Basics of signal processing (5)

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(DIAG, Via Ariosto)

Material for this section of the course

- Matlab notebooks available here:
  - https://drive.matlab.com/sharing/d5ad1819-5e50-442a-81fc-6017505d91f3
    - NEng_1920_04_Filt.mlx (cont'd)

27 May 2020 (b)

Brain-Computer Interfaces

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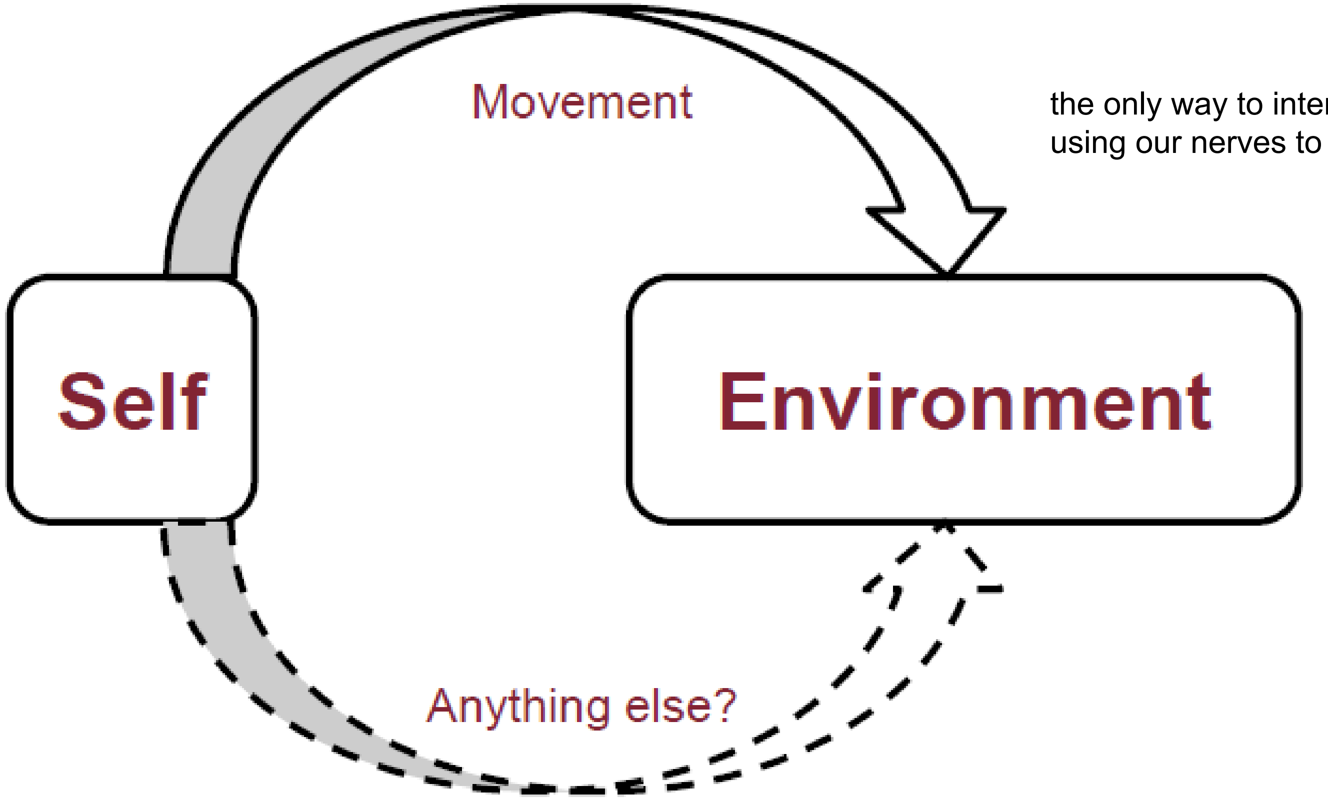
Material for this section of the course

- References:
  - Wolpaw J and Wolpaw E (eds.), Brain-Computer Interfaces
    ch. 1,6, 12, 13

Natural interaction with the environment

how human or animals interact with the environment



the only way to interact with the environment is by using our nerves to muscles

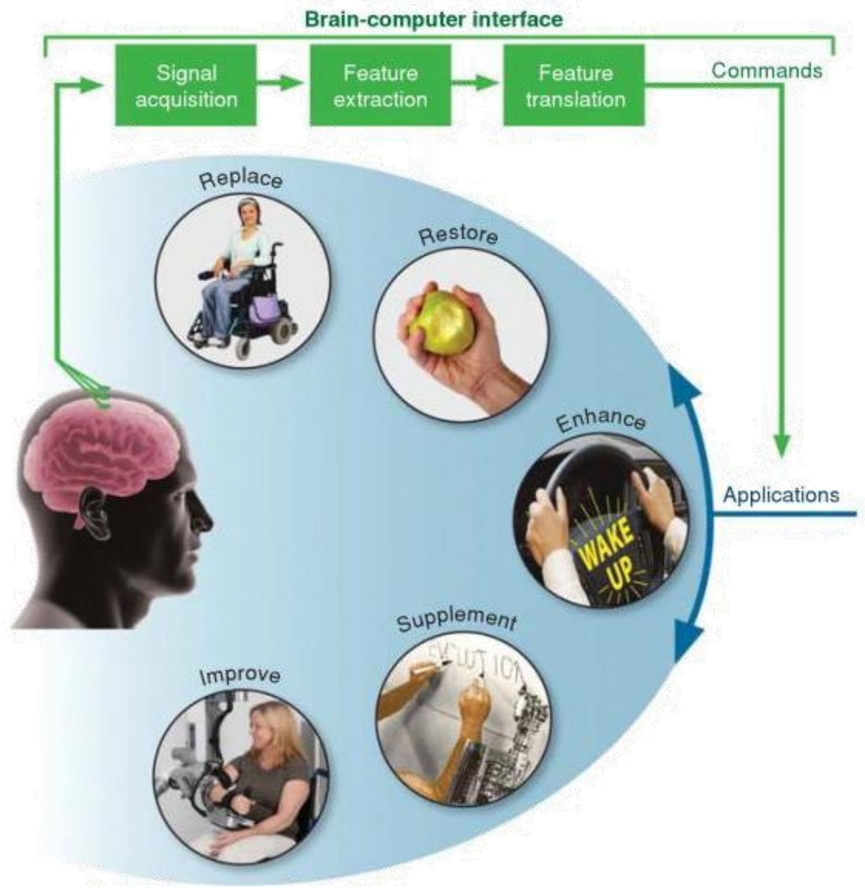
Natural and BCI outputs

really it includes also the spinal cord, but we intend the brain

Control Nervous System: allows any animal to interact with the environment

- The **natural** CNS function is to produce muscular and hormonal outputs that act on the outside world or the body.
- BCIs require the CNS to produce entirely new, **artificial** kinds of outputs, far from its natural function.

