Neuronale Informationsverarbeitung für Gehirn-Computer Schnittstellen

Neural Information Processing for Brain-Computer Interfaces

Outline of the lecture

1. A history of research on brain-computer interfaces (BCIs)
2. Cognitive neuroscience
3. Recording neural activity
4. Signal Processing
5. Machine Learning
6. Spatial filtering of EEG/MEG signals
7. Paradigms for non/semi-invasive brain-computer interfacing
8. Practical day: Building a first BCI

Outline of the current lecture

3. Recording neural activity
   - Single-cell recordings
   - Local field potentials
   - The electrocorticogram (ECoG)
   - Electroencephalography (EEG)
   - Magnetoencephalography (MEG)
   - Functional magnetic resonance imaging (fMRI)
   - Near infrared spectroscopy (NIRS)

Single-cell recordings

- One of the most important technological advances in neurophysiology was the development of methods to record single neuron activity
  - Researchers are able to describe the response characteristics of individual increases or decreases in the activity of neurons correlate with stimulation of sense or behaviour

- Singe-cell recordings in human brains are rare because the single neuron activity is recorded with an electrode system
  - The electrode system is usually used to measure intracellular causing long-term damage to brain cells

  - Hence, single-cell recordings mainly exist from laboratory animals

Single-cell recordings

- For recording single cells, a thin electrode is inserted into the animals brain
  - Changes in electrical activity can be measured when the electrode is in vicinity of a neuronal membrane
  - More reliable and better recordings are achieved with intracellular recordings which entails long-term damage of the brain cells

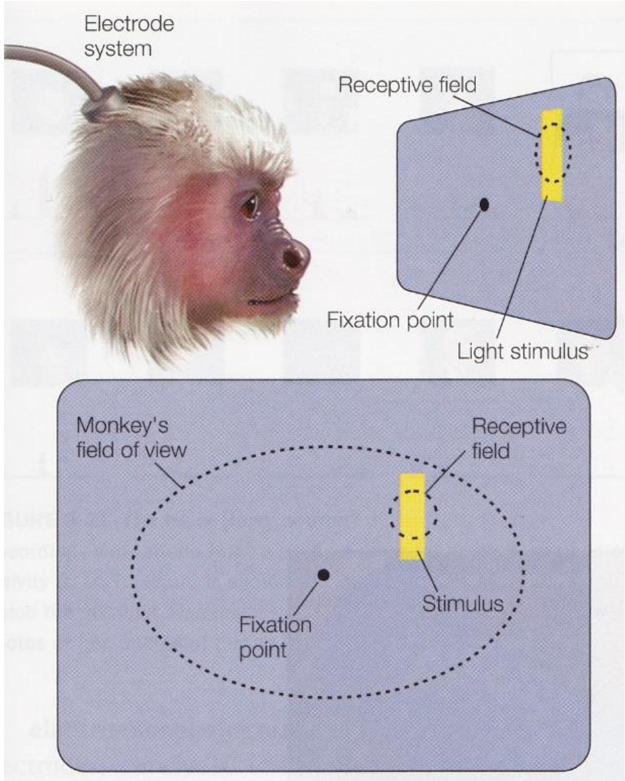
- Extracellular recordings of a “single cell” as an alternative to the intracellular recordings is preferred to avoid long-term brain cell damage
  - *A new problem arise:* We have no guarantees that the measurements at the electrode tip corresponds to the activity of a single neuron

  - How to regain the measurements of solely the single recorded neuron?
    - Record the activity of the neurons in the vicinity and use computer algorithms subsequently to differentiate the pooled activity into the respective single neuron contributions

Single-cell recordings

- Further significant advances comes from the examination of higher brain centers to study changes in activity related to goals, rewards, and emotions

- The single-cell recording has been used extensively to study the visual system of primates
  1. The researcher must look for a vicinity of his interest to record
  2. Examine the response characteristics of the specific neurons versus the receptive field (limited region of space in which the stimulus triggers the neurons in our vicinity of interest) of the stimulus
     - Receptive fields and their topological map (retinotopic) are no disjoint sets (**!**)



