University of Essex

School of Computer Science and Electronic Engineering

CE803 – Human-Machine Interaction

Part II – Lecture 2

- **Brain-Computer Interfaces**

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BCIs

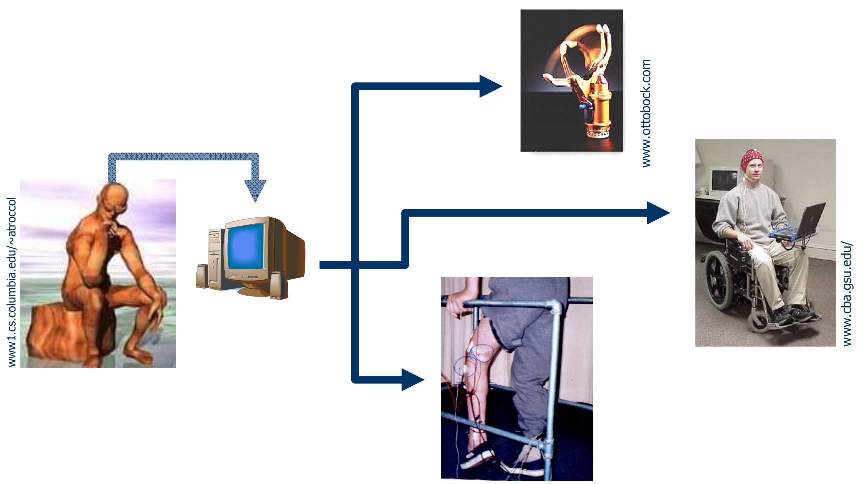
- Supplementary reading:

- F. Sepulveda (2011) 'Brain-actuated control of robot navigation'. Chp. 9, in A. Barrera (Ed.), Advances in Robot Navigation, Intech Open Access, ISBN 979-953-307-007-9.
- J-R. Wolpaw, N. Birbaumer, D.-J. McFarland, G. Pfurtscheller and T.-M. Vaughan, "Brain-computer interfaces for communication and control", *Clin. Neurophysiol.* vol. 113(6), pp. 767-91, Jun 2002.

(pdf files available in the CE803 web page)

Overview

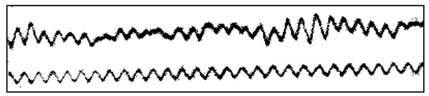
Brain-Computer Interfaces



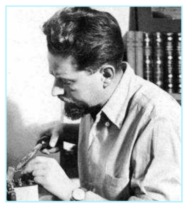
Overview

Electroencephalography (EEG):

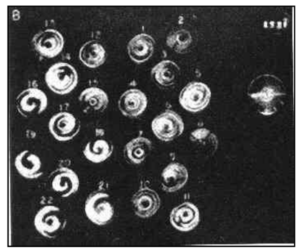
Hans Berger (1873-1941)



First EEG recorded - H. Berger, c. 1928



W. Gray Walter (1910-1977)

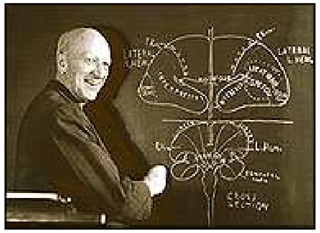


Walter's Toposcope 1936-57

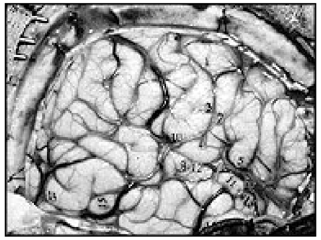
Pictures from: http://www.epub.org.br/cm/n03/tecnologia/historia.htm

Overview

Into the Brain



Wilder Penfield
(1891-1976)

