Modulation of sensory-motor rhythmic activities for improving BCI training in neurorehabilitation

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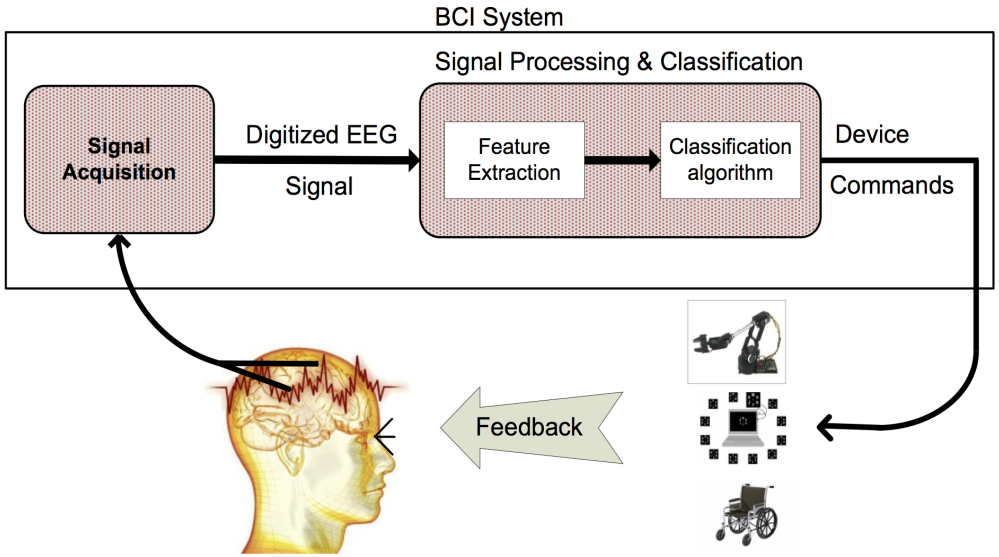
Brain-Computer Interface (BCI)

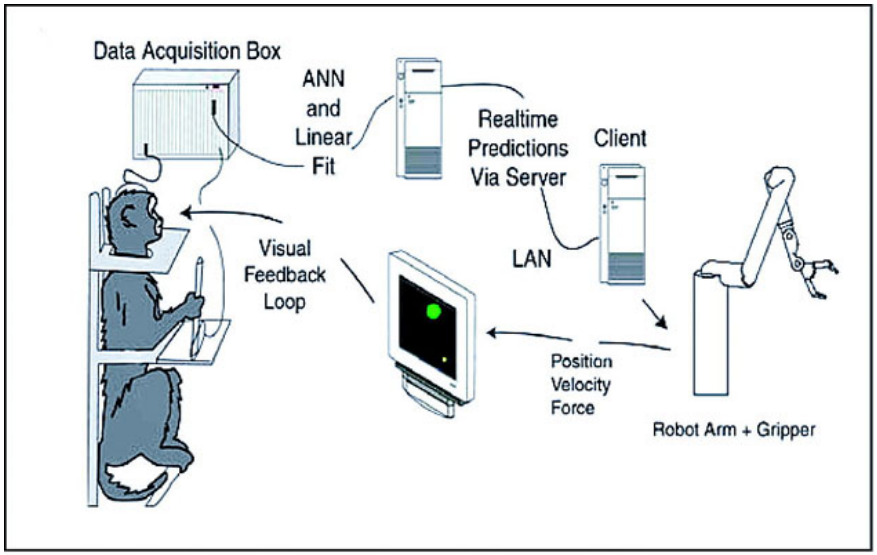


Adapted from Wolpaw et al. (2002).

- A direct communication pathway between the brain and an external device (wikipedia).
- Research on BCIs began in the 1970s (UCLA, DARPA).
- The 2013 BCI Meeting attracted 315 registrants from 29 countries representing 165 research laboratories

A) Invasive:

In or on the cortex, intracortical BCI, ECoG



Carmena, Nicolesis, et al. (2003), Learning to control a brain-machine interface for reaching and grasping by primates. PLoS Biology, 1:193:208.

B) Non-Invasive:

On skull, EEG based BCI

Trejo, Rosipal, et al. (2001-2004), NASA Ames,

Types of EEG Waves in Non-invasive BCI

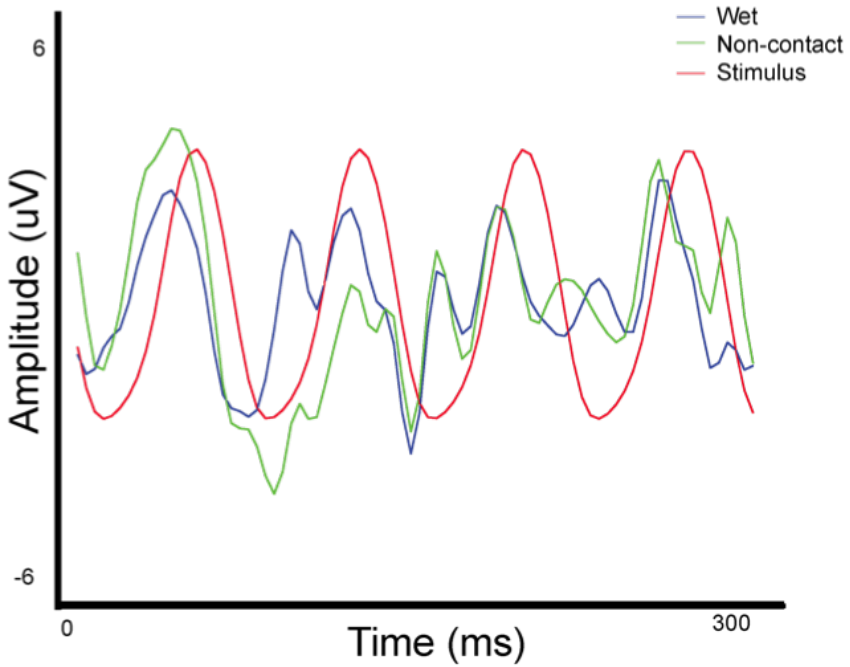
Evoked:

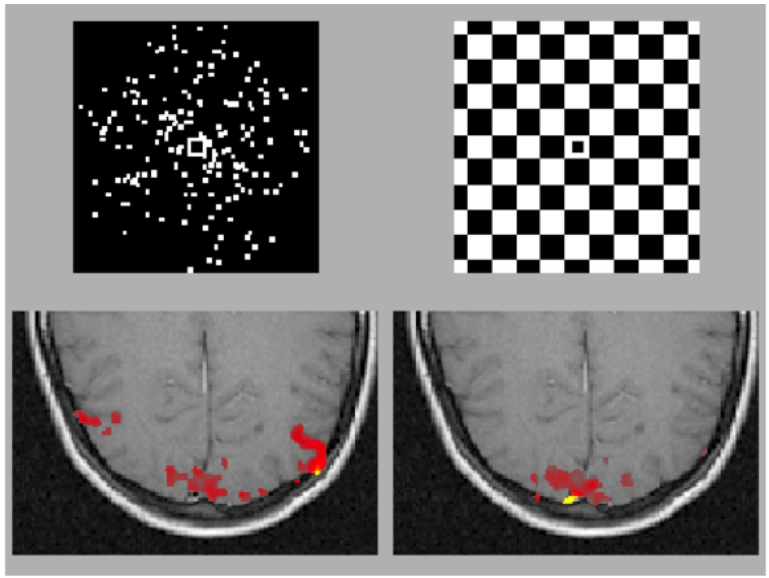
- event-related potentials (ERPs)
  P300, spell-checker
- steady-state visual evoked potentials (SSVEP)
- ...

Self-paced:

- slow-cortical potentials
- sensorimotor rhythms (SMR)
  synchronization / desynchronization (ERS/ERD)
  μ, β
- EEG recordings of mental activity
- ...

Repetitive patterned visual stimulation produces a frequency following (or doubling) response in primary visual cortex, which is easily recorded by occipital EEG electrodes.



