BCI FOR REHABILITATION OF MOVEMENT

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Lecture Outline

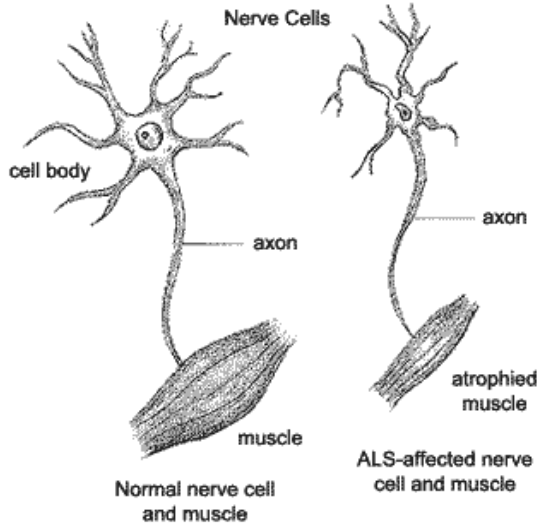
- Possible clinical use
- Plasticity
- Bypass
  - Muscle control mechanisms
  - Orthosis
  - FES
  - Neuroprosthesis
- Motor imagery as neurological rehabilitation technique
  - Restoration of CNS functioning

Possible Clinical use of BCI

- Communication
  - Locked in state (LIS)

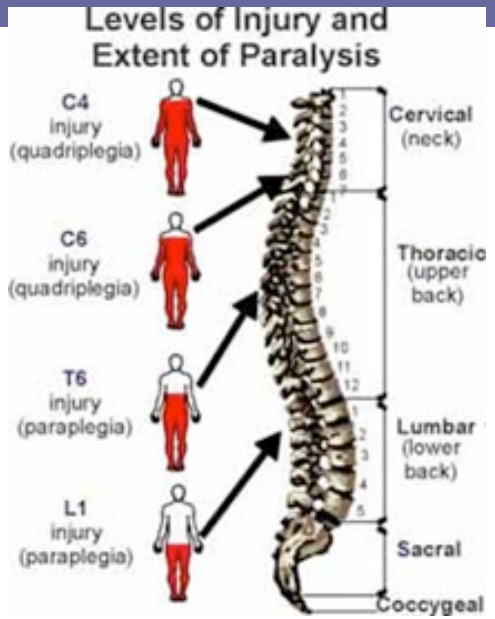
    A condition in which a patient is aware and awake, but cannot move or communicate due to complete paralysis of nearly all voluntary muscles in the body except for the eyes
  - Complete locked in state (CLIS)

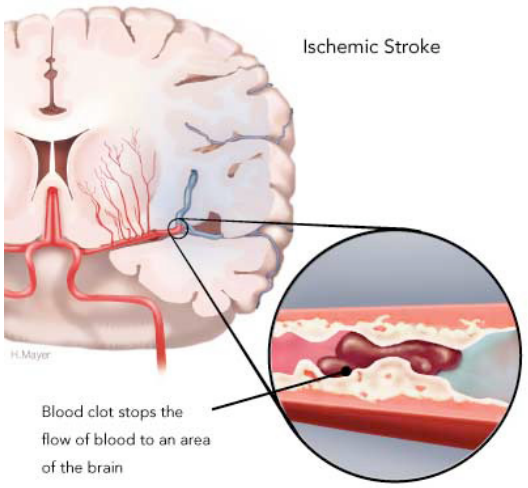
    Paralysis of ALL muscles
  - Amyotrophic lateral sclerosis (ALS)
    - a progressive, fatal, neurodegenerative disease caused by the degeneration of motor neurons
    - Atrophy of muscles
  - Brainstem strokes
  - High cervical spinal cord injury



Possible Clinical Use of BCI

- Orthosis/prosthesis/neuroprosthesis
  - amputation
  - Paralysis of limbs
    - Spinal cord injury
      - damage to fiber tracts (white matter) that carry signals to and from the brain
    - Stroke
      - Rapidly developing loss of brain function(s) due to disturbance in the blood supply to the brain. This can be due to ischemia (lack of blood supply) or due to a hemorrhage
- Rehabilitation of movement
  - Stroke





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Plasticity

Changing of neurons, organization of their networks and their functions via new experiences

- Old view: structural changes in cortex limited to childhood
  - Learning: only via changing of connection strength
  - Areas involved in memory are highly plastic
- More recent view: all areas of the brain are plastic
  - Cortical input deprivation
    - Deprived areas will eventually become activated in response to other (adjacent) inputs

Plasticity in Braille reading

- Sensorymotor cortex representation of “reading” finger enlarges
- Recruitment of occipital (formerly ‘visual’) cortex for tactile information processing

