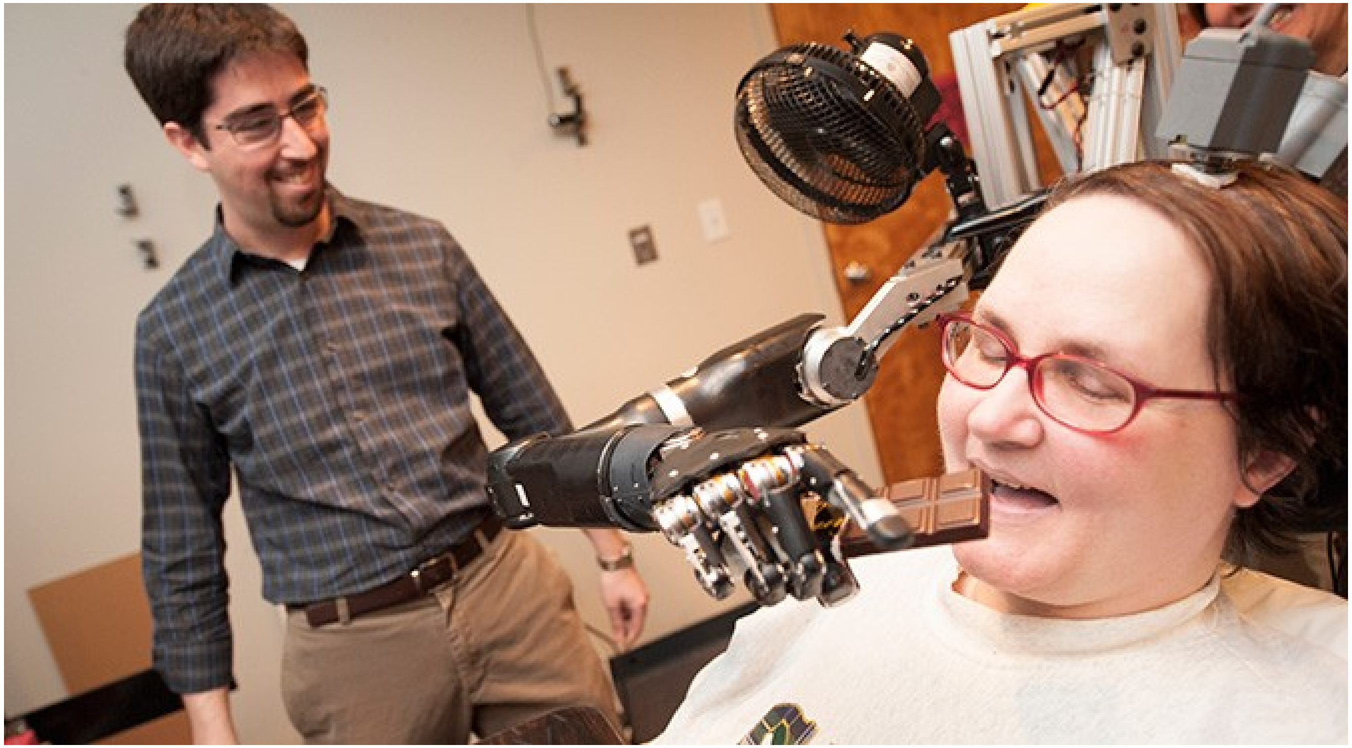
POLITECHNIKA GDAŃSKA

BCI

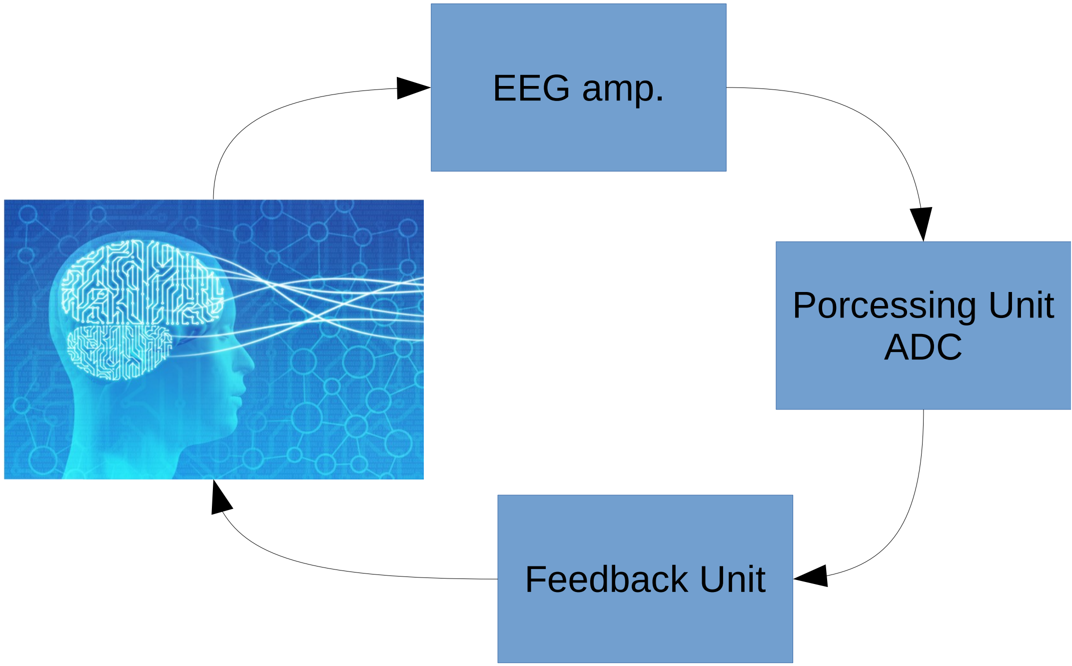
Tomasz Kocejko

POLITECHNIKA
GDAŃSKA

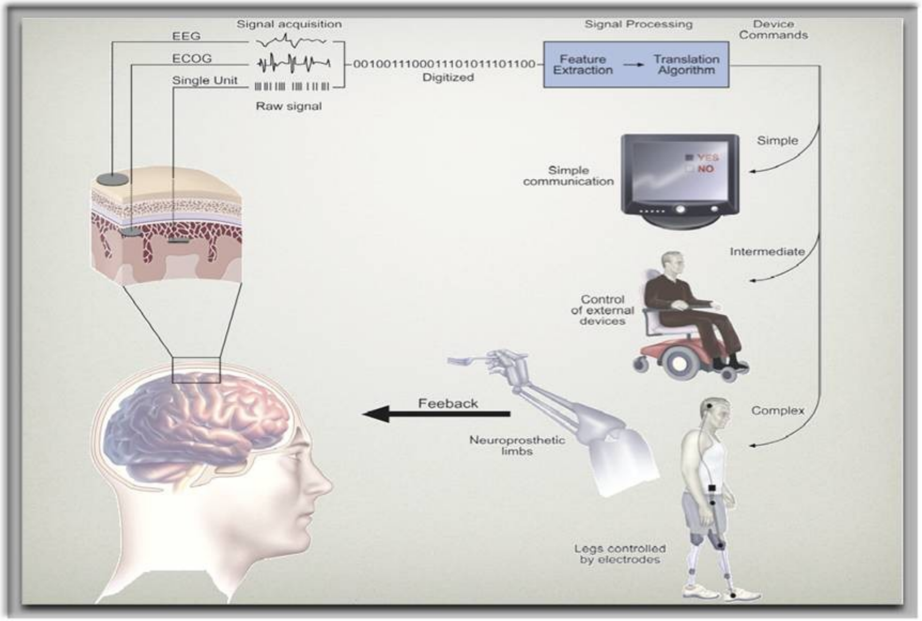


BCI definition

“The goal of BCI technology is to give severely paralyzed people another way to communicate, a way that does not depend on muscle control.” (Wadsworth Center)



BCI (or BMI) is a direct communication pathway between a brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.



Types of BCI

Active BCI: “An active BCI is a BCI which derives its outputs from brain activity which is directly consciously controlled by the user, independently from external events, for controlling an application.”

Reactive BCI: “A reactive BCI is a BCI which derives its outputs from brain activity arising in reaction to external stimulation, which is indirectly modulated by the user for controlling an application.”

Passive BCI: “A passive BCI is a BCI which derives its outputs from arbitrary brain activity without the purpose of voluntary control, for enriching a human - computer interaction with implicit information.

