Brain-Computer Interfaces

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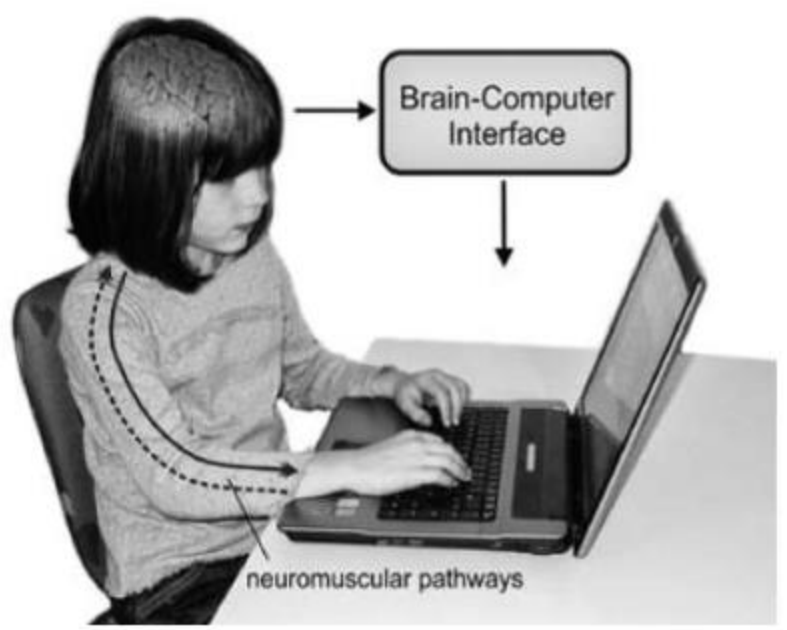
Introduction

- Communication or control systems that allow real time interaction between the human brain and external devices without the need of peripheral nerve or muscle activation.

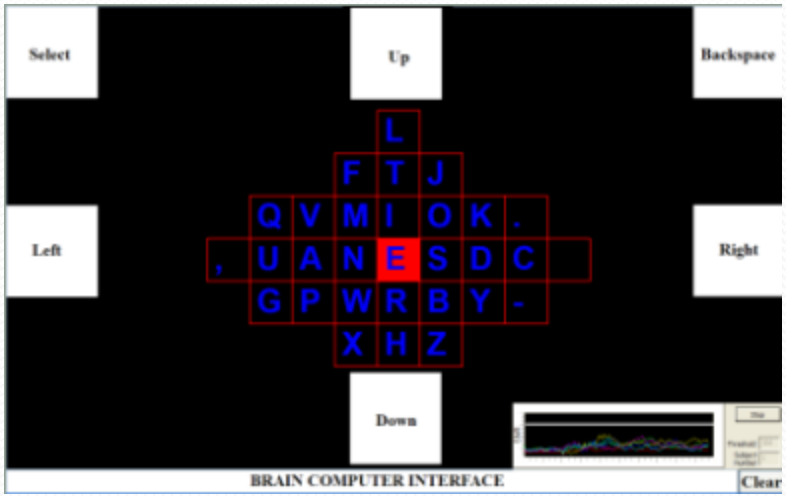


Applications

- Individuals who are severely disabled by disorders such as
  - ALS
  - Brainstem stroke
  - Spinal-cord injuries
  - Muscular dystrophies
  - Chronic peripheral neuropathies

Communication

- Yes/No Communication
- Spellers



Movement Control

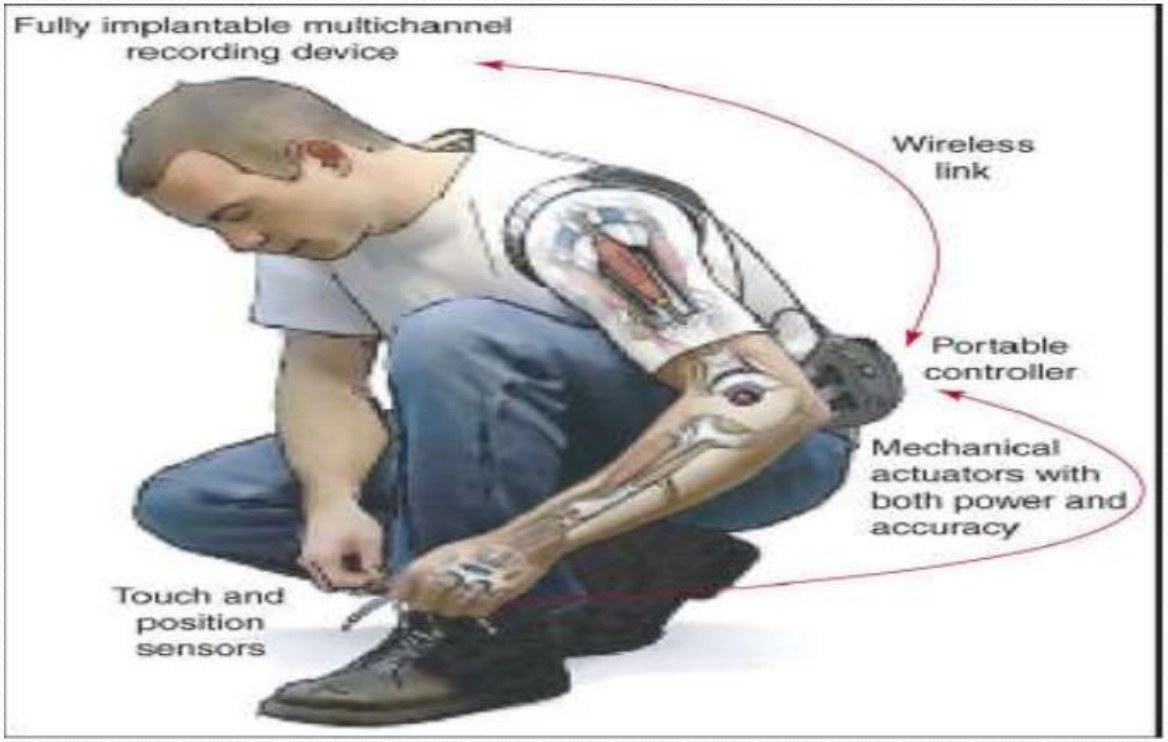
- Restoration of independent locomotion is another important issue for paralyzed people.