What a Brain-Computer Interface is

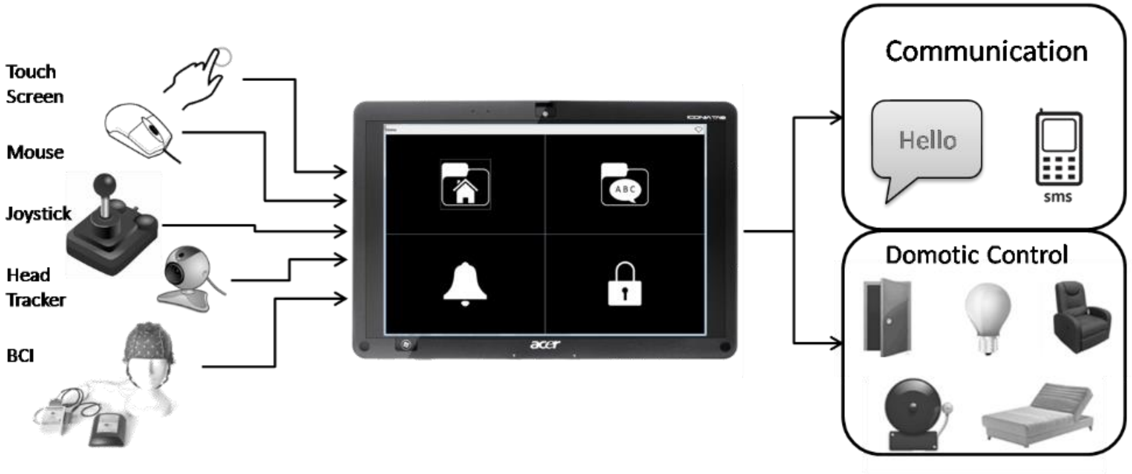


A BCI is a system that measures CNS **activity** and converts it to **artificial** output that replaces, restores, enhances, supplements, or improves **natural** CNS output and thereby changes the ongoing interactions between the CNS and its external or internal environment

Wolpaw and Wolpaw, 2012

Replace: BCIs to improve communication and control

Non-invasive (P300-based) BCIs for communication and environmental control: Assistive BCIs



IOP Publishing — Journal of Neural Engineering
J. Neural Eng. 8 (2011) 025028 (6pp) doi:10.1088/1741-2560/8/2/025028

Workload measurement in a communication application operated through a P300-based brain–computer interface

A Riccio[1,2,8], F Leotta[1,3], L Bianchi[1,4], F Aloise[1], C Zickler[5], E-J Hoogerwerf[6], A Kübler[5,7], D Mattia[1] and F Cincotti[1]

frontiers in HUMAN NEUROSCIENCE — ORIGINAL RESEARCH ARTICLE, published: 12 November 2013, doi: 10.3389/fnhum.2013.00732

Attention and P300-based BCI performance in people with amyotrophic lateral sclerosis

Angela Riccio[1,2*], Luca Simione[2,3], Francesca Schettini[1,4], Alessia Pizzimenti[5,6], Maurizio Inghilleri[5], Marta Olivetti Belardinelli[2,7], Donatella Mattia[1] and Febo Cincotti[1,4]

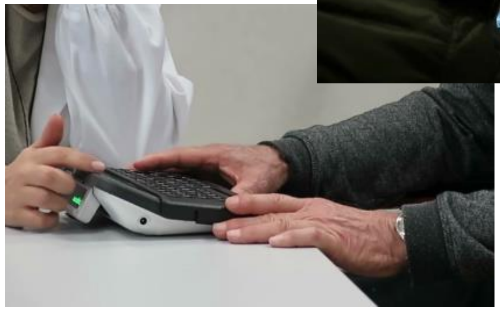
ACRM — Archives of Physical Medicine and Rehabilitation
journal homepage: www.archives-pmr.org
Archives of Physical Medicine and Rehabilitation 2015;96(3 Suppl 1):S46-53

ORIGINAL ARTICLE

Assistive Device With Conventional, Alternative, and Brain-Computer Interface Inputs to Enhance Interaction With the Environment for People With Amyotrophic Lateral Sclerosis: A Feasibility and Usability Study

Francesca Schettini, PhD,[a,b,*] Angela Riccio, PhD,[a,c,*] Luca Simione, PhD,[a,d] Giulia Liberati, PhD,[a,e] Mario Caruso, MS,[b] Vittorio Frasca, MD,[f] Barbara Calabrese, PhD,[g] Massimo Mecella, PhD,[b] Alessia Pizzimenti, MSc,[h] Maurizio Inghilleri, MD, PhD,[f] Donatella Mattia, MD, PhD,[a] Febo Cincotti, PhD[a,b]

Assistive Technology Service at FSL – BCIs at work…



Sar@-t

BCI in AT-centers

one of the hardest limit is the cost because we need a good EEG system and this usually costs several thousands of euro. Moreove BCI is a slow system but not an accurate system

- Brain-Computer Interface as an alternative channel to access Assistive Technologies for communication disorders is **not currently available** in the AT-centers portfolio.

- A step forward such availability would consist in BCIs **integration with existing AT inputs** thus, resulting in a personalized hybrid BCI-based communication device.

- To generate **profiles of patients** that would potentially use the BCI as an additional/alternative channel for AT-access.

Restore: BCIs to improve recovery from brain injuries

another approach is to reinforce the Natural NN that control the movement of our arm by performing motor imagery

when we can't move a part of the body, but the part is present, the problem is the brain

