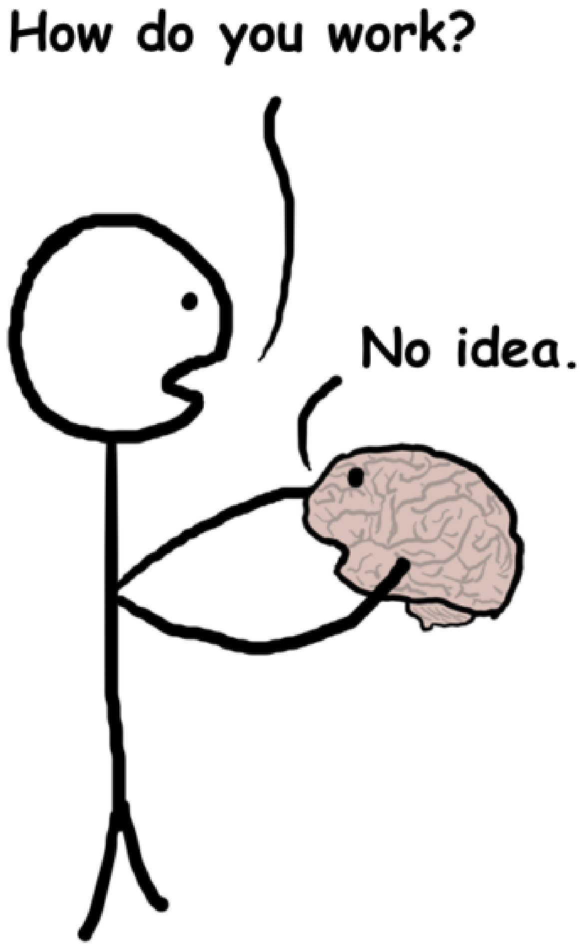
Brain-Computer Interfaces in psychology

Karla Matić | KU Leuven, BCCN Berlin

32nd EFPSA Congress in Malta, April 2018

Today's menu

- What are BCIs in theory
  - Interface part
  - Brain part
  - Computer part
- Example: BCIs in research of motor preparation
- What are BCIs in practice
  - BCIs for communication
  - BCIs for control
  - BCIs and virtual reality and gaming
- Groupwork: build your own BCI



Disclaimers

- What you can expect
  - to get a very general grasp of how non-invasive EEG-based BCIs work
  - to learn a thing or two about EEG components used for control of BCIs
  - a LOT of videos and fun-facts
- What you shouldn't expect
  - technical stuff
  - expertise of any sort
  - DIY instructions
  - futuristic narrative

What are BCIs (in theory)?

Definition(s) | Brainy part | Computer part | Interface part

[some examples of BCI applications]
https://www.youtube.com/watch?v=JCkYIrFWIsQ

A brain–computer interface (BCI), sometimes called a neural-control interface (NCI), mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a direct communication pathway between an enhanced or wired brain and an external device. (Wikipedia)

Brain-computer interfaces (BCIs) are devices that directly read brain activity and use it in a real-time, closed loop system with feedback to the user. Unlike all other interfaces, BCIs do not require movement. Instead, the information from the brain is translated into messages or commands without relying on the body's natural output pathways. (BCI research – state-of-the-art summary, 2017)

Brain-computer interface (BCI) is a name for a setup consisting of both hardware and software made for recording, real-time analysing, and feeding back neural activity to the user. (my words)

A brain–computer interface (BCI), sometimes called a neural-control interface (NCI), mind-machine interface (MMI), direct neural interface (DNI), or brain–machine interface (BMI), is a **direct communication** pathway between an enhanced or wired brain and an external device. (Wikipedia)

Brain-computer interfaces (BCIs) are devices that **directly** read brain activity and use it in a **real-time**, closed loop system with **feedback** to the user. Unlike all other interfaces, BCIs do not require movement. Instead, the information from the brain is translated into messages or commands without relying on the body’s natural output pathways. (BCI research – state-of-the-art summary, 2017)

Brain-computer interface (BCI) is a name for a setup consisting of both hardware and software made for recording, **real-time** analysing, and **feeding back** neural activity to the user. (my words)

Takeaway #1: The brain-computer interfaces are so cool because

a.) neural activity is analysed in *real time*

b.) the communication between brain and device is two-way (*feedback*)

BRAIN

- brain does stuff
- we record that stuff and call it names = components or features

COMPUTER

- analysis of signals in real time
- machine learning
- feeding back to the user

INTERFACE

- *usually*: the whole interface for real-time feedback setup (user interface)
- *here*: interface for recording neural activity (hardware interface)