Neuromodulation

- Neuromodulation to replace lost senses

Neurorehabilitation

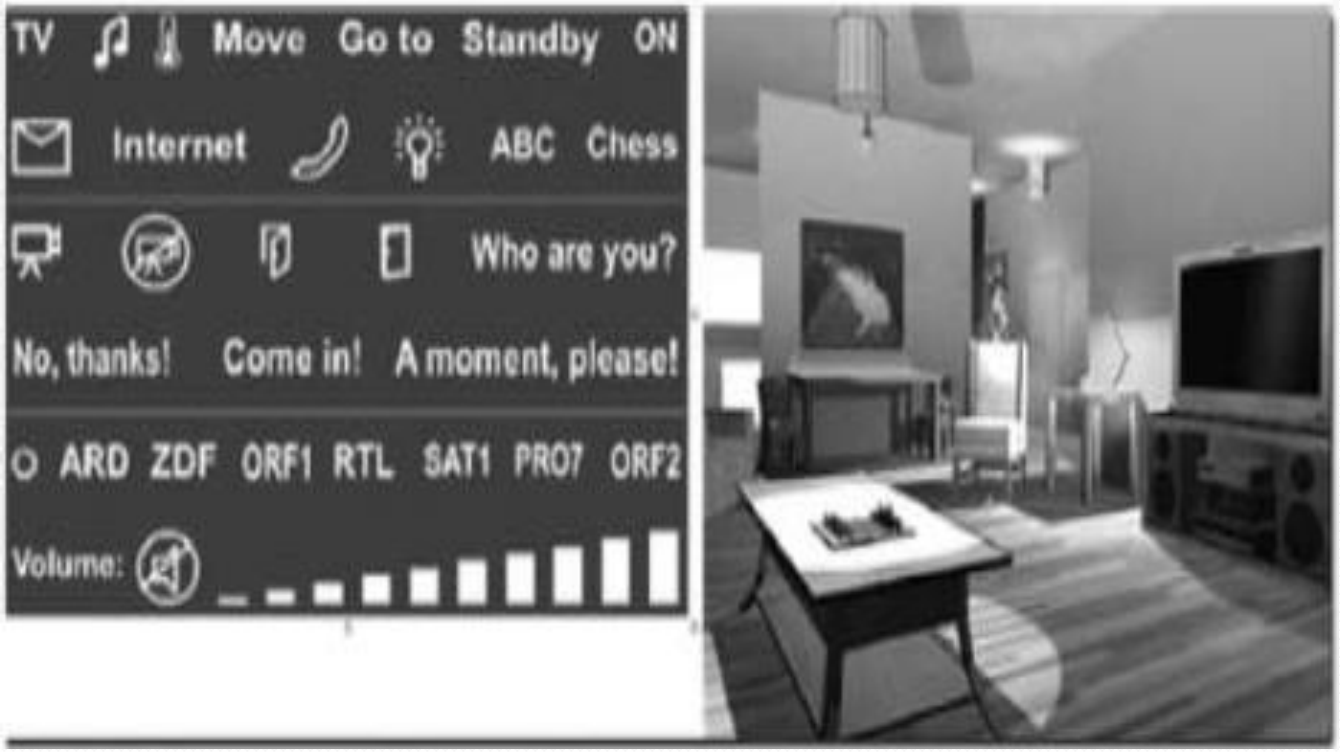
- Control of prosthetic limb
- Grasp restoration



Environmental Control

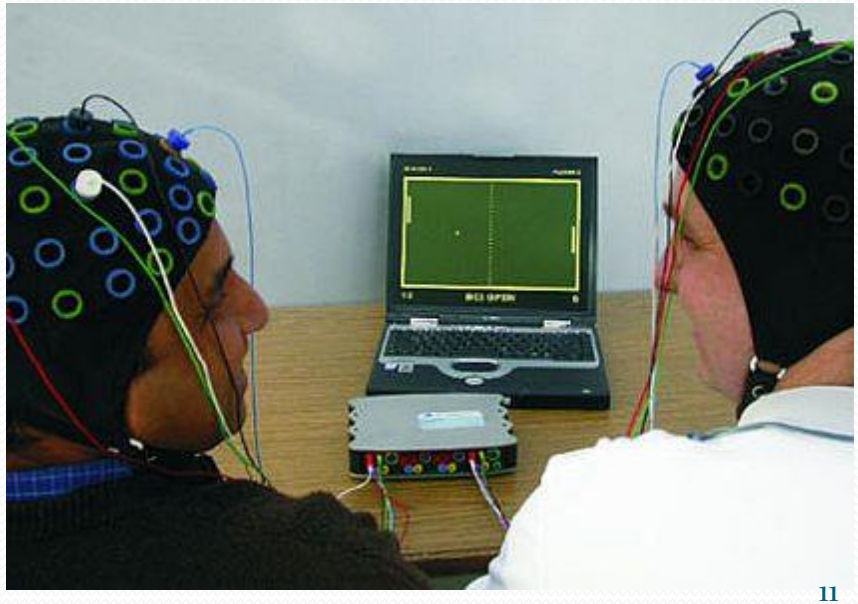
- BCI-based environmental control could greatly improve the quality of life of severely disabled people.
- People with severe motor disabilities are often homebound.
- Effective means for controlling their environments- like controlling room temperature, light, power beds, TV would increase their well-being and sense of independence

Environmental Control



Recreation

- Gaming
  - Mindflex – EEG controlled obstacle course (2007)
  - OCZ Technology (2008) created a device for playing games controlled by EMG
  - NeuroSky – Star Wars Force Trainer (2009)
- Virtual Reality
- Music