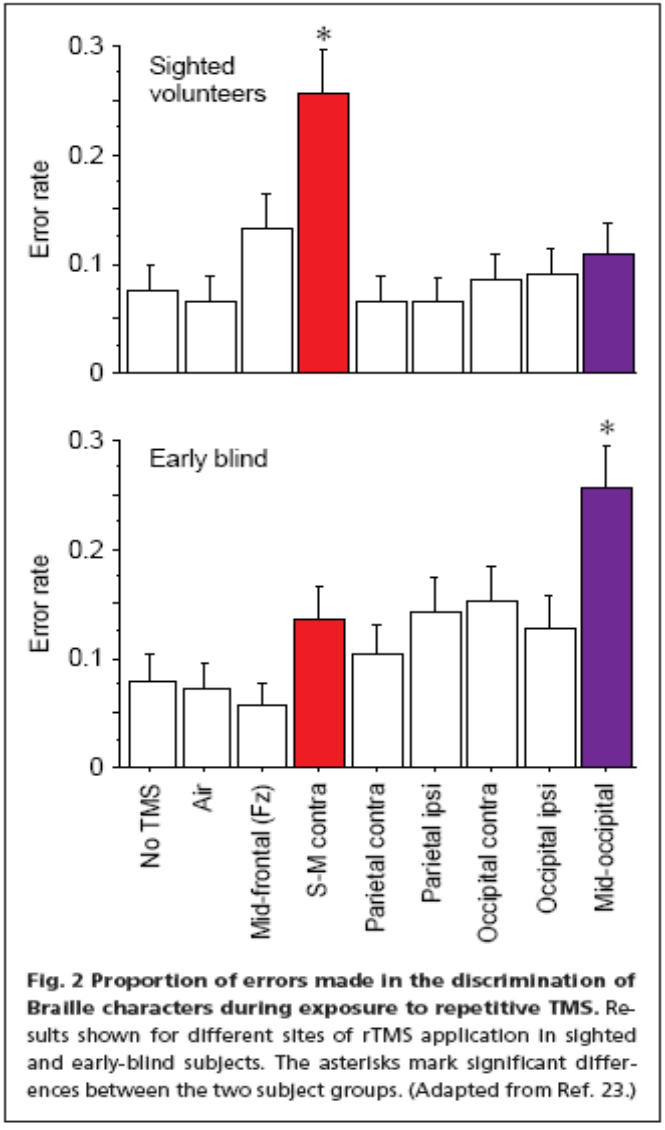
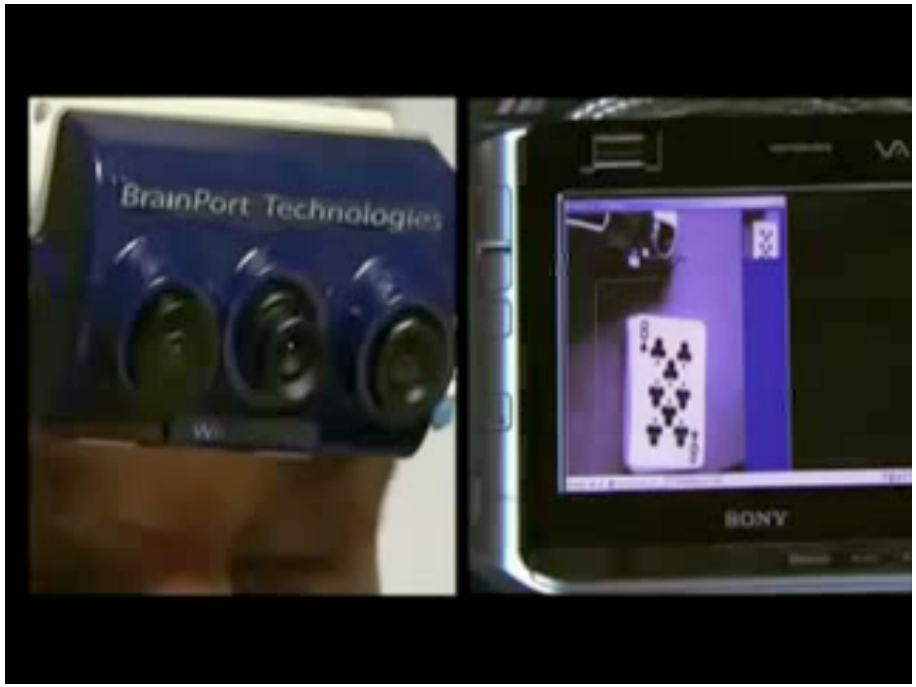


Fig. 2 Proportion of errors made in the discrimination of Braille characters during exposure to repetitive TMS. Results shown for different sites of rTMS application in sighted and early-blind subjects. The asterisks mark significant differences between the two subject groups. (Adapted from Ref. 23.)

Plasticity in blindness



Plasticity in BCI (1)

- Learning to control BCI
  - Start with motor imagery
  - Training: imagined movement less important?
  - BCI control becomes more automatic
    - Similar to conventional muscle-based skills
    - Different from motor learning
      - When movements become automatic, brain activity decreases
  - Need for adaptive BCI

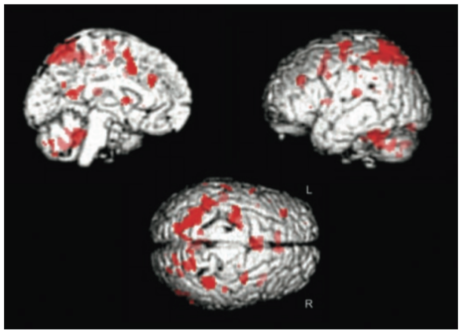


FIG. 2. Brain areas more activated at pretraining stage than that at automatic stage during performing sequence-12 ($P < 0.001$, uncorrected). Results were rendered over a standard anatomical brain.