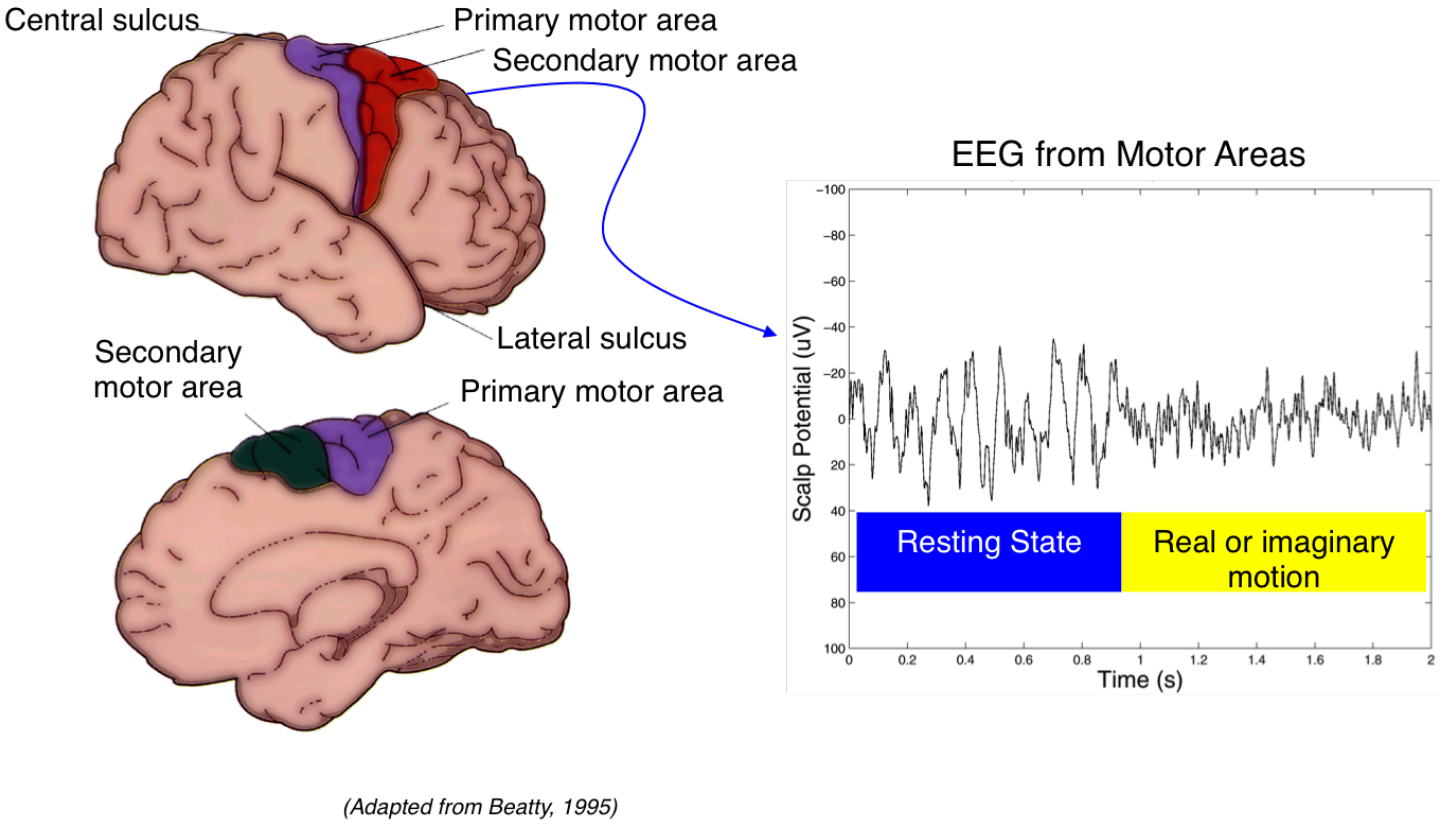


Demo from David Heeger's lab at NYU

SSVEP-based BCI

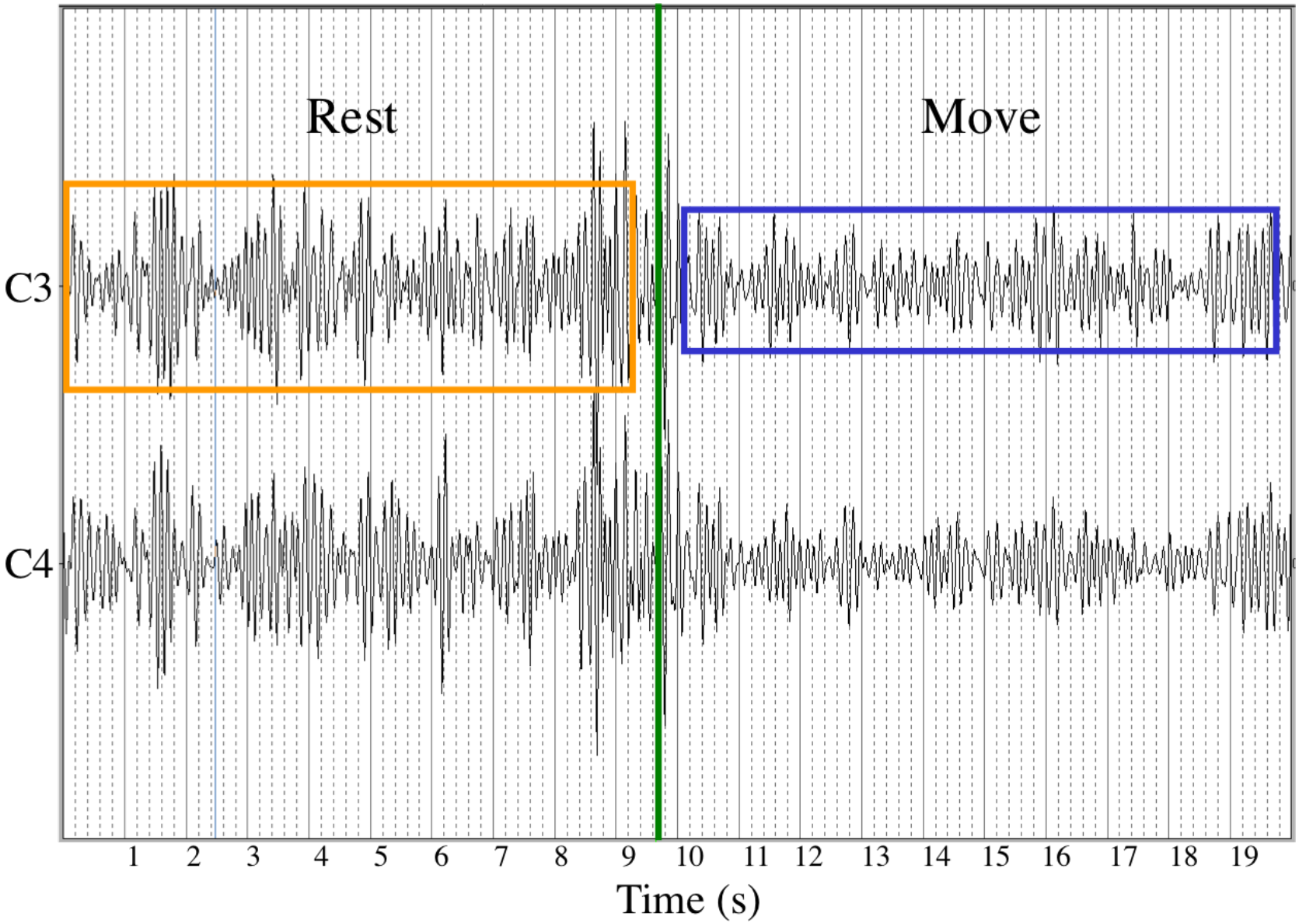
Trejo, Rosipal, et al. (2001-2004), NASA Ames,

Desynchronization of SMR



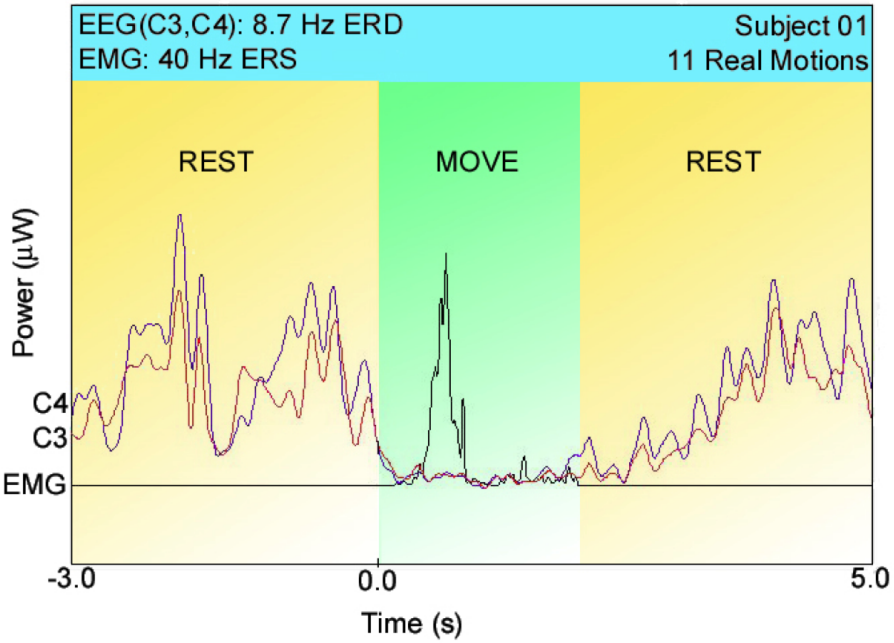
(Adapted from Beatty, 1995)