POLITECHNIKA GDAŃSKA

BCI Tech

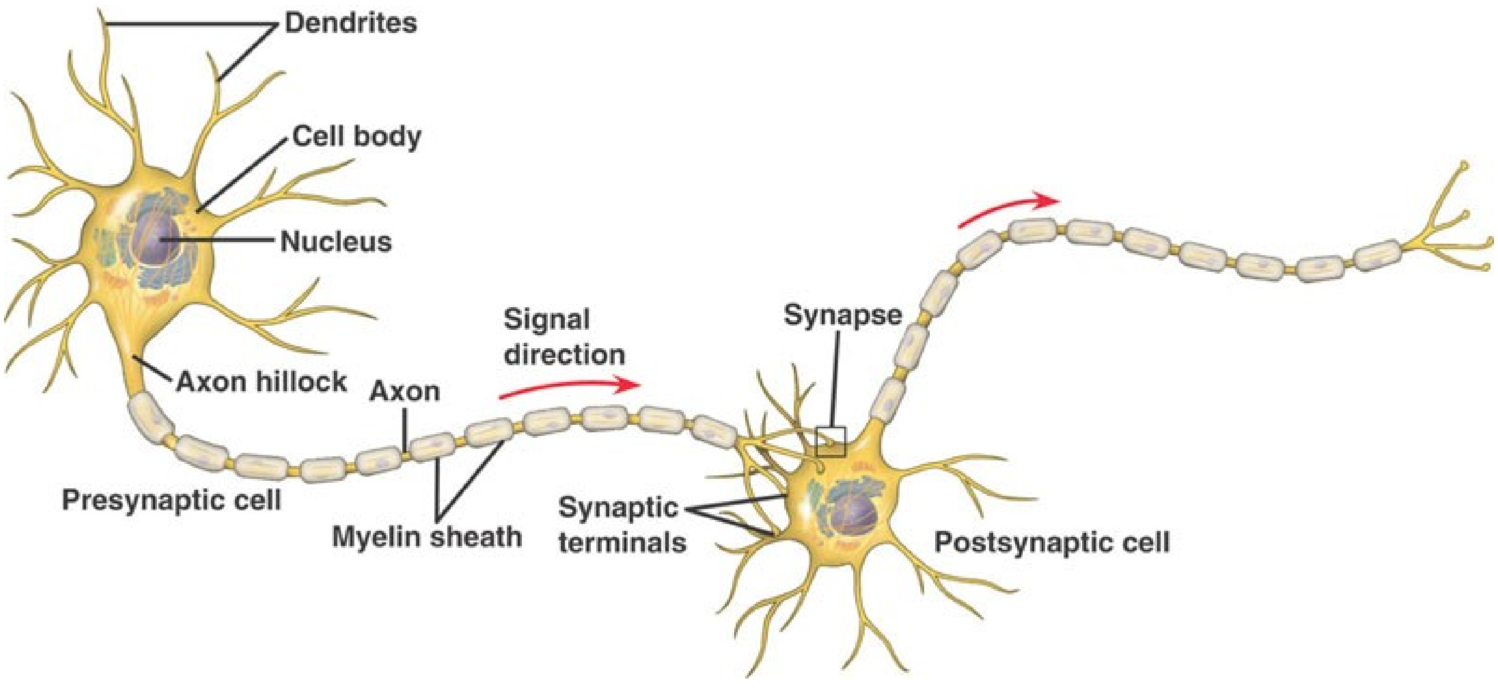
Intentional Control
- typing
- brain actuated prosthesis
- rehabilitation (stroke recovery)
- gaming, art
- hands free applications

BCI Technology
- machine learning
- adaptive signal processing
- neuroimaging

Monitoring cognitive states
- NFT for ADHD
- NFT for pain reduction
- Neurousability
- Neuromaceting
- Car safety

Brain…

- The brain consists of hundreds of thousands of cells, so-called neurons. In fact, there are about 100 billion neurons in the human brain, which are all heavily interconnected.
- Neurons typically consist of a cell body and one or more dendrites which all end at synapses.

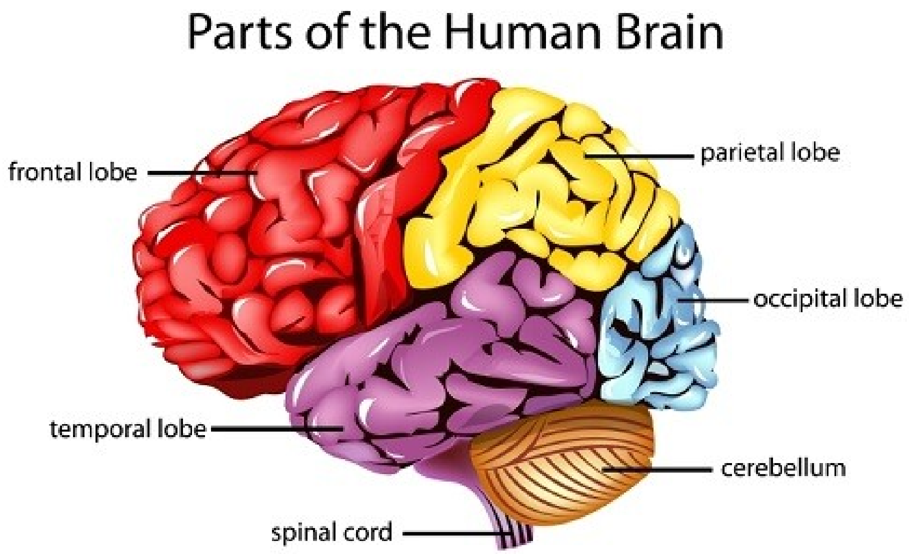


- Synapses act as gateways of inhibitory or excitatory activity between neurons. This means that synapses
  - propagate information impulses across neurons
  - prevent the passage of information from one neuron to the next

Brain...

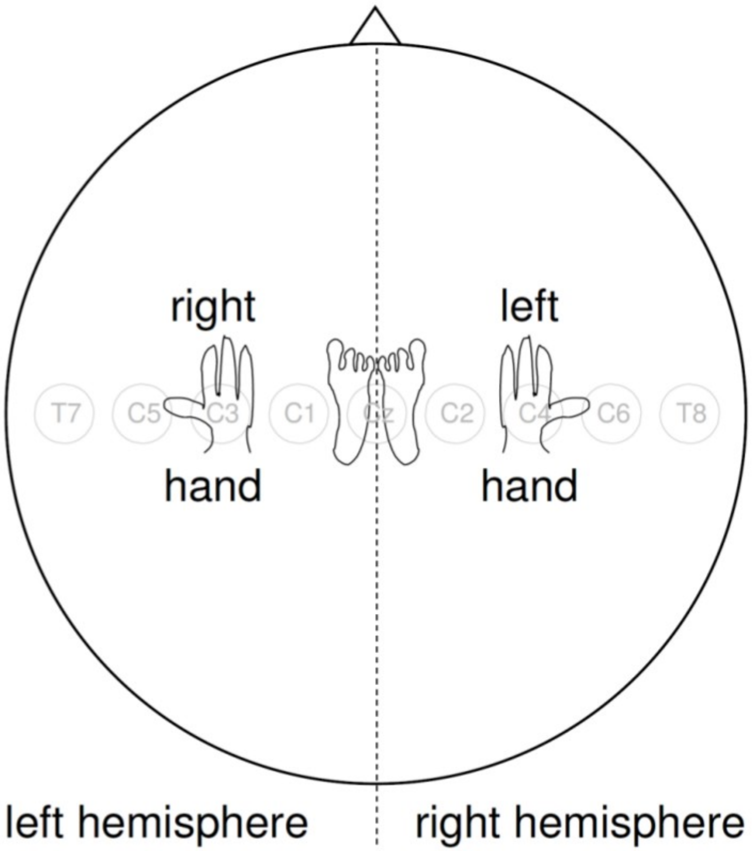
- synaptic transmission is triggered by the release of neurotransmitters (dopamine, epinephrine, acetylcholine, etc.), which causes a voltage change across the cell membrane.
- Any synaptic activity generates a subtle electrical field, which is also called postsynaptic potential. Postsynaptic potentials typically last tens to hundreds of milliseconds.

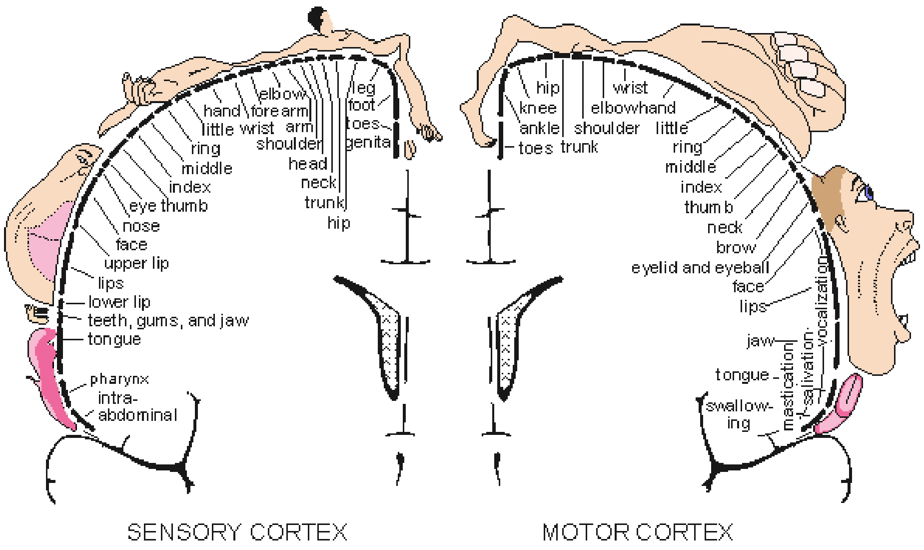
Brain...