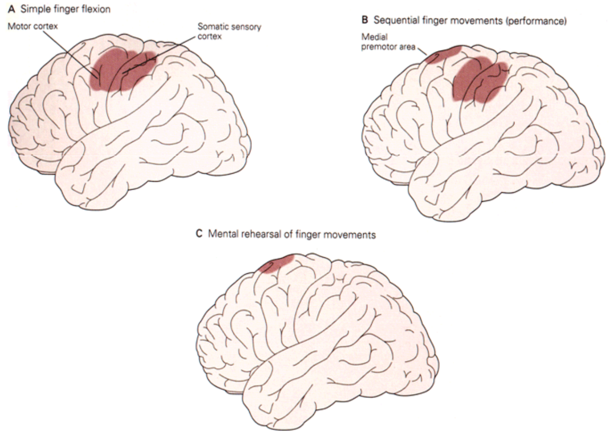


Penfield's experiments on
living humans

Pictures from: http://www.pbs.org/wgbh/aso/tryit/brain/cortexhistory2.html

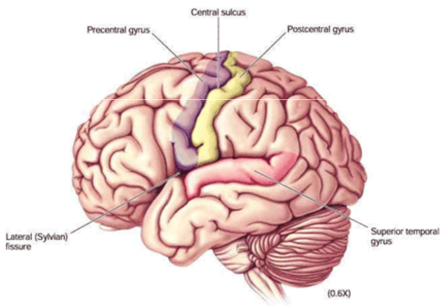
Overview

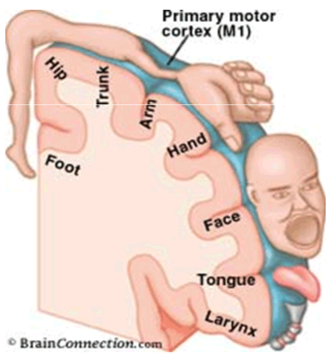
Cortical Organization



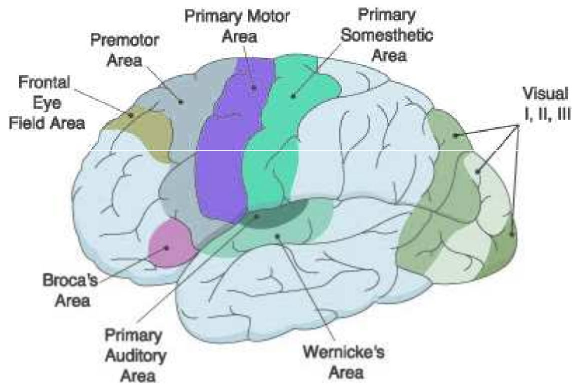
from Kandel *et al.*, 2000

Overview
Cortical Organization



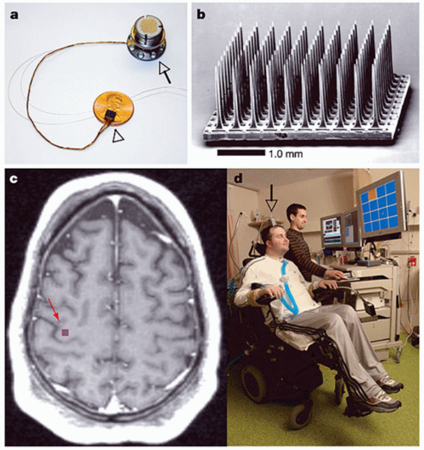


Overview
Cortical Organization



Overview

- Donoghue's group (Nature 442, 164-171, 2006)

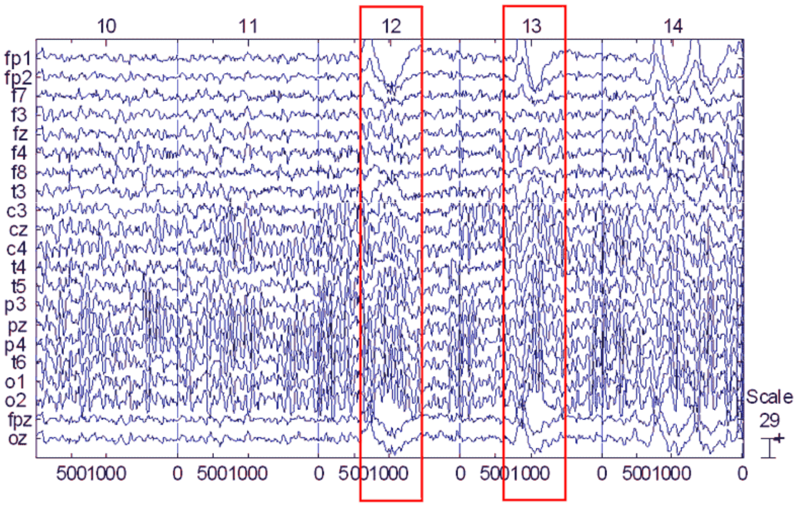


Measuring Brain Activity

- Invasive:
  - Implanted systems ➔ *risk, cost, durability problems*
  - Positron emission, PET-Scan ➔ *radiation, cost, slow response*
- Non-invasive:
  - Magneto-encephalography, MEG ➔ *large equipment, cost*
  - Functional MRI ➔ *large equipment, cost, slow response*
  - Near-Infrared ➔ *slow response, long term effects unknown*
  - Electroencephalogram, EEG ➔ *limited resolution, but*
    - low cost
    - fast response (i.e., short latency events can be seen)
    - portable