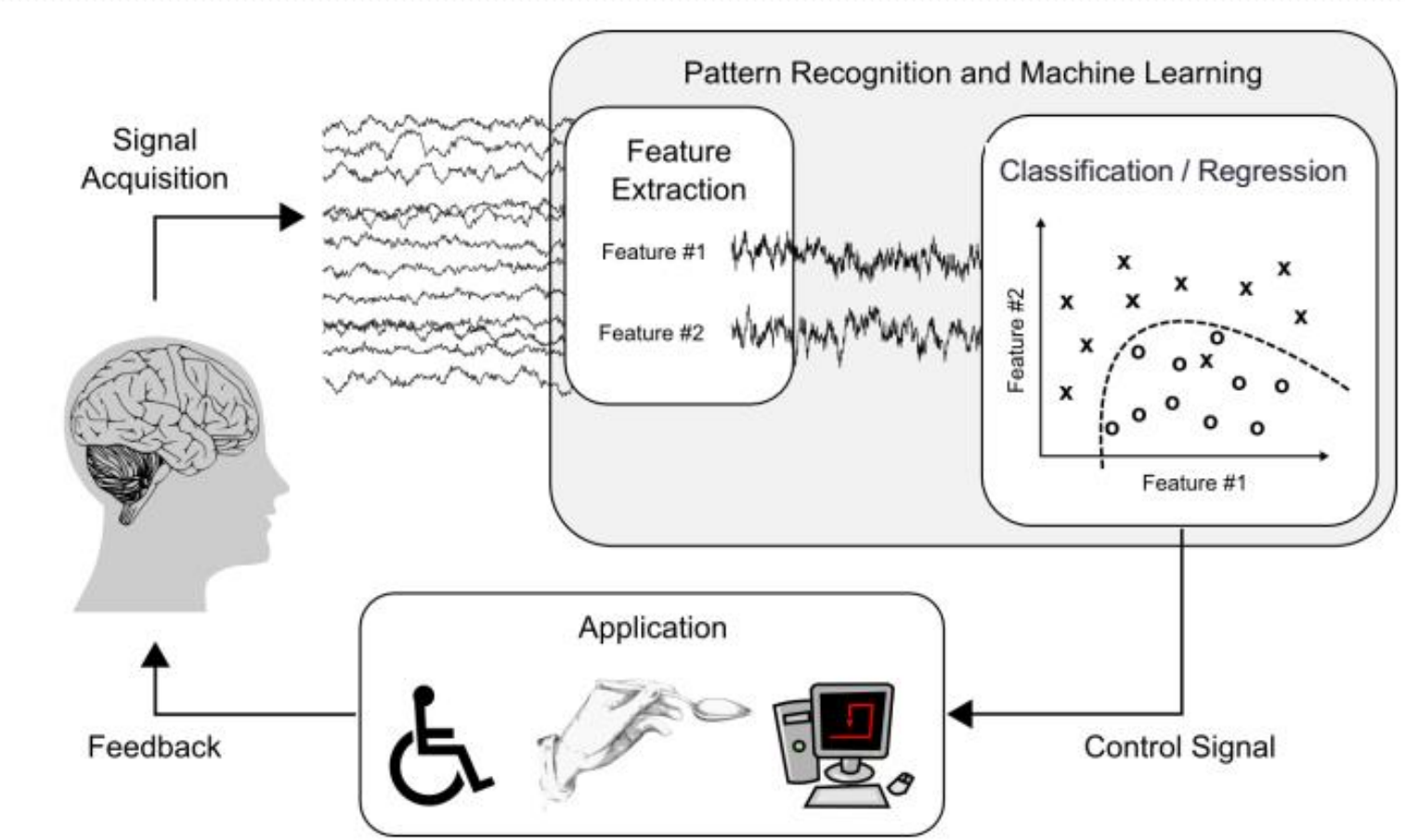


Brain Computer Interfaces

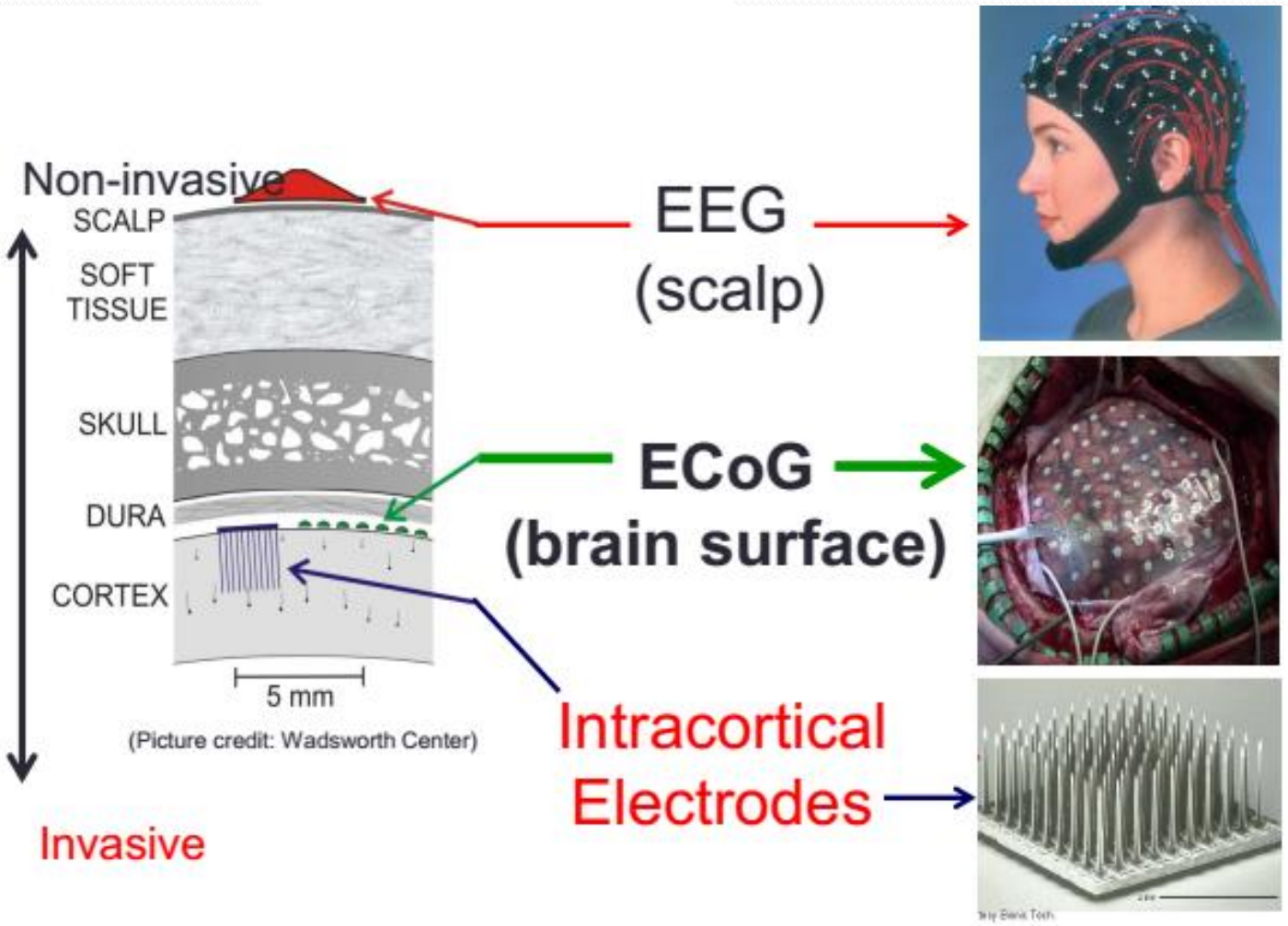
- Many Applications ->
  Many Engineering Requirements ->
  Many Architecture Considerations

- But in general: need to **isolate**, **translate**, and **utilize** a neural signal