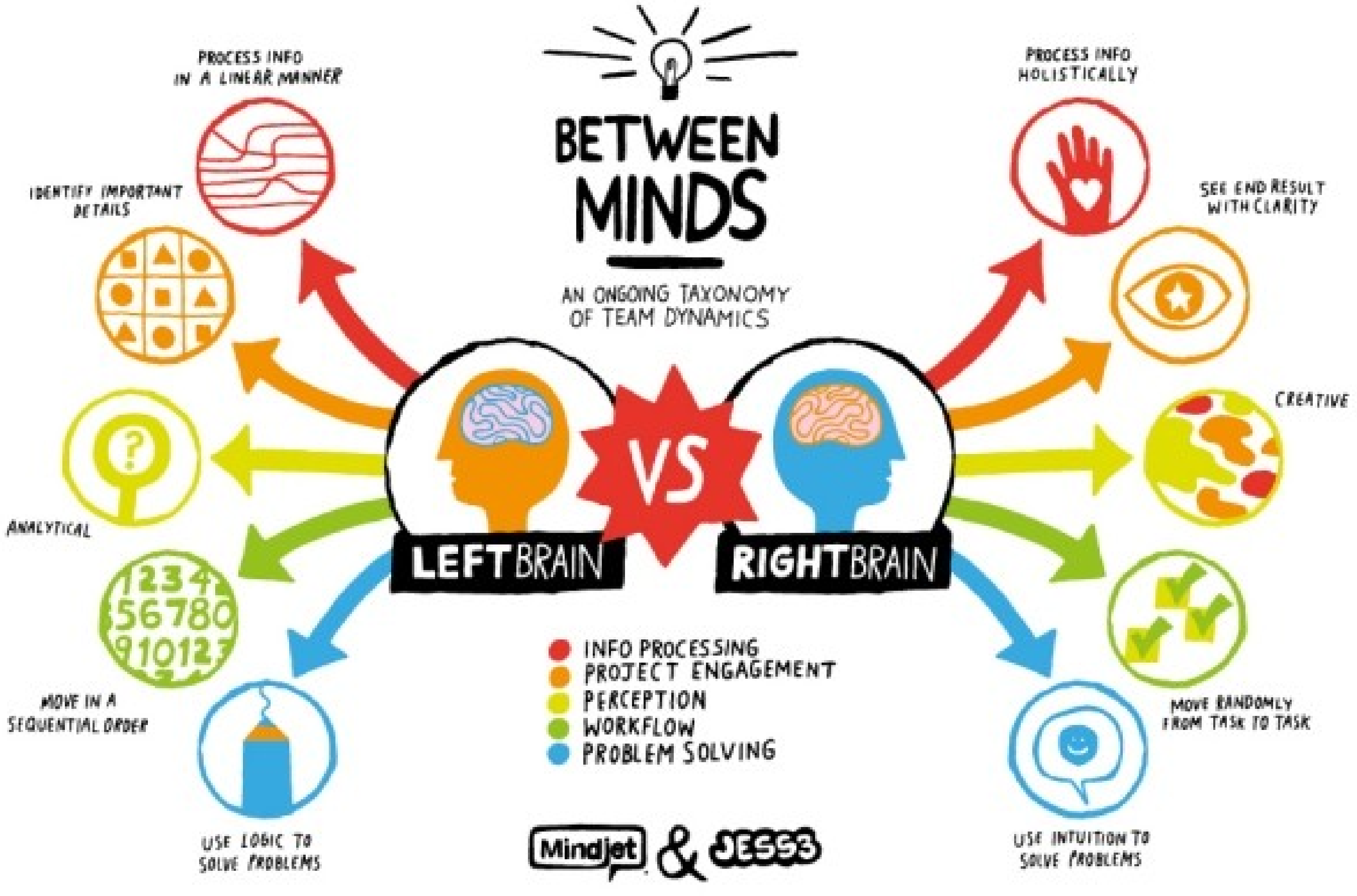


- Brain Steam - it controls autonomic body processes such as heartbeat, breathing, bladder function and sense of equilibrium.
- The Cerebellum - responsible for regulation and control of fine movements, posture and balance
- Occipital lobe is the visual processing center of our brain
- Temporal lobe is associated with processing sensory input to derived, or higher, meanings using visual memories, language and emotional association
- Parietal lobe is all about integrating information stemming from external sources as well as internal sensory feedback from skeletal muscles, limbs, head, eyes, otoliths etc
- Frontal lobe is the region where most of a conscious thoughts and decisions are made.

Brain...

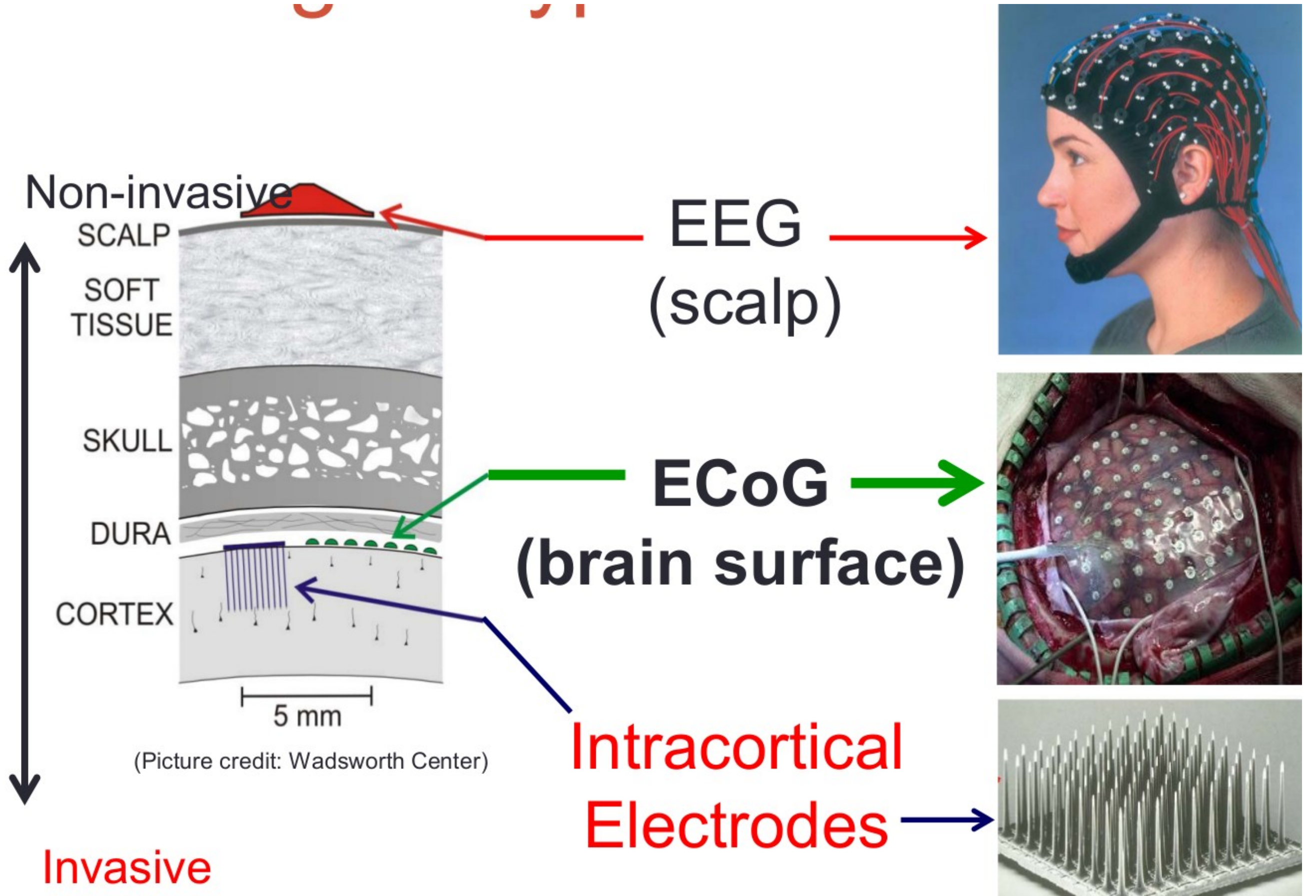

right
hand
left
hand
T7
C5
C3
C1
Cz
C2
C4
C6
T8
left hemisphere
right hemisphere


SENSORY CORTEX
MOTOR CORTEX
elbow
hand
forearm
little
wrist
arm
ring
shoulder
middle
head
index
neck
eye thumb
trunk
nose
hip
face
leg
foot
toes
upper lip
lips
lower lip
teeth, gums, and jaw
tongue
pharynx
intra-
abdominal
hip
knee
ankle
toes
trunk
wrist
elbow hand
shoulder
little
ring
middle
index
thumb
neck
brow
eyelid and eyeball
face
lips
jaw
tongue
swallow-
ing
mastication
salivation
vocalization


BETWEEN MINDS
AN ONGOING TAXONOMY OF TEAM DYNAMICS
PROCESS INFO IN A LINEAR MANNER
IDENTIFY IMPORTANT DETAILS
ANALYTICAL
MOVE IN A SEQUENTIAL ORDER
USE LOGIC TO SOLVE PROBLEMS
PROCESS INFO HOLISTICALLY
SEE END RESULT WITH CLARITY
CREATIVE
MOVE RANDOMLY FROM TASK TO TASK
USE INTUITION TO SOLVE PROBLEMS
LEFT BRAIN
VS
RIGHT BRAIN
INFO PROCESSING
PROJECT ENGAGEMENT
PERCEPTION
WORKFLOW
PROBLEM SOLVING
Mindjet & JESS3

Types of BCI

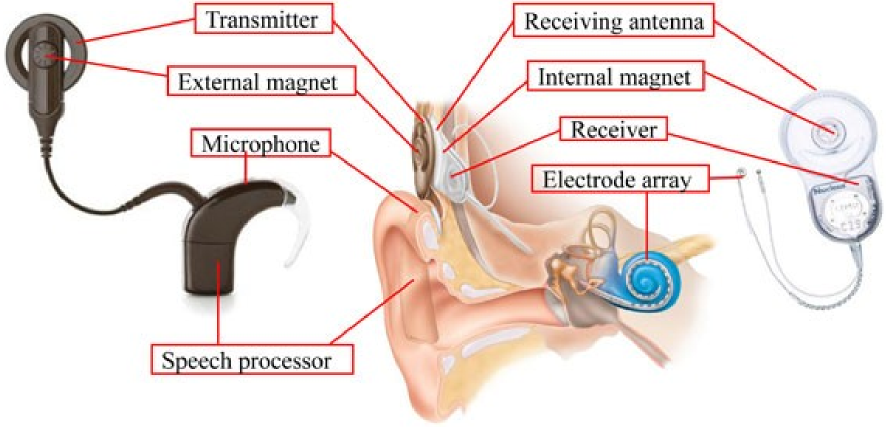
- EEG
- FNIRS
- FMRI
- EcoG
- INTERCORTIAL
- NeuroChips