BCI allows to have a feedback of what the brain is learning

The promise of BCIs in neurorehabilitation medicine – Rehabilitative BCIs

Neurorehabilitation

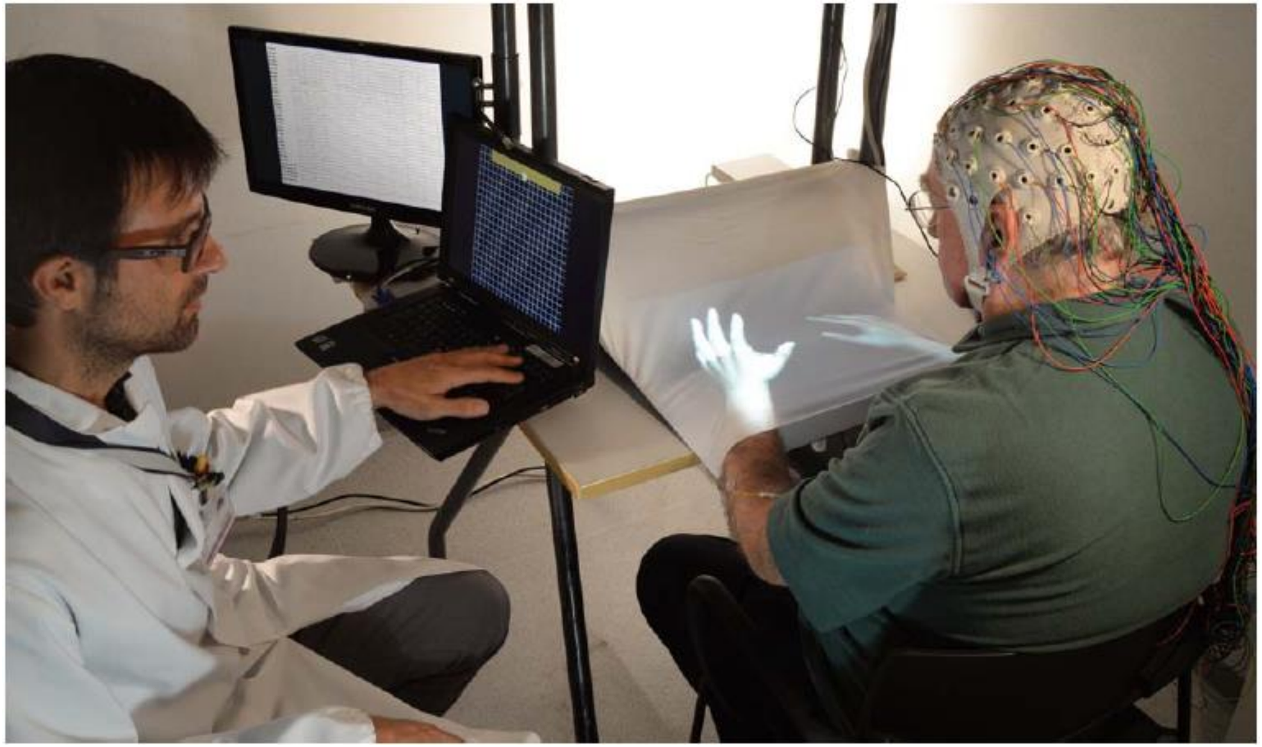
- Extensive task-oriented training program
- Feedback on (overt) performance
- Adherence to intervention
- Retraining brain areas associated to function
- Enhance neuroplasticity

BCI technology

- Can directly measure signals from (damaged) cortical areas and translate them into close-to normal motor outputs providing online feedback on performance
- BCI –based training can thus, promote re-training of brain activity and induce adaptive plasticity

Rehabilitative BCIs in post-stroke functional motor recovery

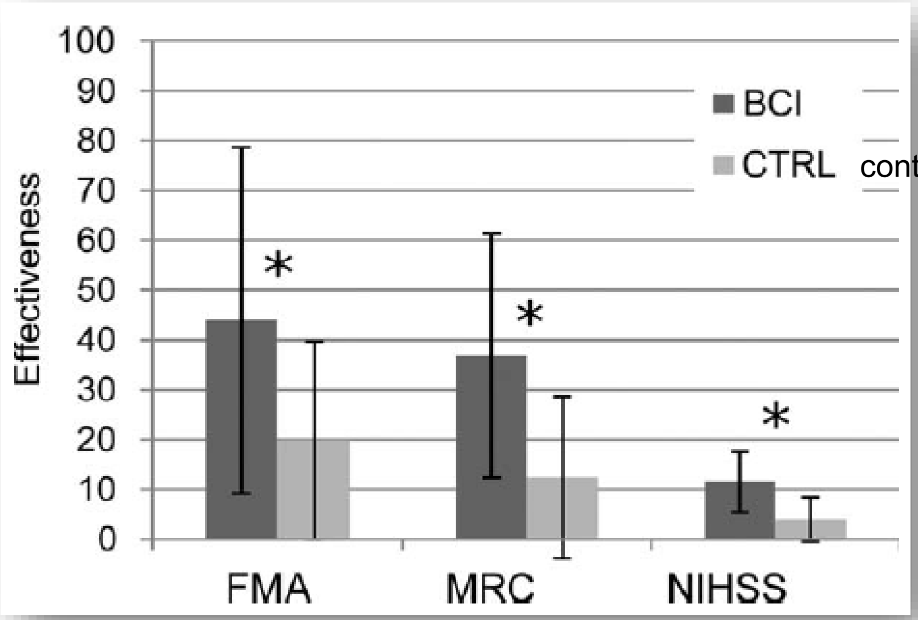
BCI based training to practice MI



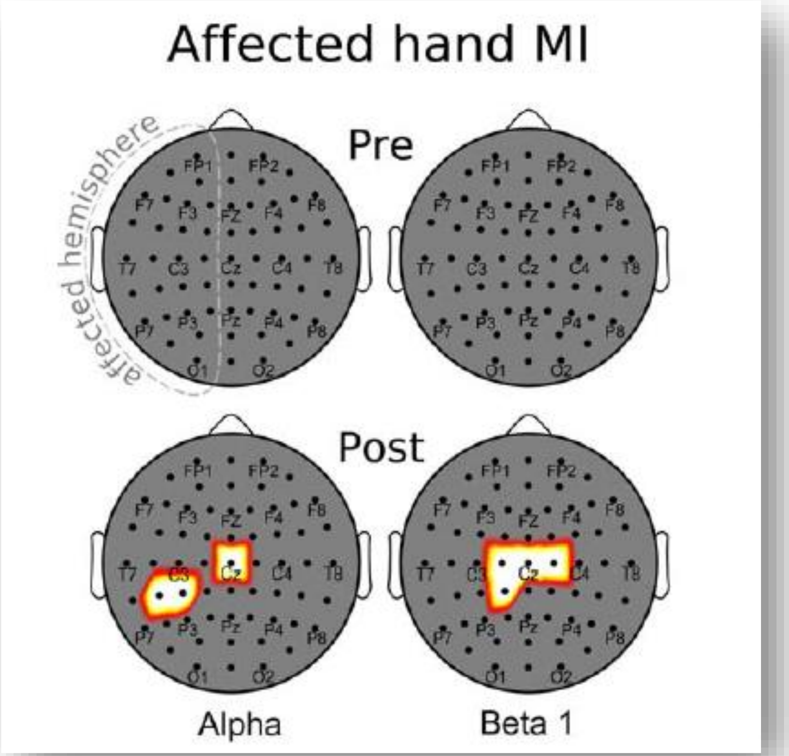
BCI prototype installed in a rehabilitative setting

- Training
  - 1 month, 3 sessions per week training of MI-BCI
  - 1 month, 3 sessions/week training MI (no BCI)
- BCI Control features
  - affected hemisphere central, centro-parietal electrodes
  - Sensorimotor relevant frequency oscillations

