Brain-Computer Interfacing
WS 2018/2019 – Lecture #01

Benjamin Blankertz

Lehrstuhl für Neurotechnologie, TU Berlin

benjamin.blankertz@tu-berlin.de

https://wiki.ml.tu-berlin.de/wiki/NT/Courses

17 · Oct · 2018

Today's Topics

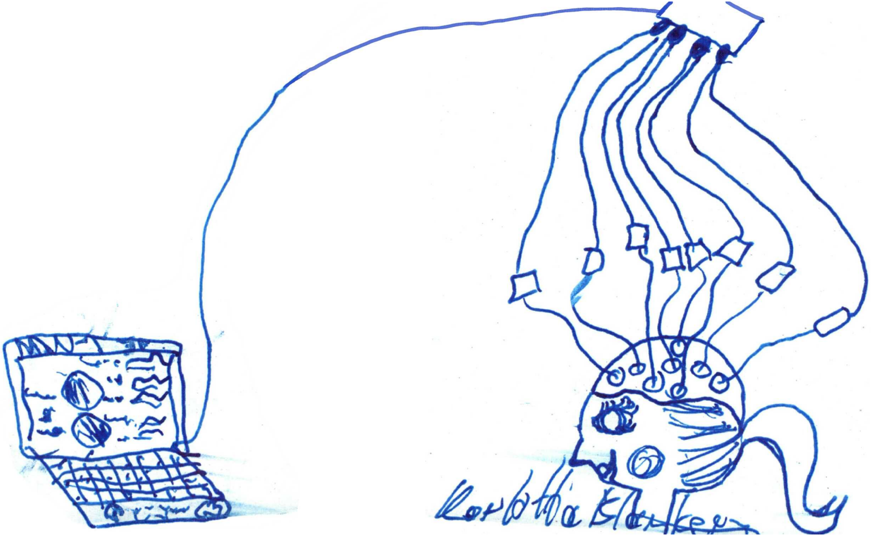
- Short overview of EEG
- Concepts of Brain-Computer Interfacing
- Challenges in real-time EEG decoding
- Overview of the history of BCI
- Novel applications of BCI technology
- Overview of the course

How can Paralyzed People Communicate?

How can Paralyzed People Communicate?

[from the movie: *Le scaphandre et le papillon* (directed by Julian Schnabel)]

Sketch of a “Brain-Computer Interface”



Real-time recognition of mental states of users based on brain activity for enriching human-machine interaction

Clinical perspectives of BCI technology

For severely paralyzed patients, e.g., diagnosed with **amyotrophic lateral sklerosis** (ALS):

BCI control of

- communication systems (for example: email, speech synthesis)
- media applications (internet or photo browser, music/TV)
- prostheses and wheel chairs

After **stroke**:

BCI-guided therapy

- for faster rehabilitation

How does that work?

BCI systems **cannot read thoughts**, but

- recognize specific, well defined control signals
- at least ...
- ... with some probability
- ... for some users.

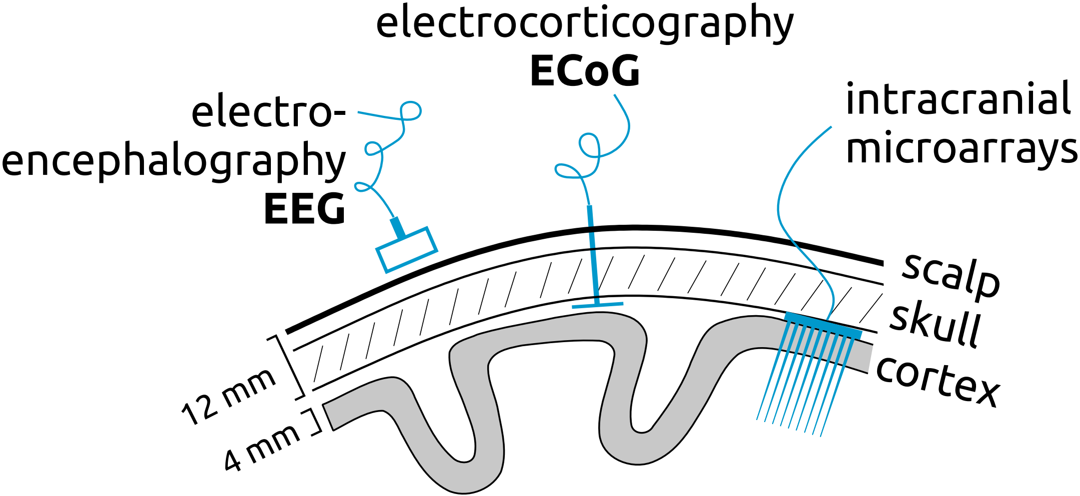
Speed, accuracy and robustness are currently rather limited.