Non-invasive
SCALP
SOFT TISSUE
SKULL
DURA
CORTEX
5 mm
(Picture credit: Wadsworth Center)
Invasive
EEG
(scalp)
ECoG
(brain surface)
Intracortical
Electrodes

- Invasive Approaches
  - Recording Activities of Neurons inside the Brain using Electrodes and Electrode Arrays (Typically only in animals eg. rats and monkeys)
  - Recording Electrical Activity from the Brain Surface (Electrocorticography or Ecog) In humans eg. patients scheduled for brain surgery
  - Implants and Neural Stimulation In animals and humans (eg. Parkinson’s patients)

POLITECHNIKA
GDAŃSKA

Cochler Implant



AB

Advanced Bionics®

BCI - noninvasiv

- Non-Invasive Brain Imaging
  - fMRI (Functional Magnetic Resonance Imaging): Measures changes in blood flow due to increased brain activity Good spatial resolution but too slow for real-time BCI
  - MEG (MagnetoEncephaloGraphy): Measures changes in magnetic fields due to neural activity Good spatiotemporal resolution but expensive and uncomfortable
  - EEG (ElectroEncephaloGraphy): Measures voltage changes at the scalp due to neural activity Good temporal resolution but poor spatial resolution Inexpensive and therefore most common in current BCIs

Signal	Cell count	Raw Magnitude	Feature Z (depends)	Spatial Specificity
EEG (non-invasive)	> 1M	~50 uV	3-5	1-5 cm
ECoG (semi-invasive?)	500K	~500 uV	10-20	3-10 mm
Intracortical (invasive)	1-???	10s of mV	Very high	< 300 um

EEG

- Measures the electrical activity of the brain by capturing electrical potential differences on the scalp surface
- Non-invasive
- High temporal resolution, but low spatial resolution
- Signal sensitive to:
  - facial muscle contractions
  - electrostatic artifacts
  - head conductivity variation,

EEG based BCI

- Typing words by flashing letters (Farwell & Donchin, 1988) Select a character (out of 36) in 26 seconds with 95% accuracy
- Move a cursor towards a target on a screen by training subjects to control the amplitude of their Mu waves (Wolpaw et al., 1991; Pfurtscheller et al., 1993) 10-29 hits/min and 80-95% accuracy after 12 45-min sessions
- Moving a joystick in 1 of 4 directions by classifying EEG patterns during mental tasks using artificial neural networks (Hiraiwa et al., 1993; Anderson & Sijercic, 1996)

Different neural responses

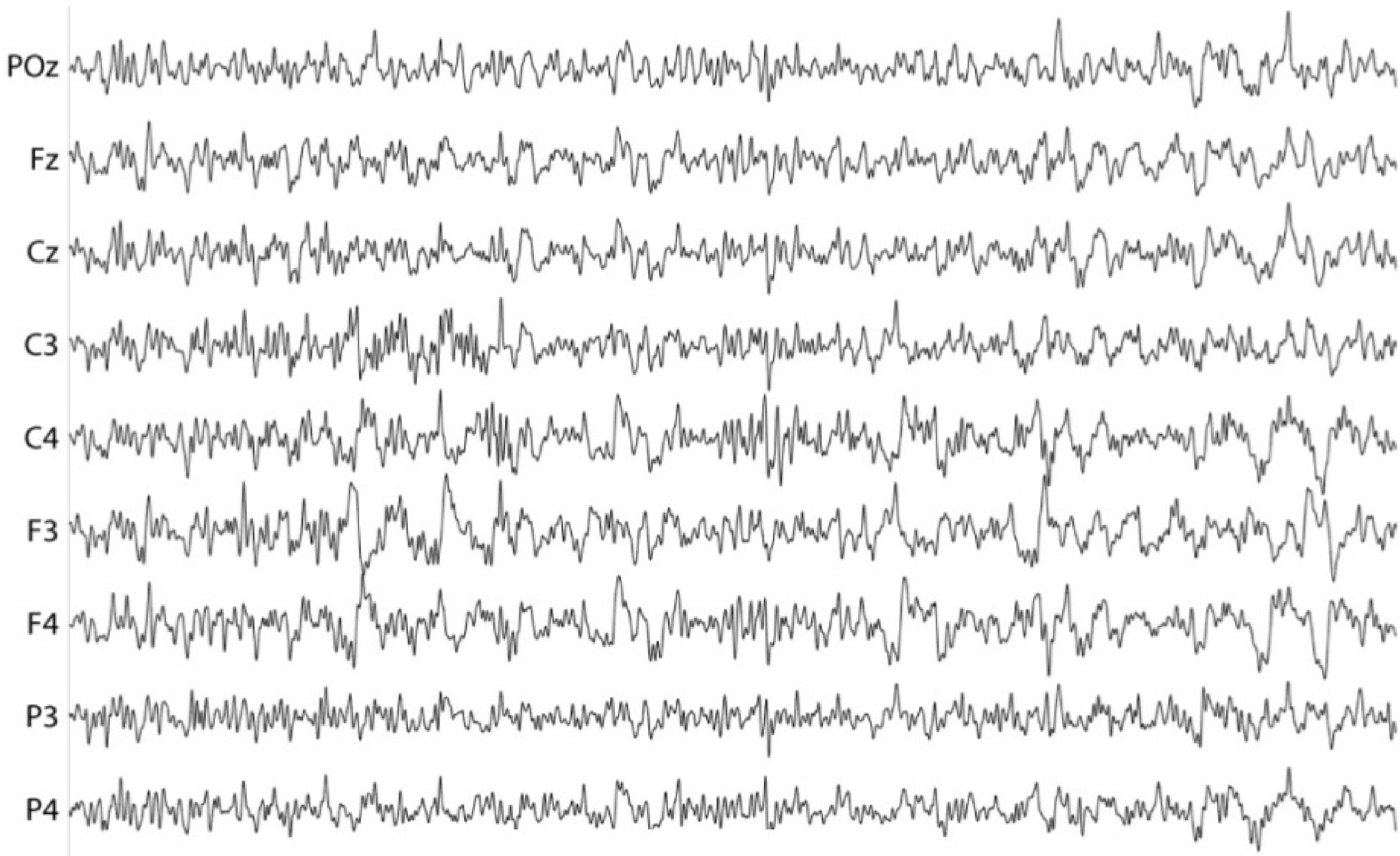
Event-related potentials (ERPs)	Event-related (de)synchronization (ERD / ERS)
Change in activity of neuronal populations → small voltage shifts	Change in synchrony of neuronal populations → change of power in frequency bands

- Exogeneous EEG components: induced by a stimulus/task
- Endogenous EEG components: ongoing brain activity

POLITECHNIKA GDAŃSKA

- In contrast to other physiological recordings (such as GSR) which often require only a single sensor, EEG recordings are done with electrode arrays, comprising various sensor numbers ranging from 10 to 500 electrodes, depending on the scope of the experiment. For faster application, EEG electrodes are mounted in elastic caps, meshes or rigid grids, ensuring that the data can be collected from identical scalp positions across sessions or respondents.

POLITECHNIKA
GDAŃSKA



electrodes

time (ms)

1000 ms

Frequency, power & phase

>> **Frequency** is the speed of an oscillation / rhythm and has the unit Hertz (Hz), which refers to the number of oscillations per second. Think of this similar to beats per minute (bpm) for songs.

>> **Power** is the amount of energy in a frequency band, typically expressed as squared amplitude. Imagine the loudness of a song. In the example above, the power of synchronized applauding was much higher – you could also say that it produces a signal with more power.

>> **Phase** is the amount of synchronization across several generators (neurons, people). Everyone clapping in unison results in perfect phase alignment. If everyone claps for themselves, there's zero phase alignment. When it comes to brain activity, there are certain theories on how external stimuli cause changes in the internal synchronization patterns. In the concert example, the return of the band (external stimulus) will cause the synchronized applause of the audience to fade.

- he signal is always a mixture of several underlying base frequencies, which are considered to reflect certain cognitive, affective or attentional states.
- Because these frequencies vary slightly dependent on individual factors, stimulus properties and internal states, research classifies these frequencies based on specific frequency ranges, or frequency bands:
  - Delat (1-4Hz)
  - Theta (4-8Hz)
  - Alpha (8-12Hz)
  - Beta (13-25Hz)
  - Gamma (>25Hz)

POLITECHNIKA GDAŃSKA

- Delta
  - present during deep non-REM sleep (stage 3), also known as slow-wave sleep (SWS).
  - The stronger the delta rhythm, the deeper the sleep
  - Delta frequencies are stronger in the right brain hemisphere
  - play a core role in the formation and internal arrangement of
  - biographic memory as well as acquired skills and learned information

- Typical studies on delta:
  - Sleep and sleep disorders
  - Alcoholism

- Theata
  - correlates with the difficulty of mental operations, for example during focused attention and information uptake, processing and learning or during memory recall.
  - Theta can be recorded from all over cortex