BCI based training to practice MI – Results



control group

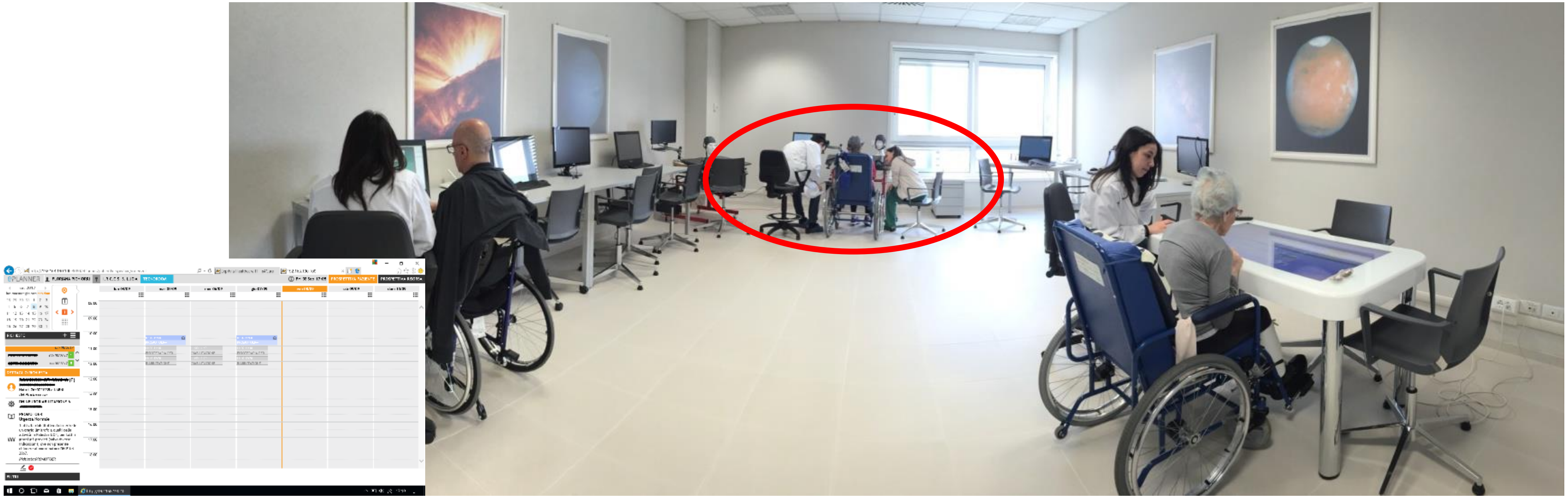


Translational step: The Promotœr

An all-in-one BCI-supported Motor Imagery training station, installed in the rehabilitation ward at Fondazione Santa Lucia

Training with the Promotœr

- 100 patients recruited (avg of 15 sessions per patients)
- Ischemic/Haemorragic Stroke (subacute and chronic); paresis/plegia of the upper limb due to a unilateral acquired brain lesion; Spinal Cord Injury (SCI, bilateral MI training)
- BCI training is performed in the context of the rehabilitation program of each patient
- Daily interaction with the clinical team



Training with the Promotœr - outlook

- Include hybrid (i.e. muscular) control features

- Implementing large clinical trial in rehabilitation ward(s):
  - To evaluate long term effect
  - To define best candidate
  - To isolate new control features (brain-network derived)

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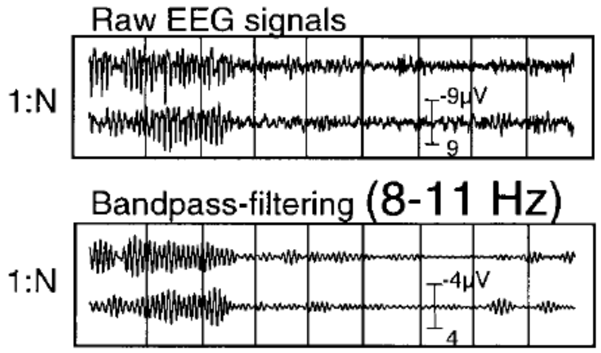
- Evaluating effects on conditions other than stroke (eg. SCI) and on relevant clinical aspects other than motor function alone (eg: pain, spasticity)