So, don't have too high expectations

- **Cursor Control (2004)**

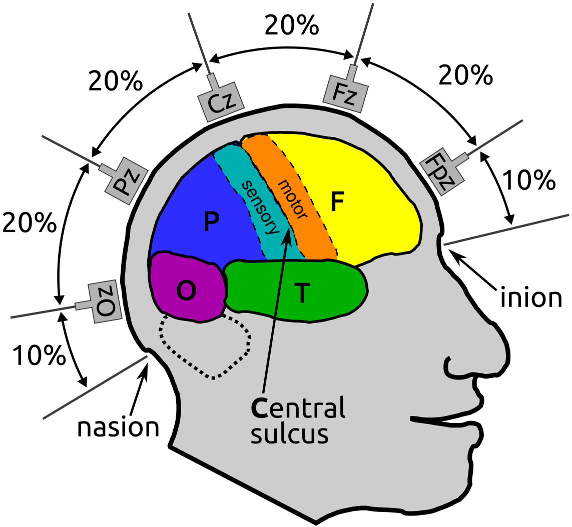
Ways to Measure Brain Activity

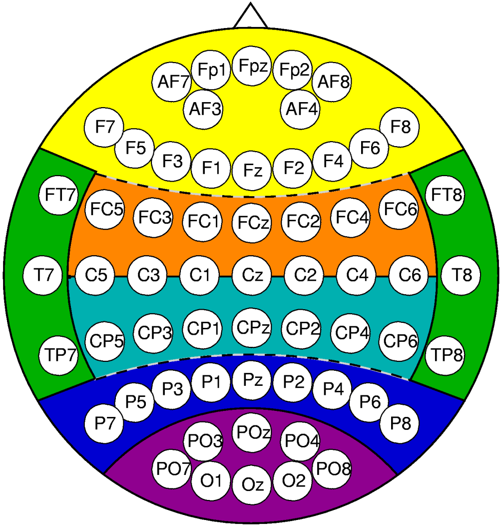
Electrical brain activity in BCIs is acquired in different ways:



Non-electrical: magnetic fields (MEG); oxygenation of blood: functional magnetic resonance imaging (fMRI), near infrared spectroscopy (NIRS)...

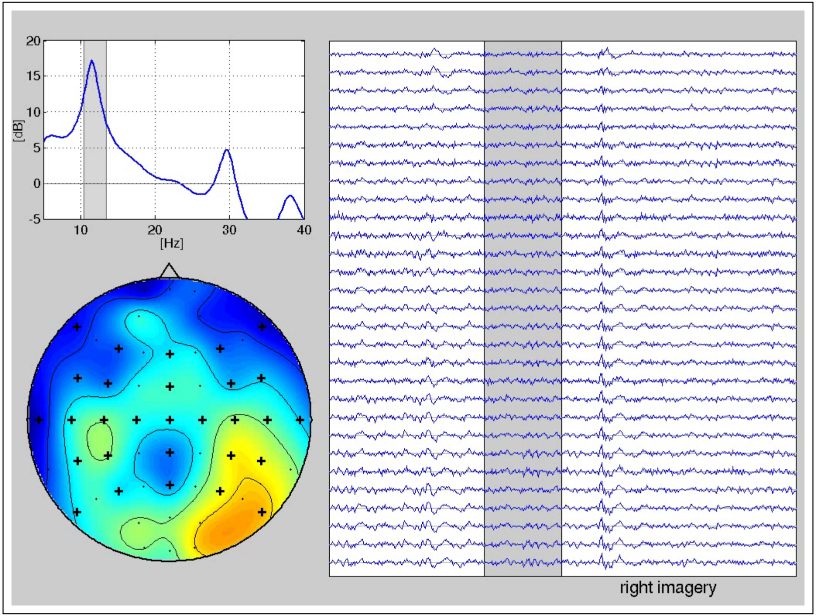
Areas of the Brain - Labels for EEG Sensor Locations





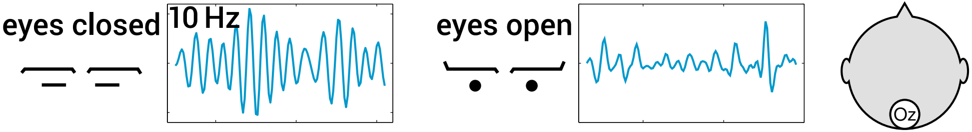
Brain lobes: **F**rontal, **P**arietal, **T**emporal, **O**ccipital.
Further anatomical landmark: **C**entral sulcus

A Look at EEG Signals

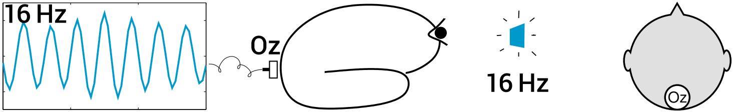


Different Occurences of Neural Activity

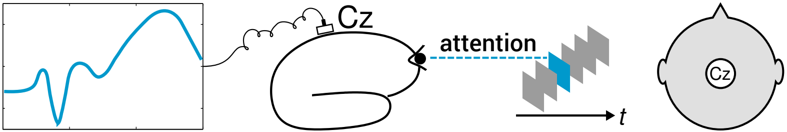
- **spontaneous oscillations**, e.g., sensorimotor rhythm (SMR), or visual alpha rhythm