Plasticity in BCI (2)

- Updating of body schema
  - Tool usage
  - Long-term usage of BCI controlled prosthetic
    - Animal studies:
      - Predict limb movement from neuronal activity
      - Control actuator with prediction
      - Limbs eventually stop moving
      - Changes in neural tuning

Lebedev et al. 2006

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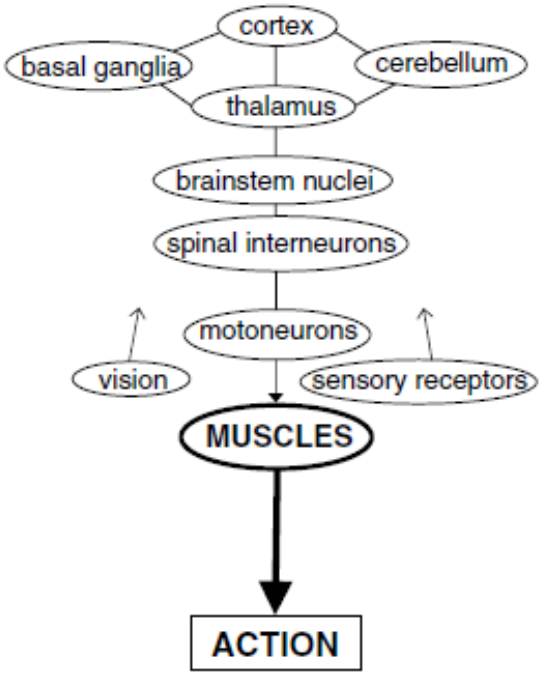
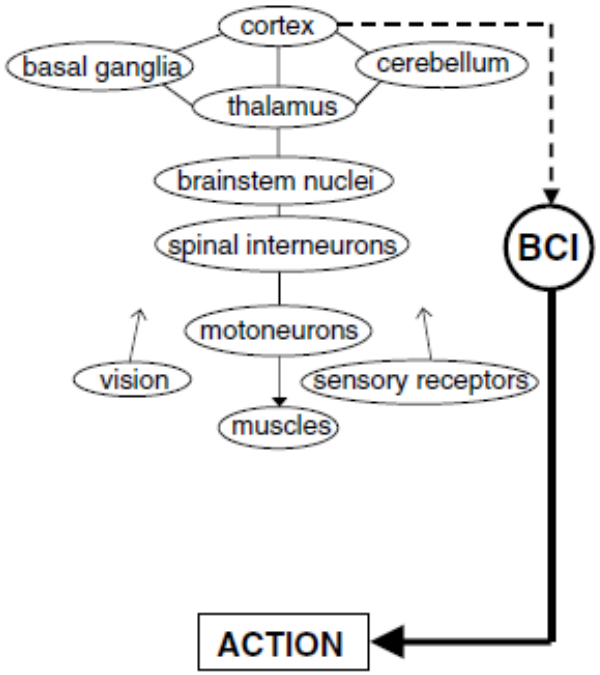
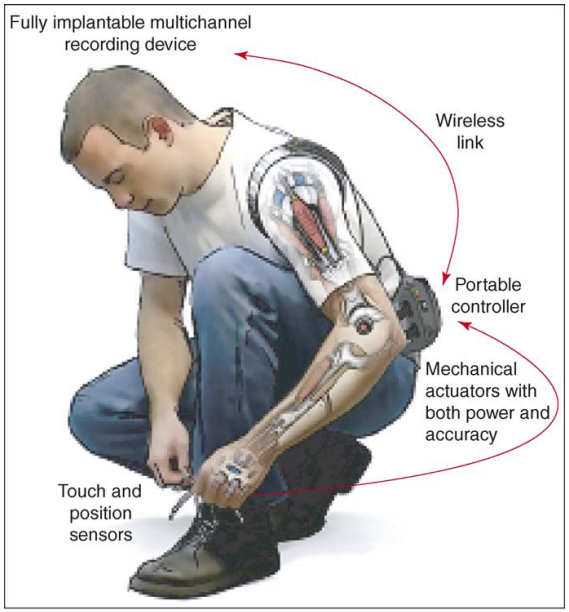
Bypass

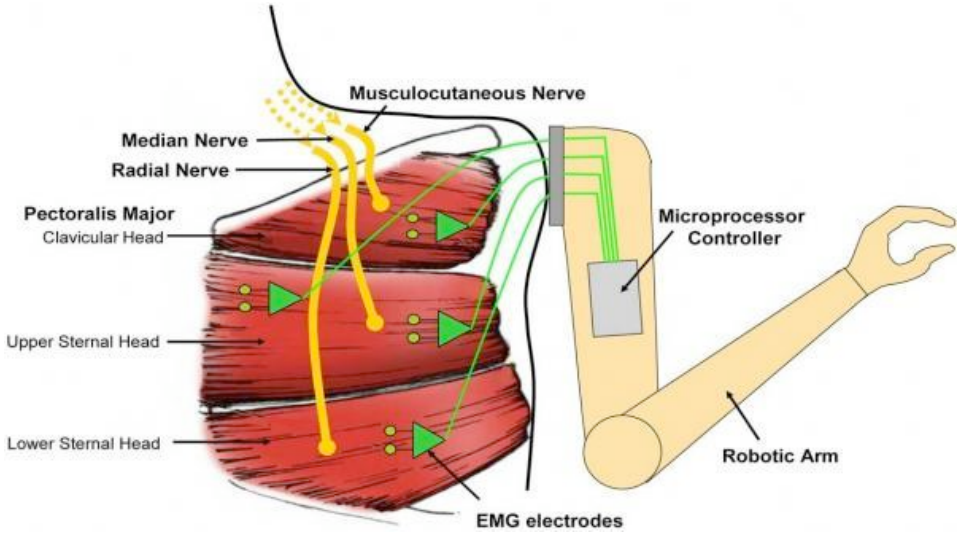

Normal CNS
cortex
basal ganglia
cerebellum
thalamus
brainstem nuclei
spinal interneurons
motoneurons
vision
sensory receptors
MUSCLES
ACTION