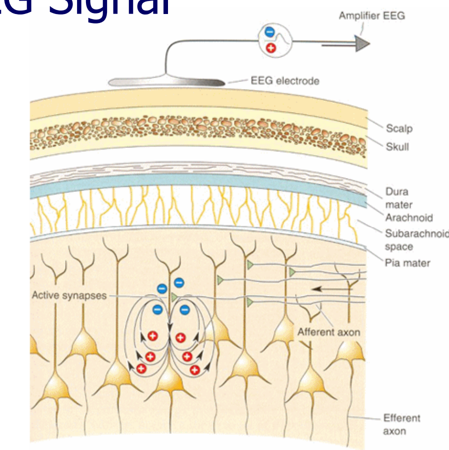
Electroencephalography (EEG)

motor imagery example



Sources of Electrical Activity in the EEG Signal

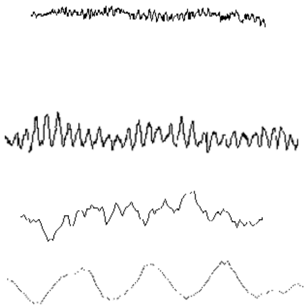
- EEG measures the current flow during synaptic excitation of the dendrites of pyramidal neurons in the cerebral cortex
- EEG is a result of joint activity of millions of underlying neurons activated together
- The amplitude of the EEG signal is proportional to the number of *synchronously* activated neurons
- The EEG signal is "blurred " version of a real activity, as signal passes through several layers of nonneural tissue (meninges, fluid, skull, skin)



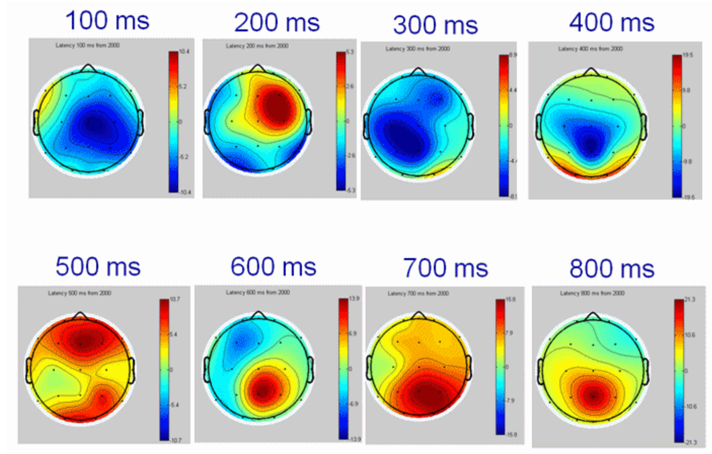
also, see last week's lecture on the generation of electrical signals in humans

Basic EEG Rhythms

- Gama (30-80 Hz)
  - Perception and consciousness, REM sleep
- Beta, two types I and II (14-30 Hz)
  - Normal less regular activity present in awake when eyes are opened or closed; Type 1 disappears during intense mental activity; Type 2 is elicited by mental activity
- Alpha (8-13 Hz)
  - Very rhythmic; normal activity in quiet and restful state; larger when eyes are closed then when opened
- Theta (4-7 Hz)
  - Infrequent, mostly in adolescents, in adults during stress
- Delta (< 4 Hz)
  - Deep sleep, infancy, brain disorders



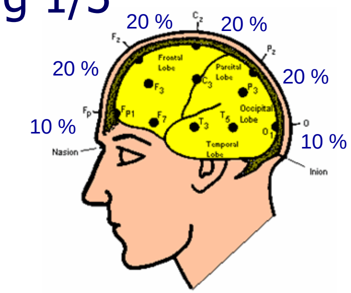
Time-Space Visualisation of ERP
(event related potentials)