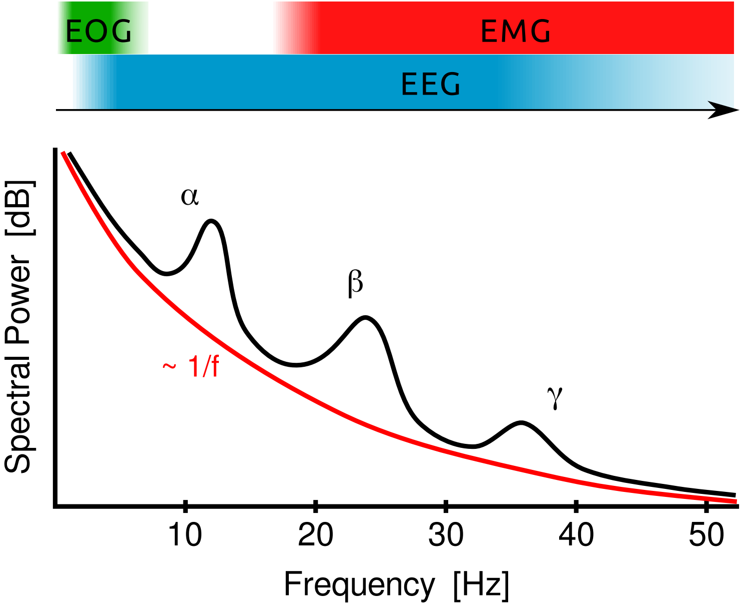
- **induced oscillations**, e.g., steady-state visual evoked potentials (SSVEP), evoked by and synchronous to a periodic external stimulus



- **transient activity**, event-related potentials (**ERPs**), time-locked to an event, most often an external stimulus; modulated by attention

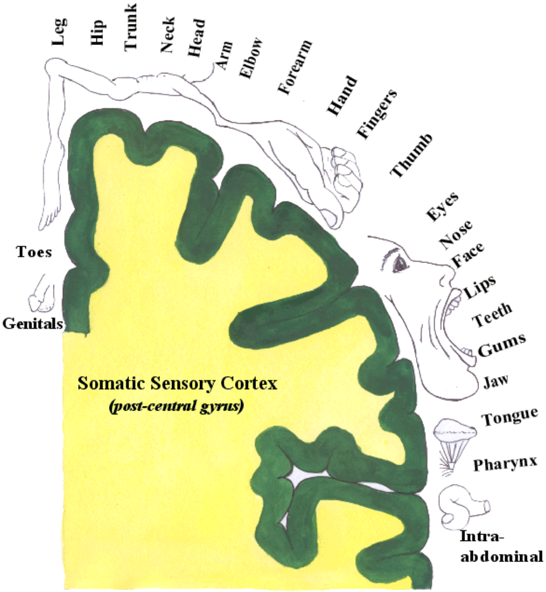


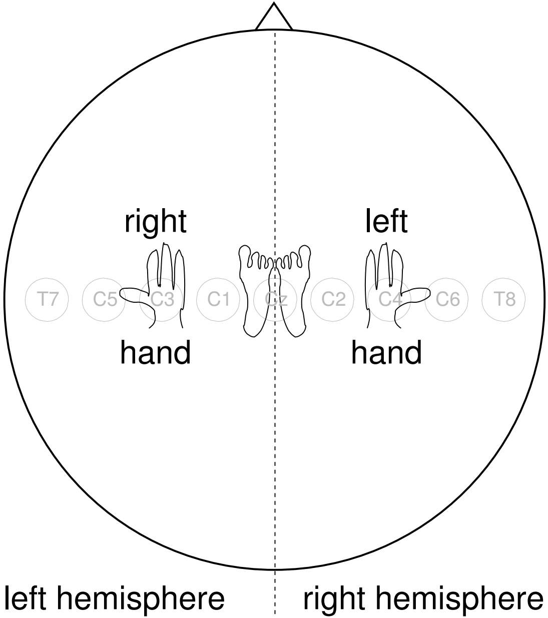
Idealized Spectrum of Macroscopic Brain Activity



- Artifacts from gaze (EOG) and muscles (EMG) are partly separated from EEG.

Topographic Mapping in Somatic Sensory Area

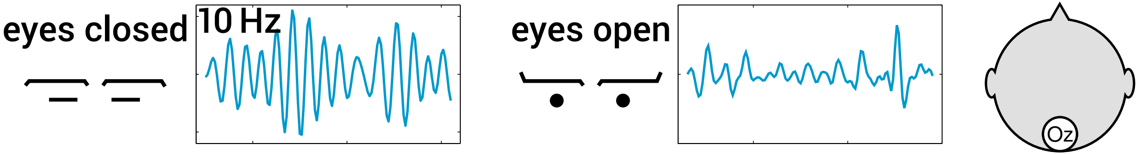




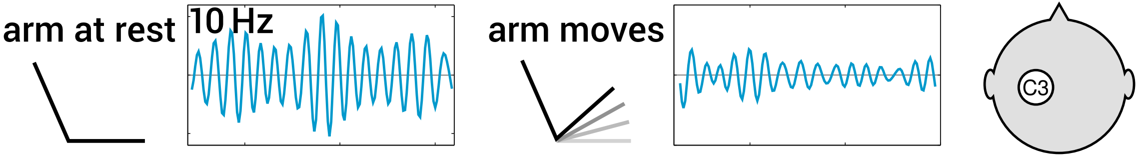
Modulation of Brain Rhythms

Most rhythms are idle rhythms. They reflect synchronous neural activity, and they are **attenuated** during active processing.