Architecture of a BCI



BCI Signal Types

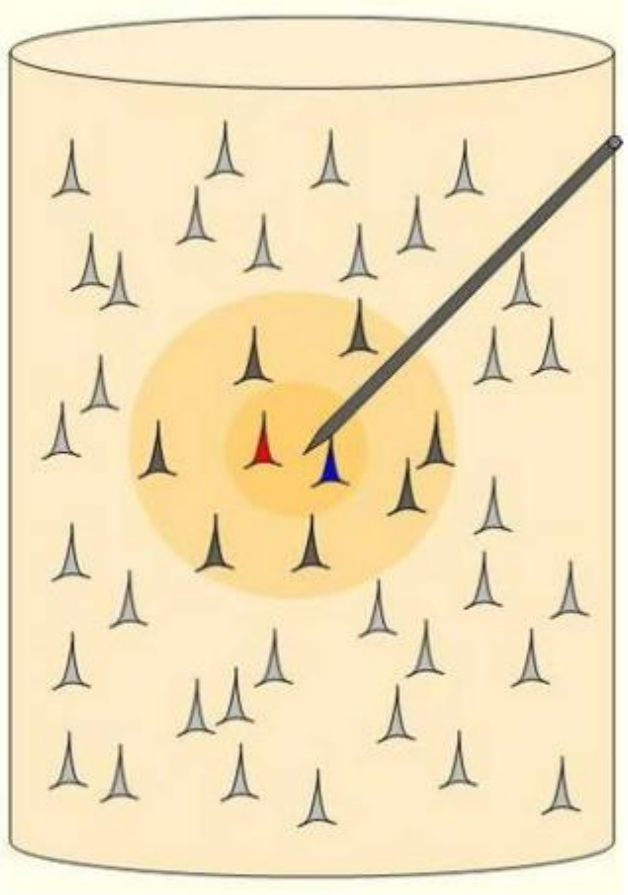


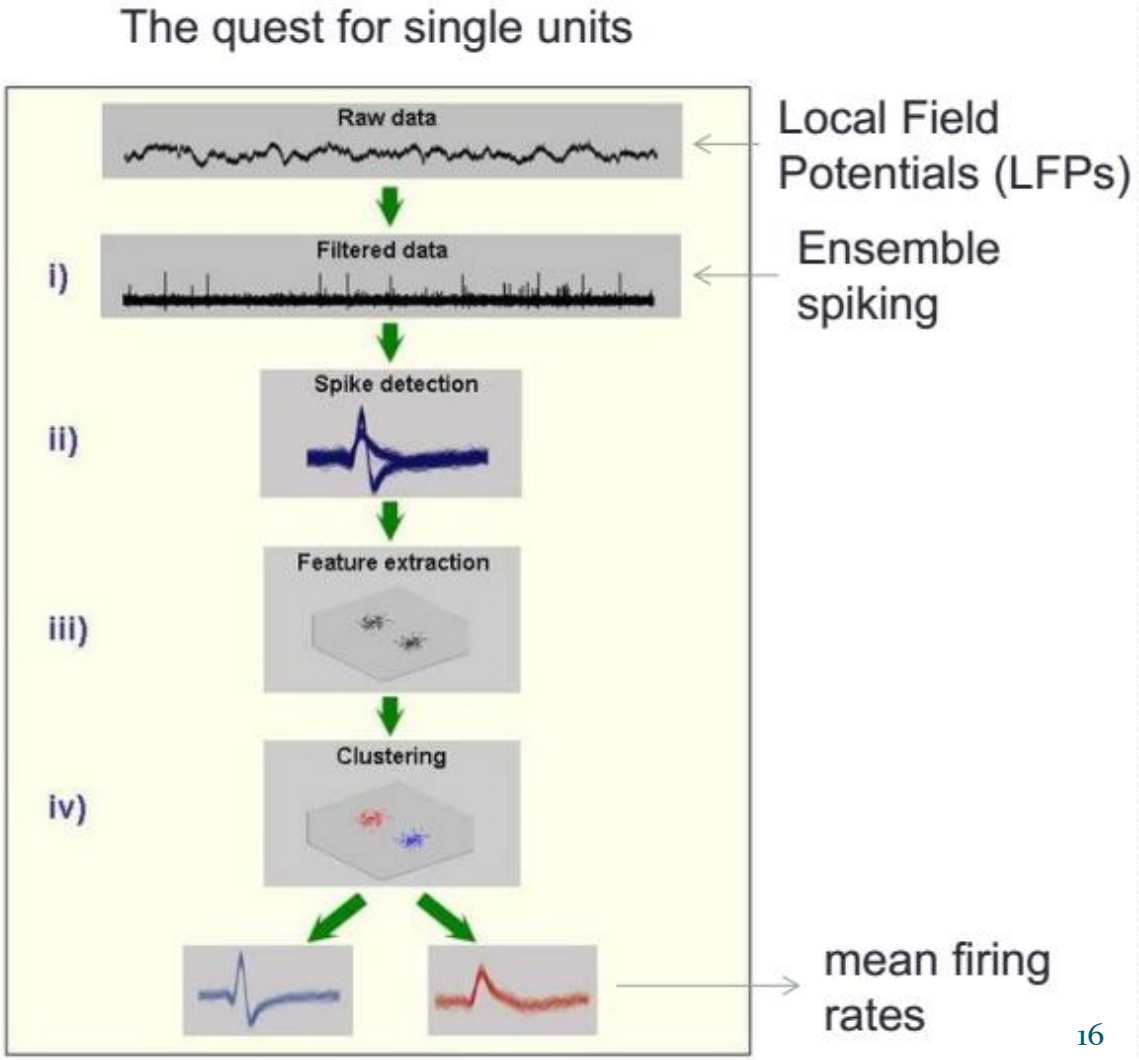
BCI Signal Types

Signal	Cell count	Raw Magnitude	Spatial Specificity	Signal Stability
EEG (non-invasive)	> 1M	~50 uV	1-5 cm	Long-term?
ECoG (semi-invasive?)	500K	~500 uV	3-10 mm	Months
Intracortical (invasive)	1-???	10s of mV	< 300 um	Days