Desynchronization of SMR

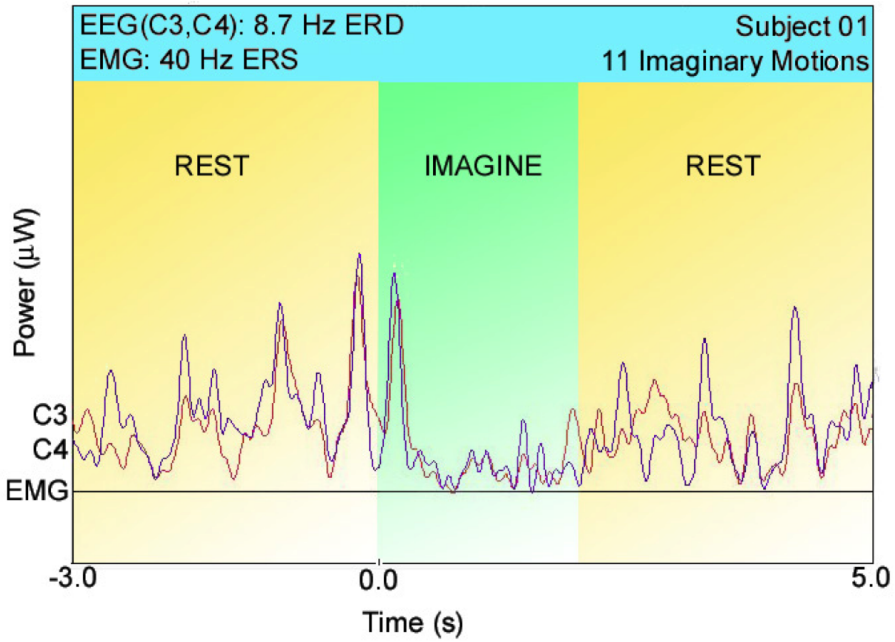


Real vs. Imagery Motion ERD

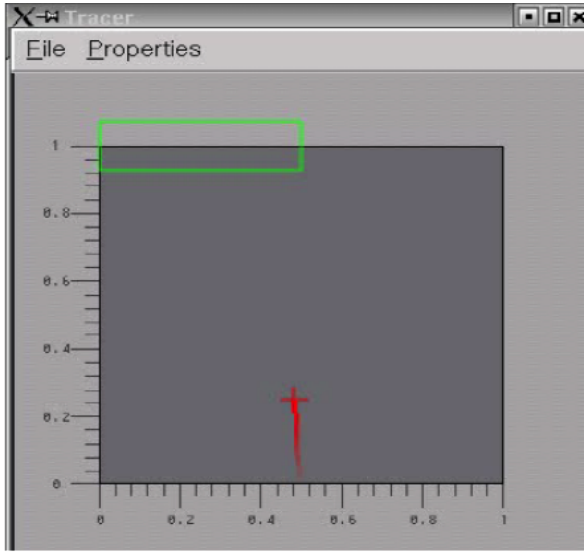
Real motion



Imagery motion

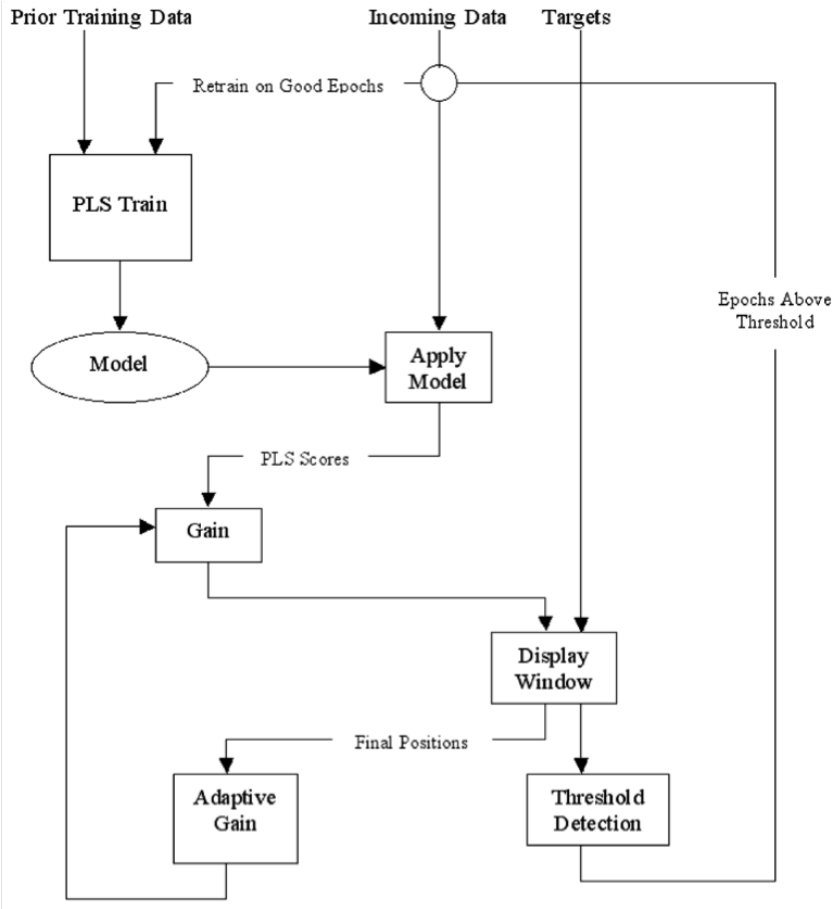


On-line PLS-based BCI-Processor



Control System for Target Practice

- **Trial by trial classification** (left, right)
  - 250 ms display update
- **Dual adaptive controller design**
  - Adaptive PLS pattern recognition
  - Adaptive gain control for motion



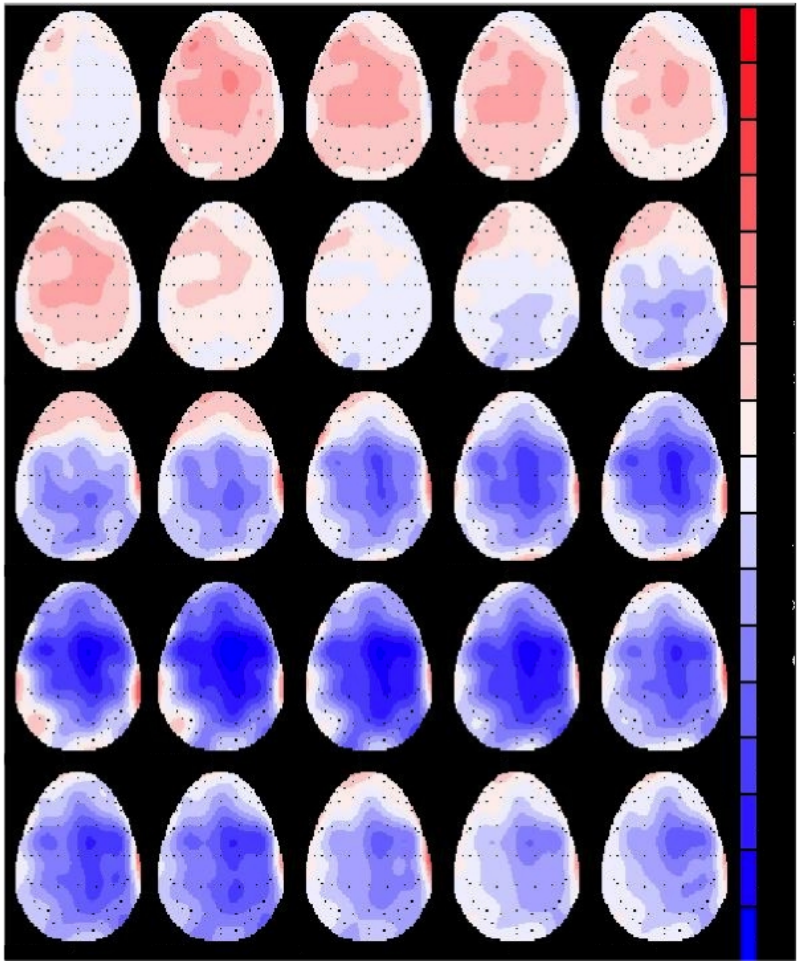
Trejo, Rosipal, et al. (2001-2004), NASA Ames,