CNS/BCI System
cortex
basal ganglia
cerebellum
thalamus
brainstem nuclei
spinal interneurons
BCI
motoneurons
vision
sensory receptors
muscles
ACTION


Fully implantable multichannel recording device
Wireless link
Portable controller
Mechanical actuators with both power and accuracy
Touch and position sensors

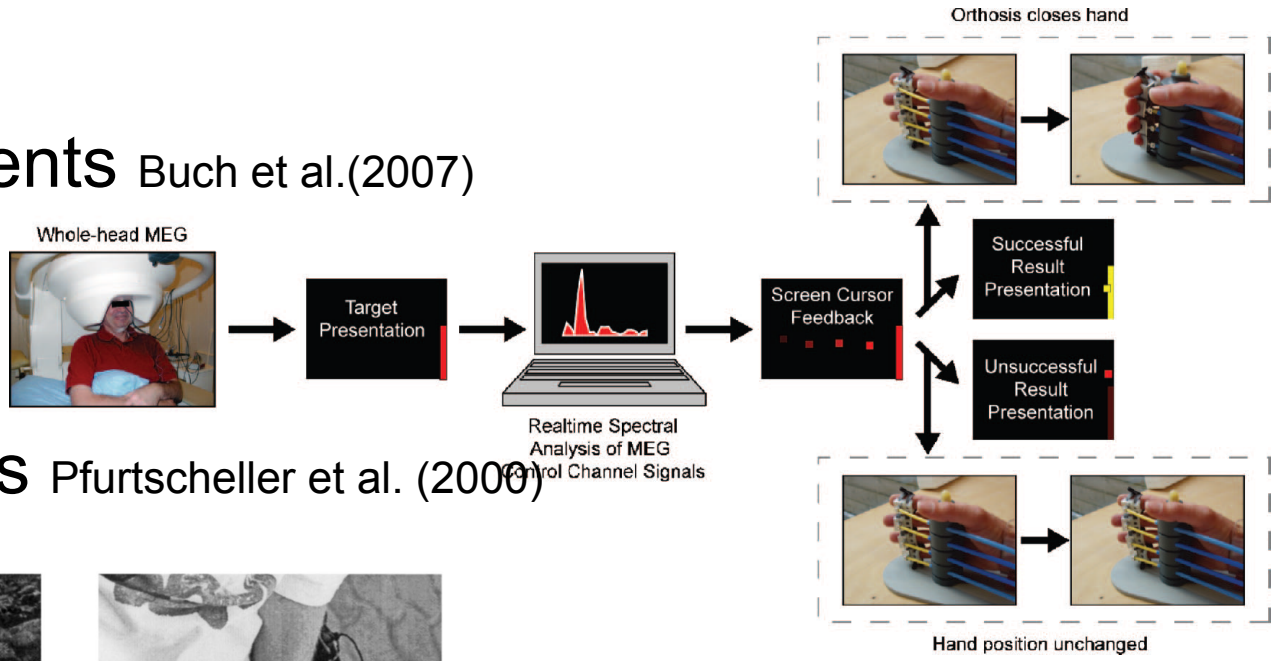
Bypass

- Dependent (muscle) control mechanisms
  - Open/close
    - Cable to opposite shoulder
    - Myoelectric
  - Finer control

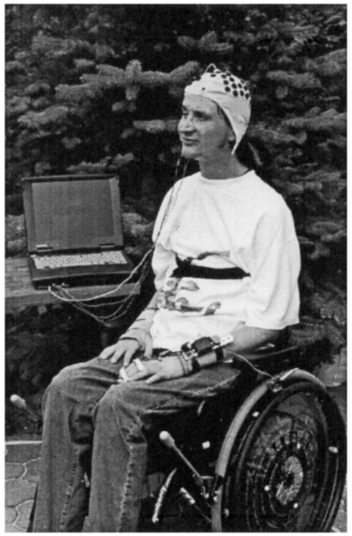


Bypass with BCI

- Orthosis
  - Stroke patients Buch et al.(2007)



  - SCI patients Pfurtscheller et al. (2000)



Bypass with BCI

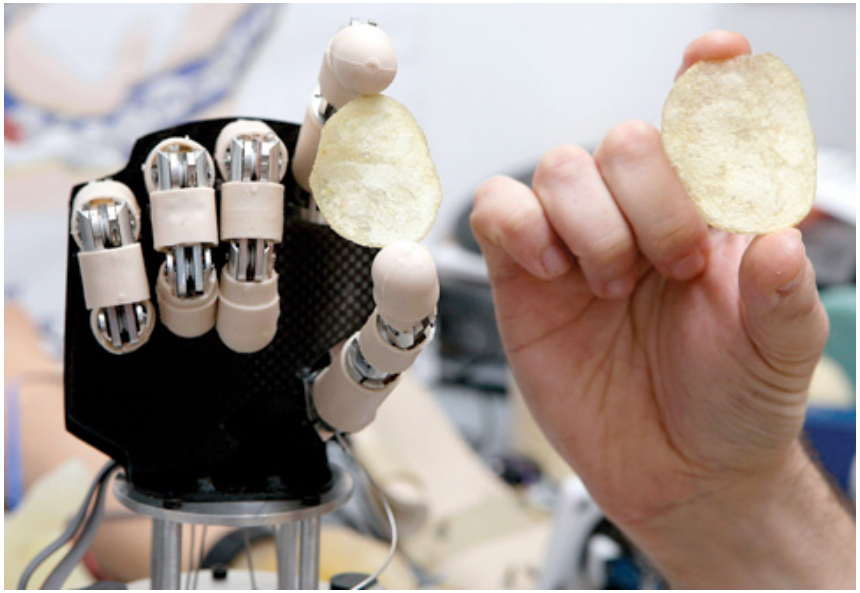
- Functional Electrical Stimulation (FES)
  - electrical currents to activate nerves innervating extremities affected by paralysis
  - Pfurtscheller et al. 2003
    - 5 phases
    - Each foot movement imagination resulted into shift to next grasp phase
    - Disadvantages