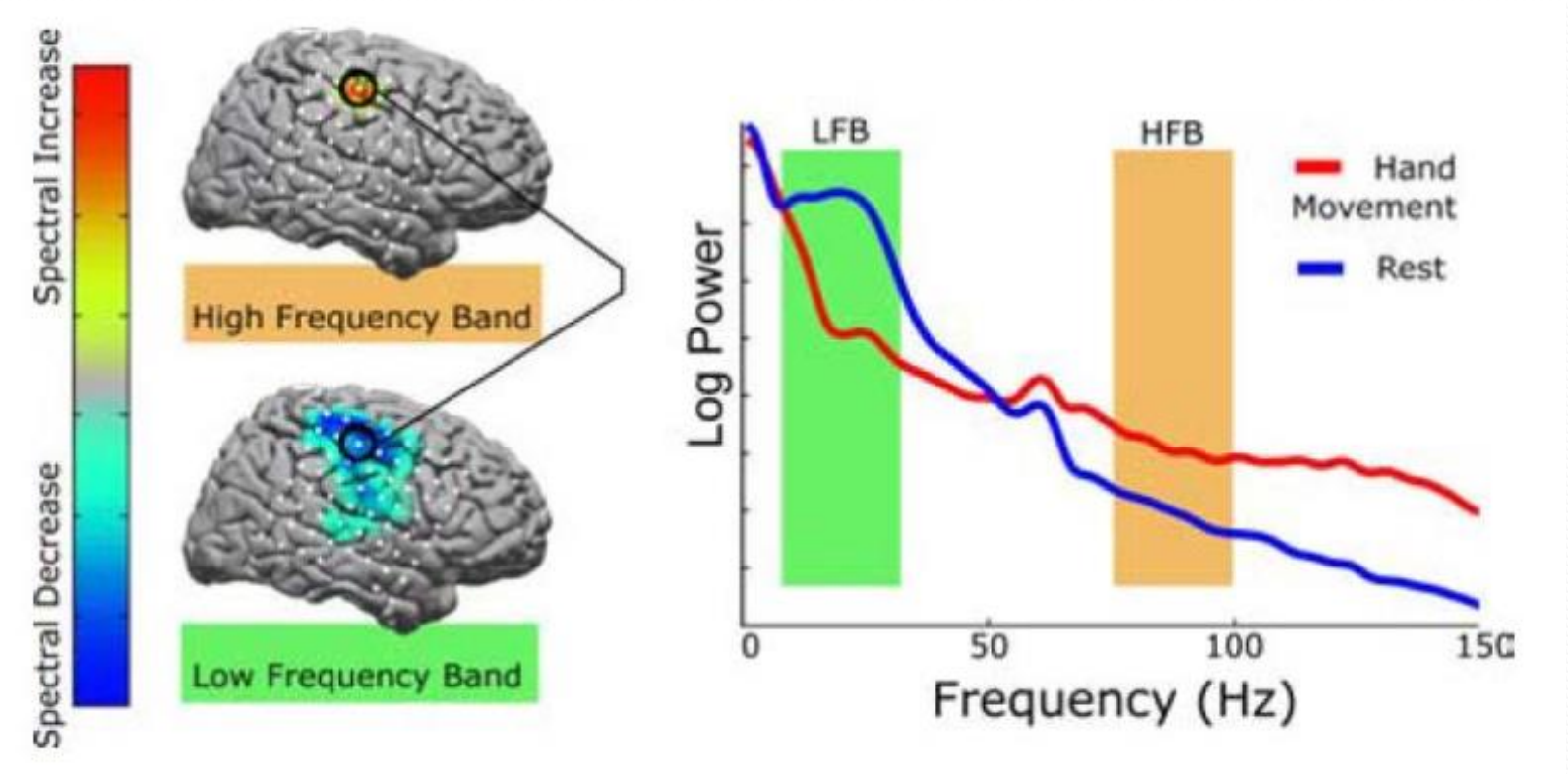
Appropriate modality choice depends on application, Consider subject population, Research/Clinical goals, Stimulation requirements.

Feature extraction, intracortical recordings



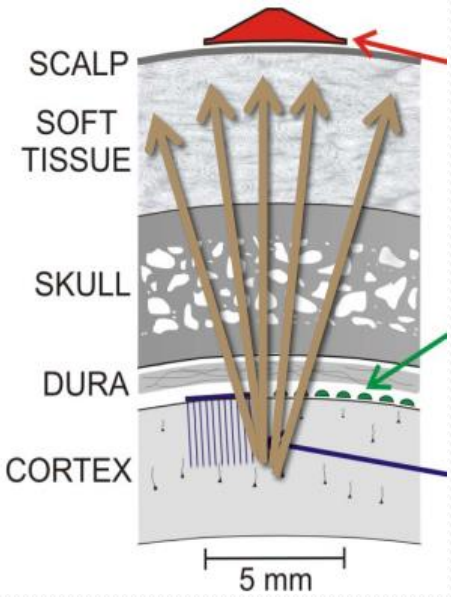


Feature extraction, ECoG and LFPs



Spectral Estimation:
STFFT
Wavelets
Band filtering and envelope detection
Auto-regressive model

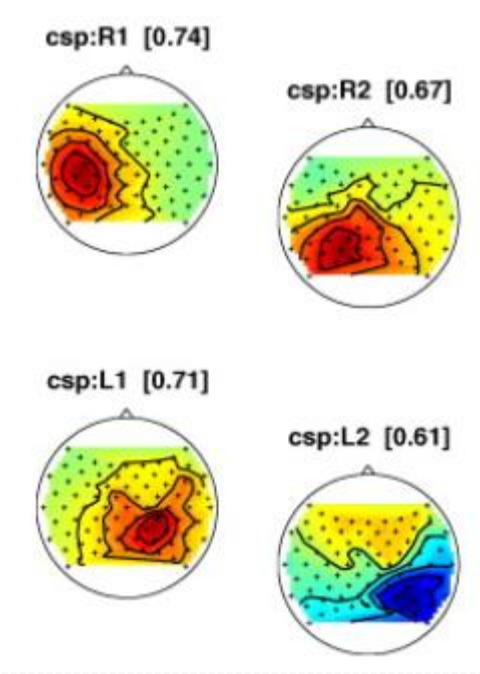
Feature extraction, EEG

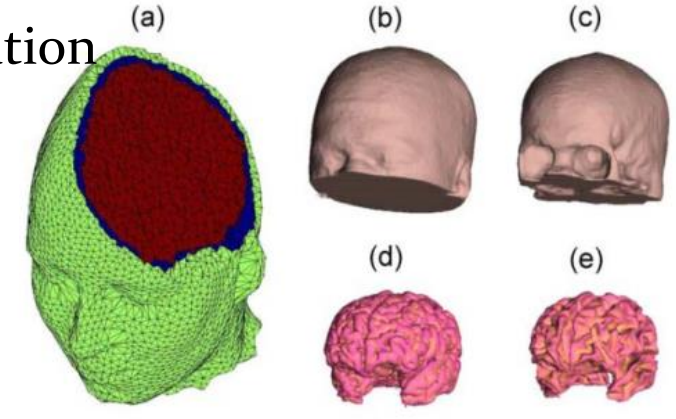


Signal spreads as it passes through meat

1) Correct for spatial spreading
- Use of spherical head model as solution to forward model
- Common Spatial Patterns
- Subject specific MRI as solution to forward model