BCI-illiteracy

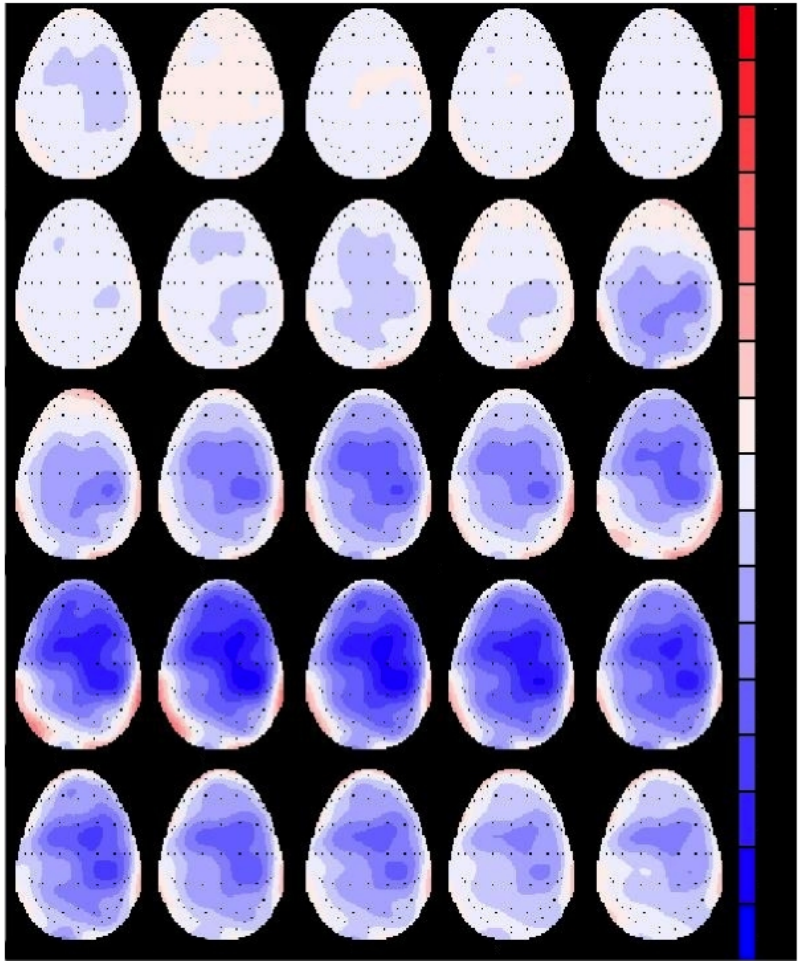
- P300: $\approx$ 27% subjects unable to use the BCI system
  Guger C, et al. (2009), How many people are able to control a P300-based brain-computer interface (BCI)? Neurosci. Lett. 462: 94-98.
- SSVEP: $\approx$ 14% subjects failed to complete spelling task
  Allison B, et al. (2010), BCI demographics: how many (and what kinds of) people can use an SSVEP BCI? IEEE Trans Neural Syst Rehabil Eng 18: 107-116
- Motor Imagery : $\approx$ 10-30%
  C. Vidaurre, B. Blankertz (2010), Towards a Cure for BCI Illiteracy, Open Access Brain topography, 23:194-198
  - Inter-subject variability (EEG trigger signals variability)
  - Day-to-day variability - How to calibrate?
  - Intention to close two control loops
  - Training protocols, strategies for motor imagery, etc.
  - Control of fatigue, engagement, etc.
  - ....

Stabilizing Subject and Day-to-day Variability

11/14/2002



01/09/2003



Rosipal, Trejo, et al. (2001-2004), NASA Ames,

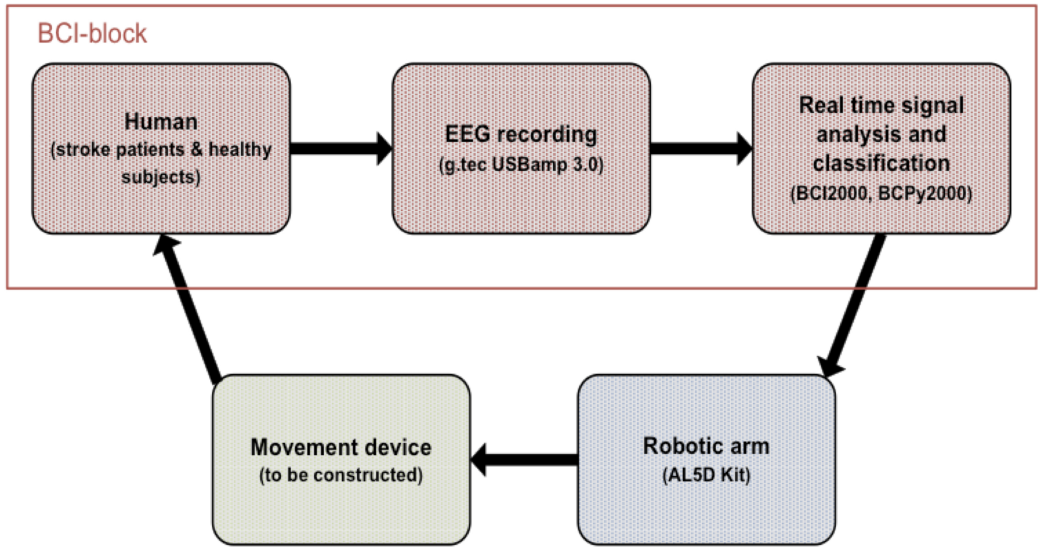
Robot-assisted Systems for Physiotherapy After Stroke

Adapted from Internet

- About 15 mil. people suffer a stroke per year (WHO)
- About 80% of stroke patients are affected by a motor impairment
- Major motor impairments: hemiparesis or hemiplegia
- About 50% of patients still show motor impairments even after months of intense rehabilitation
- Robotic systems for stroke rehabilitation were developed
  - They allow standardized and individually tailored physical training
  - But it seems that this form of therapy is not superior to conventional manual high-intensity physical therapy
  - What is missing? How to close the loop?

Closing the loop:
sensory feedback - motor control - movement execution

Adapted from
Gomez-Rodriguez, M. et al (2010), Closing the Sensorimotor Loop ... Proc. of IEEE Inter. CSMC.



Rosipal, R. et al. APVV-0668-12

Obejctives

- Searching important neurophysiological correlates of motor functions; stable over time and leading to motor improvement in stroke patients
- Searching suitable BCI training protocols for stroke patients
- Pre-training prior BCI
  - Mirror neurons - mirror box
  - SMR - Neurofeedback
- Monitoring psychological factors and applying suitable countermeasures
- Novel classification and data analysis methods - multi-way analysis methods in BCI

Mirror-box Training Prior BCI

- Mirror neurons fires both when an animal acts and when the animal observes the same action performed by another animal (Rizzolatti & Craighero, 2004; Keysers 2010).
- Oberman et al. (2007) observed the same ERS/ERD of SMR when subjects were instructed to watch videos of human or robotic arms executing different movements.
- Action observation can enhance the beneficial effects of motor training on motor system formation in patients with stroke (Celnik et al. 2008, Ertelt et al. 2007, Saleh et al. 2014).