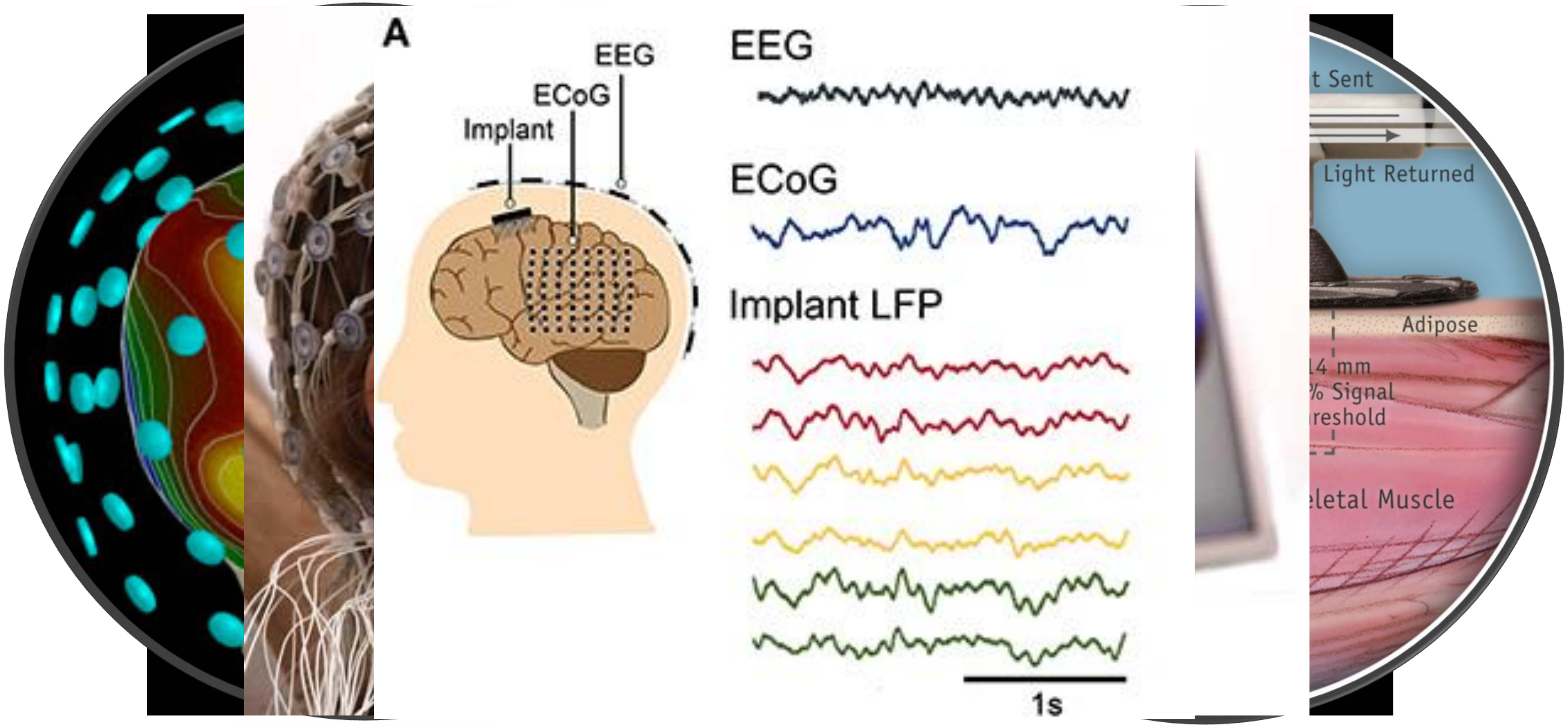
Brain-Computer INTERFACE

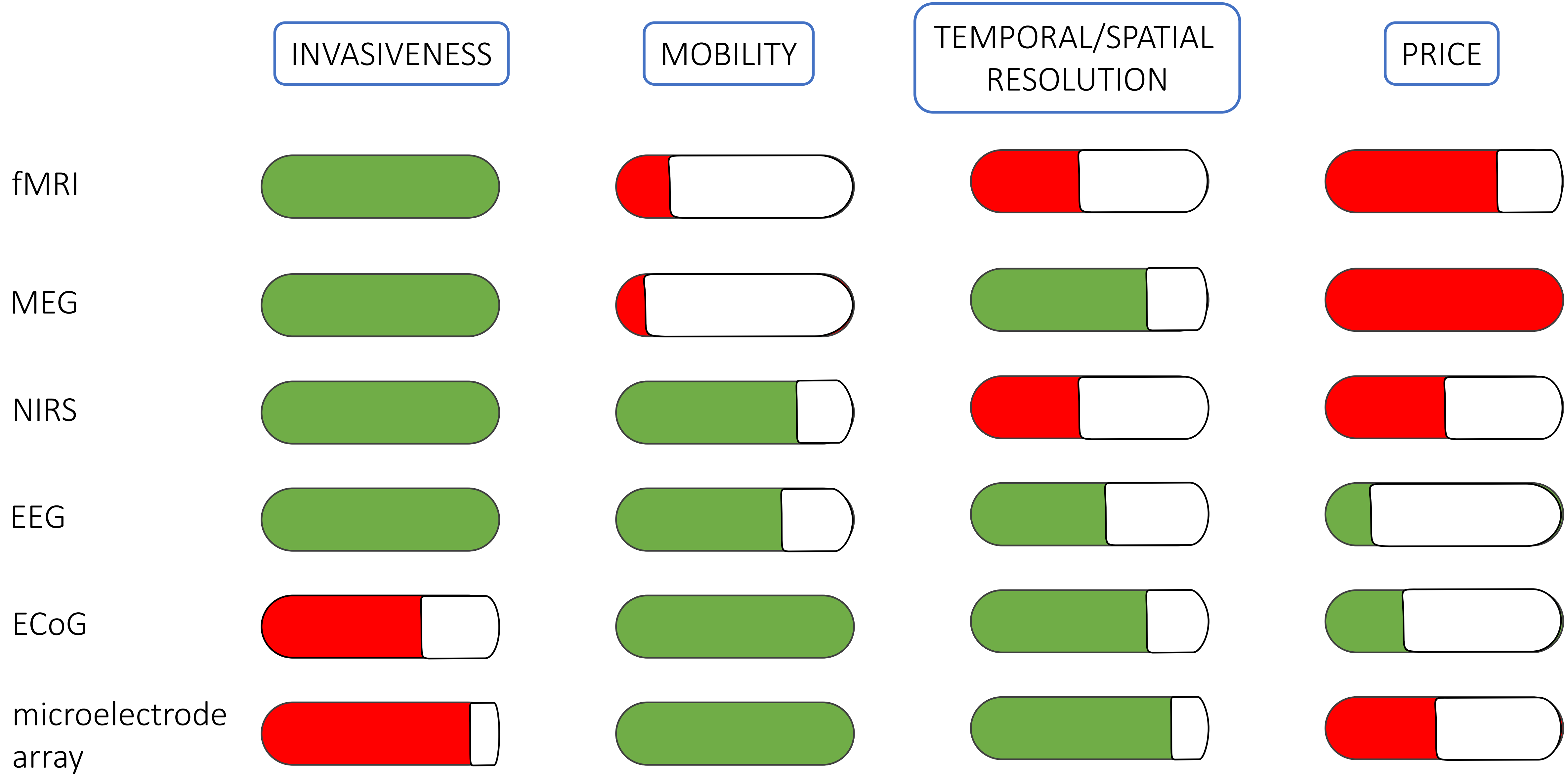
Techno intermezzo:

„A boundary across which two independent systems meet and act on or communicate with each other„

- **user interface** – allows user to communicate with a computer system (e.g., keyboard, mouse, menus of a computer system)
  - > BCI in a broader sense
- **hardware interface** - hardware devices connected to communicate and transfer information (e.g., wires, USB ports)
  - > devices for reading out and translating electrical activity of neurons

Modalities for recording brains



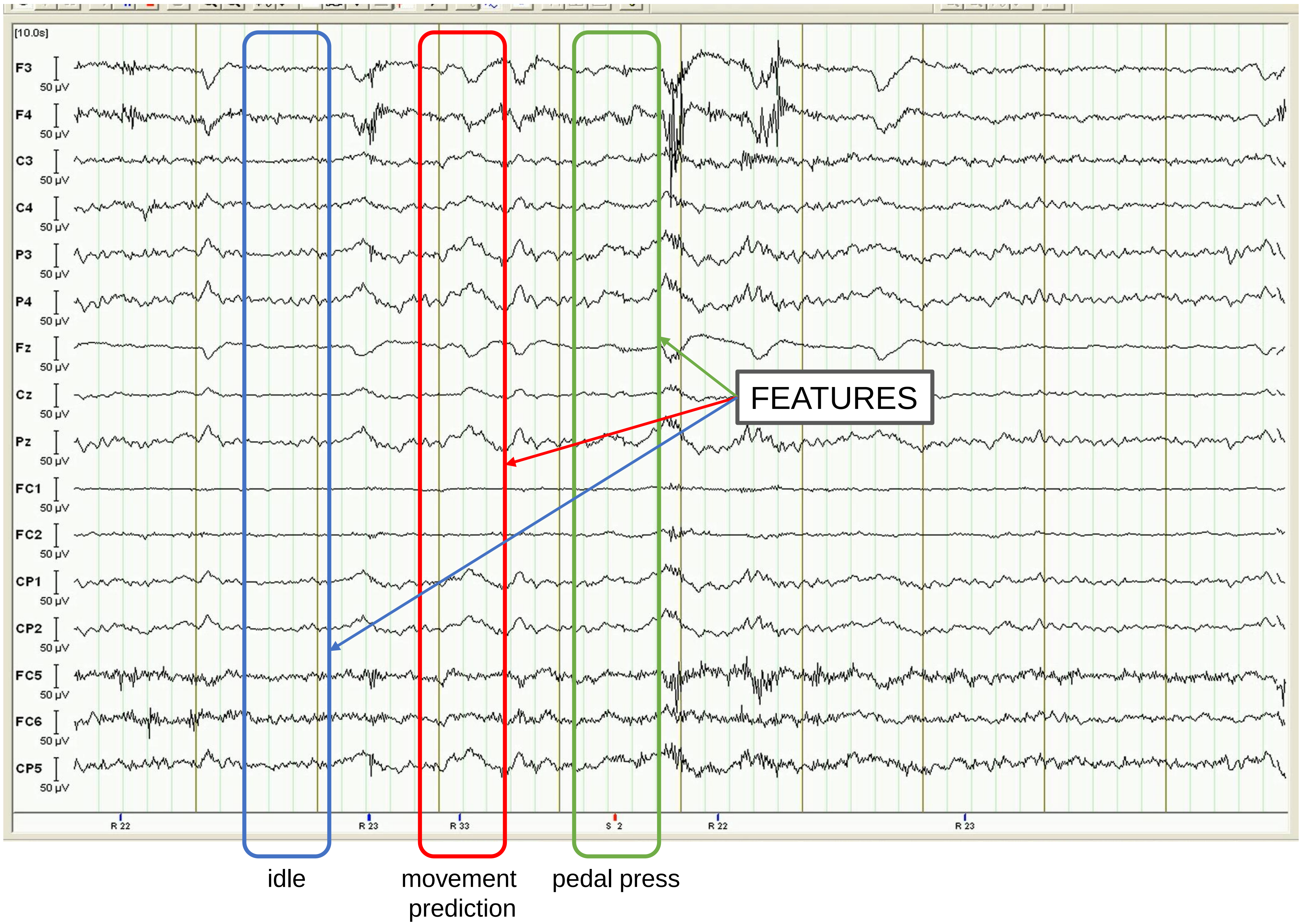

INVASIVENESS
MOBILITY
TEMPORAL/SPATIAL RESOLUTION
PRICE
fMRI
MEG
NIRS
EEG
ECoG
microelectrode array

Takeaway #2: EEG-based BCIs are the most common because:

a.) they're **mobile** and **non-invasive**

b.) they're **cheap** enough to be accessible to everyone

c.) they have a fair (but far from perfect) **ratio of temporal and spatial frequency**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F3
F4
C3
C4
P3
P4
Fz
Cz
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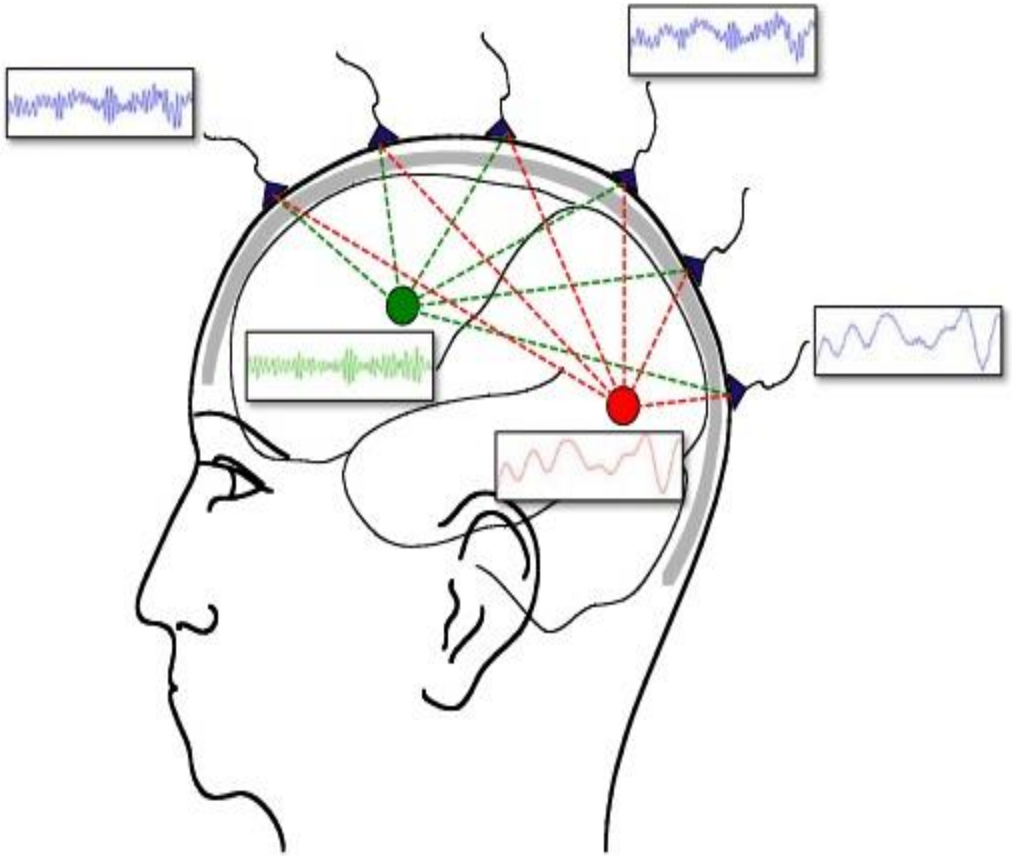
FC1
FC2
CP1
CP2
FC5
FC6
CP5
50 µV
R 22
R 23
R 33
S 2
R 22
R 23
FEATURES
idle
movement prediction
pedal press

BRAIN – Computer Interfaces

Neuro intermezzo:

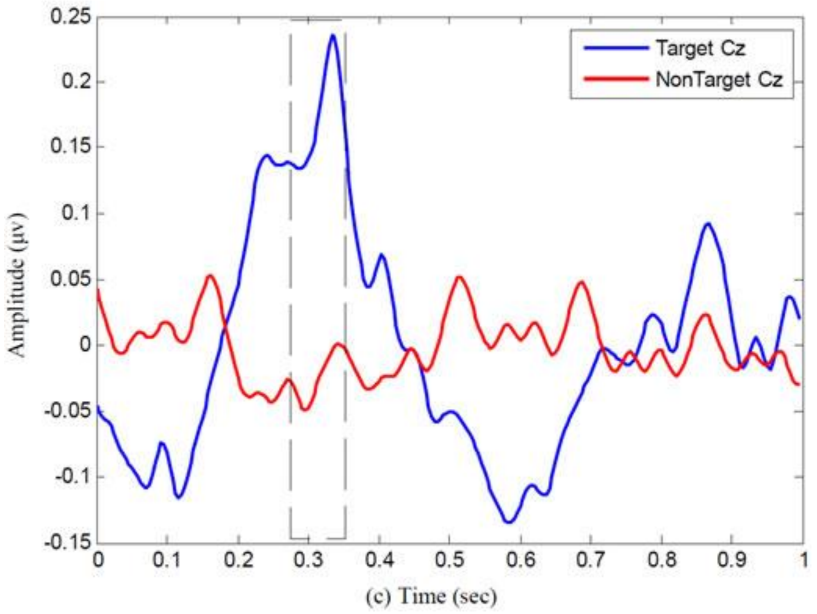
- *encoding*: translating mental processes into neural activity – generating neural activity
- *decoding*: deducing from neural activity about mental processes

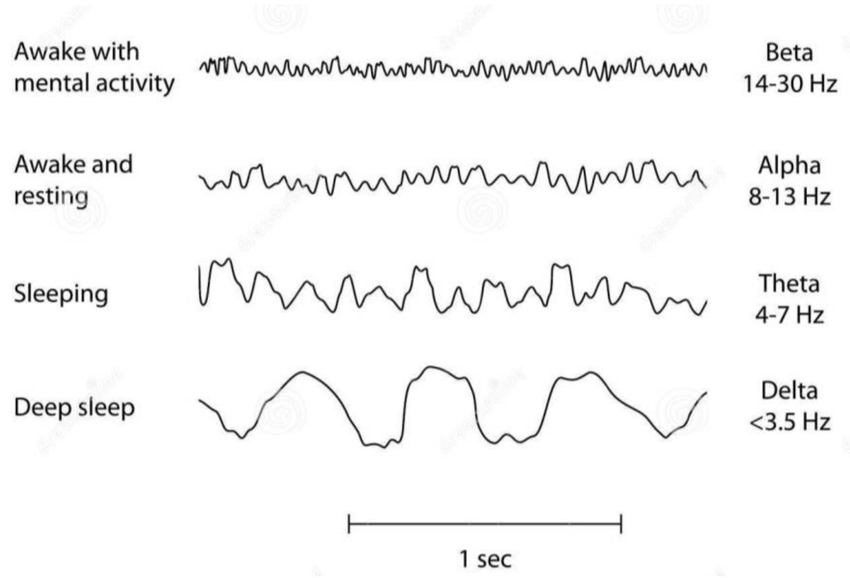
- feature extraction & pattern identification



Features, features everywhere

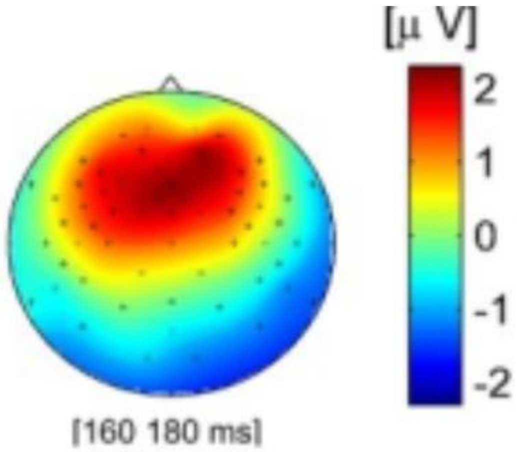
- EEG waveforms are generally classified according to their frequency, amplitude, and shape (including scalp location and distribution)