2) Apply same spectral estimation techniques used in ECoG

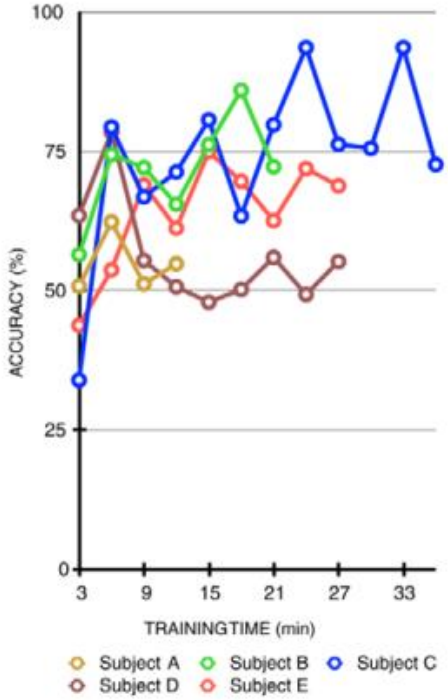


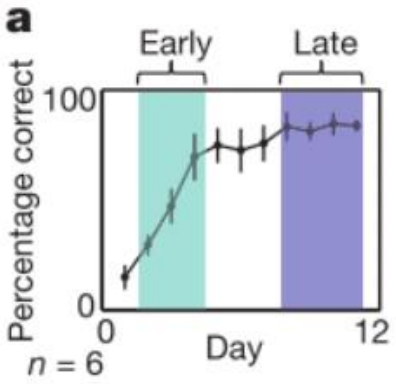


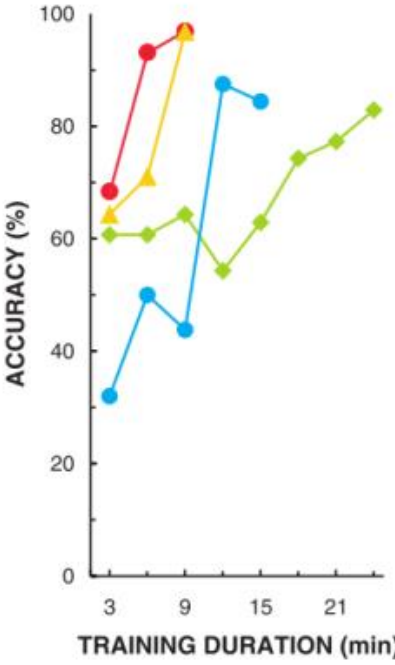
Classification

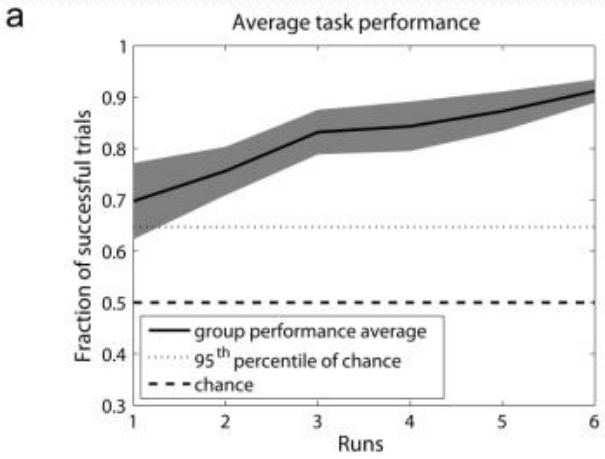
- Intracortical recordings:
  - Translation of neural signal to one or more continuous variables
  - Kalman Filter, Neural Networks, ARMA Models, etc
- ECoG
  - Translation of neural signal to one or more continuous variables, High SNR allows us to be lazy.
- EEG
  - Much harder computational problem, because of low SNR Neural signal typically translated to discrete variable with pre-defined (and pre-trained) number of states
  - SVM, Naïve Bayes, Decision Trees, Random Forest, Neural Network, on and on…