POLITECHNIKA GDAŃSKA

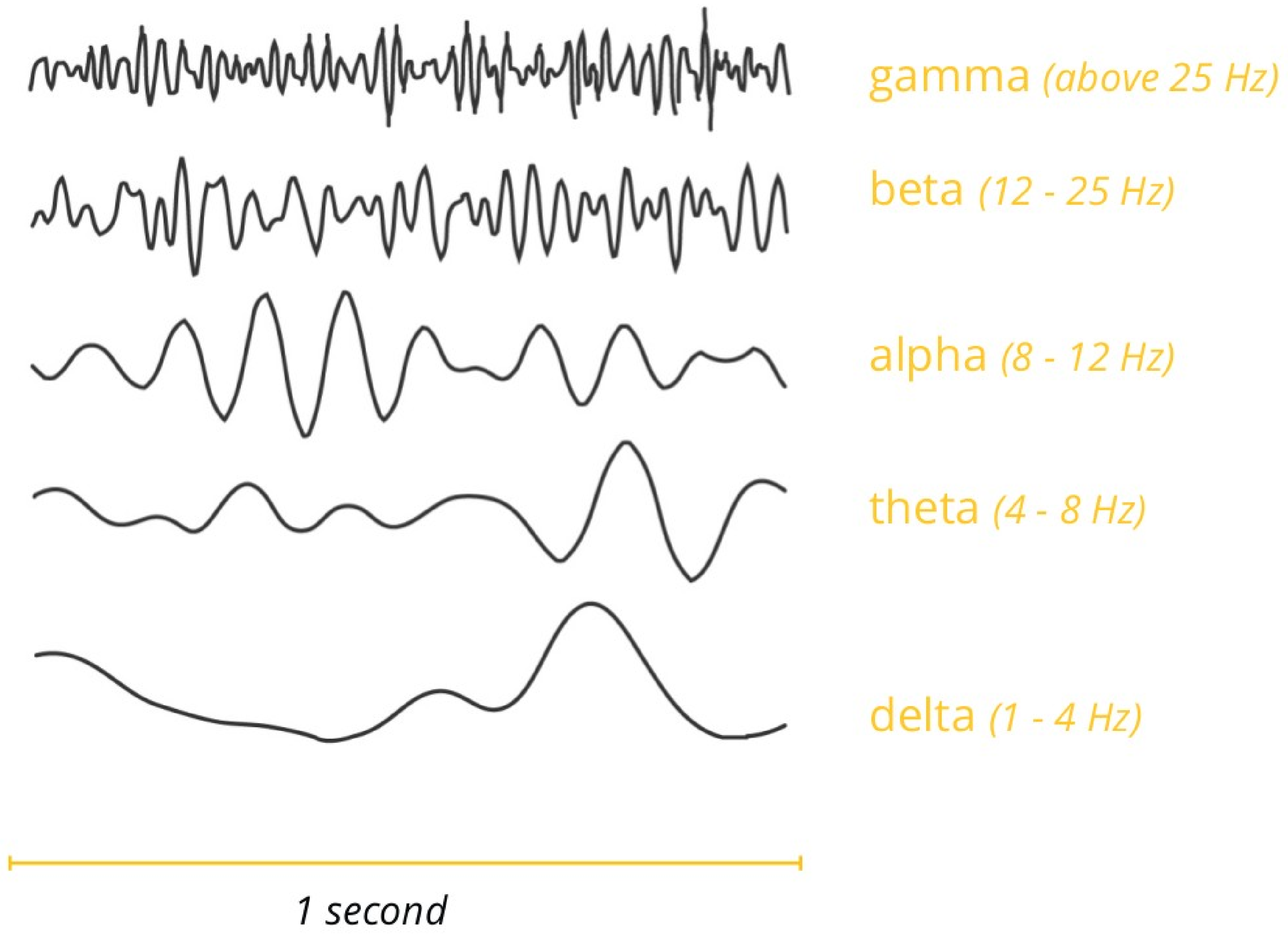
- Typical studies on theta:
  - N-back task. In this task, respondents see rapid sequences of letter, number or icon stimuli on screen. At the same time, they have to remember the element N steps back and respond if the element showed certain characteristics
  - Spatial navigation (theta have been found to increase in complex maze systems or at key landmarks along a route)
  - Brain monitoring in operational environments (aircraft trafci, vessel control)

- Alpha
  - is generated in posterior cortical sites, including occipital, parietal and posterior temporal brain regions.
  - increased levels of alpha band power during mental and physical relaxation with eyes closed
  - alpha power is reduced, or suppressed, during mental or bodily activity with eyes open

- Typical studies on alpha:
  - Meditation
  - Biofeddback traning (Increased levels of alpha power are interpreted as deeper relaxation. This is particularly useful in rehabilitation scenarios or for clinical populations, for example children suffering from ADHD.
  - Attention (Poor performers and distracted respondents generally show higher amounts of alpha power)

- Beta
  - This frequency is generated both in posterior and frontal regions.
  - Active, busy or anxious thinking and active concentration are generally known to correlate with higher beta power.

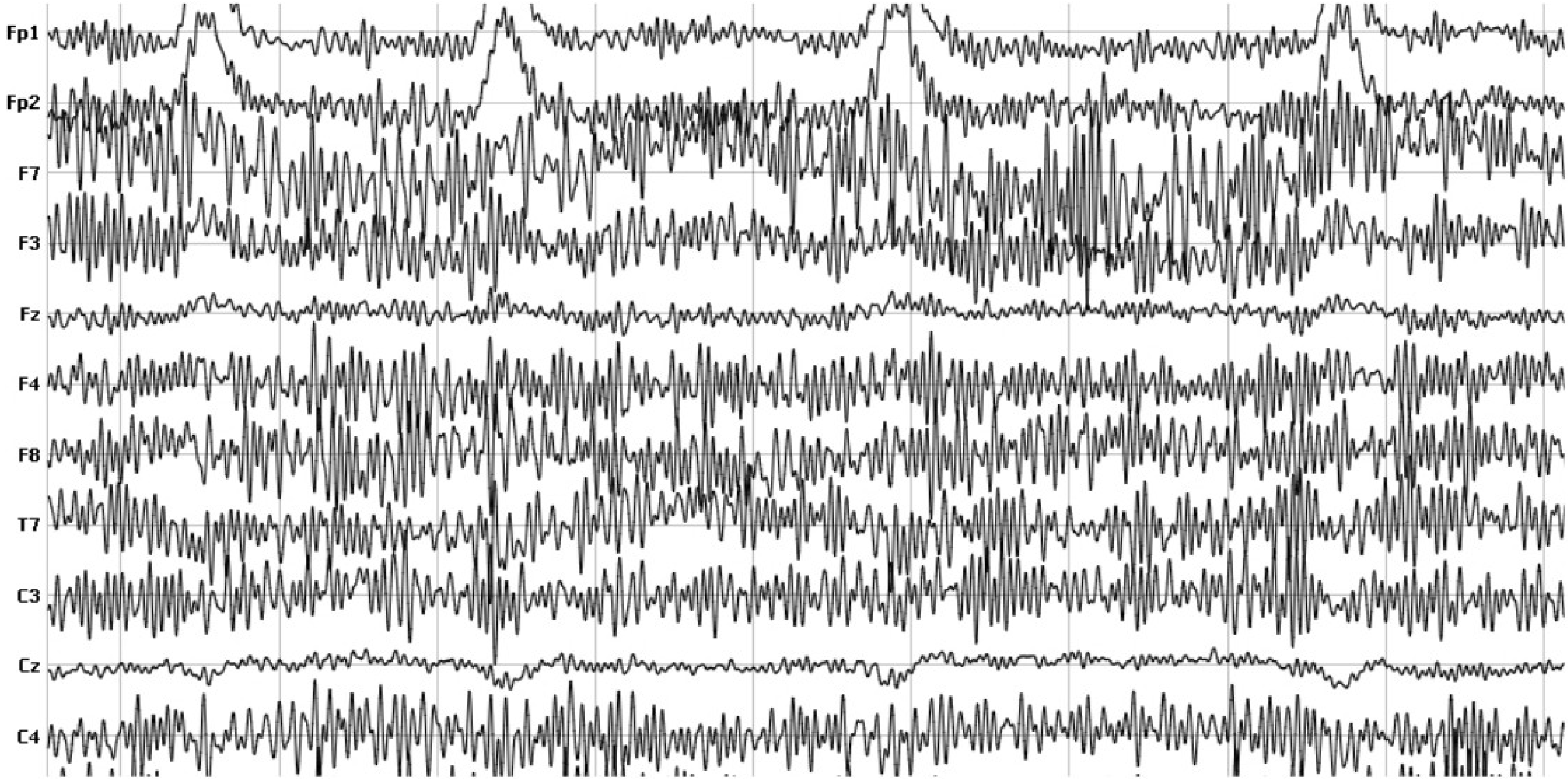
- Typical studies on beta:
  - Motor control
  - Stimulant-induced alertness. Beta frequencies are often monitored during stimulation with extreme light / sound stimuli and psychostimulants modifying levels of alertness and attentional processing.



gamma (above 25 Hz)
beta (12 - 25 Hz)
alpha (8 - 12 Hz)
theta (4 - 8 Hz)
delta (1 - 4 Hz)
1 second