Bypass with BCI

- Neuroprosthesis Muller-putz 2005
  - Implanted FES (8 channels)
  - 3 phases
  - Imagined movement of left hand switched neuroprosthesis to next phase

Bypass

- Untill now only simple applications
  - Open/close
- More complex applications
  - Mulitdimensional movement
    - Robot arm
    - Neuroprosthetic



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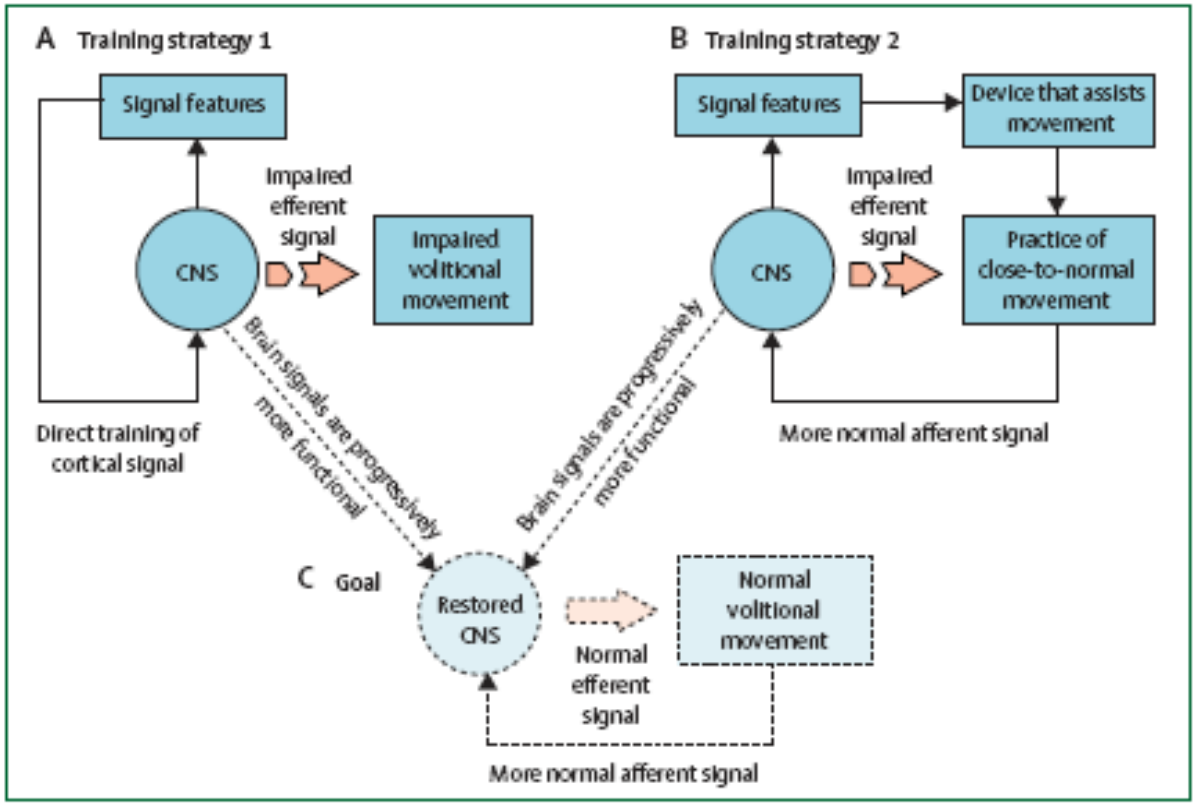
BCI for neurological rehabilitation of movement (mostly still hypothesis)

- Induce and guide activity-dependent plasticity



Daly & Wolpaw, 2008

Motor imagery

- Brain areas involved in movement planning and execution are also active during imagination of movement
  - Prefrontal cortex
  - Pre-motor cortex
  - Supplemental motor area
  - Cingulate cortex
  - Parietal cortex
  - Cerebellum
  - Primary motor cortex?
- Motor imagery
  - Optimizing execution of movements in athletes
  - Facilitate in learning of movements
  - Representation of a movement must already exist

Motor imagery in rehabilitation (without BCI)

- Recovery after stroke
  - Natural recovery up to 6/12 months
- Motor imagery for stroke rehabilitation
  - Makes use of the brain's plasticity
    - Reorganization of cortical representations
  - Beneficial effects on post-stroke motor recovery

Recently published results

- Training of sensorimotor rhythms can influence reaction times (Boulay et al. 2011 Clinical Neurophysiology)
- MI-based BCI training increases the motor cortical excitability (Piochiorri et al. 2011 Journal of Neural Engineering)