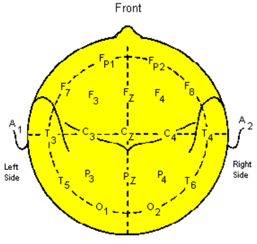


ERP of imaginary right hand movement

EEG Recording 1/3

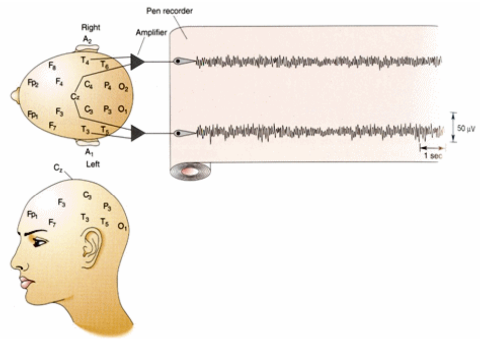
- Electrodes placed according to 10-20 electrode placement system
- Based on the relationship between the location of an electrode and the underlying brain area
- Frontal F, Parietal P, Occipital O, Temporal T, Central C
- Left-odd numbers, right-even numbers, z midline
- Smaller numbers closer to the midline position





EEG Recording 2/3

- Small voltage fluctuation (few tens of µV) between selected pair of electrodes
- Reference: common reference average reference, bipolar
- Distance measured between
  - Nasion and inion
  - Left and right ear
- Typical sampling frequency 128 or 256 samples/s

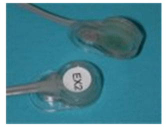


Common reference in this case is electrode Cz

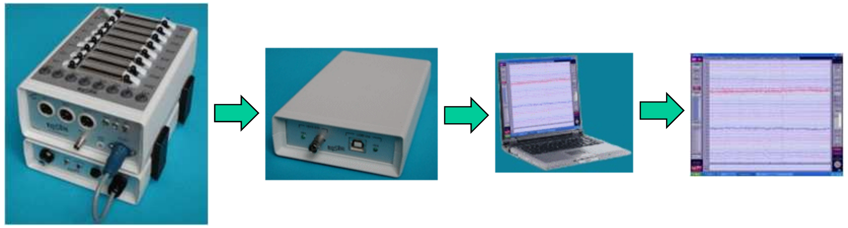
EEG Recording 3/3

- EEG recording: from 1-2 to 256 electrodes
- High resolution EEG
  - > 64 electrodes;
  - distance between electrodes < 2.5 cm
- Electrode material Ag-AgCl
- Additional recordings
  - Electro-oculogram EOC
  - Electromyogram EMG
  - Electrocardiogram ECG

Biosemi System for EEG Recording



- Amplifier-A/D converter-PC

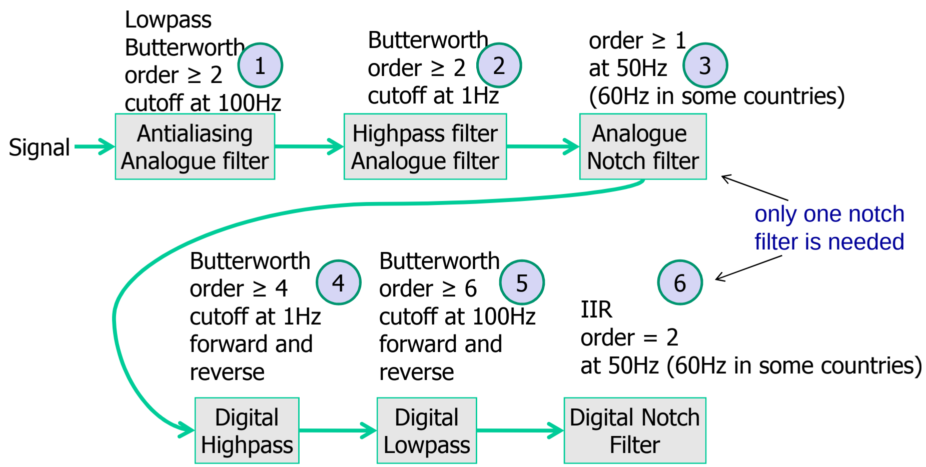


Sources of Noise in EEG Recordings

- Transient activity
  - High-frequency instrumentation activity
  - Muscle activity (mainly frontal and temporal)
  - Movements of head and body
  - Electrocardiographic activity (main cardiac dipole producing R wave is oriented right-left; posterior-anterior)
  - Pulse-wave artefacts from blood pulse waves
- Instrumentation artefacts
  - 50 or 60 Hz background noise
  - Low frequency drift (electrode polarisation and motion)