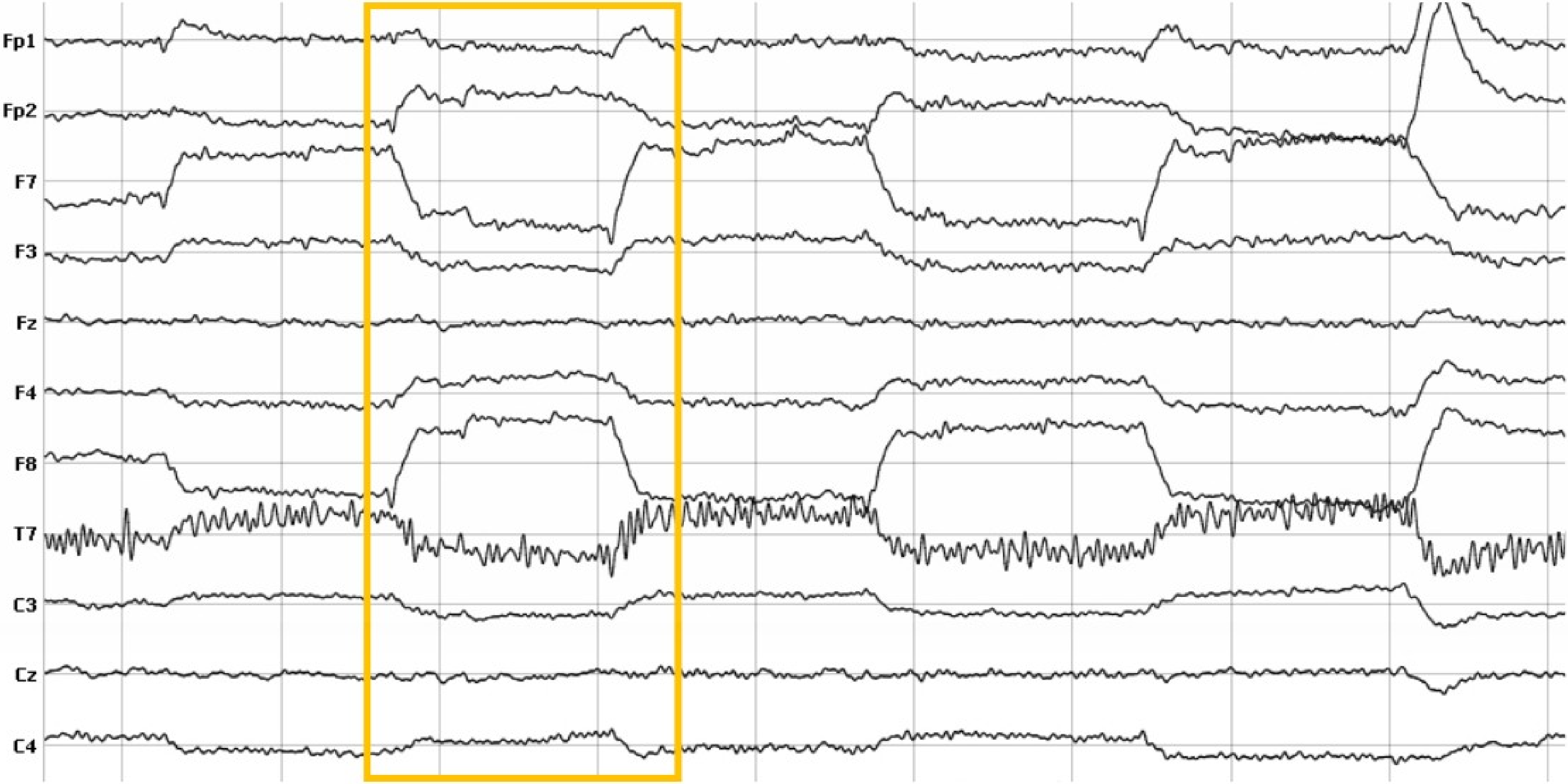
- Noise in EEG
  - From muscle activity
  - From eye movements
  - From blinks