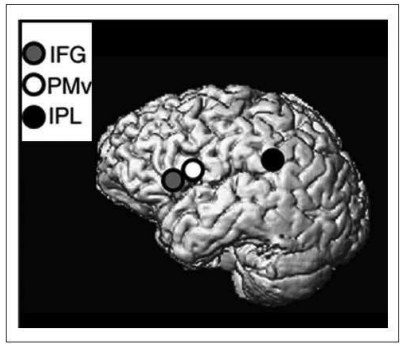
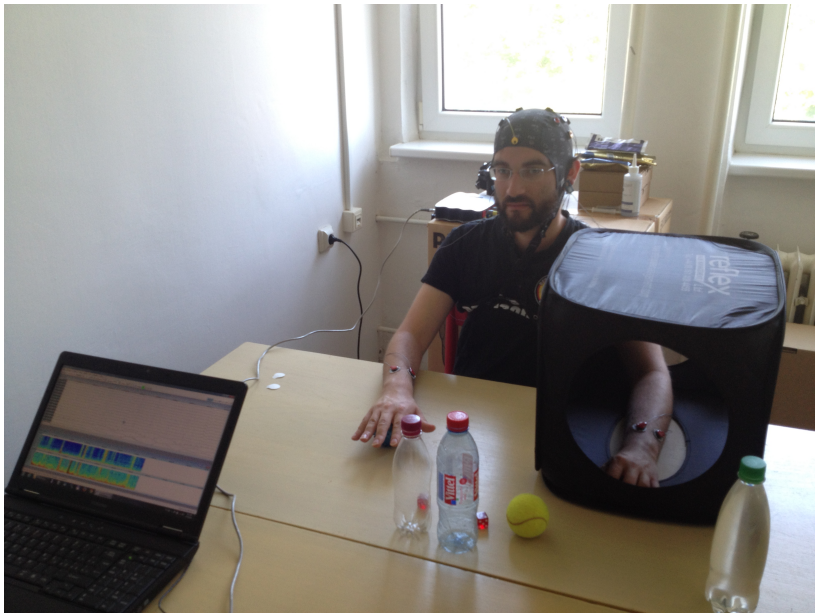


Figure 1. The core mirror neuron system, including the inferior parietal lobule (IPL), ventral premotor cortex (PMv), and inferior frontal gyrus (IFG).

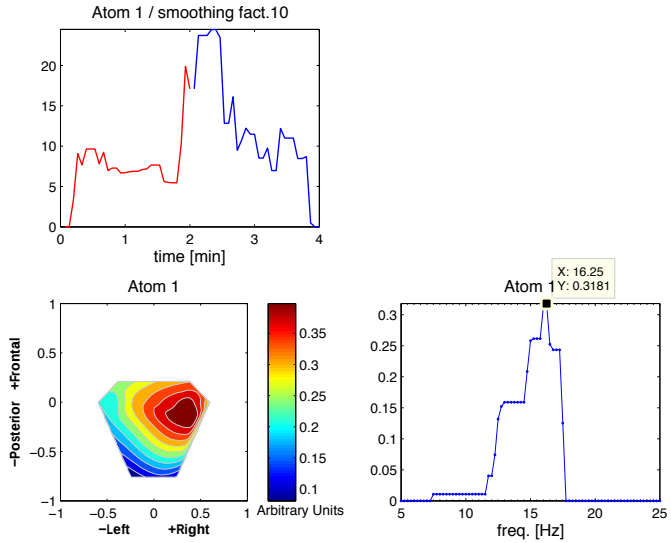
Taken from Garrison et al. (2010). Figure comprises motor-related brain regions. Action observation appears to activate the motor system similarly to execution, generating an internal representation of action that may be a target for stroke neurorehabilitation.

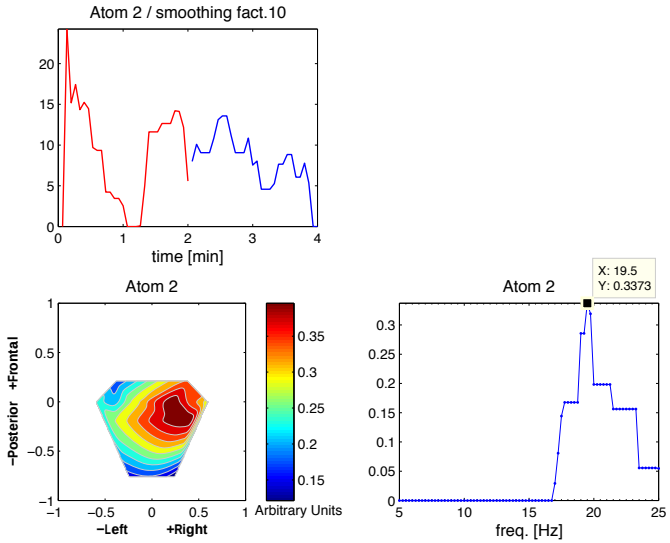
Mirror-box Training

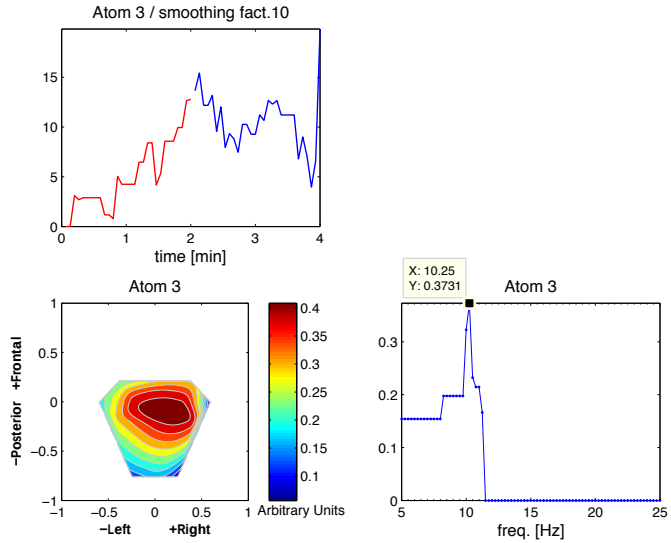


- A block of 10 different upper-arm and hand movements following physical training of subjects after stroke.
- Four blocks including mirror-box, blinded mirror-box, bimanual and single hand movements.
- Control group of healthy volunteers.

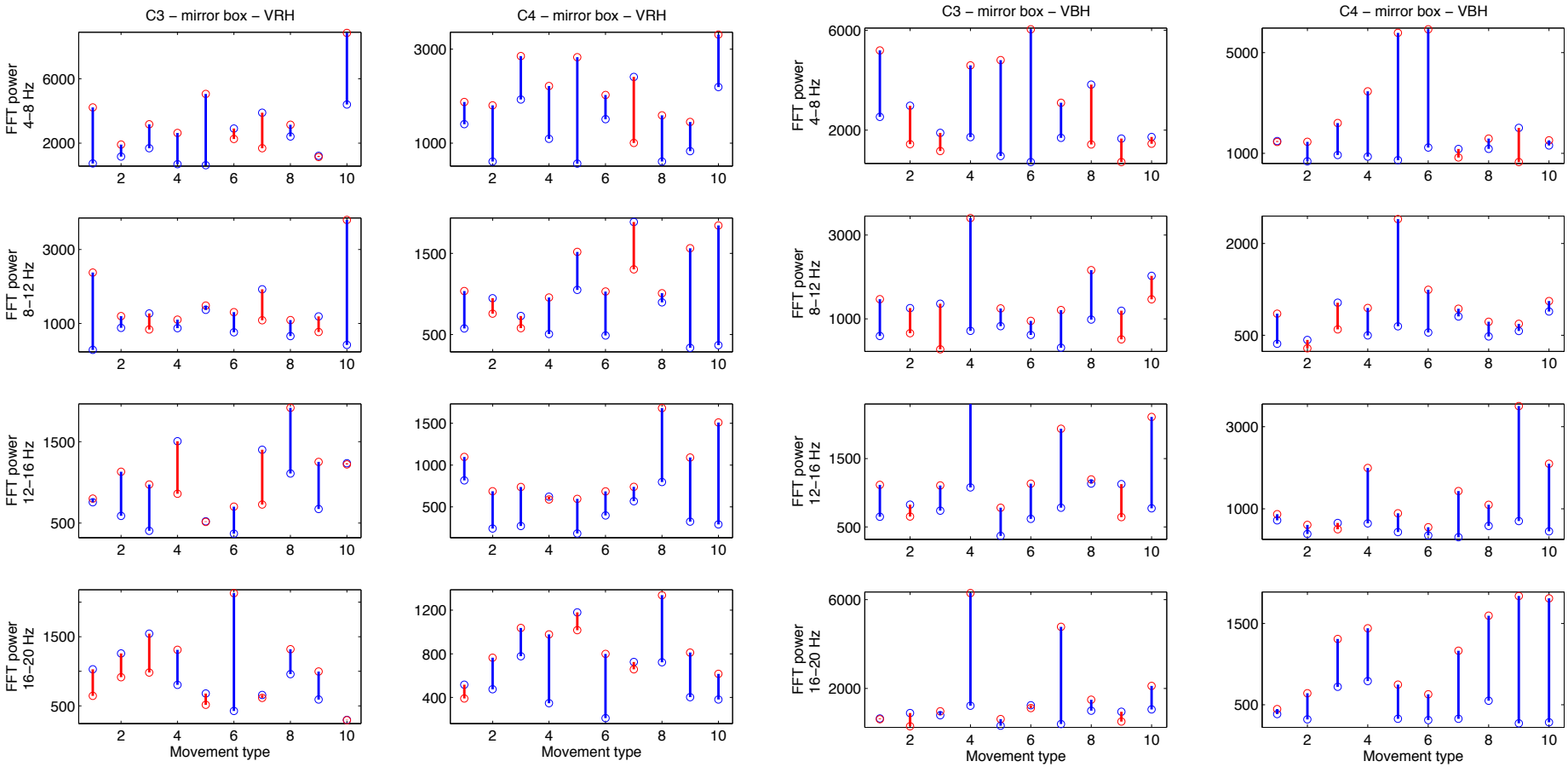
- Atomic PARAFAC decomposition of eyes-open two minutes rest blocks prior and after mirror-box training.