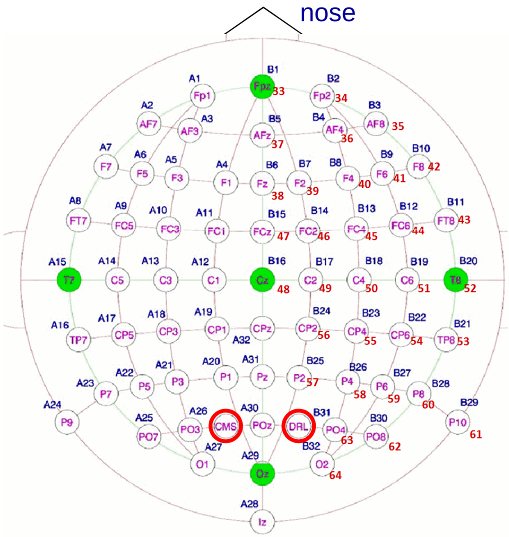
EEG Pre-Processing

Note: the 'signal' below is often subtracted from another common reference location



64-Channel Biosemi EEG Set Up

CMS and DRL: circuit referencing



Further EEG Processing: 'Referencing'

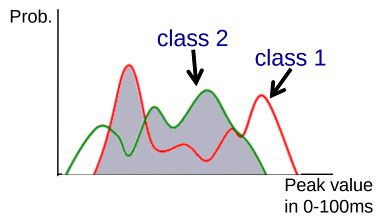
- Removal of common environmental noise:
  - subtraction done sample by sample in time domain
- Reference outside the scalp (**ear or mastoid**):
  - one of the ear lobes or mastoid locations (or the average between the left and right ones) is used the reference.
  - most popular approach.
  - useful to study waves that are over several, but not all, channels (e.g., the P300 wave).
- **Scalp average** reference:
  - used to investigate the difference between one channel and the rest of the scalp.
  - useful for rough localization of function (e.g., movement imagination vs. other tasks)

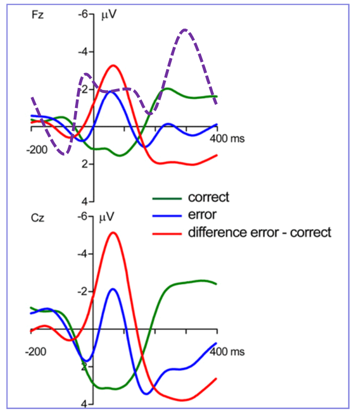
Further EEG Processing: 'Referencing'

- **Laplacean**:
  - subtraction of a channel from the average of the ones surrounding it.
  - very useful for maximizing spatial differences, e.g., to distinguish between imagination of movement for different limbs if their control areas are near each other in the cortex.
- Overall referencing effects:
  - removal of common noise
  - removal of 50Hz intereference
  - BUT, may lose wanted information (e.g., the P300 wave may disappear) if the wrong type is used.

Statistical EEG Problems

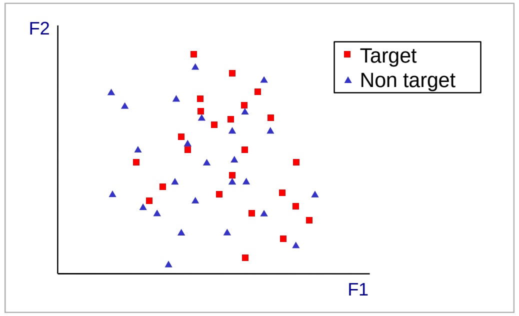
- Need classification with <1s of data
- Stochastic signals
  - Single values are not reliable
  - Need statistical distributions
  - EEG distributions shift very quickly
- Non-stationary
  - shifting frequency components
- Very large class overlap:





Statistical EEG Problems

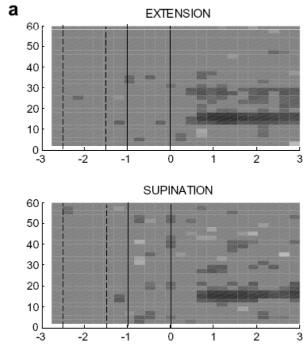
- Often need multi-feature classification

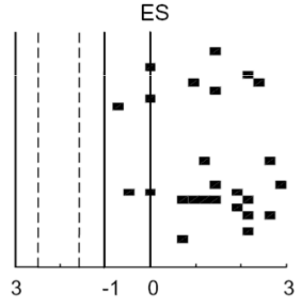


- Solutions:
  - Better intelligent classification algorithms
  - Better/more visual/auditory/etc. stimuli design
  - Try other mental states

Estimating Class Separation

- Davies-Boulding Index or similar
  - class overlap
  - smaller is better
- Statistical significance



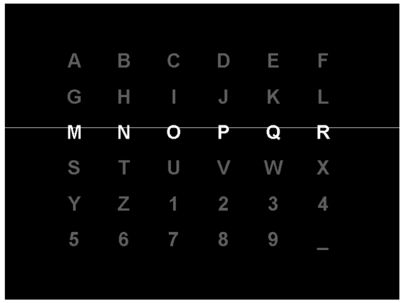


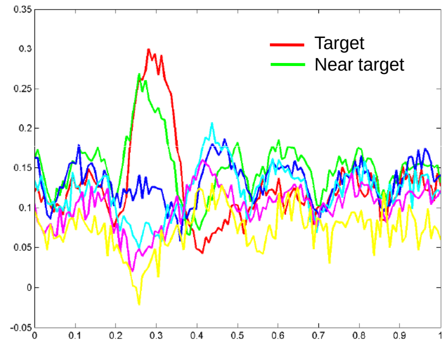
Vuckovic & Sepulveda (2008). Clin. Neurophys., 119: 446-458..

Traditional BCI Approaches

- P300
- Mu rhythm control
- Steady state visual evoked potentials (SSVEP)
- Error potential
- Slow cortical potentials
- Motor Imagery
- Various other tasks

P300

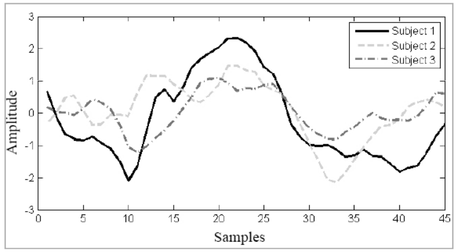


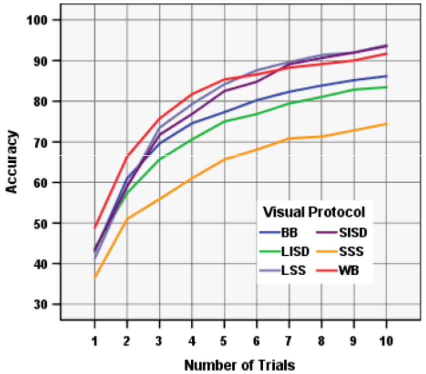


Citi et al., GECCO 2004.

P300

Recorded in many areas, but predominantly in Cz and just behind it

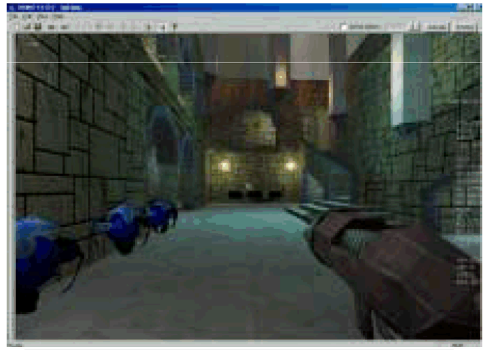




Salvaris & Sepulveda, IEEE-EMBC 2007.