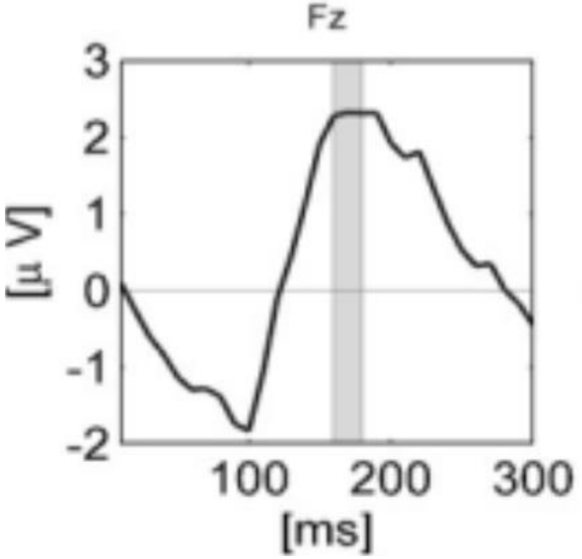




Features, features everywhere

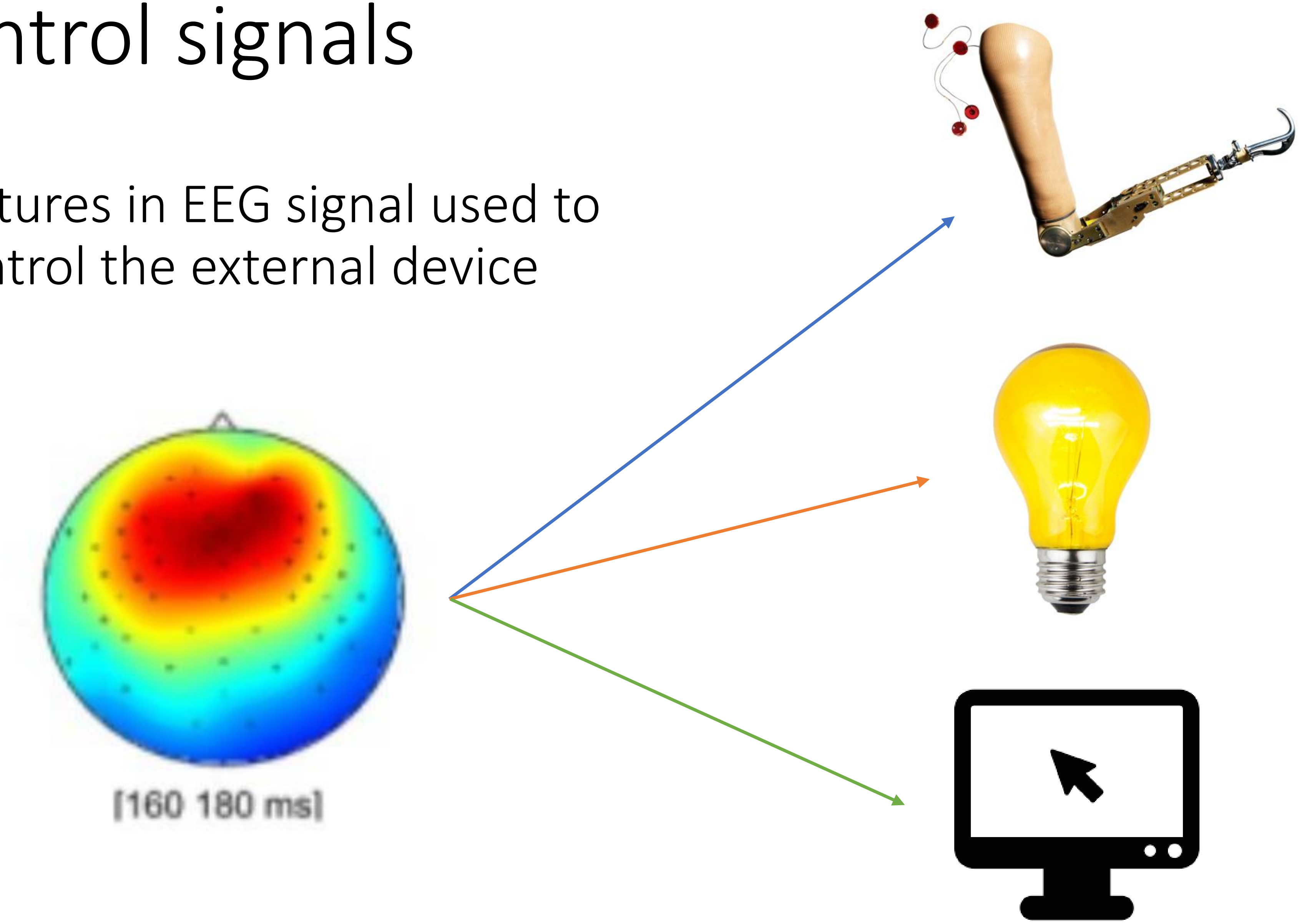
- visual alpha rhythm (open/closed eyes)
- event-related potentials (ERPs)
  - e.g. P300, N100, RP
- visual evoked potentials (VEP; SSVEP)
- sensorimotor rhythm (SMR)
  - event-related synchronisation (ERS)
  - event-related desynchronisation (ERD)





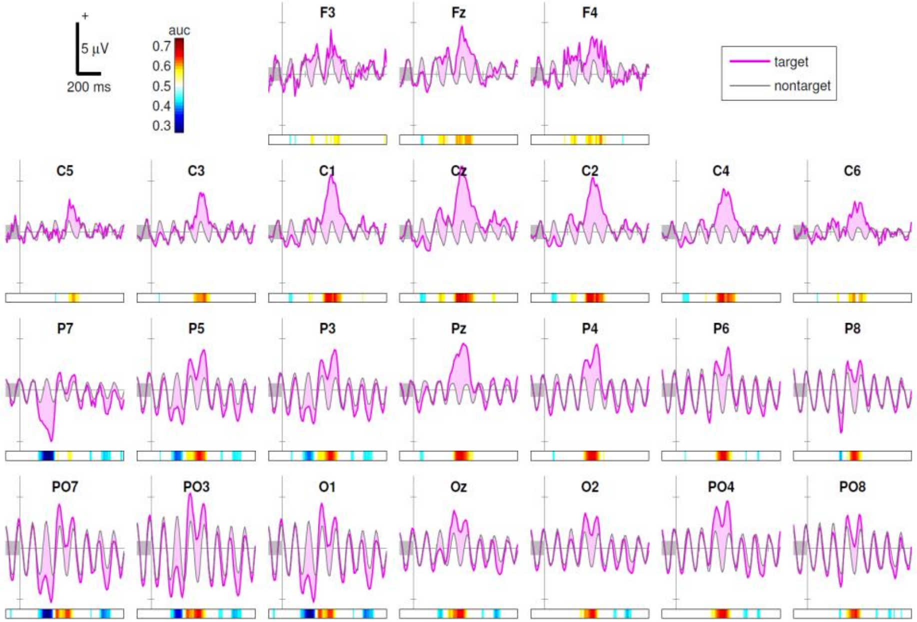
Control signals

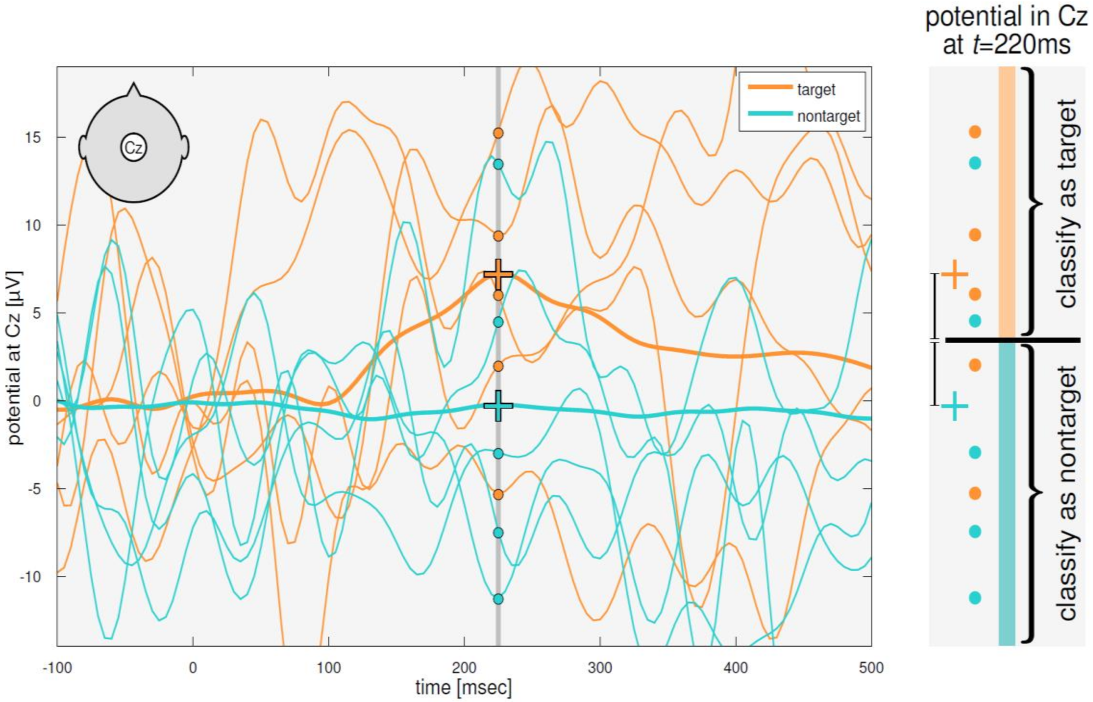
- features in EEG signal used to control the external device



Techno intermezzo:

- *univariate feature*: amplitude of P300 component at peak time at Cz
- *multivariate feature*: spatio – temporal (multiple electrodes at multiple time-points)



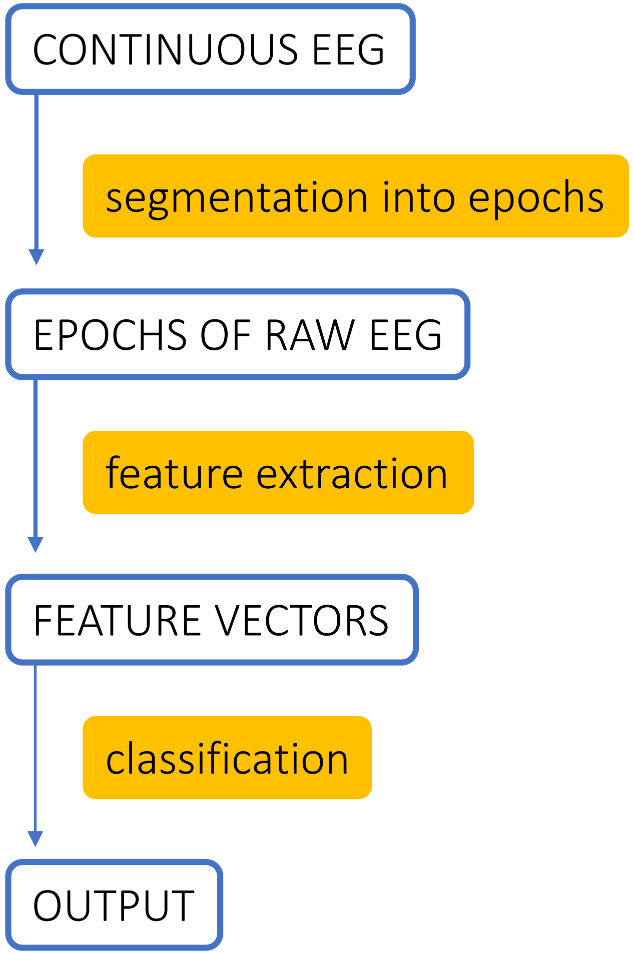


Figures from Blankertz, 2014 (video lecture)