- α-rhythm (around 10 Hz) in visual cortex:



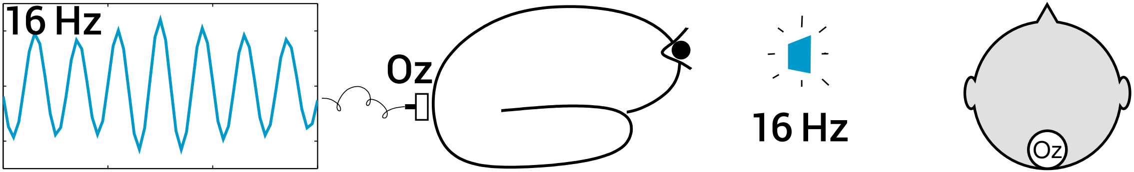
- μ-rhythm (around 10 Hz) in motor and sensory cortex:



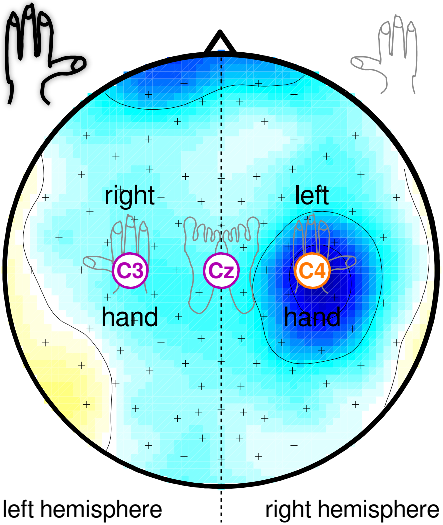
Note the Difference: Induced Oscillations

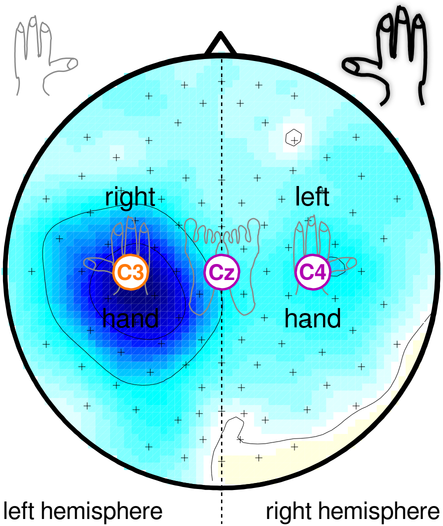
A different kind of oscillations are the

- induced oscillations, e.g., steady-state visual evoked potentials (SSVEP), auditory steady-state response (ASSR), which are evoked by and synchronous to a periodic external stimulus.



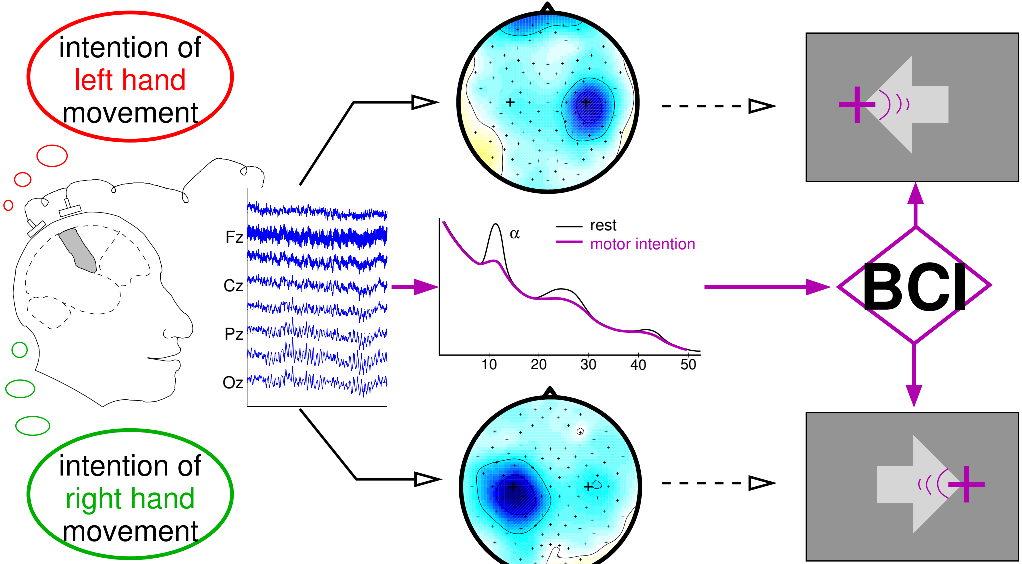
This is an example of exogeneous brain activity (as ERPs), while the examples from the previous slide represent endogeneous activities.