Mu Rhythm

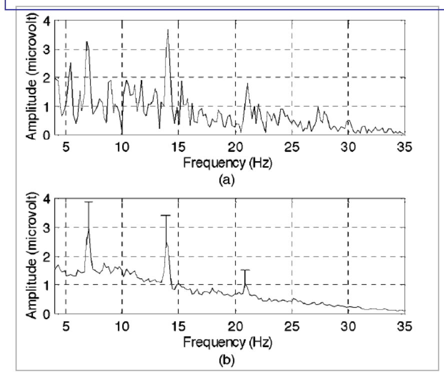
- Alpha (8-12Hz) over the motor areas
- Participants trained to control Mu rhythm level
- Left-right control of scenery

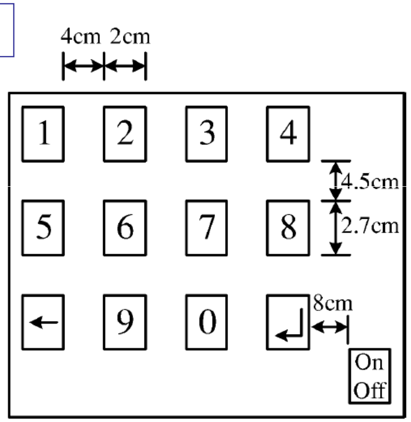


Pineda et al. (2002). IEEE-TNSRE, 11(2): 181-184

SSVEP
steady state visual evoked potential

Recorded over visual cortex





Cheng et al. (2002), IEEE-TBME 49(10):1181-1186.

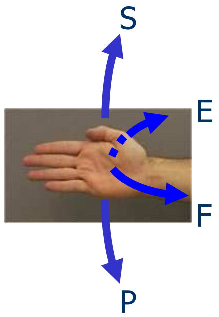
Motor Imagery

- Mental rehearsal of movement
- Different limbs easier to distinguish: location
- Band power (0.5Hz to 75Hz)

VIDEO

Motor Imagery
Same Limb

- Right hand
- Stimulus sequence:
  - Visual clue (wrist movement type):
    - Pronation
    - Supination
    - Flexion
    - Extension
  - Sound clue
- Gabor transform features
- Up to 90% correct, 70% average



Sepulveda et al. 2004, 2005, 2006

The Asynchronous Problem

- (Pseudo) spontaneous
- Onset detection done separately?
- Or, continuous classification
- Our choices:
  - mental task repetition during allowed period
  - aiming at continuous classification

Mental Tasks

TASK	DESCRIPTION
1	Auditory Recall
2	Navigation
3	Sensorimotor Attention, Left hand
4	Sensorimotor Attention, Right hand
5	Calculation
6	Imaginary Movement, Left hand
7	Imaginary Movement, Right hand

Sepulveda, Dyson, Gan (2007). IEEE-EMBC07.

Various Mental Tasks

- Auditory recall:
  - 'Select a familiar tune and listen to it in your mind. Do not mouth lyrics or make movements related to the tune'
- Navigation:
  - 'Select a place familiar to you. When prompted, imagine yourself in this location. Try to visualize the objects around yourself and move slowly within the environment'
- Sensorimotor attention:
  - 'Focus your attention on your left thumb. Attempt to concentrate on the physical feelings you receive from it without actually attempting to move it'.
  - Done for left and for right thumbs

Various Mental Tasks

- Calculation:
  - 'Select either addition or subtraction, and an integer between 1 and 10. When prompted, pick a random number and perform the operation selected using the integer. Repeat this with the result of the operation'
- Imaginary movement:
  - 'Imagine extending your left wrist. Rather than visualizing the hand moving, try to concentrate on the perceptions associated without actually performing the movement'
  - Done for left and for right hands

Mental Tasks

Class Separation

Task Combination	Incidence
1 5	4
1 3	3
1 7	2
2 7	2
2 6	2
3 5	2
2 3	2

Classification

Task Combination	Incidence
1 5	4
3 5	4
2 3	3
5 6	3
2 5	2
2 6	2
4 5	2

TASK	DESCRIPTION
1	Auditory Recall
2	Navigation
3	Sensorimotor Attention, Left hand
4	Sensorimotor Attention, Right hand
5	Calculation
6	Imaginary Movement, Left hand
7	Imaginary Movement, Right hand

PII - Lecture 2 Study Guide

From this week's material, you should:

- Know and understand the various stages of EEG signal processing and why there are necessary.
- Know the various filter types and order used
- Understand why signal referencing is used
- Understand the three main types of referencing
- Know the basic statistical properties of EEG signal that lead to the need for intelligent algorithms
- Know about the most common BCI approaches