Local field potentials

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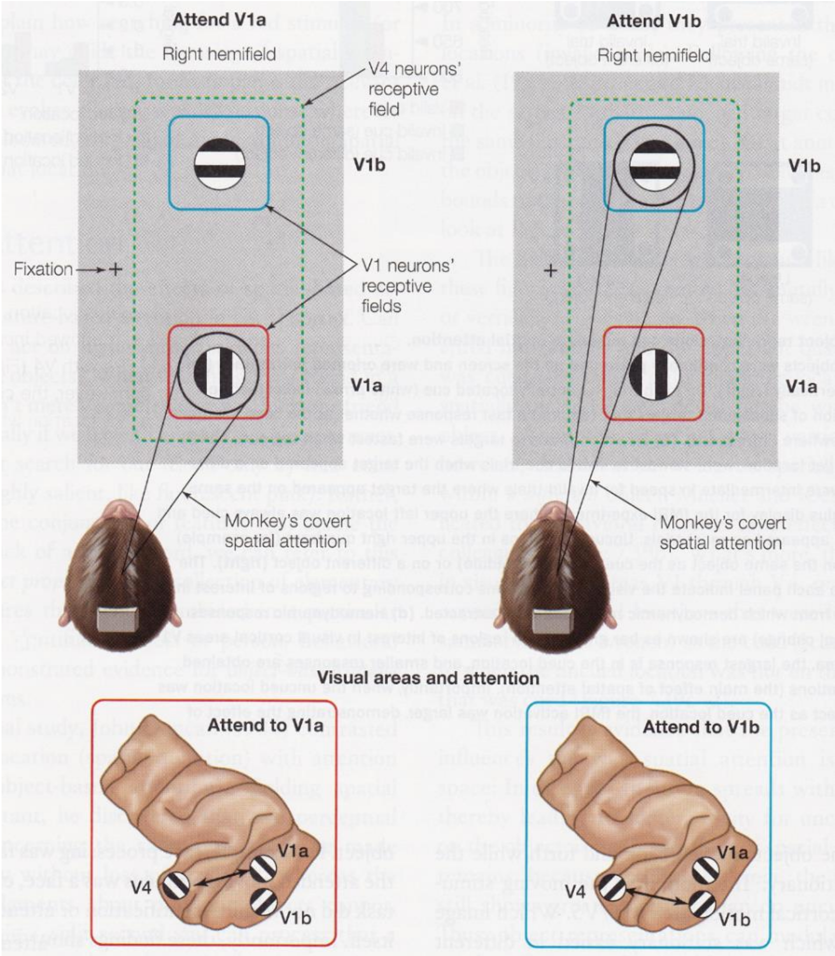
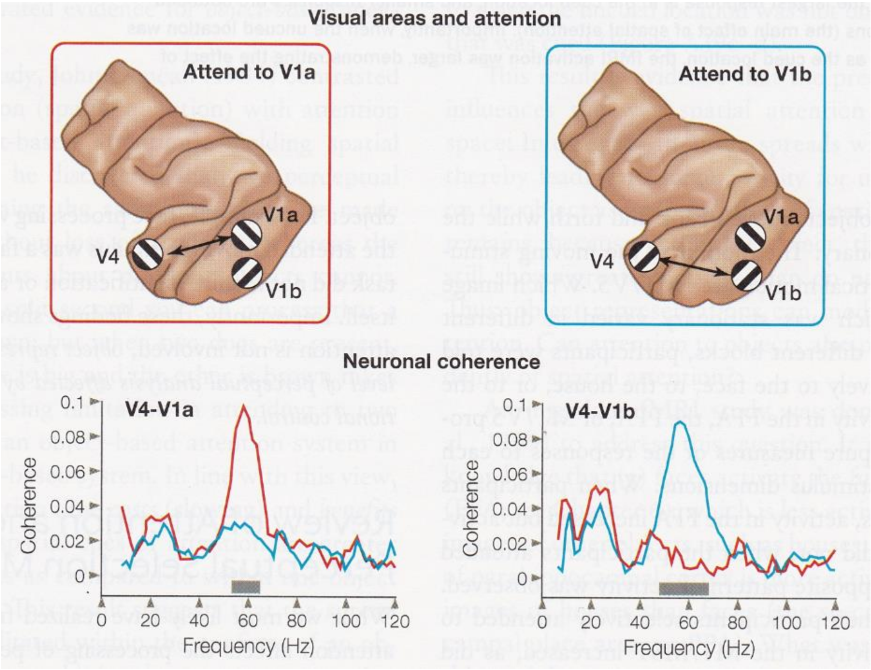
- Focus of attention on a stimulus causes higher visual areas to primarily represent the attended stimulus
  - However, we are not aware of the exact mechanism modulated by the neurons in this area
- Neurons that code the receptive field location of an attended stimulus show increased synchrony in their activity (e.g. V1/BA17 and V4/BA19)
- Pascal Fries et al. tested the above mentioned model in monkeys