EEG features for BCI

Neuroelectrical features for BCIs

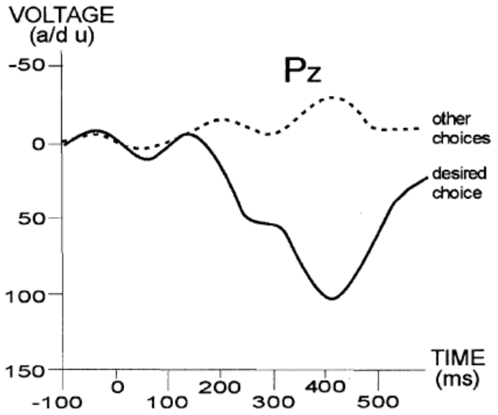
4 types of features of the EEG

ERD-ERS



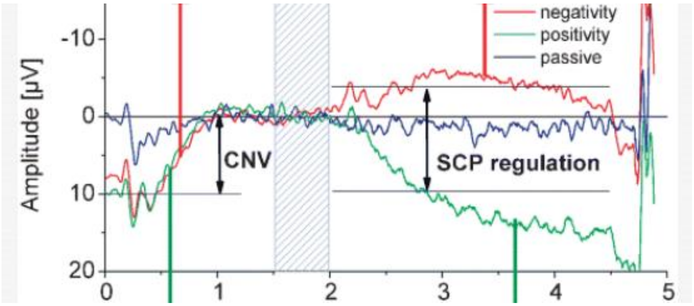
spontaneous EEG

Rhythms



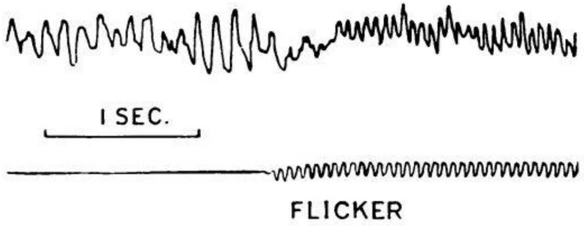
Evoked potentials

Slow Cortical Potentials



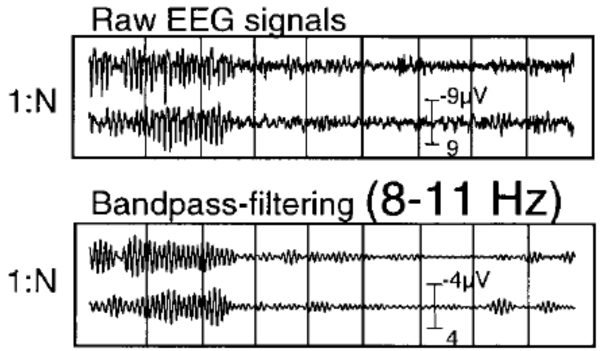
Evoked Potential

Steady-state EPs

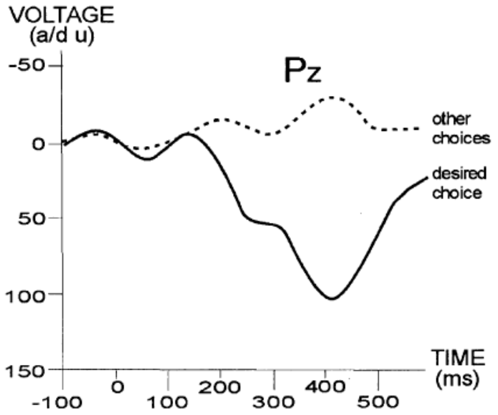


ELECTROENCEPHALOGRAM FROM THE OCCIPITAL REGION, SHOWING THE CHANGE FROM THE α RHYTHM TO THE FLICKER RHYTHM WHEN THE EYES ARE OPENED AND THE SUBJECT LOOKS AT A SCREEN LIT BY A FLICKERING LIGHT. THE RATE OF FLICKER (17 A SECOND) IS SHOWN BY THE PHOTO-ELECTRIC CELL RECORD BELOW.

Neuroelectrical features for BCIs

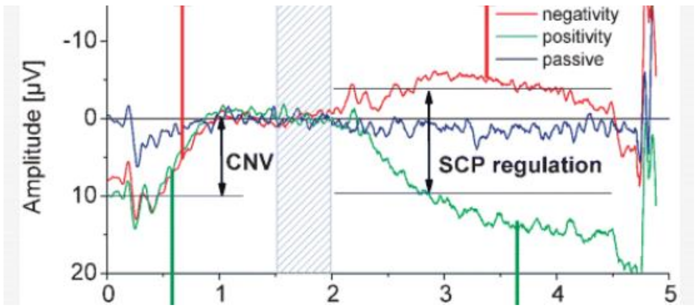


Rhythms

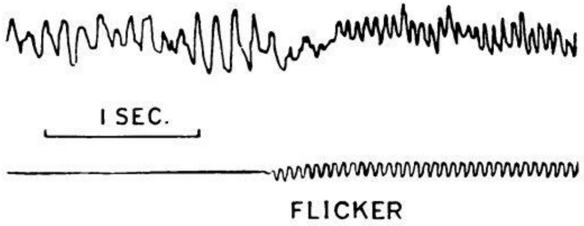


Evoked potentials

Slow Cortical Potentials



Steady-state EPs



ELECTROENCEPHALOGRAM FROM THE OCCIPITAL REGION, SHOWING THE CHANGE FROM THE α RHYTHM TO THE FLICKER RHYTHM WHEN THE EYES ARE OPENED AND THE SUBJECT LOOKS AT A SCREEN LIT BY A FLICKERING LIGHT. THE RATE OF FLICKER (17 A SECOND) IS SHOWN BY THE PHOTO-ELECTRIC CELL RECORD BELOW.

P300 Potential

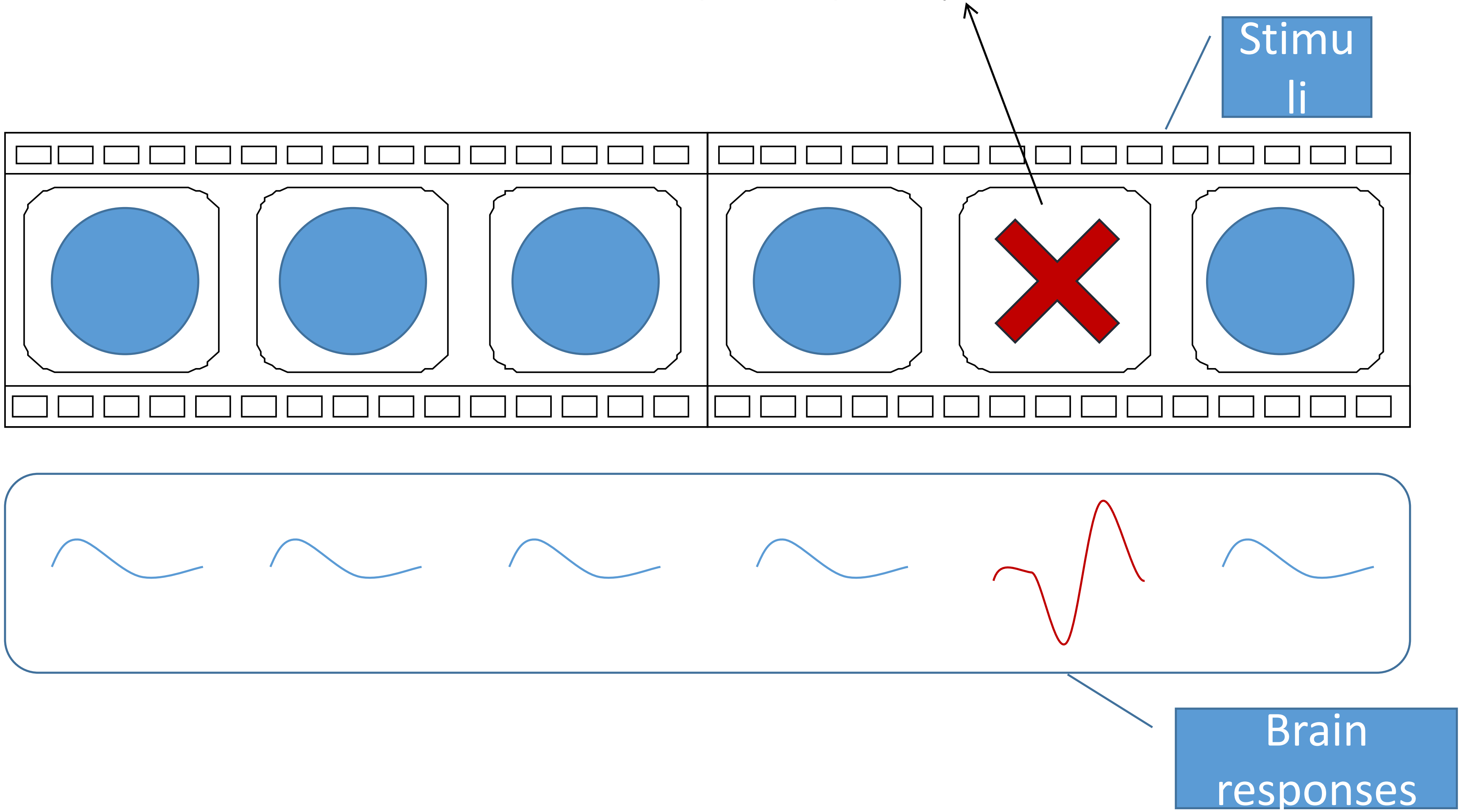
positive deflection around 300 millisec

- The P300 is an endogenous event-related potential (ERP) component in the EEG and occurs in the context of the “oddball paradigm”
- It follows unpredicted sensory stimuli or stimuli that provide salient (relevant) information
- Requires averaging to improve signal to noise ratio