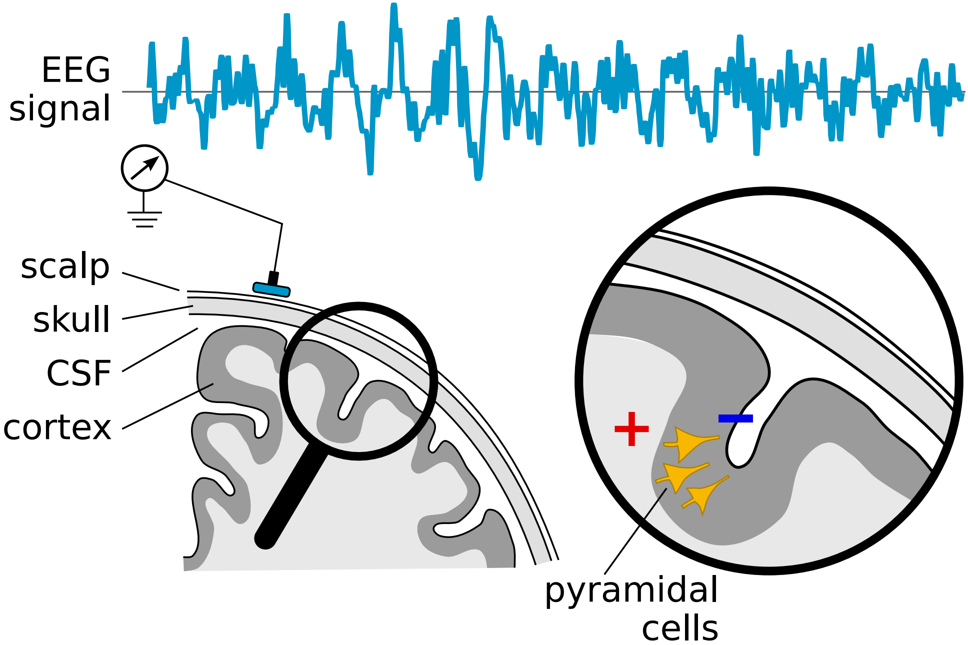
During an imagined hand movement, the activity in the contralateral hemisphere changes.

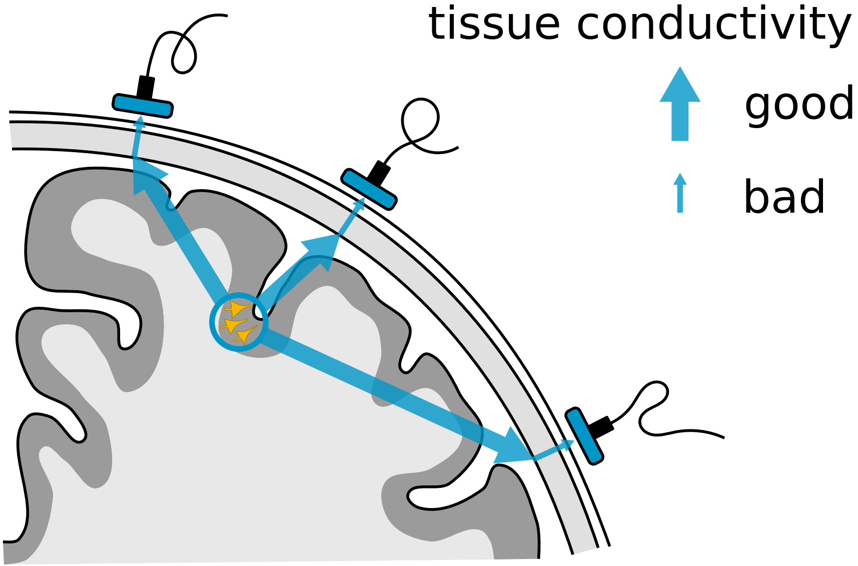
BCI Approach based on SensoriMotor Rhythms (SMRs)



▶ The concept is simple - what are the challenges?

Generation of EEG Signals

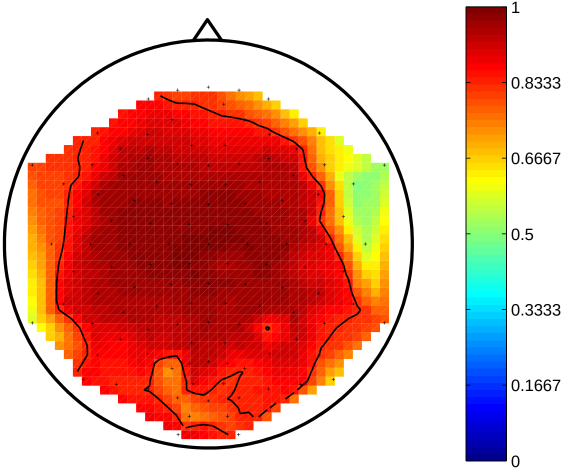




The signal arrives with almost equal intensity at different scalp locations due to the different tissue conductivities.