Local field potentials

- Monkeys were trained to fixate a central crosshair and presented drifting grates separated in visual space (which were also attended covertly)
- Distinct populations in V1 were stimulated due to the retinotopic organization and small receptive field sizes (ca. 1° visual angle)
- In higher order visual areas (e.g. V4) that have much larger receptive fields, the same stimuli falls within the receptive field of the same (V4) neuron



Local field potentials



- The researches hypothesized that the spatial synchronization of early and late stages of the visual hierarchy (V1 and V4 respectively) is supported by **selective synchronization of local field potentials** (LFPs) in the process

- A local field potential is the cumulated electrical current from a neuron's dendrites
  - Local field potentials occur in the gamma-band (ranging from 60-80 Hz)

The electrocorticogram (ECoG)

- An electrocorticogram (ECoG) records electrical current directly on the surface of the brain (outside or beneath the dura matter)

- Only appropriate for people who undergo neurosurgical treatment
  - Provides useful clinical information such as to identify the location and frequency of abnormal brain activity

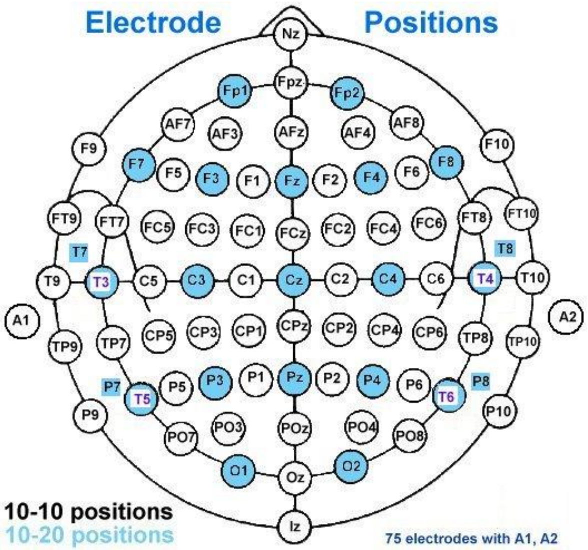
  - Implants remain in place for a week (i.e. there is time to conduct cognitive task related experiments)
    - Invasive measurement method, hence not applicable for everyone and everyday use

  - Measurements of electrical current *before* passing through the skull and scalp

  - Less distortion than in EEG (cleaner signal results in excellent spatial and temporal resolution)
    - High-frequency brain activity (gamma-band) detection without distortion possible

Electroencephalography (EEG)

- An electroencephalography (EEG) records activity of populations of neurons (regional) on the scalp
  - Usually measurements with 20 to 256 electrodes embedded in an elastic cap
  - You can find an extensively mapping from Brodmann areas to electrode position – and vice versa – here
- The tissue of the brain, the skull and the scalp conducts the electrical current enabling (imprecise) recording of neural