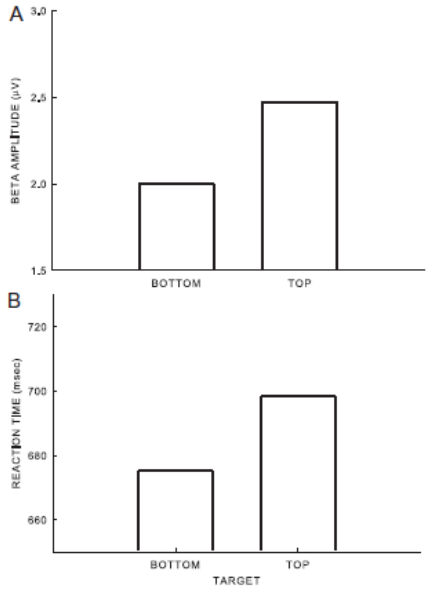
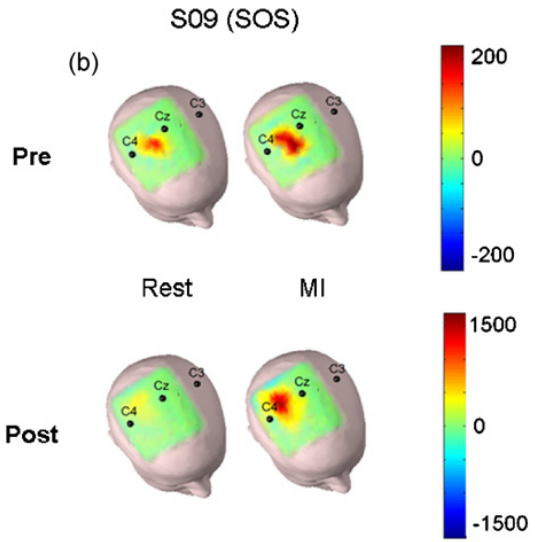
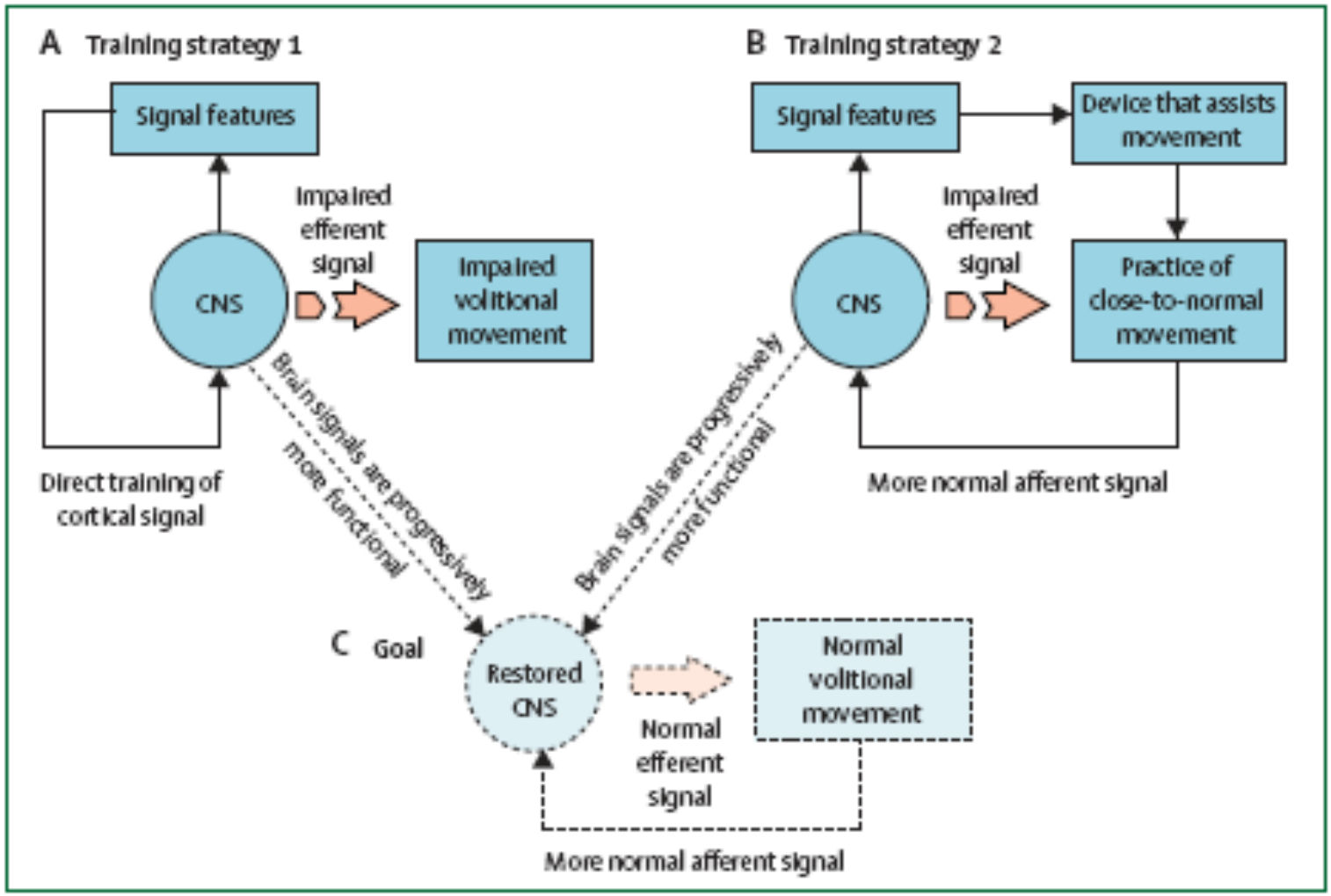


Fig. 5. Summary of testing effects. (A) Average amplitude of the control feature during bottom and top targets. (B) Average reaction times for Go trials during bottom and top targets.