Mind Spatial Smearing!

- Raw EEG scalp potentials are known to be associated with a large spatial scale owing to volume conduction.
- In this typical example data set, most of the channels are highly correlated:



The map shows the correlation coefficient of each channel with channel Cz in the center.

Consequences of Volume Conduction

From the application perspective, volume conduction has both, positive and negative consequences.

Positive

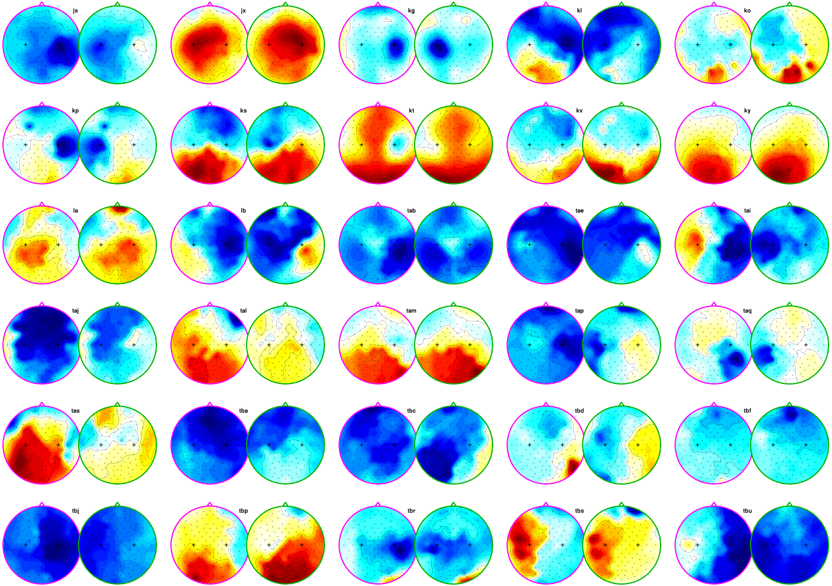
- Exact sensor position does not matter
- Less sensors required (?)

Negative

- Information spatially smeared
- Hard to decode from specific areas

Second Challenge in Analyzing EEG Data

- Subject-to-subject variability



What is the Cause of Those Variabilities?

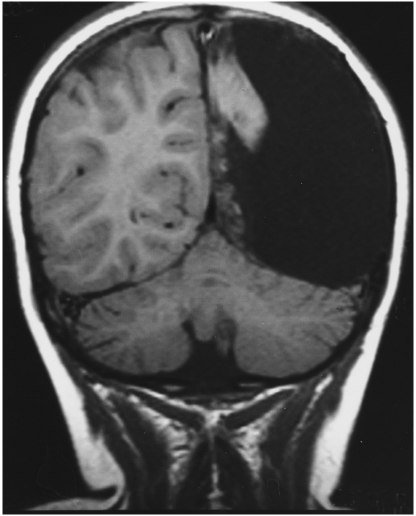
The human brain is very plastic, in particular during the early development.

THE LANCET **359**(9305), p. 473, 2002.

Clinical picture

Half a brain

Johannes Borgstein,
Caroline Grootendorst



This 7-year-old girl had a hemispherectomy at the age of 3 for Rasmussen syndrome (chronic focal encephalitis). Intractable epilepsy had already led to right-sided hemiplegia and severe regression of language skills. Though the dominant hemisphere was removed, with its language centres and the motor control for the left side of her body, the child is fully bilingual in Turkish and Dutch, while even her hemiplegia has partially recovered and is only noticeable by a slight spasticity of her left arm and leg. She leads an otherwise normal life.

Variabilities Caused by Plasticity ...

Plasticity can, e.g., be observed in musicians

Increased Cortical Representation of the Fingers of the Left Hand in String Players

Thomas Elbert, Christo Pantev, Christian Wienbruch, Brigitte Rockstroh, Edward Taub

... and nowadays also due to smartphone usage:

Use-Dependent Cortical Processing from Fingertips in Touchscreen Phone Users

Anne-Dominique Gindrat[5], Magali Chytiris[5], Myriam Balerna[5], Eric M. Rouiller, Arko Ghosh