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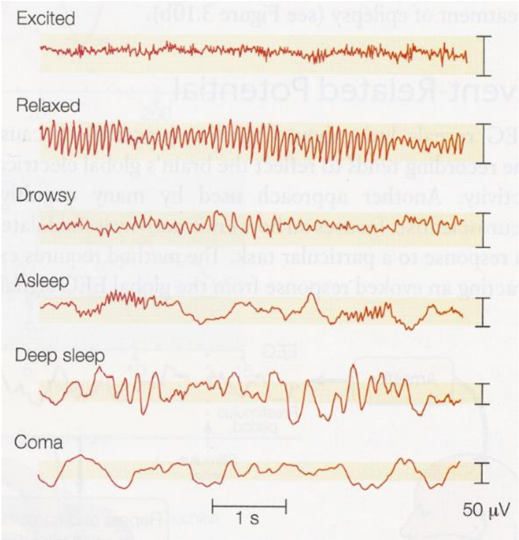
Electroencephalography (EEG)

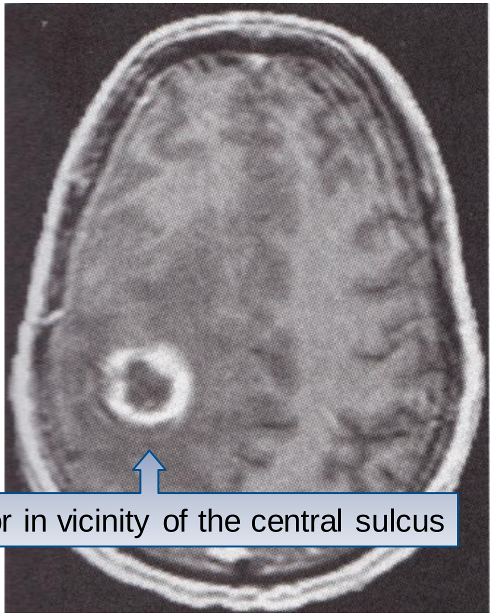
- Due to imprecise recordings, there is the need to compare each fluctuating voltage at each electrode to a reference electrode
  - The reference electrode is usually located at the mastoid bone at the base of the skull

- Furthermore, EEG yields a continuous recording of the overall brain activity
  - Hence we obtain a *predictable* correlate of EEG signatures and behavioral states proving to have many clinical applications



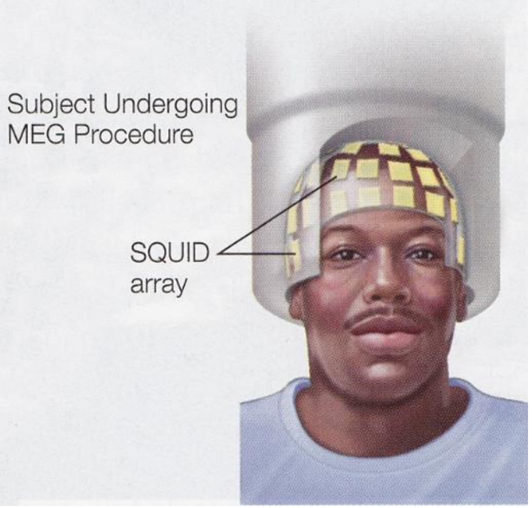
Magnetoencephalography (MEG)

- The MEG measures small magnetic fields which are perpendicular to the electrical current affiliated with synaptic activity
  - Magnetic fields are not distorted by the brain tissue, skull, and scalp
  - Averaging multiple MEG trials yields the event-related field (ERF) which has a greater spatial resolution than the ERP
    - Locating a source of a signal with MEG data is more accurate than with EEG data
- Why not always use the MEG if it superior to the EEG?