Brain – COMPUTER Interfaces

- multivariate features
- machine learning
- classification algorithms

- machine learning algorithms for classification
  - calibrate (training phase)
  - cross-validation
  - apply (test phase)
- mostly supervised algorithms (SVM, LDA)



Takeaway #3: To do a reliable classification of mental states with BCI:

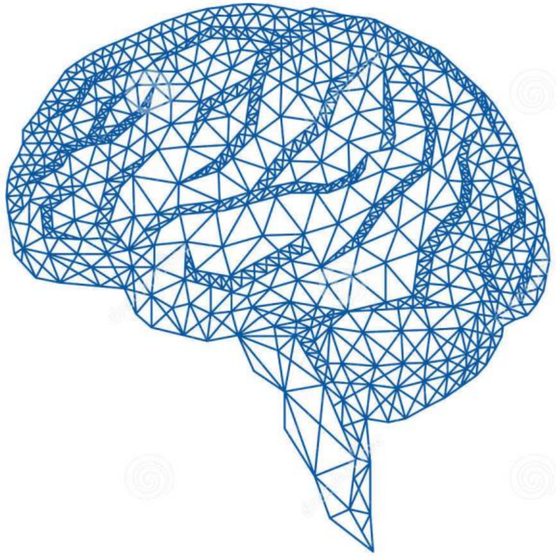
a.) we need to use **multivariate features** to describe brain activity

b.) we need very smart computers (**machine learning**) to recognise patterns in these features

c.) these features, either internal or external, are used as **control signals** to interact with machine devices

BCI as a research tool

Example of using BCI to study movement preparation

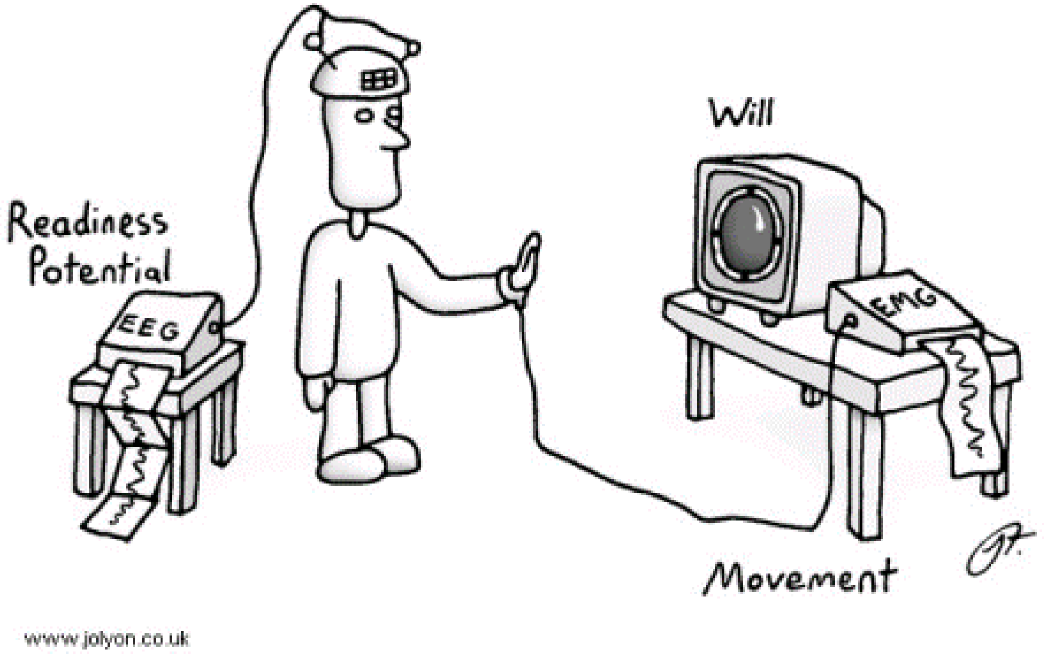


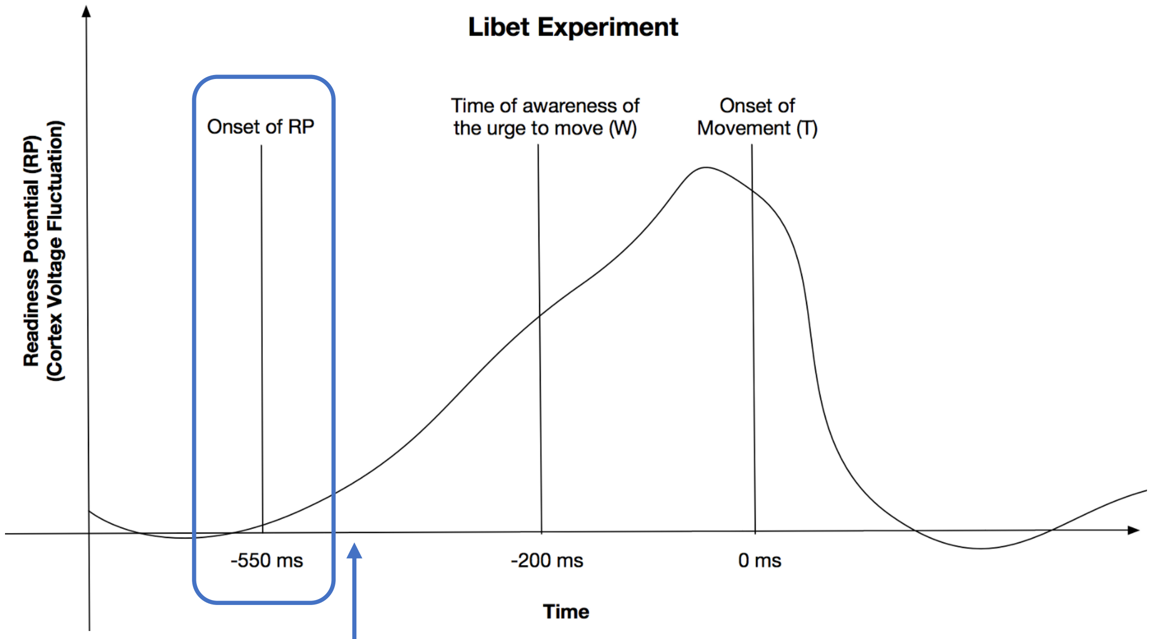
Clinical VS research

- *enhance scenario*: enhance human functions or user interactivity by adapting the device to their current mental state
- *research tool scenario*: real-time analysis of neural signals is used to investigate and understand brain and cognitive functions

- before: clinical purpose (for communication and control)
- today: research tool, entertainment, cognitive enhancement