Noise from muscles



POLITECHNIKA GDAŃSKA

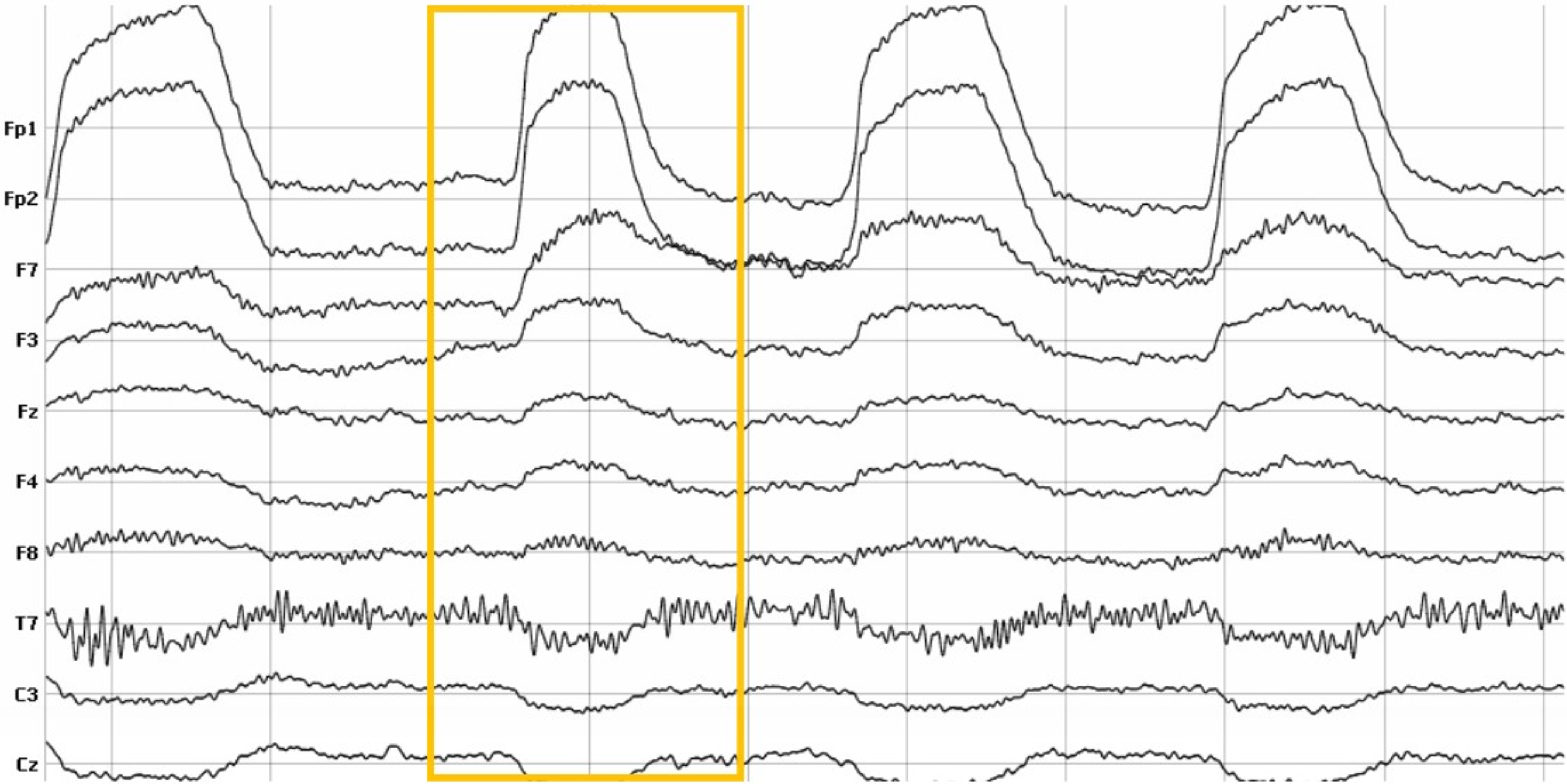
Noise from eye movements



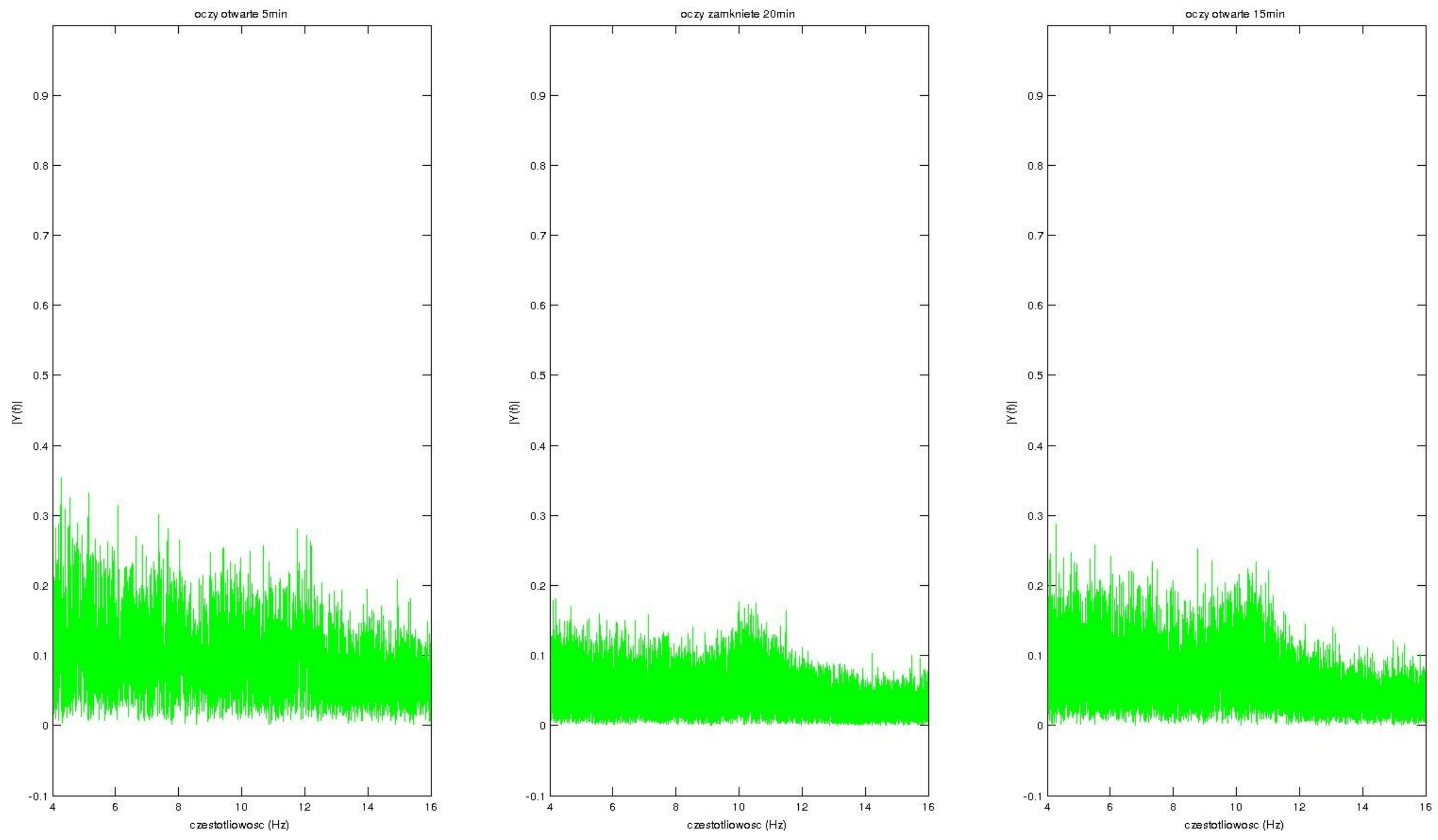
POLITECHNIKA GDAŃSKA

Noise from eye blinks

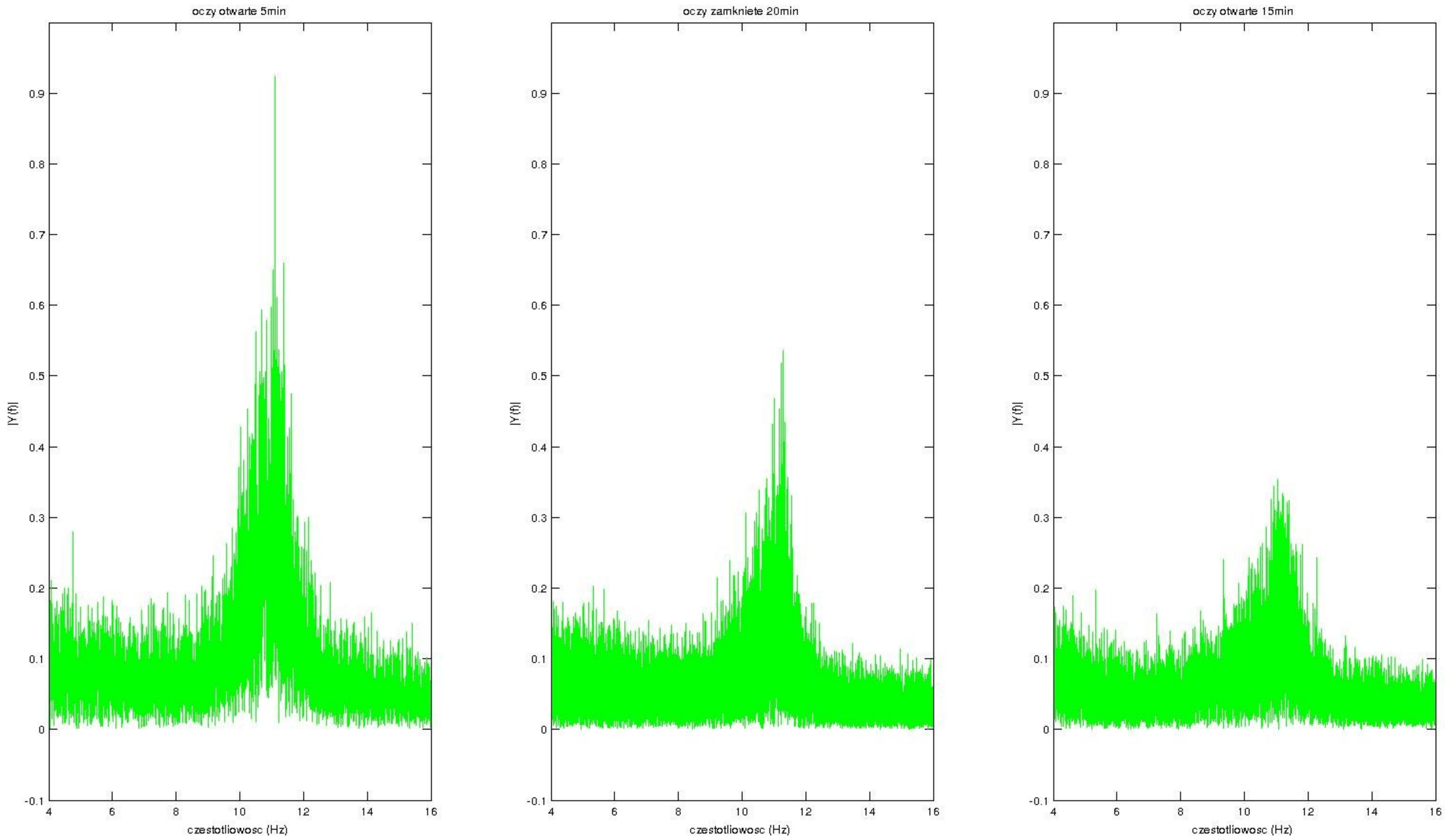
Blinking:



Drowsiness detection



Drowsiness detection




TU
Graz
GRAZ BCI
WORLD OF WARCRAFT
BCI CONTROLLED
Laboratory of Brain-Computer Interfaces
Graz University of Technology
Austria

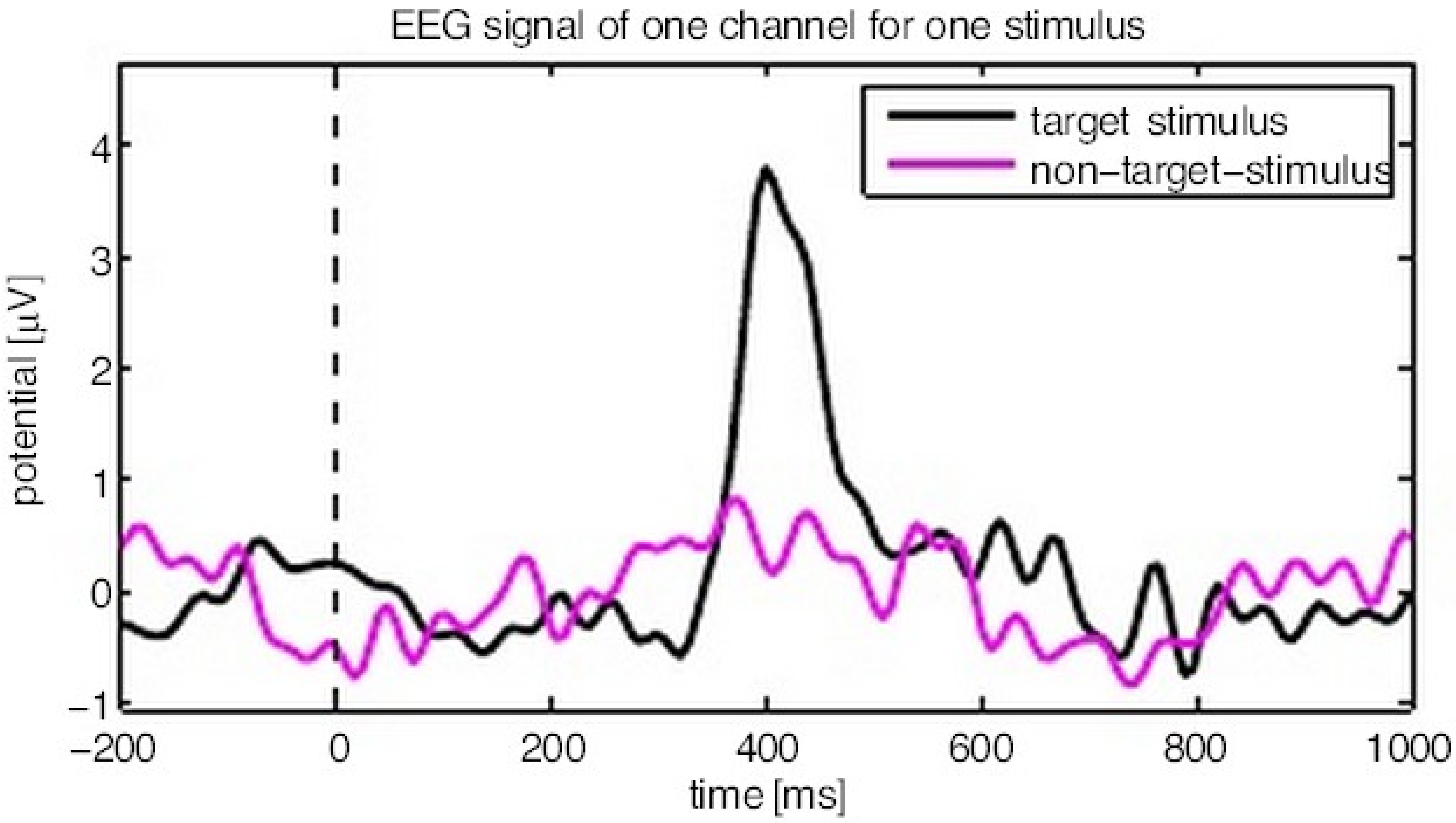
P300

- The P300 is an event-related potential (ERP) endogenous component that has a positive deflection that occurs in the scalp-recorded electroencephalogram (EEG) and typically elicited approximately 300 ms after the presentation of an infrequent stimulus (such as visual, auditory, or somatosensory)

P300

- The presentation of infrequent stimuli evokes a positive deflection in the EEG over parietal cortex about 300 ms after stimulus presentation. This response has been termed the "P300" or potential.