BCI for rehabilitation of movement



Daly & Wolpaw, 2008

Motor learning

- Efficiency and speed of recovery depends partly on availability of information provided by motor activity
- Sources of information for motor learning
  - Proprioceptive
  - Tactile
  - Vestibular
  - Visual
  - Auditory

Recent published results

- Case report of partial chronic stroke recovery after combined physiotherapy and BCI (Caria et al. 2011 Psychophysiology)

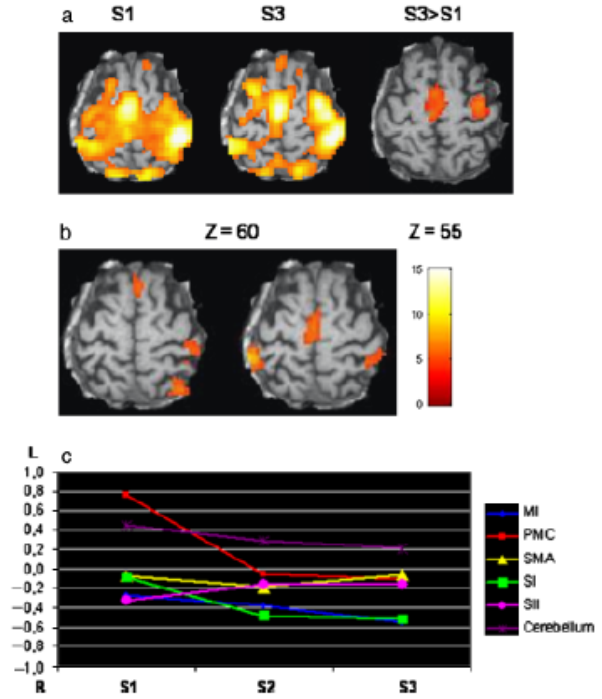


Figure 2. fMRI and PPI results during the paretic hand motor task execution. a. Activated areas during S1, S3, and comparing S3 to S1. b. Areas covarying with the right ipsilesional premotor cortex. c. Lateralization index (LI).

Table 1. *Clinical Assessment*

Motor	FMA passive	FMA sensory	FMA motor	WMFT functional ability	MAS	GAS
S1 (baseline)	37	5	13	7	8	−2
S2	39	5	19	9	4	+2
S3	41	6	24	13	4	−1
% change from baseline	10.8	20	84.6	85.7	50	

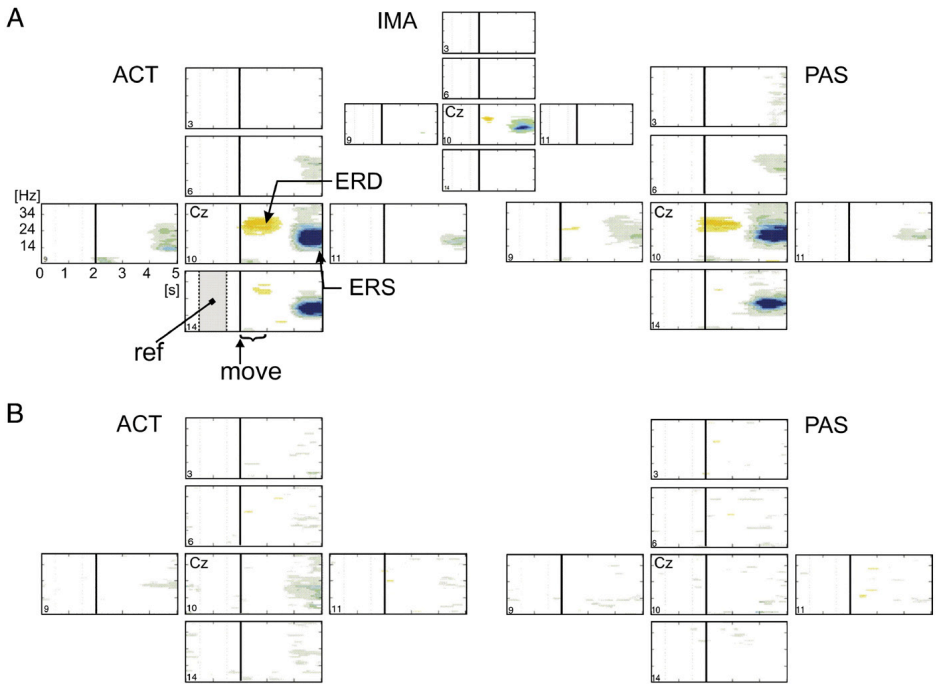
Note: FMA (passive movement and pain: 0 = maximum disability, 48 = normal; sensory loss: 0 = maximum disability, 12 = normal; motor function: 0 = maximum disability, 66 = normal), WMFT (0 = maximum disability; 80 = normal), MAS (spasticity, 0 = normal; 36 = maximum disability), GAS (− 2 = outcome much less than expected, 0 = program goal/expected outcome; 2 = outcome much better than expected; as the patient scored +2 in S2, the S3 baseline was reset to allow detection of a further improvement).