From Selllers & Donchin 2006, clinph

Oddball stimulus

in this case the brain, not only responds beacuse it has seen a stimulus, but it responds in a specific way because I deliver aware stimulus



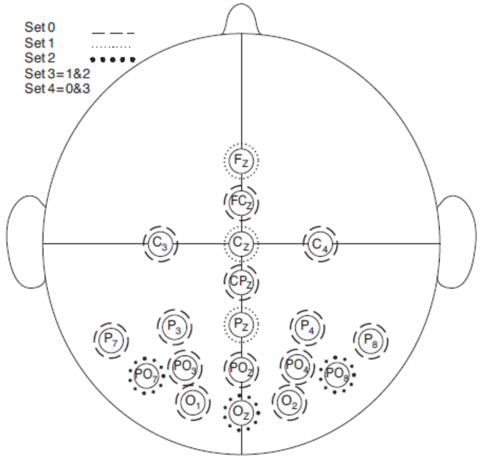


Figure 12.2 Electrode locations evaluated for use in a P300-based BCI by Krusienski et al. (2008). EEG was recorded from 64 electrodes. The sets of electrodes shown here (i.e., dashed, dotted, bold-dotted circles) were compared in regard to offline classification accuracy as described in the text.

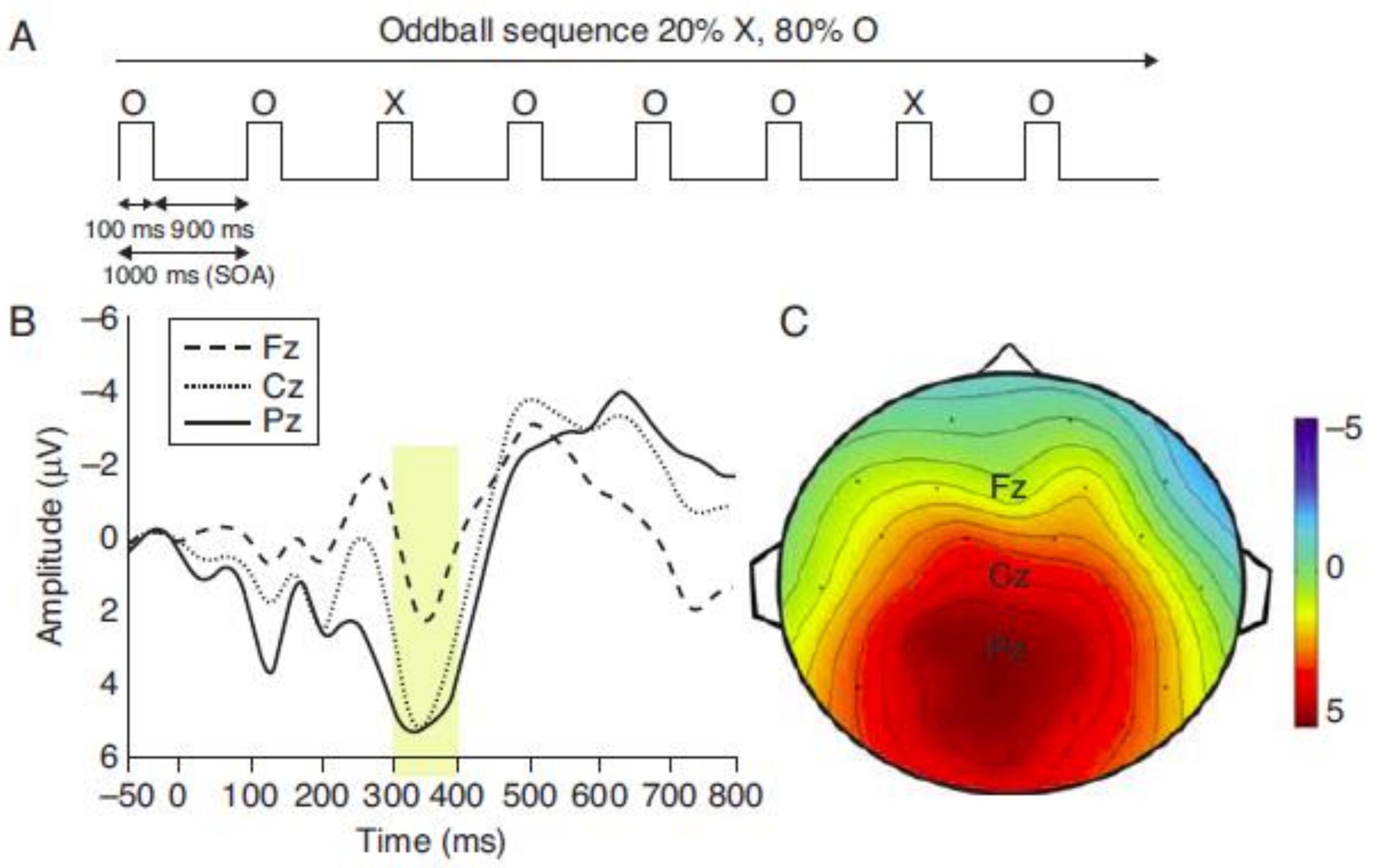
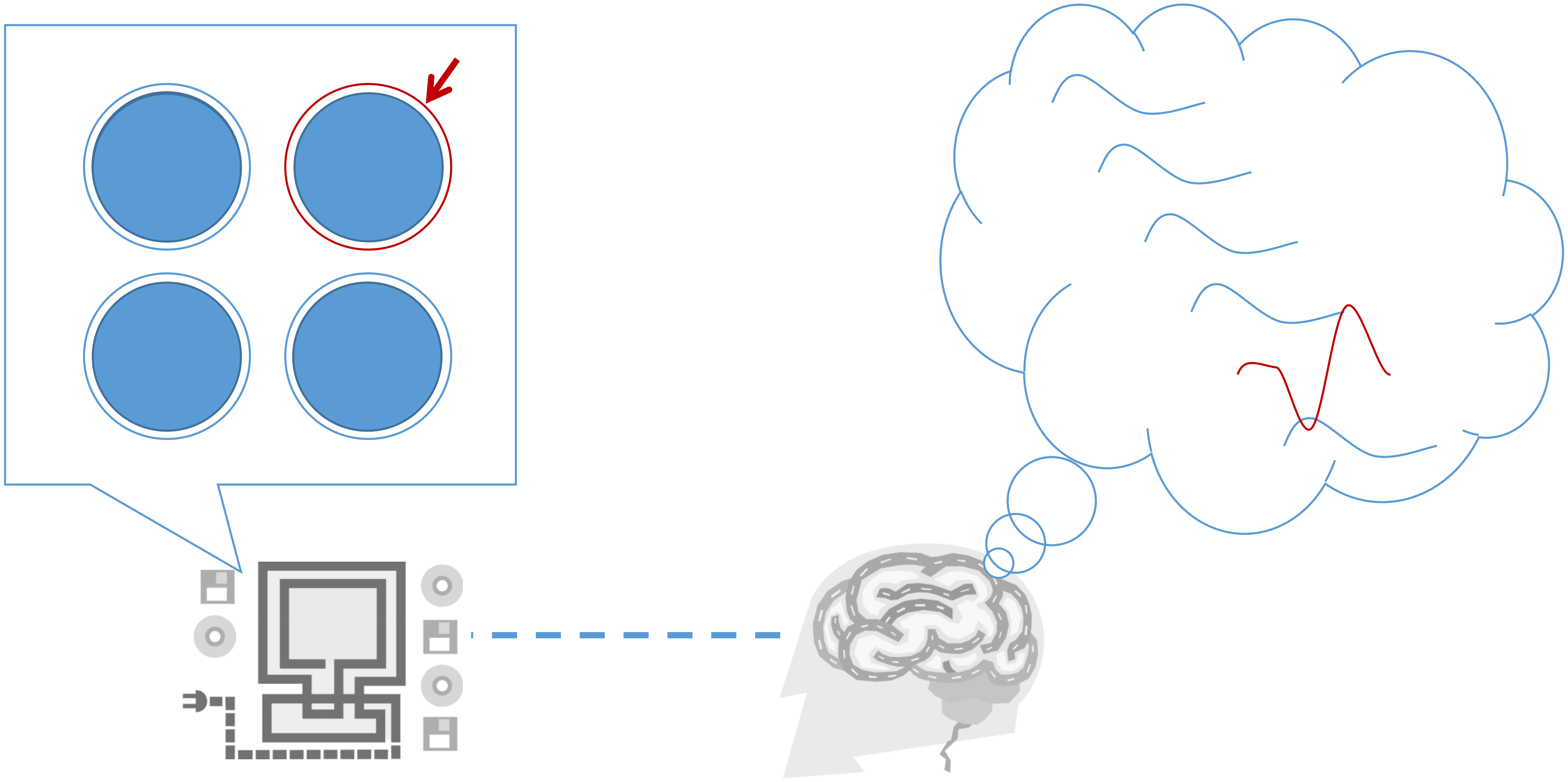