Magnetoencephalography (MEG)

- The MEG has two major drawbacks:
  1. The surface of the skull needs to be parallel to the electrical current flow
     - Most cortical MEG signals are of neurons that tend to be located in sulci
  2. The magnetic fields of the brain are extremely weak to be effective and hence the MEG requires a room that is magnetically shielded from **all** external magnetic fields
     - The data is collected from super-conducting quantum interference device (SQUID) arrays that need to be kept colder than 4 degrees Kelvin (i.e. colder than *-269.15ºC*) encased in large liquid-helium cylinders



Functional magnetic resonance imaging (fMRI)

- Functional magnetic resonance imaging (fMRI) exploits the fact that local blood flow is increased in active parts of the brain

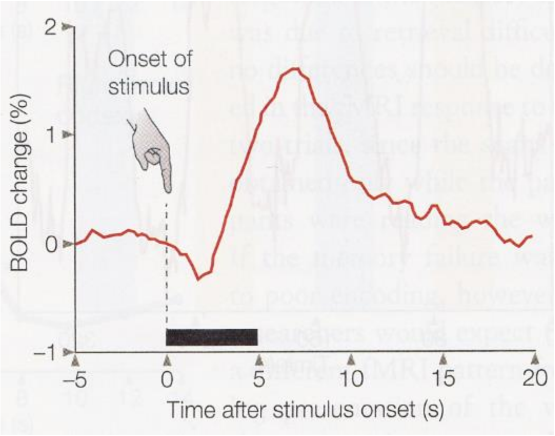
- The fMRI is similar to the traditional magnetic resonance imaging (MRI)
  - The MRI machine builds up a magnetic field
  - Radio waves causes the protons in hydrogen atoms to oscillate
  - A detector measures local energy fields that are emitted as the protons return to the orientation of the original magnet field

Functional magnetic resonance imaging (fMRI)

- fMRI has the focus on the magnetic properties of deoxyhemoglobin (deoxygenated form of hemoglobin)
  - Deoxyhemoglobin is – in contrast to oxyhemoglobin – paramagnetic (weakly magnetic in the presence of magnetic fields)

  - fMRI detectors measure the ratio of oxyhemoglobin to deoxyhemoglobin referred to as the **blood oxygen level-dependent** (**BOLD**) effect

  - Results are generally reported as an increase in BOLD change
    - This change occurs because when a region of the brain becomes active, the amount of blood directed to this area increases
    - An increase in the BOLD response is observed after a few seconds although neural events occur after milliseconds



- fMRI yields an indirect measure of neuronal activity

Near infrared spectroscopy (NIRS)

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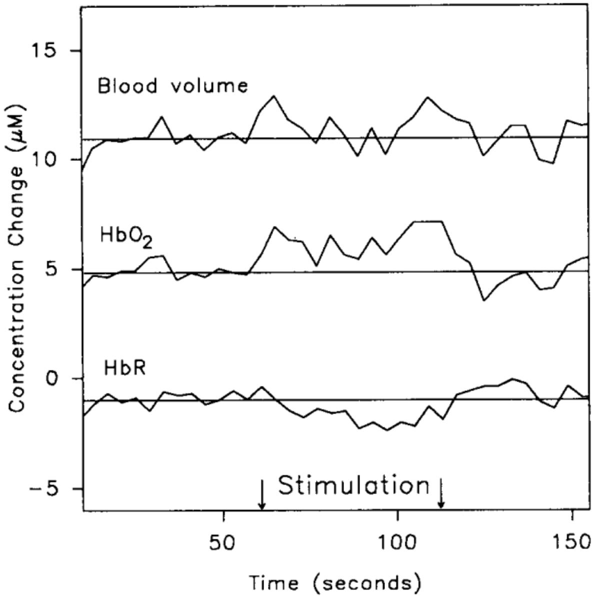
- Optical measure of tissue absorbance of light at several wavelengths in the spectral region (i.e. around 700 – 1000nm)
  - Determination of concentration changes of oxygenated hemoglobin, blood volume and oxygenated cytochrome-oxidase during brain activation
  - Penetrates biological tissue and bone, obeying the Lambert-Beer law for determination of tissue concentration
  - Most NIRS studies have been performed in newborns where infrared light is transmitted through the entire head
  - Typical findings are an increase in HbO_2 and a decrease in HbR during brain activation



- NIRS is a simple and flexible method to assess hemodynamic alterations during brain activation

Literature

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