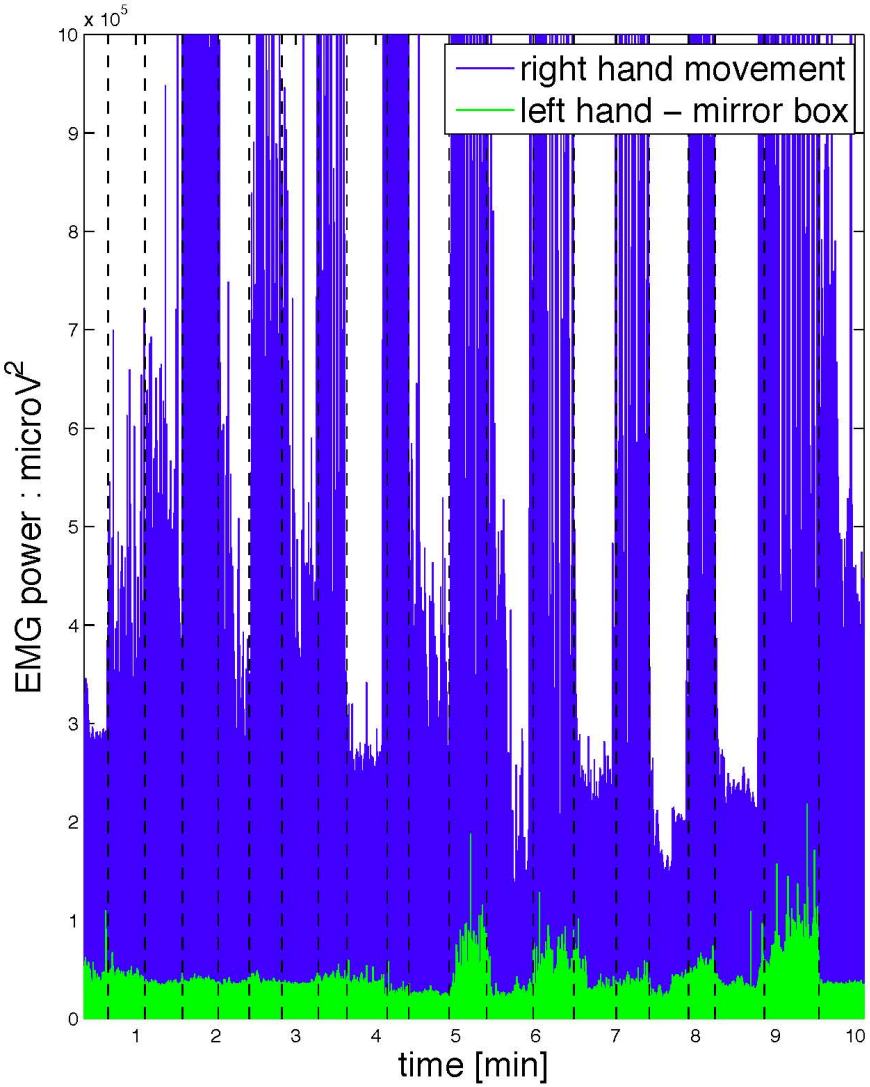


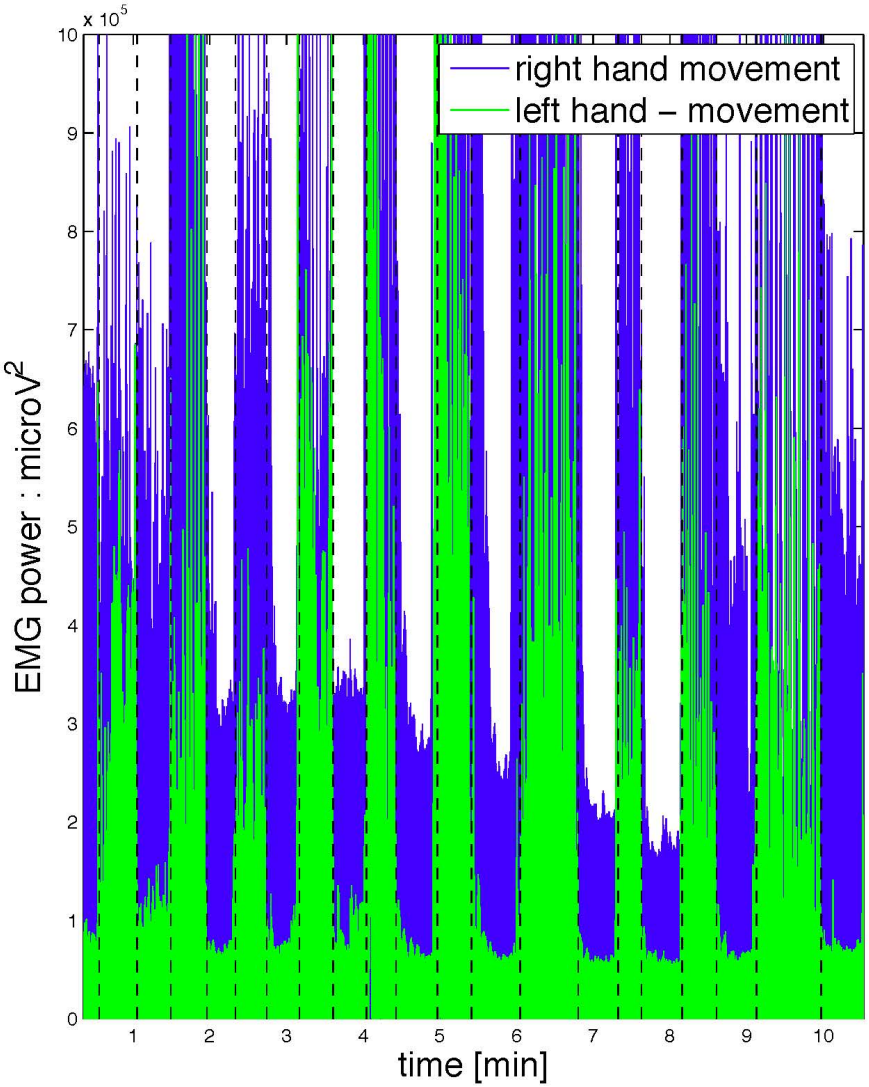


Mirror-box Training - C3 vs C4 / mirror-box-RH vs mirror-box-VBH



Mirror-box Training





SMR Neurofeedback (NFB) Training Prior BCI

Well-controlled studies indicate that NFB training can:

- improve cognitive performance, attention, memory consolidation, sleep quality, etc.
  Vernon (2003), Schabus et al., (2013), ...
- increase specific motor related cortical activation, SMR
  Kober et al. (2013), Witte et al. (2013), ...
- be useful in clinical practice (ADHD, TBI, PTSD, ...)
  Arns et al., (2014), Sterman (2000), ...