Movement preparation and intention awareness



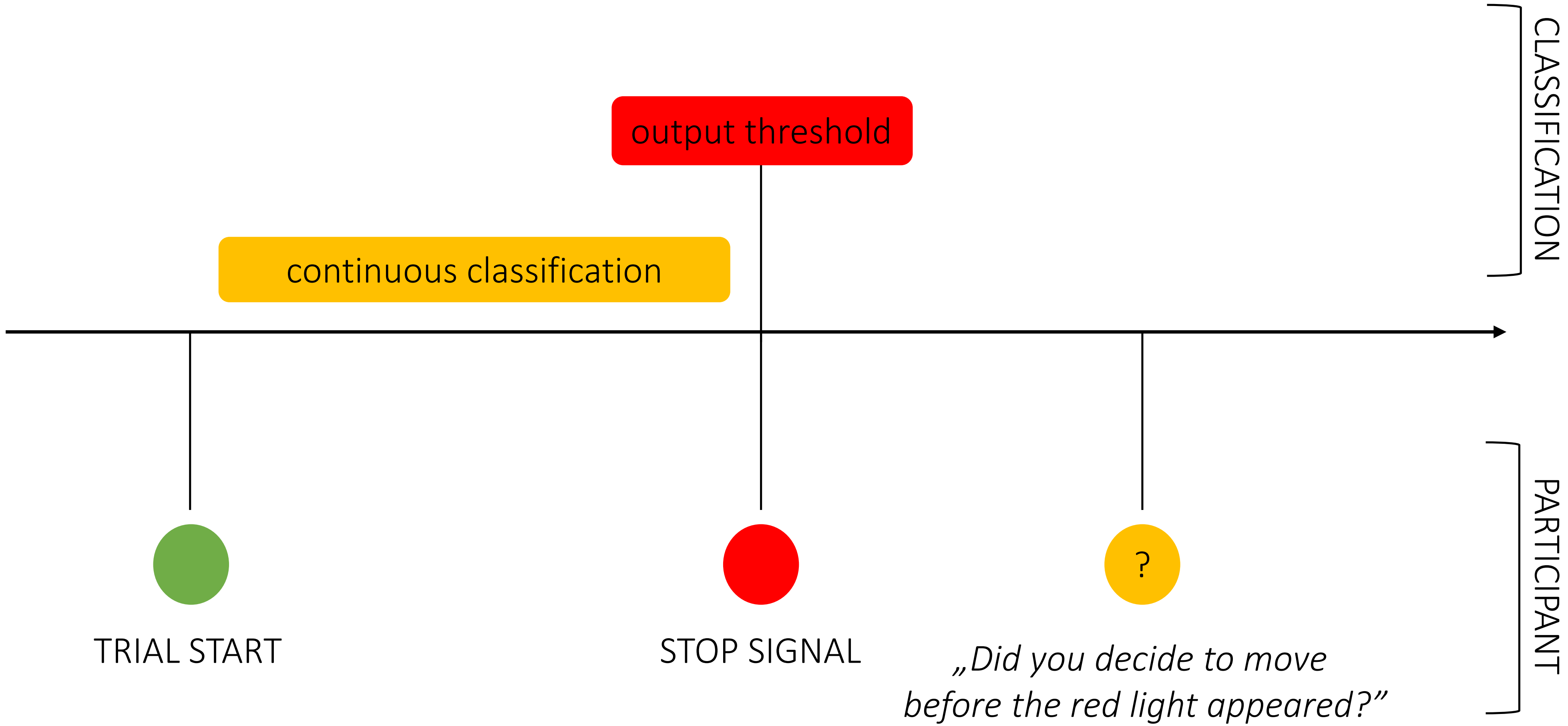


BCI: stop signal

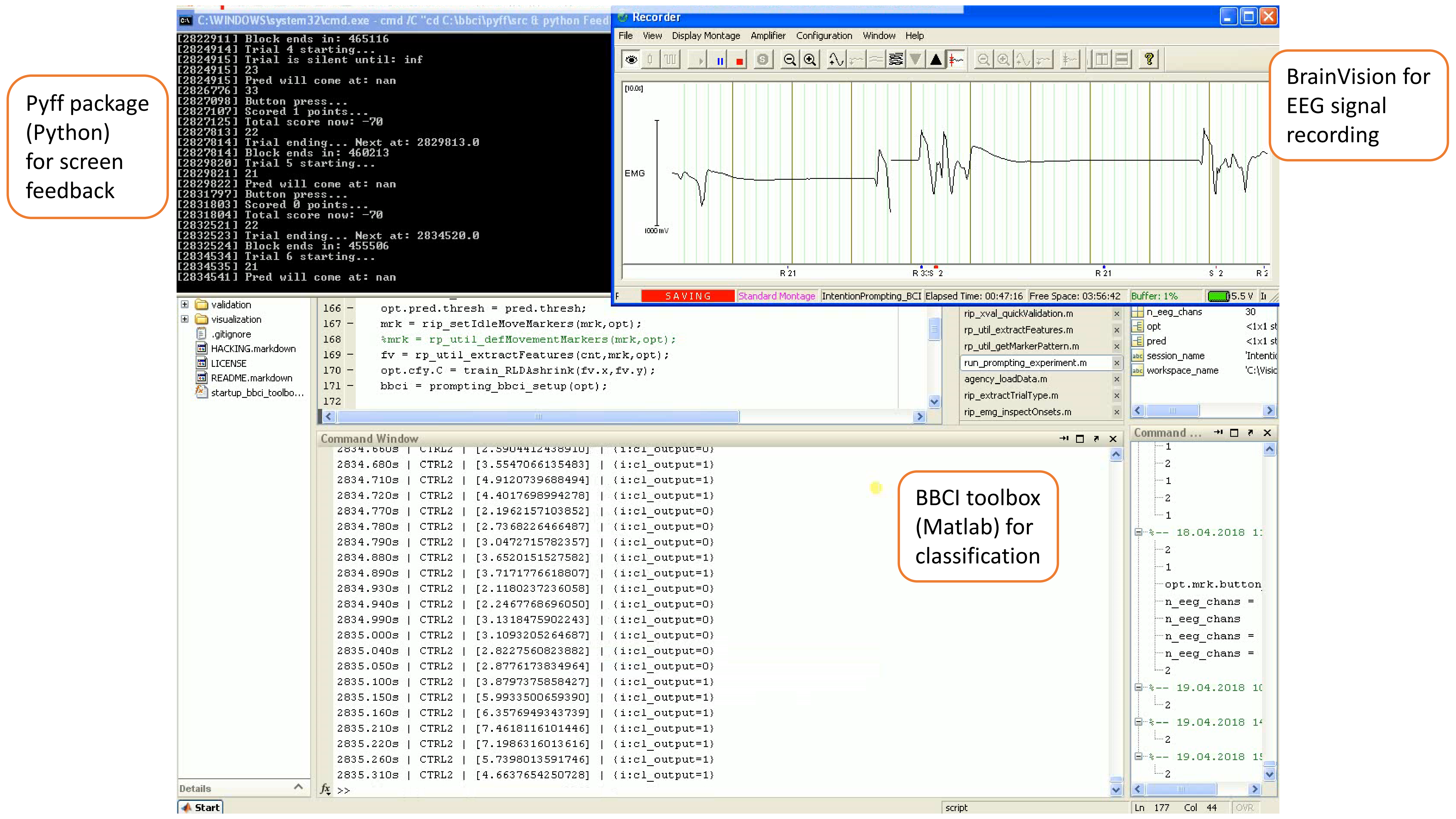
veto

intention prompting

Movement preparation and intention awareness




[10.0s]
F3
F4
C3
C4
P3
P4
Fz
Cz
Pz
FC1
FC2
CP1
CP2
FC5
FC6
CP5
50 µV
R 23
R 33
R 33
S 2
R 22
S 2
R 22
Ready
SAVING
Standard Montage
IntentionPrompting_BCI
Elapsed Time: 00:49:44
Free Space: 03:29:03
Buffer: 1%
5.5 V
IntentionPrompting_motor


Pyff package (Python) for screen feedback
BrainVision for EEG signal recording
BBCI toolbox (Matlab) for classification
C:\WINDOWS\system32\cmd.exe - cmd /C "cd C:\bbci\pyff\src & python Feed
Recorder
File View Display Montage Amplifier Configuration Window Help
EMG
SAVING
Standard Montage
IntentionPrompting_BCI
Elapsed Time: 00:47:16
Free Space: 03:56:42
Buffer: 1%
opt.pred.thresh = pred.thresh;
mrk = rip_setIdleMoveMarkers(mrk,opt);
%mrk = rp_util_defMovementMarkers(mrk,opt);
fv = rp_util_extractFeatures(cnt,mrk,opt);
opt.cfy.C = train_RLDAshrink(fv.x,fv.y);
bbci = prompting_bbci_setup(opt);
Command Window
validation
visualization
.gitignore
HACKING.markdown
LICENSE
README.markdown
rip_xval_quickValidation.m
rp_util_extractFeatures.m
rp_util_getMarkerPattern.m
run_prompting_experiment.m
agency_loadData.m
rip_extractTrialType.m
rip_emg_inspectOnsets.m
n_eeg_chans
opt
pred
session_name
workspace_name
Start

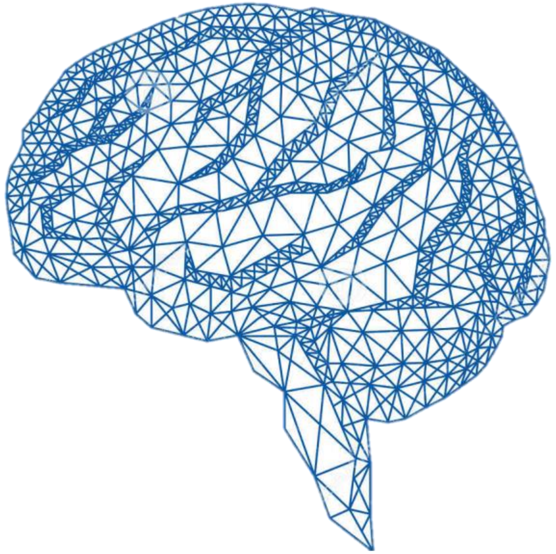
Takeaway #4: BCIs can be used in research purposes:

a.) as an interactive tool for shedding a new light on mechanisms underpinning cognitive processes