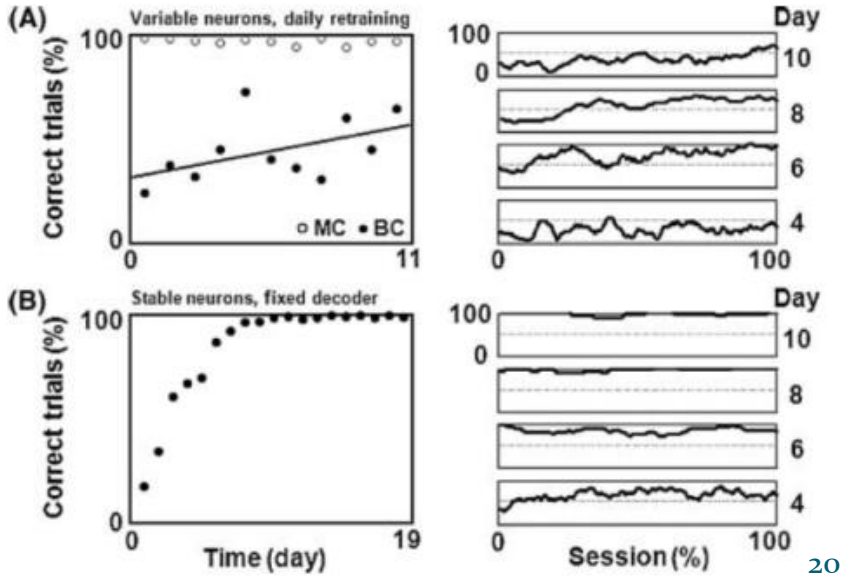
An Inherent Problem



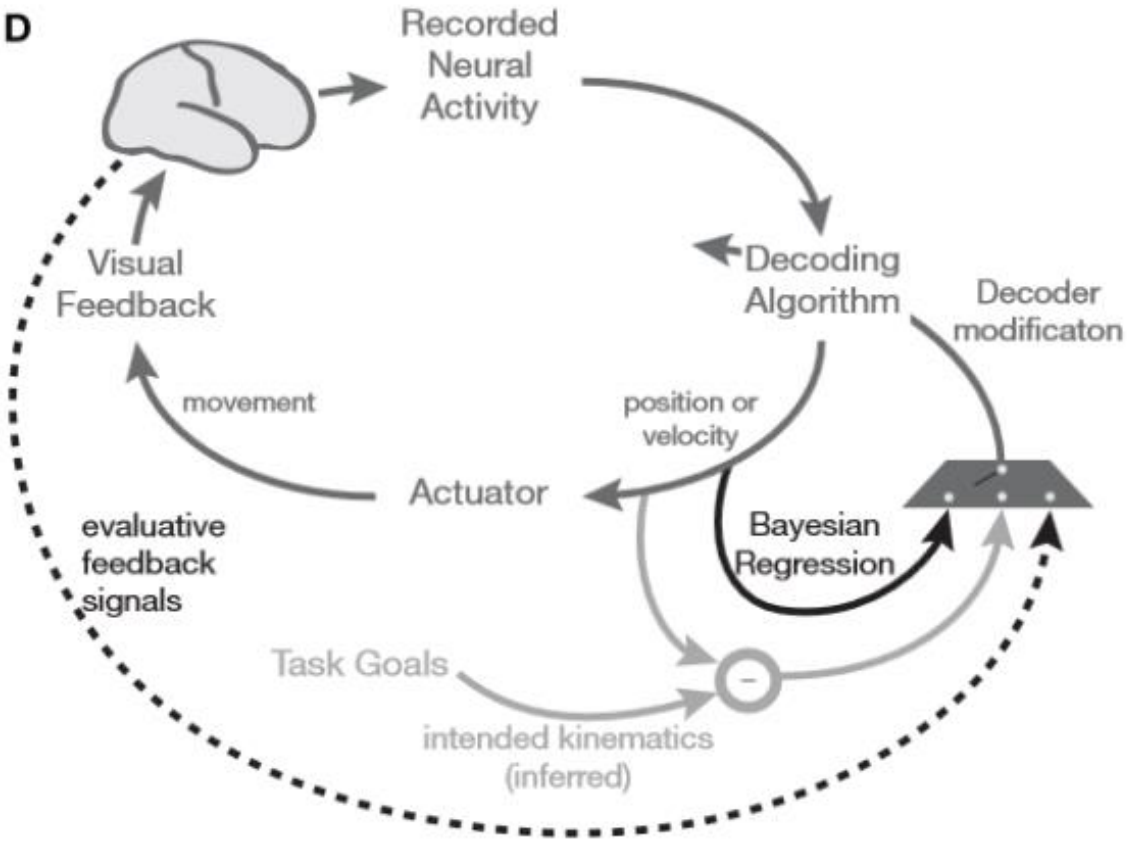






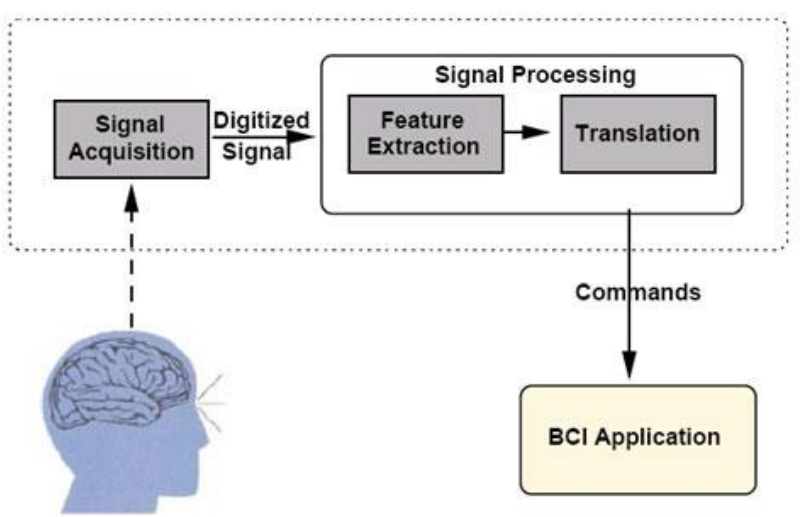


Closed-loop decoder adaptation



BCI– Electrophysilogical Activities use

- SCP Slow Cortical Potentials
- Mu Movement Imagination
- P300, SSVEP ERP-Analysis
- cortical neurons, direct brain interfaces



SSVEP BCIs

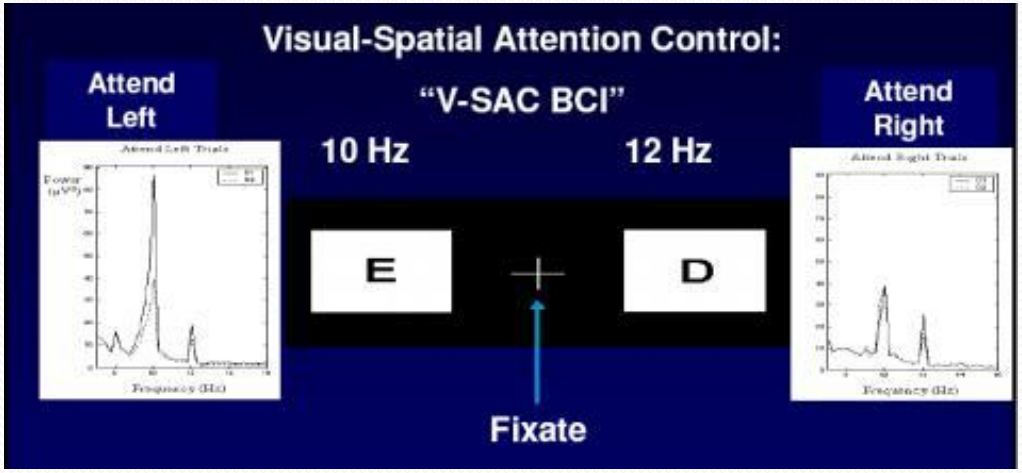
- Steady State Visual Evoked Potentials

derived from the visual (occipital) cortex

- Focussing attention to visual stimuli of different frequency

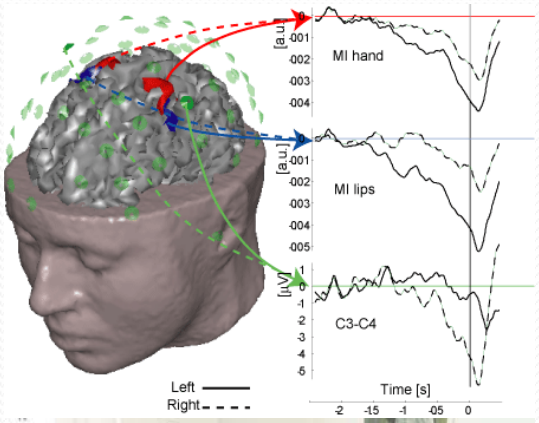
shows up in the EEG freqeuncy bands

- Relibable and high transfer rate, but some prerequisites (eyes)