Lateralized Attention Network Test (LANT)

- The LANT was developed for measuring selective attention in each hemisphere. It includes:
  - *Conflict Resolution*
  - *Spatial Orienting*
  - *Alerting*
  - *Inhibition of Return*
- The LANT is sensitive to individual differences
  - *In Handedness and in Gender*
  - *In Personality. E.g., anxiety, empathy*
  - *In Social Relations, e.g.,*
    - *Sensitivity to discrimination*
    - *Conditions of teamwork*
- Performance can be optimized by:
  - *Adapting to the complementary diurnal rhythms of the attentional networks in the two hemispheres*
  - *Providing individually emotionally relevant background and spatial cues*
  - *Modulating the attention networks of the two hemispheres, e.g., by using*
    - *meditation / relaxation*
    - *EEG Biofeedback*

Trejo, Zaidel, Rosipal (2012-2014), PDT, UCLA

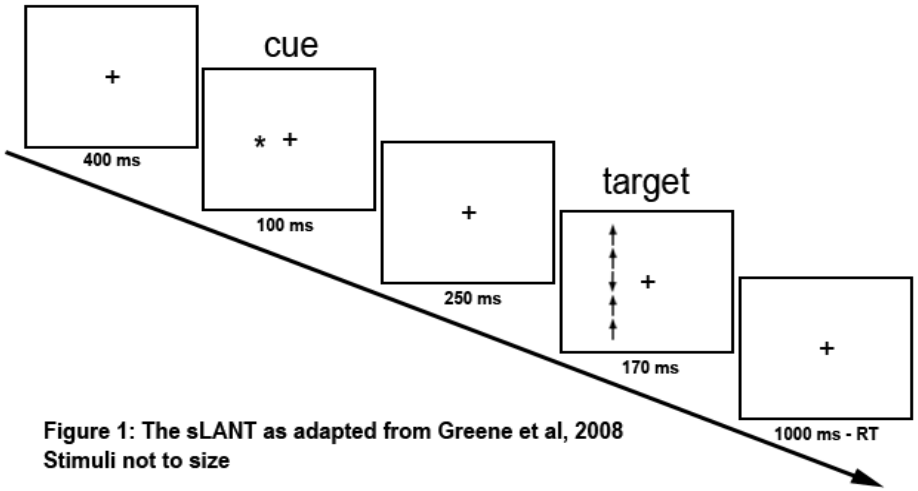
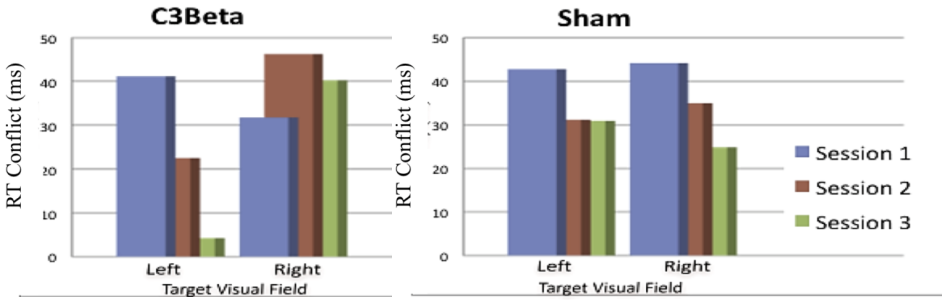
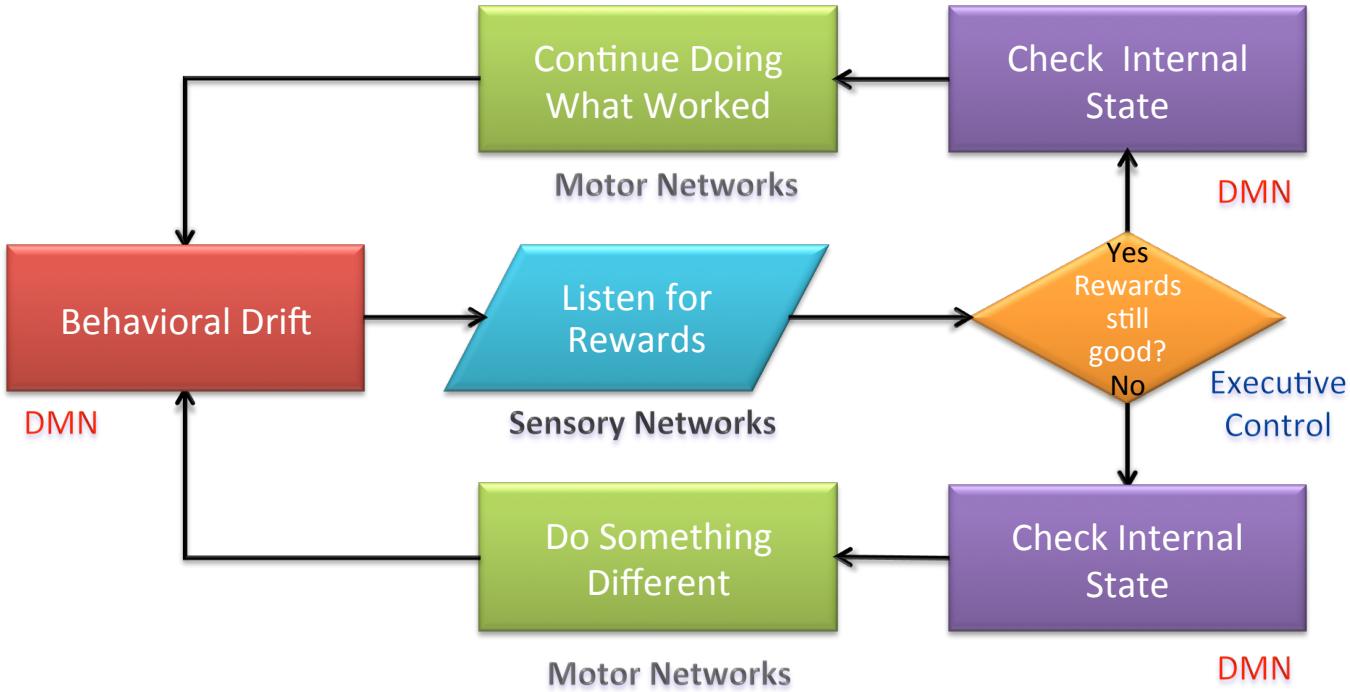