b.) as a tool for providing neurofeedback about mental states

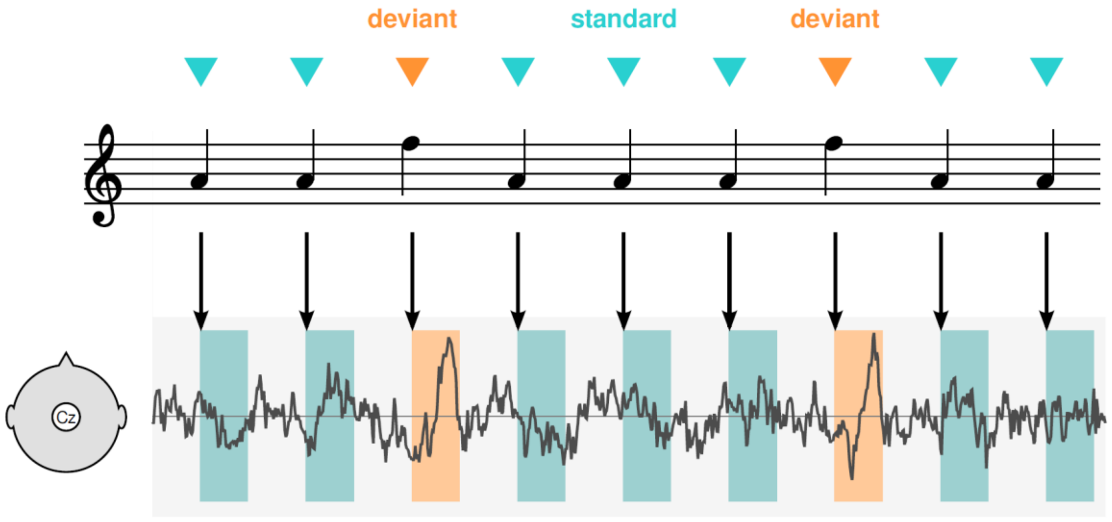
BCIs for communication

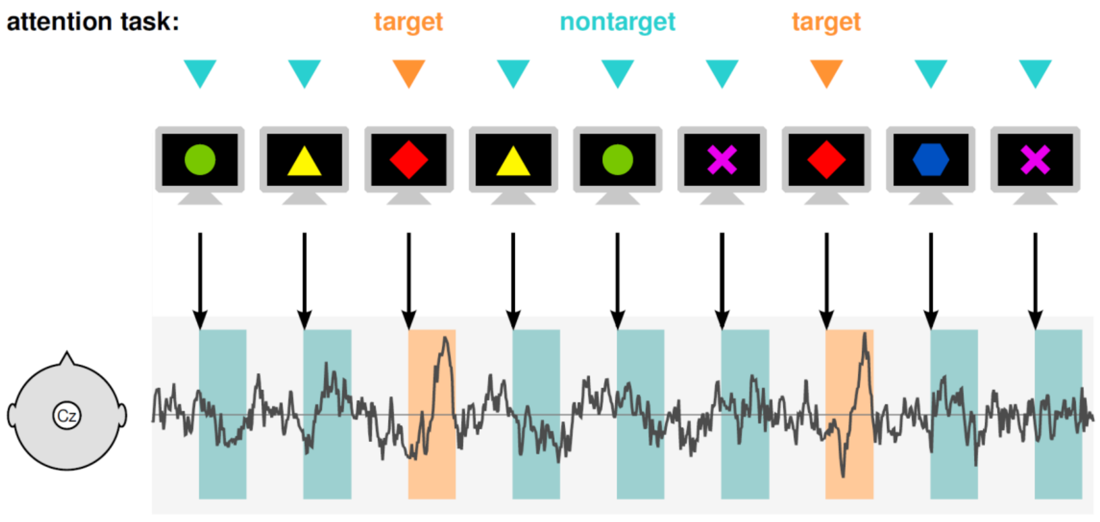
The oddball paradigm | P300 virtual keyboard | motor imagery virtual keyboard



The oddball paradigm

- consecutive presentation of target and non-target stimuli and recording the neural potential (*P300 component*) related to attention to target stimulus





Figures from Blankertz, 2014 (video lecture)

[BCI P300-based virtual keyboard]
https://www.youtube.com/watch?v=y3lGJVnSSsg&list=PL7MrK4YEO7vURKrSrSYAEfx01RJ-ulpwo