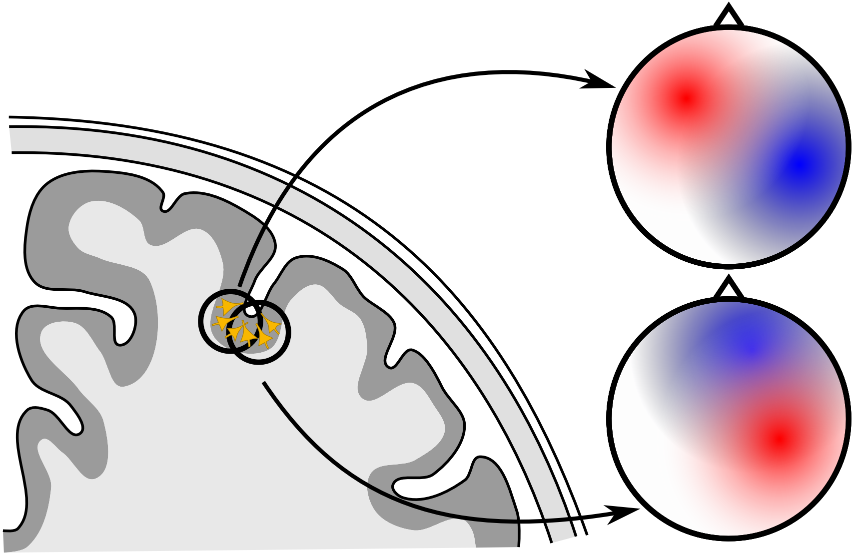
[5] Co-first author

Published Online: December 23, 2014

Open Archive

DOI: http://dx.doi.org/10.1016/j.cub.2014.11.026 | CrossMark

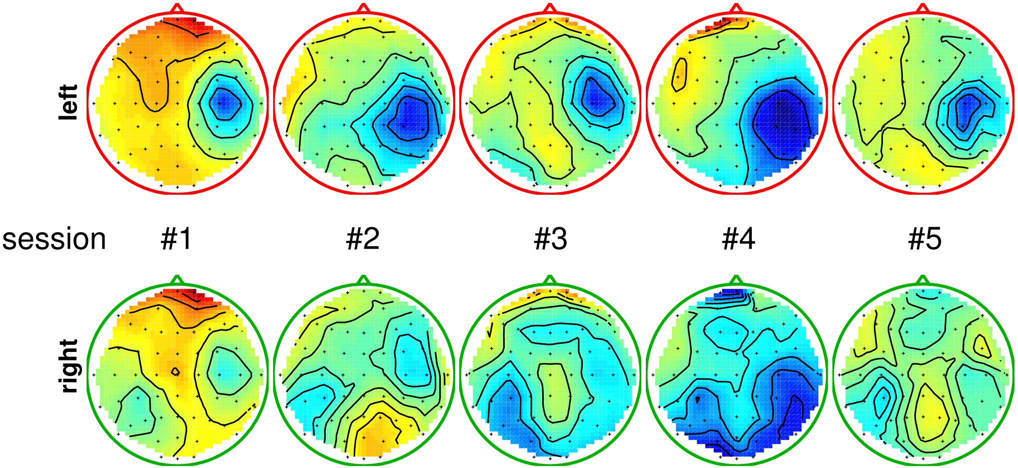
The cortex is strongly folded. A small shift locally on the cortex, can result in largely different EEG patterns:



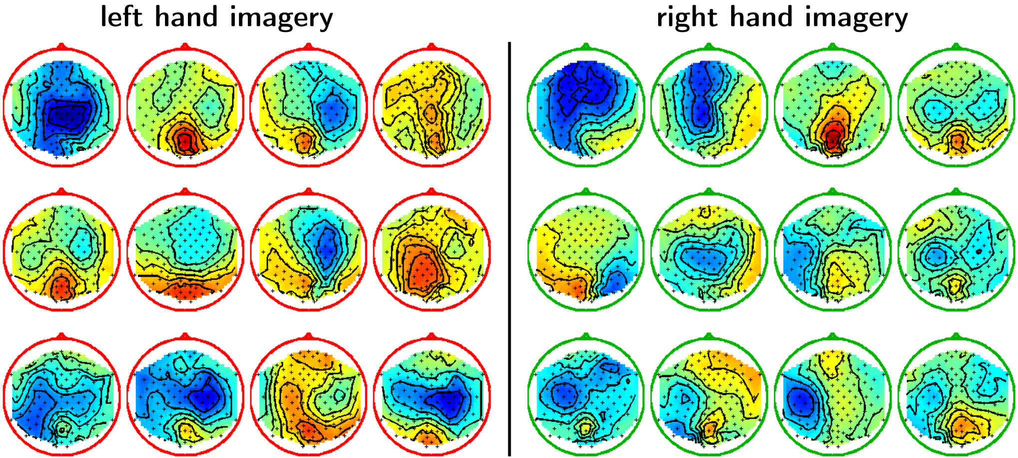
Consequence

As a consequence, **multi-variate** analysis of EEG signals on single subject basis is recommended.