Figure 1: The sLANT as adapted from Greene et al, 2008
Stimuli not to size

Training Beta at C3 Selectively Reduced Conflict in the Right Hemisphere

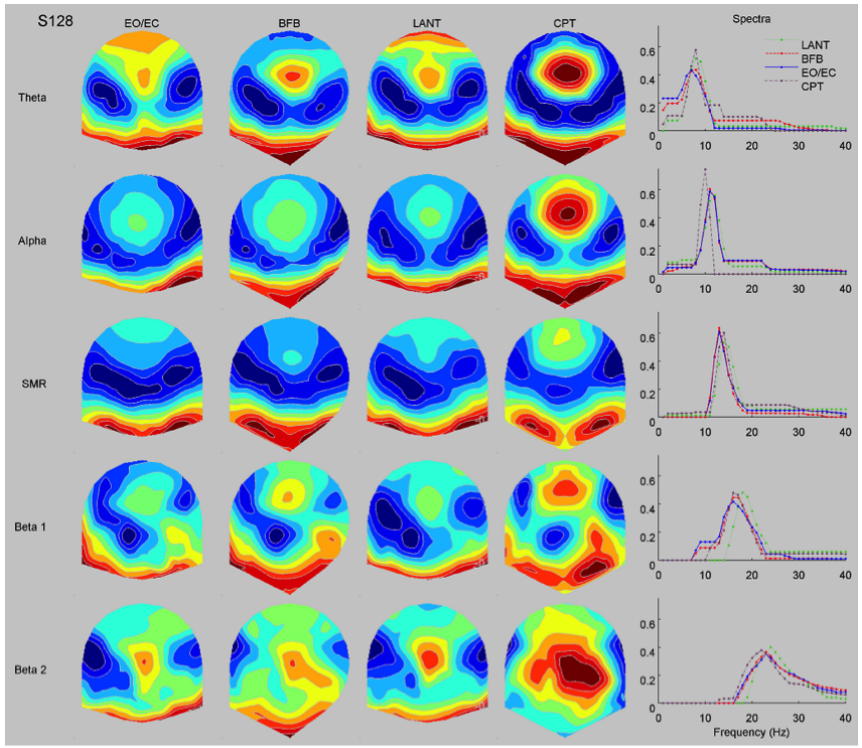


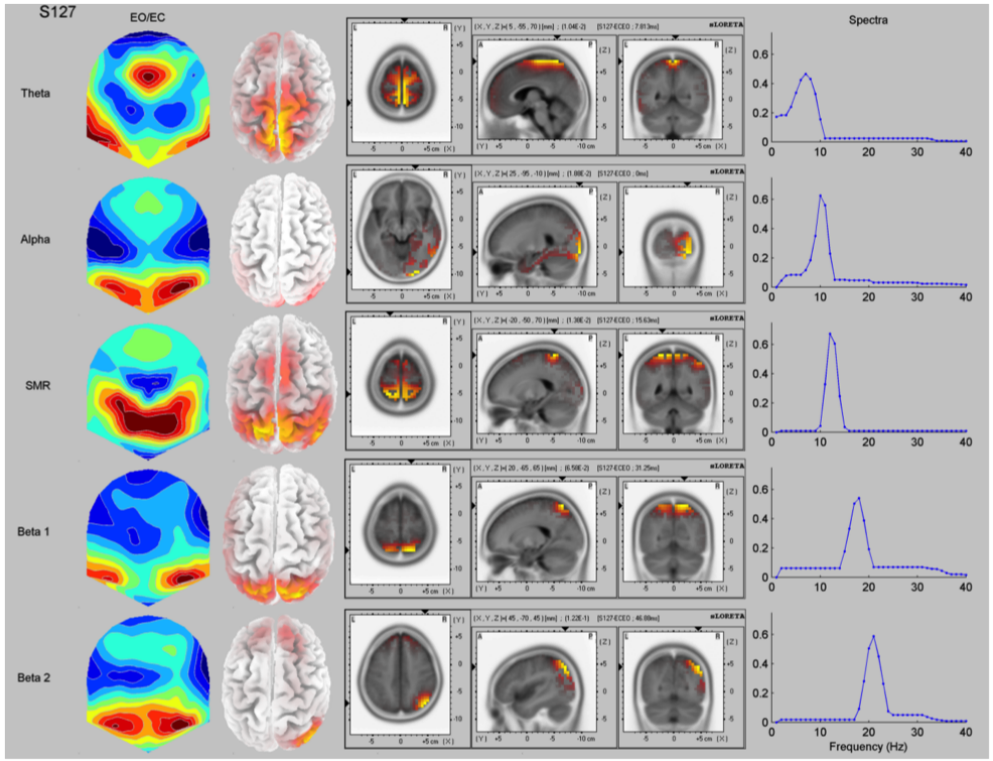
A (Network) Model of EEG Biofeedback for Performance Enhancement



Trejo, Zaidel, Rosipal (2012-2014), PDT, UCLA

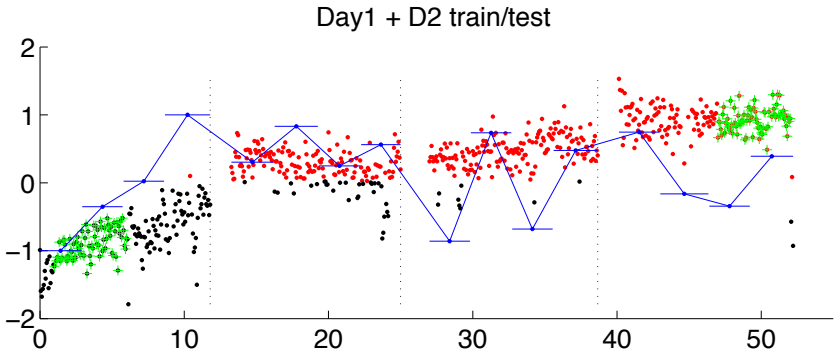
Multi-way Analysis and Inverse Cortical Mapping

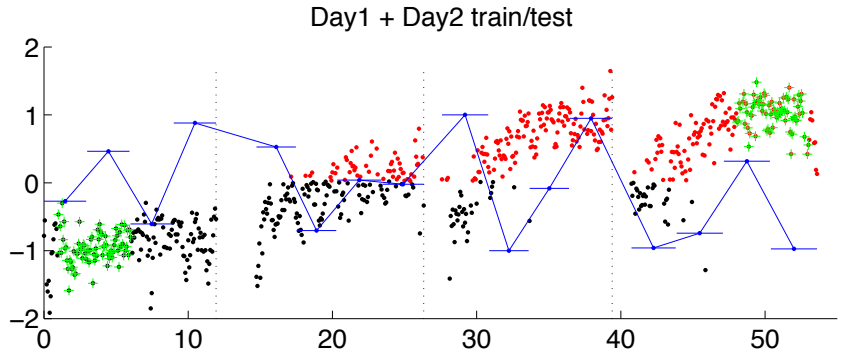


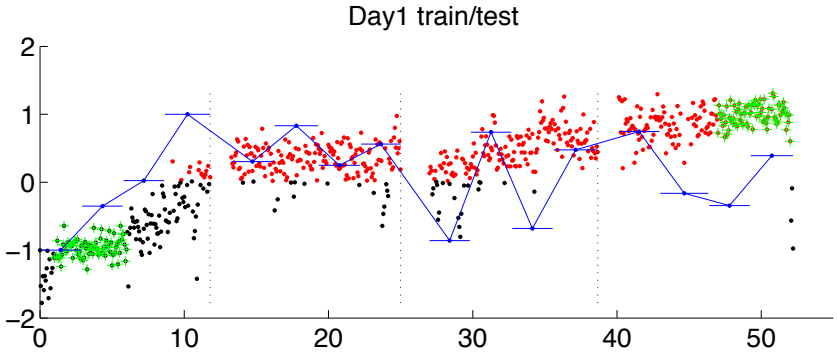


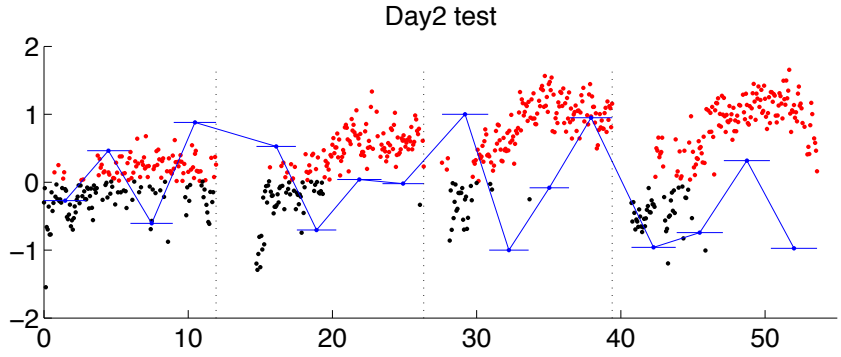
Rosipal, Trejo, Zaidel, et al. (2010-2014), PDT, UCLA

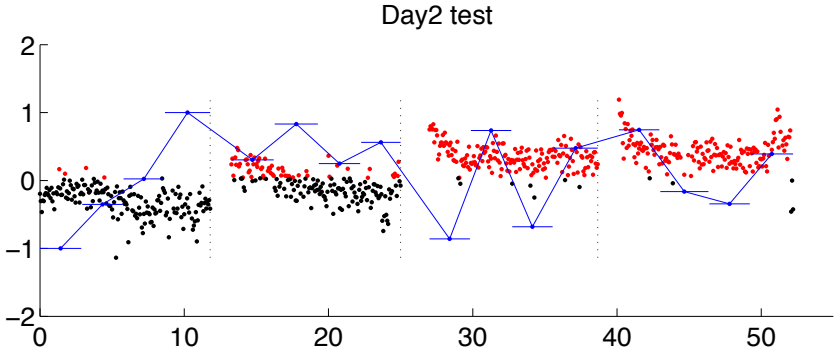
Cognitive Status (Fatigue) Prediction - An Example from eLANT Experiment

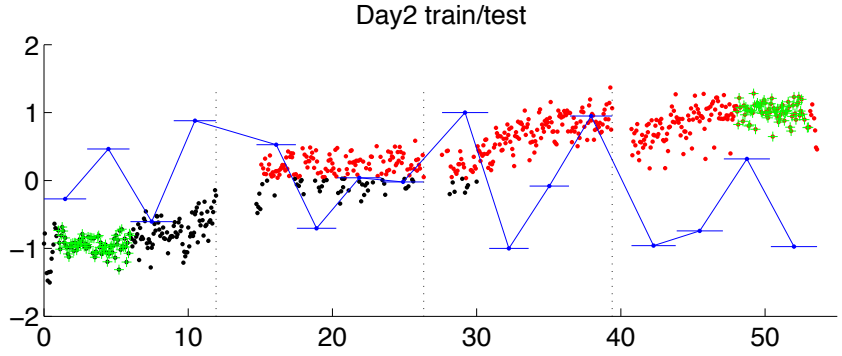












Rosipal, Trejo, Zaidel, et al. (2010-2014), PDT, UCLA

Concusions

- Efficient BCIs can be constructed
- Well-design BCI training protocols can improve BCI-illiteracy and decrease necessary training time
- BCIs in neurorehabilitation represents promising avenue to improve motor-related recovery of patients after stroke
- Pilot studies and results indicate that mirror-box training can be transformed to measurable neurophysiological (EEG) effects
- If the presented concept of training, methodological and algorithmic procedures for BCI-robot-assisted neurorehabilitaiton system is valid needs to be proved.
  We have started ! ... 10/2013 - 09/2017