POLITECHNIKA GDAŃSKA



POLITECHNIKA GDAŃSKA

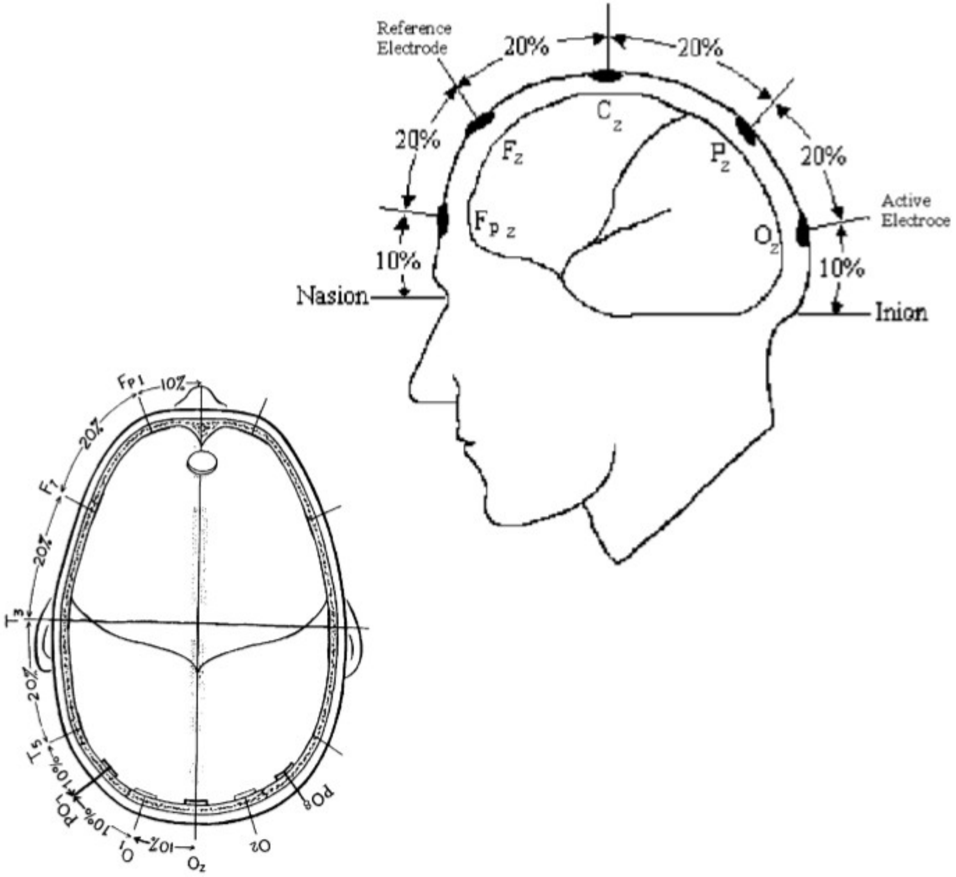
- A P300 is usually elicited if four conditions are met:
  - A random sequence of stimulus events must be presented.
  - A classification rule that separates the series of events into two categories must be applied.
  - The user's task must require using the rule.
  - One category of events must be presented infrequently.

- Last for 150-200ms
- Triangular shape
- The peak potential is 2-5 uV
- The peak potential is less than the brain's background activity
- Is typically enhanced by averaging over multiple responses

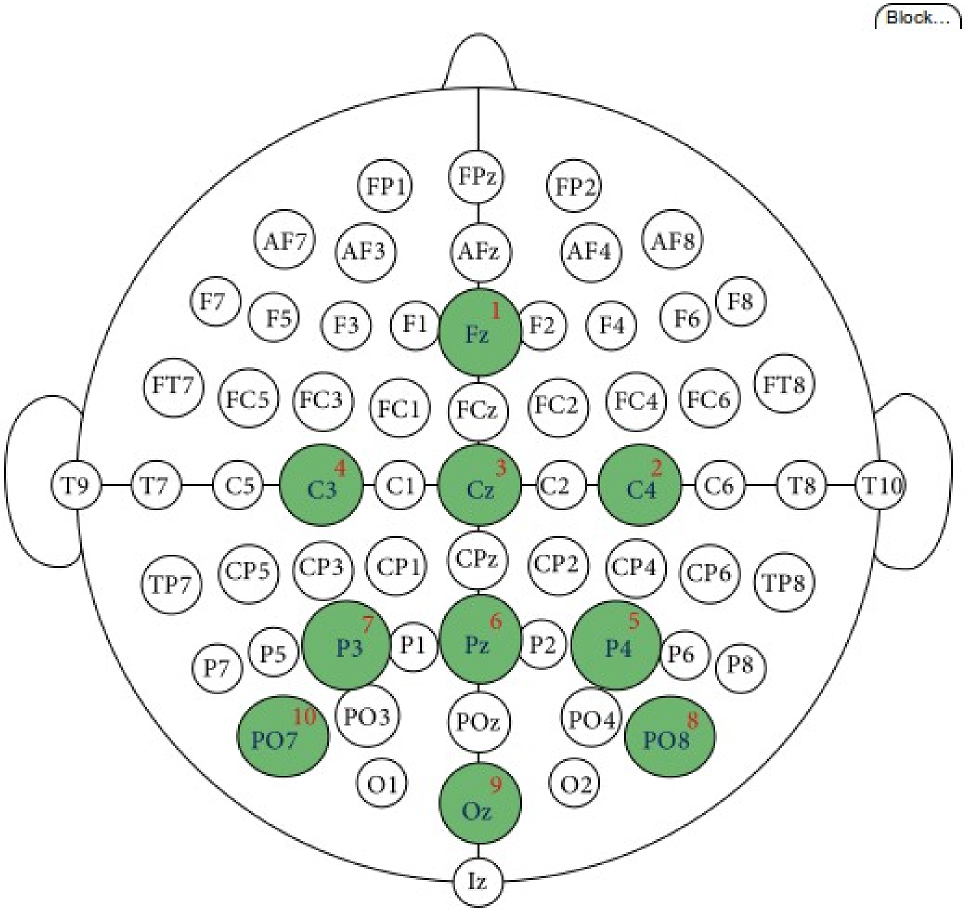
P300 (VEP) - electrodes

- Standard silver-silver chloride or gold disc surface electrodes are recommended for recording VEPs. The electrodes should be fixed to the scalp and maintained using procedures recommended by the manufacturer.
- The electrode impedances should be below 5 kOhms and equal to reduce electrical interference

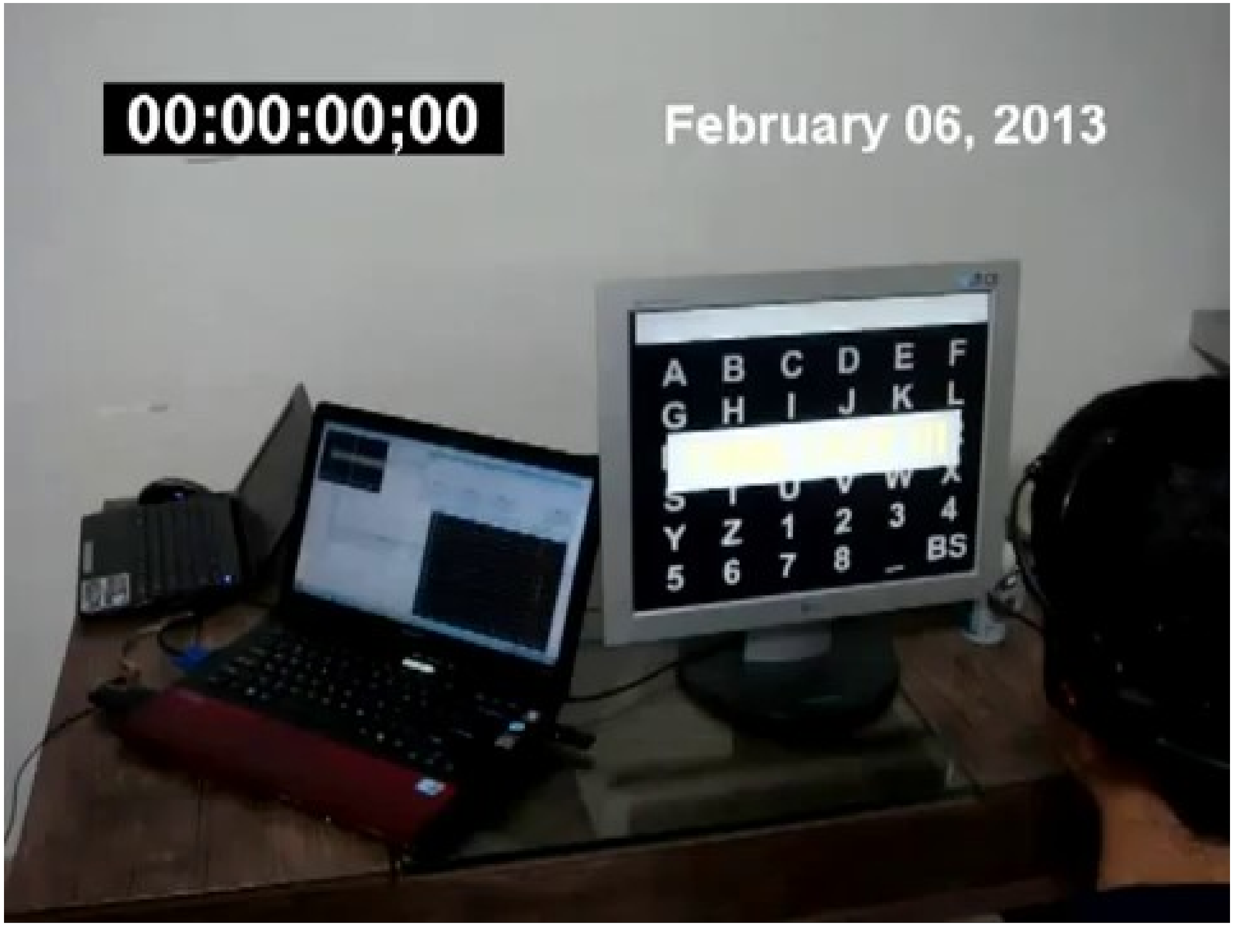
P300 (VEP) - electrodes



P300 – experimental electrode palcement



POLITECHNIKA GDAŃSKA



POLITECHNIKA GDAŃSKA

- … Dziękuję za uwagę