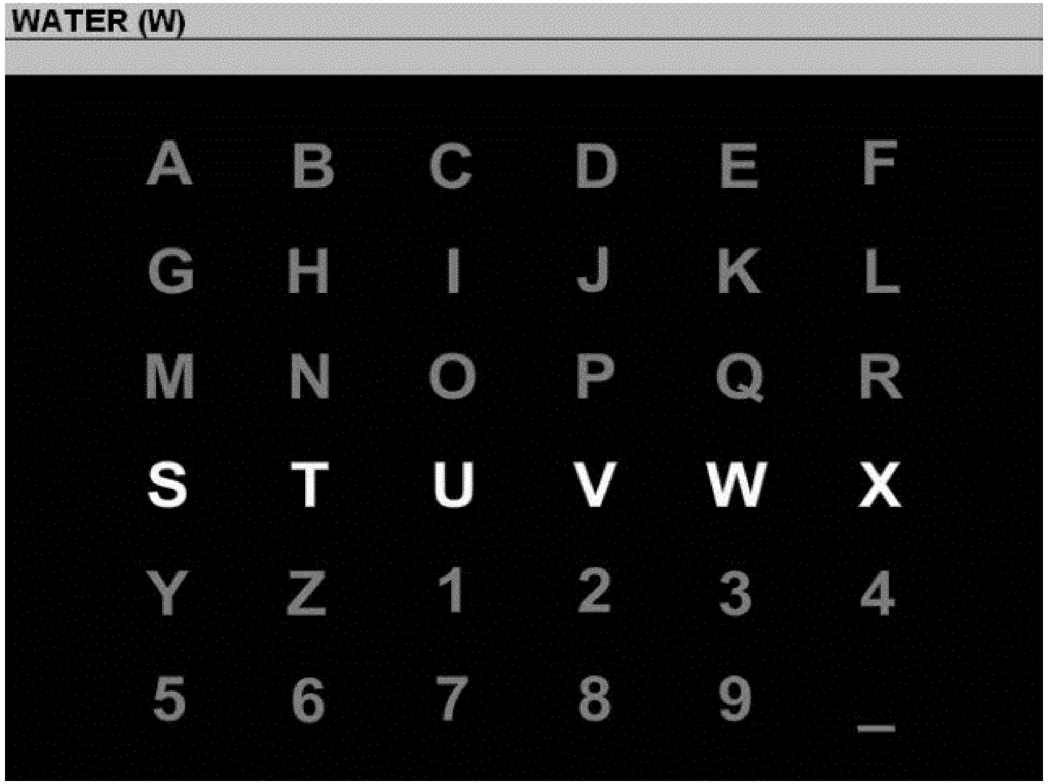


Figure 12.1 *(A). Time course of rare (i.e., oddball) (X) and common (O) stimuli in a standard oddball protocol. (B) Average oddball ERPs from a subject for electrode locations Fz, Cz, and Pz, showing a progressively larger positive deflection from frontal, to central, to posterior sites. The convention used here shows positive amplitude down and negative amplitude up. (C) Topographical distribution of the average ERP amplitude 300–400 msec after the oddball stimulus. The large positive ERP component (i.e., P300) is maximum at Pz and is widely distributed over posterior-parietal regions.*