Possibilities/Difficulties for patients

- Decreased ERD/ERS in paraplegic patients
  - Caused by time after injury

Healthy subjects

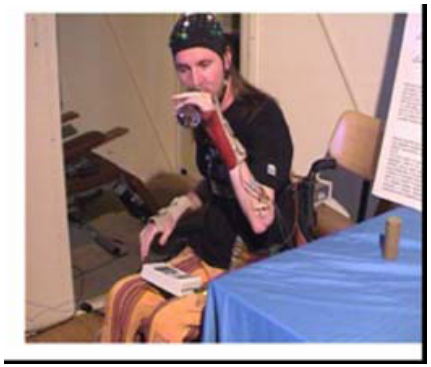
Patients

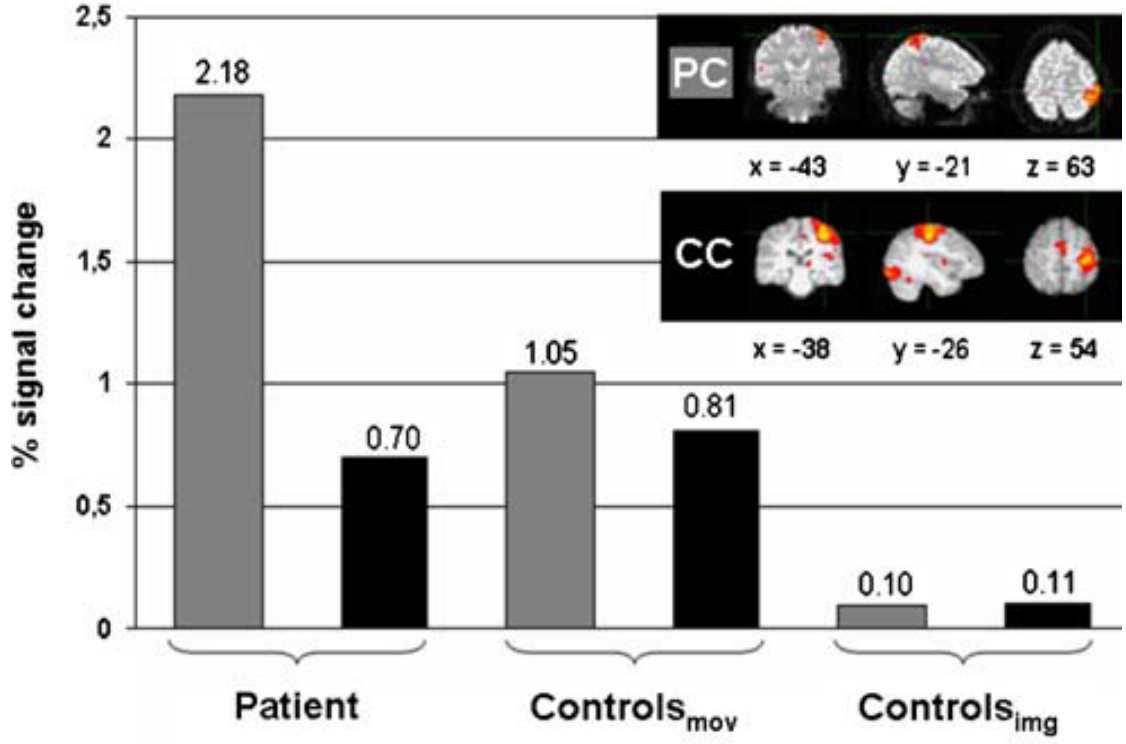


Müller-Putz et al. 2007

Possibilities/Difficulties for patients

- Training can preserve sensorimotor cortex activity (1 SCI patient)
  - Extensive training

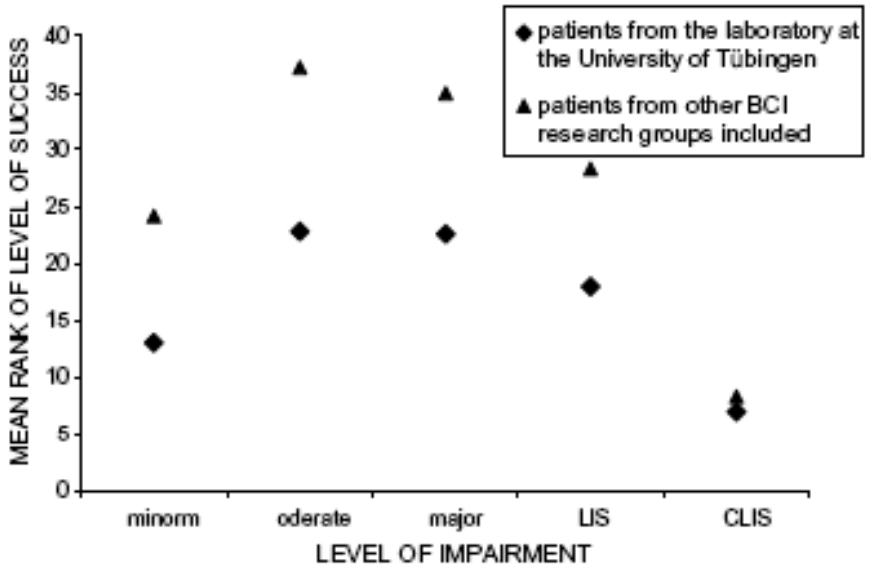




Enzinger et al. 2008

Possibilities/Difficulties for patients

- Not many patients studies (yet)
- Different signals in patients?
  - CLIS patients



  - Transfer to CLIS?

Questions?