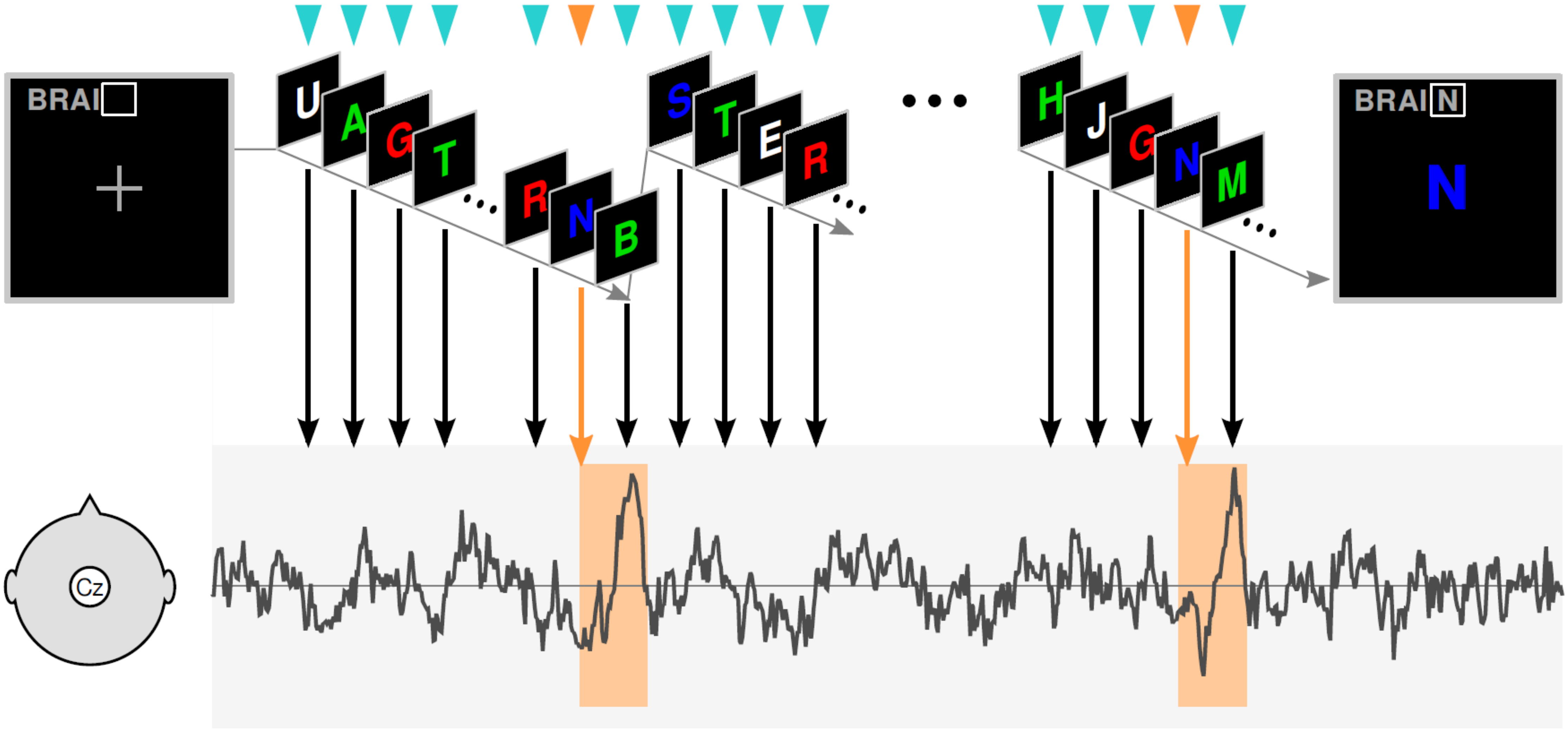


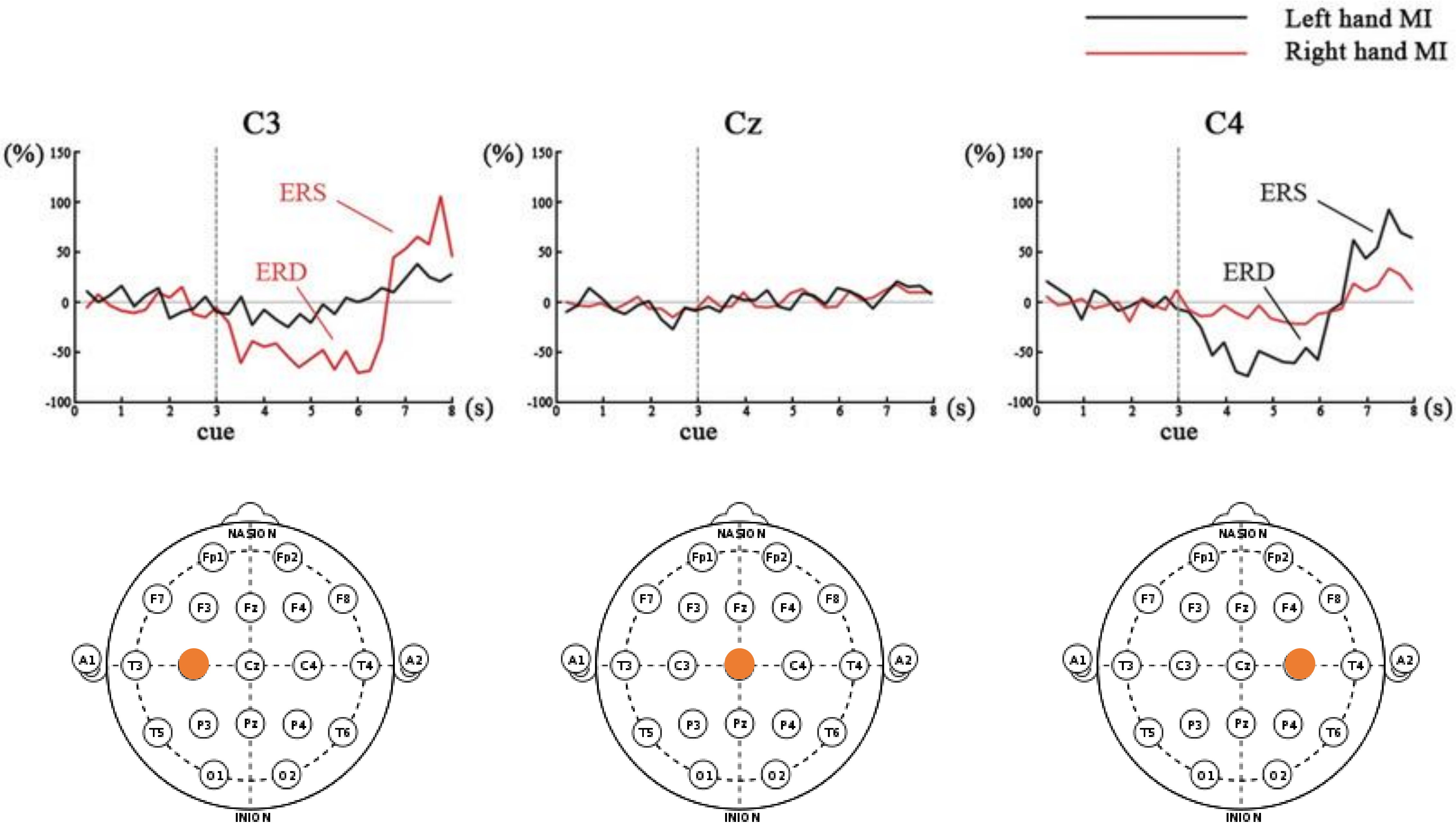
Figure from Blankertz, 2014 (video lecture)

Event-related desynchronization (ERD)

Techno intermezzo:

- *sensorimotor rhythm*: what we see in EEG recordings over the sensorimotor cortex (in frequency domain)
  - *mu* (8-11Hz) or *beta* (12-32Hz) frequency bands
- EEG features of motor imagery tasks
  - changes in *mu* rhythm: event-related synchronization (ERS) and desynchronization (ERD) in motor imagery and execution

[ERD-based virtual keyboard – HOMEMADE!]
https://www.youtube.com/watch?v=Kz3oEGxxUA4



Left hand MI
Right hand MI
C3
Cz
C4
(%)
ERS
ERD
cue
(s)
NASION
INION
Fp1
Fp2
F7
F3
Fz
F4
F8
A1
T3
C3
Cz
C4
T4
A2
T5
P3
Pz
P4
T6
O1
O2

Takeaway #5: BCIs can be used for communication:

a.) as virtual keyboards based on attention processes

b.) as virtual keyboards based on motor imagery

Takeaway #5.1: EEG-based BCIs CANNOT be used for communication based on decoding of semantic imagery

BCIs for control

Exoskeleton | Prosthetic arm | Semi-autonomous car

[an SSVEP-based exoskeleton for control of lower limbs]
https://www.youtube.com/watch?v=jeLghZ8GASA

[BCI semi-autonomous car]
https://www.youtube.com/watch?v=iDV_62QoHjY

[DARPA's invasive BCI for control of prosthetic arm with sensory feedback]
https://www.youtube.com/watch?v=A4BR4Iqfy7w

Takeaway #6: BCIs can be used for control:

a.) using event-related desynchronization in motor imagery as a feature

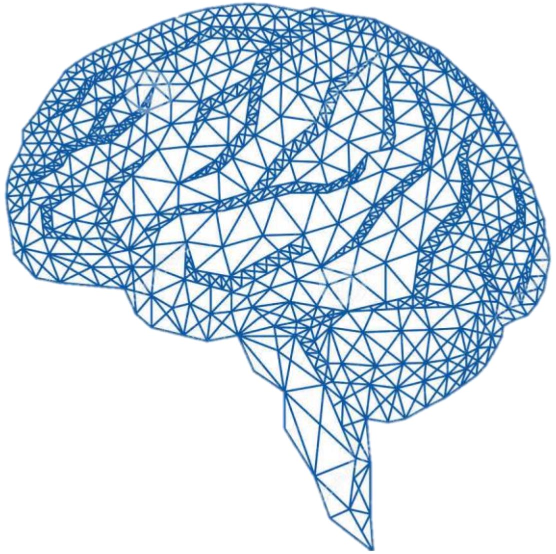
b.) using preparatory signals (readiness potentials) in motor imagery

c.) using noninvasive (EEG) and invasive (ECoG, LFP) methods – note that features are much different in invasive interfaces

BCIs in VR and gaming

Cybathlon 2016 | Brain-pong | Neurable |

Black Mirror: Are we there yet?



[Cybathlon 2016 – competition in BCI-based game]
https://www.youtube.com/watch?v=5jGcNbQhbg8

- Cybathlon event organised in Zurich
- BCI: motor imagery for control of the game
  - ROTATE: the avatar rotates (dances) over the playing pads (blue)
  - JUMP: the avatar jumps over spikes (purple)
  - SLIDE: the avatar slides under the "dangerous rays" (yellow)
  - NO INPUT: on the natural fields (gray), the pilot must "think nothing" to prevent the avatar from slowing down
- Event-related desynchronization or lateralised readiness potential

[Student project: BCI alpha-waves-based brain pong]
https://www.youtube.com/watch?v=8MTx9RZ8qao

[virtual reality gaming with Neurable]
https://www.youtube.com/watch?v=1A3QJJIvXww

[The Black Mirror S03E02: an invasive BCI-based augmented reality game]
https://www.youtube.com/watch?v=PdptmzBVZLo

Takeaway #7: BCIs can be used in gaming and VR:

a.) for very simple controls, and only several of them, and only after neurofeedback training

b.) to control the behaviour of characters on the screen or in VR

Takeaway #7.1: BCIs CANNOT be used to create an artificially augmented reality using your thoughts. Yet.

To sum up

- Brain-computer interfaces are so cool because of *real-time* and *two-way* communication
- Currently most comonly used BCI interfaces are based on EEG
- To control a BCI, we need to define features – neural correlates of mental processes
- BCIs can be used:
  - in research, as a tool for studying cognitive processes or providing neurofeedback
  - for communication, as virtual keyboards based on attention (P300) or motor imagery (ERD)
  - for control, using motor imagery or preparatory potentials as control signals
  - in gaming and VR, in similar ways like controling devices, but combined with virtual environment
- BCIs are not taking over the world, but they are powerful and growing quickly

Activity & Discussion time

References & further reading

Technical stuff

- a gentle introduction to single-trial ERP classification (virtual speller, multivariate features): http://videolectures.net/bbci2014_blankertz_signal_processing/
  - reading: Blankertz et al., 2011
- other lectures (with slides) from Berlin BCI winter school on neurotechnology: http://videolectures.net/bbci2014_berlin/

Applications

- BCIs beyond communication and control: Blankertz et al., 2016
- State-of-the-art in BCI research (2017): Guger, Allison & Lebedev, 2017
- BCI for studying vollition and intention in movement preparation (stop signal paradigm): Schultze-Kraft et al., 2016

References & further reading

Light read and videos

- Quick & easy overview of recent BCI developments here
- A nice blog on BCIs
- Ethical considerations of BCI technology: blogpost (and article)
- On P300 (oddball paradigm) and ethics: here
- TED talk of a colourblind guy who uses BCI to hear colours
- TED talk on mind reading with brain scanners (not BCI, but very relevant)
- short but sound posts on BCIs here and here
- blogpost on Elon Musk's company Neuralink for brain-to-brain communication (lengthy but so worth it)

References & further reading

Research groups and products

- Berlin Brain-Computer Interface research group (BBCI)
- BBCI toolbox for real-time and post-hoc analysis in Matlab (documentation and code)
- Some fun BCI-based products: Neurable, Emotiv, Openwater (NIRS-based BCI in development)
- A top-10 BCI start-ups overview (2017)
- DARPA funded BCI research: here

Thanks for your attention!

questions: karla.matic@bccn-berlin.de

slides: github.com/kmatic94