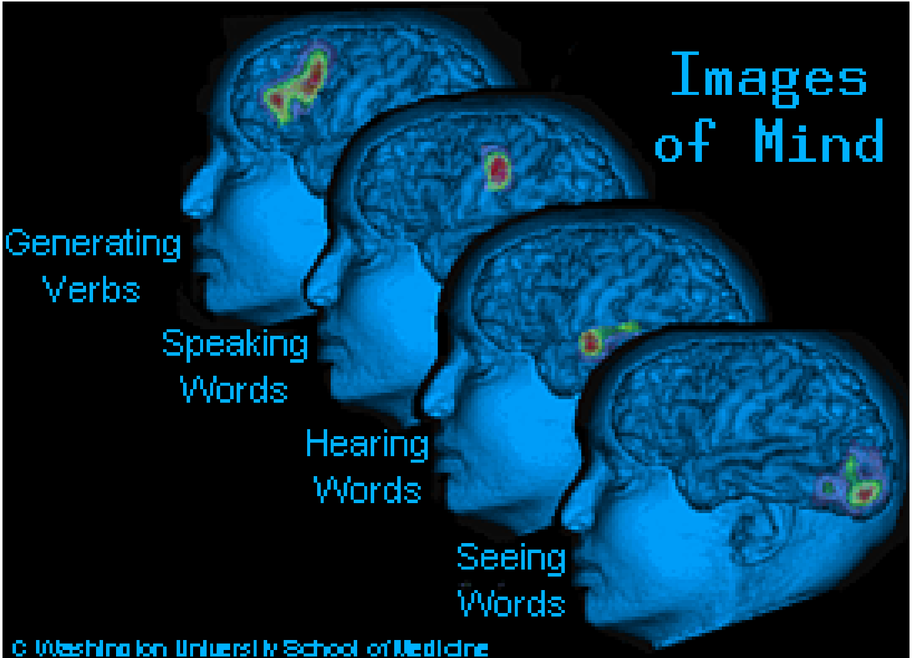
- Subject-to-subject variability
- Session-to-session variability



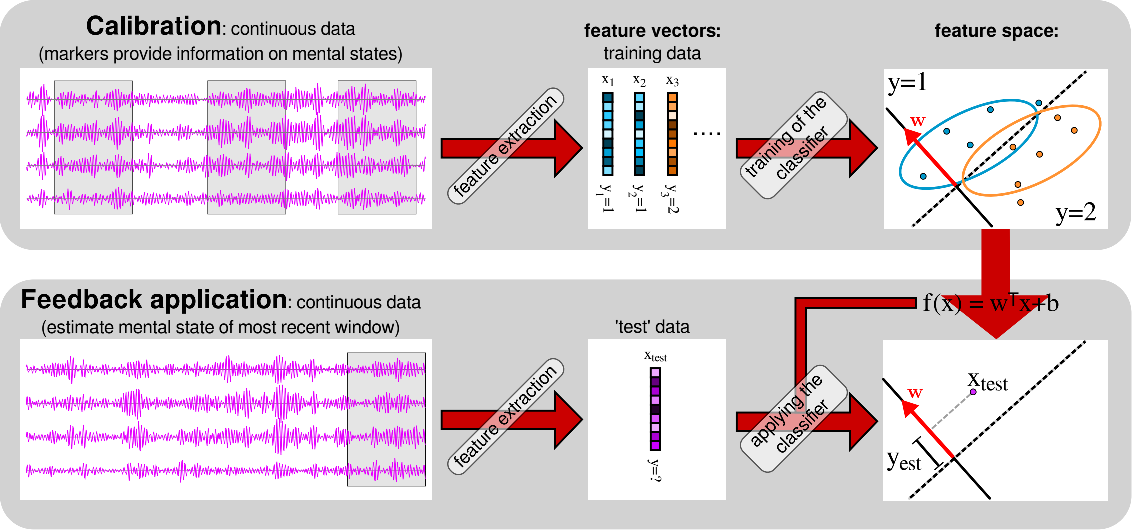
- Subject-to-subject variability
- Session-to-session variability
- Trial-to-trial variability



Large Number of Simultaneously Active Areas



Taking into account the considerable variabilites a reasonable approach is to use machine learning techniques and adaptive signal processing.



Overview of the course

Time-locked activity

- ERP analysis
- spatio-temporal features
- LDA with shrinkage

Spontaneous oscillations

- spectra; ERD/ERS analysis
- log variance (band-power) features
- CSP analysis

Linear model of EEG

- propagation from sources to sensors (and back)
- interpretation of discriminative models

Special topics

- issues in validation
- signal decomposition methods
- adaptation of classifiers

Remark about the Tutorials

For the tutorials, there are programming tasks that deal with the analysis of EEG/BCI data.

Programming will be done in **pyhton** using the **jupyter** environment.

Tutorials start on October 24th.

Lessons Learnt

After this lecture you should

- have an idea about EEG and the basic functioning of BCIs
- be aware of the limitations of BCIs
- know about potential non-medical applications of neurotechnology
- have notice about the history of BCIs
- be familiar with the labels of EEG sensor positions

References I

- Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., and Taub, E. (1995).
  Increased cortical representation of the fingers of the left hand in string players.
  Science, 270(5234):305.
- Gindrat, A.-D., Chytiris, M., Balerna, M., Rouiller, E. M., and Ghosh, A. (2015).
  Use-dependent cortical processing from fingertips in touchscreen phone users.
  Curr Biol, 25(1):109–116.