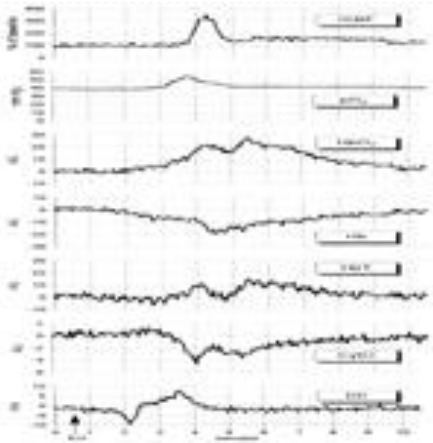


SCP BCIs

- Detection of slow cortical potentials (SCPs)
- Needs DC EEG Amplifiers
- First successful device end 1990‘s:
  - Niels Birbaumers Thought translation device
  - intensive training was necessary to gain
  - control over the SCP waves



Patinet using TTD to write a letter



SCPs:

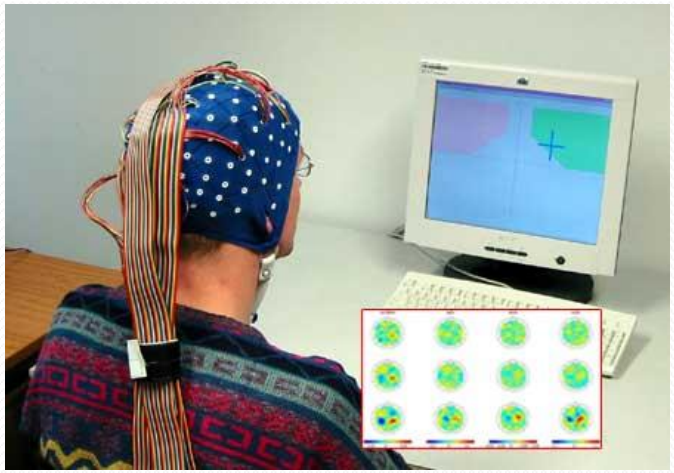
DC-shifts, slow negativation of cortical areas

Preparation of movement and cognitive tasks,

Several hundert milliseconds before the task

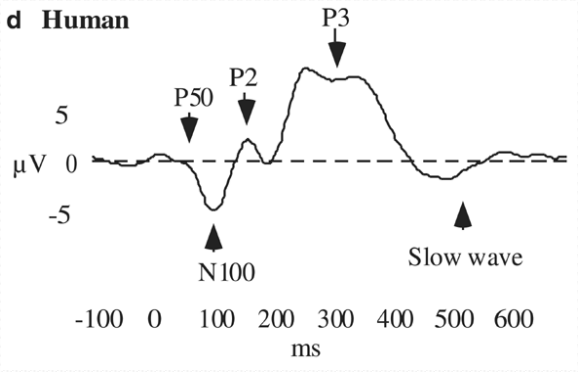
μ-rhythm BCIs

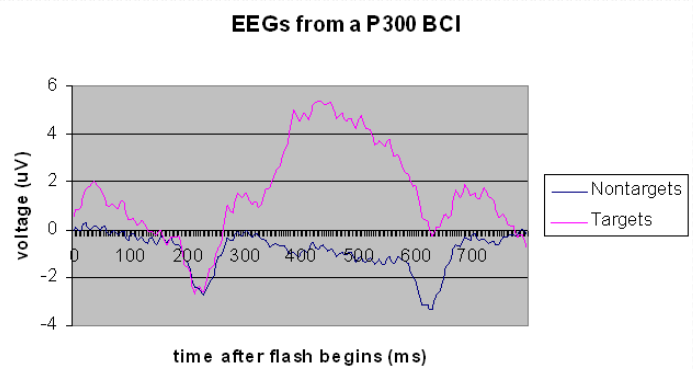
- μ–rhythm is the idle-rhythm of the motor cortex
- Frequencies around 10 and 18 Hz.
- ERD / ERS – event related desynchronisation / synchronisation
- Movements or imagination of movements inhibit the μ–rhythm



P300 BCIs

- P300 wave – posivite component in the event related potential, 300ms after a stimulus
- Natural response to events considered as important
- Selection of a symbol: count the flashes, algorithm averages trails and finds a P300





P300 runtime user interface

BCI- μ / P300 comparison

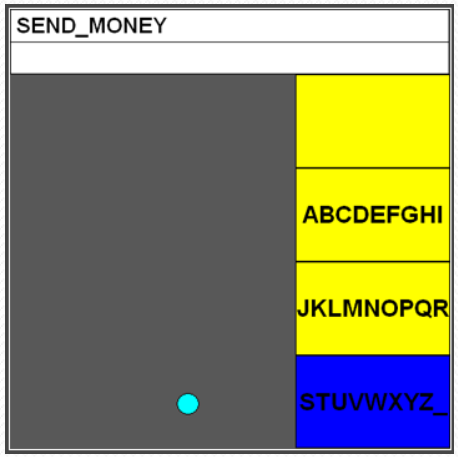
μ - BCIs

Require training

2D-control possible

Movement imagination

Affected by movement



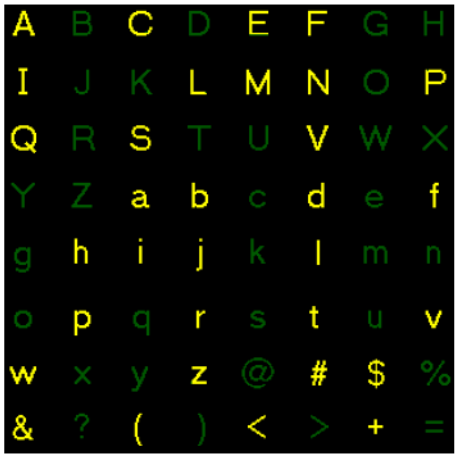
P300 BCIs

Do not require training

1D control only

concentration / decision

Affected by distraction



Limitations

- Getting a good signal is hard
- Interpretation of signals is hard
- BCIs are currently fairly inaccurate in terms of classifying neural activity
- Surgery needed for electrode placement
- Invasive BCI prone to develops scar tissue

Ethical Considerations

- How can you obtain consent for a BCI from someone that can't communicate?
- Do the benefits outweigh the risks?
- What happens if someone wants to keep a thought secret and BCI detects it?
- What is the limit of what we will do with BCI?
- Could people use BCI to interrogate someone?

Future

- BCI technology seems very applicable in a wide variety of areas whether it be medically or commercially
- Possibilities of how far the systems can go is virtually limitless
- Control of sub vocalization and more advanced EEG processing could lead to telepathic communication and active learning mechanisms
- Virtual Gaming
- Mind Reading
- Brain to Brain Interfaces (BBI)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Thank You!