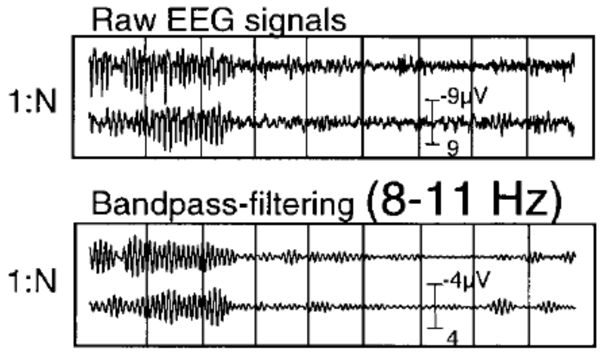
Relevant stimulus



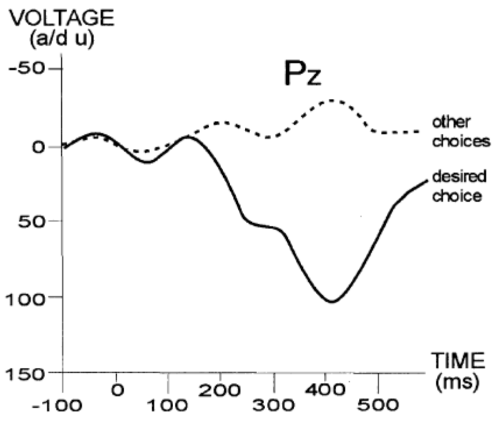
A BCI speller based on the P300 potential



Neuroelectrical features for BCIs

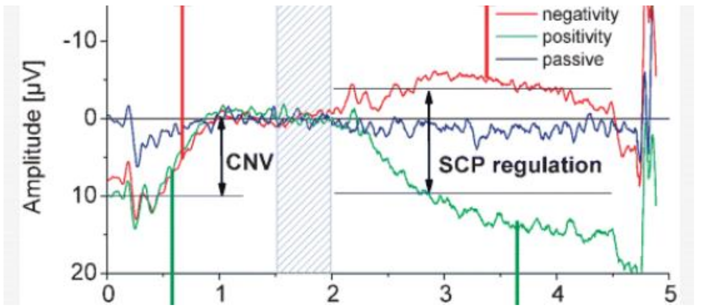


Rhythms

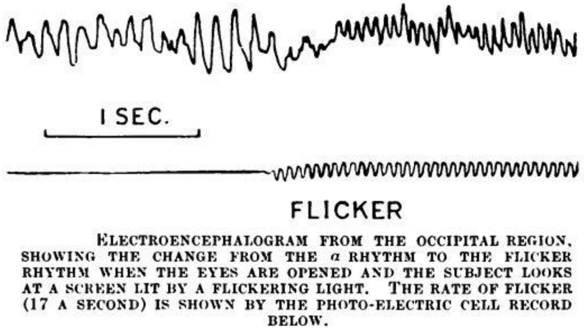


Evoked potentials

Slow Cortical Potentials



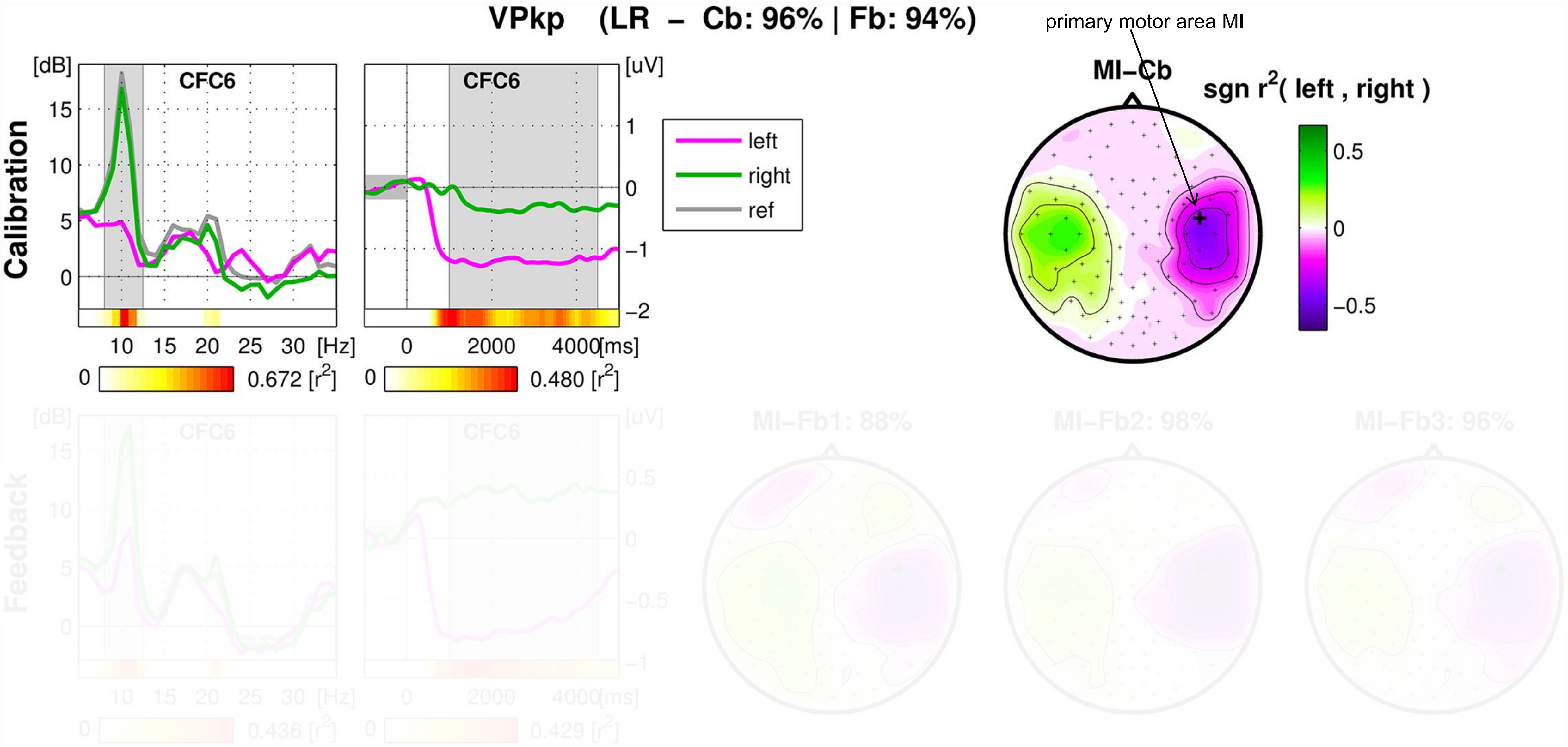
Steady-state EPs



Sensorimotor Rhythms

- SMR is an oscillatory EEG detected on the central electrode sites (over the sensorimotor cortex)
- It is associated with inhibition of motor activity
- Reacts to execution and imagination of movement
- Tonic (i.e. stationary) and phasic (i.e. time-varying) spectral modulation

the grey line and the green line are superimposed in the alpha band, while the purpleline is very desinchronized in the alpha band.



From Sannelli et al., 2019. PLoS ONE

BCI basato sui ritmi sensorimotorio