Brain Computer Interfaces: A novelty of 21st century for people with neuromuscular disorders

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What is Brain Computer Interface (BCI)

- **Vidal 1973**: “Can observable electrical brain signals be put to work as carriers of information in person-computer communication or for the purpose of controlling devices such as prostheses?”

- **BCI**: use the electrical activity obtained from the brain to control a computer application or devices
  - unique, multimodal, and multisensory solution both for communication and environment control, as well as for rehabilitative therapy

- **Social and clinical impact**
Motor-Impaired people

- Neuromuscular disorders (NMD): gradually loss of muscle activity that affects speaking, walking and executing fine motor gestures ➔ deterioration of social life and activity

- Current technological devices:
  - not adaptable in every environment
  - don’t support adjustable equipment and as result not useful
  - don’t cover a wide variety of users’ abilities and needs (e.g. eye gaze technology, “Dragon Dictate large-vocabulary speech recognition system”)
  - “Midas touch problem” (Majaranta, Päivi and Räihä, 2002)
BCI systems

- **Non-Invasive**
  - Electroencephalography (EEG)
  - Near-infrared spectroscopy (NIRS)
  - Functional electric stimulation (FES)
  - Transcranial magnetic stimulation (TMS)
  - Functional magnetic resonance imaging (fMRI)

- **Invasive**
  - Electricorticography (ECoG)
  - Multi Unit Activity (MUA)
  - Single Unit Activity (SUA)
  - Local field potentials (LFP)
EEG based BCI for Communication/Rehabilitation

EEG Recording/Control Mechanisms

- P300
- SCP
- SMR (ERD/ERS)
  - alpha (8-12 Hz)
  - mu (8-12 Hz)
  - beta (18-26 Hz) rhythm

Brain Computer Interface
- Spelling
- Select letters/words
- Web searching
- Brain games
- Control of electrical/domestic devices
- Virtual environments
- Painting

Rehabilitation/Training
- Motor imagery
- Control of assistive devices
- Improvement of motor function

Potential Users
- Amyotrophic Lateral Sclerosis ALS
- Spinal Muscular Atrophy SMA II
- Duchenne Muscular Dystrophy DMD
- Spinal Cord Injury SCI
- Cerebral Palsy CP
- Multiple Sclerosis MS
- Arnold-Chiari Malformation A-CM
- Muscular dystrophy MD
- Stroke
- Parkinson

Regain Motion, Independence, Better Communication, Social Integration
EEG-BCI Modalities

- P300
- SMR
- SCP

EEG

PC

Eye-Tracker
EEG- BCI Modalities
Rhythms in the EEG signals—sensorimotor areas (i.e. μ-rhythm and β-rhythm) typically change with movement, i.e. either while watching someone to perform a movement or during motor imagery.
self-regulation of $\mu$-rhythm or $\beta$-rhythm amplitudes in the absence of any movement or sensation, and can use this to move a cursor to a specific position of the computer screen, to select letters, or to operate an orthotic device (Wolpaw and McFarland, 2004).

SMR-based control is achieved through activation and deactivation of the central motor loops (e.g., MI of left hand) (Pfurtscheller and Neuper, 2001).

SMR-based BCI a potential solution for motor rehabilitation (Ono et al., 2014; Pfurtscheller et al., 2000).

2 distinct power changes: event-related desynchronization (ERD) - 2 seconds before movement and is sustained with continuous movement and event-related synchronization (ERS) post-movement beta synchronization, after the end of movement.

Disadvantages increased amount of training sessions and time that is necessary to gain sufficient Classification Accuracy.

Different MI (left hand vs. right hand) do not produce "reliable and reasonably robust differences in power, at least at one or more frequencies and/or electrode sites" $\Rightarrow$ effective communication may not be possible (Karat and Vanderdonckt, 2009).
Rehabilitation

The most commonly used EEG-based modality, which is an event-related potential (ERP) associated with an unexpected stimuli that provides task-relevant information (Baykara et al., 2015).
P300 has been the focus of BCI research due to:

- ease of evocation and consistency
- little initial training of the subject
- gives users the opportunity to communicate at rates of 25–30 bits/min which means that word processing is approximately 2–4 words/min (~12 letters/min)

Meta-analysis (Marchetti et al., 2014): P300-speller BCIs with ALS participants, Classification Accuracy (CA) to be in the order of 74%, much lower than 90% that has been set as the minimum threshold for ALS participants (Huggins et al., 2011).

P300-BCI systems could be affected by overall clinical severity (Hoffmann et al., 2008) and worse performance during the sessions may be detected in motor impaired ALS patients due to a habituation effect (Sellers and Donchin, 2006) VS both in terms of ERP response as well as Classification Accuracy, the P300 modality can be a reliable tool for EEG-BCI operation of ALS participants (Daniel Álvarez, 2014).

Disadvantage: the low Information Transfer Rate (ITR) of P300 EEG-BCIs especially for motor-impaired people (Holz et al., 2013; Mauro et al., 2011; Mugler et al., 2010; Nam et al., 2012).
Voluntary regulation of different brain areas with area specific effects on behavior and cognition. Need substantial training to produce SCP. Positive or negative voltage shifts can be learnt and used for basic word processing and other simple control tasks
SCP

- Voluntarily changing the polarity of the SCP amplitude, motor-impaired participants can move a cursor on a computer screen by selecting letters and writing messages.
- “Descartes” system accesses internet by using SCP:
  - great difficulty in selecting an icon or a picture as a link on a Web page or to select from an alphabetically sorted decision tree, when several links have the same name (A. a Karim et al., 2006).

- **Disadvantage** raises some issues:
  - Participant had to exceed or to remain below 7.7μV for operating the system.
  - This restriction doesn’t seem a sufficient solution for everyday use.

- Although still slow, in the majority of studies SCP speller (the so-called “TTD”) was around 1 letter per minute, it satisfied the requirements for a successful BCI, which could connect the motor-impaired person to the worldwide web (Niels Birbaumer et al., 2000; Hinterberger et al., 2003).
Discussion (I)

- Participants at severe level of paralysis of Locked-In state:
  - Importance of investigating new solutions for people who are severely paralyzed.
  - Critical need of severe paralyzed motor-impaired people for communication with any possible way even at late stages

- BCIs may eventually be used routinely to replace or restore communication and control for motor-impaired people.

- Commonly studied EEG-based BCI modalities have pros and cons: P300- positive peaks, needs no training and ITR 15-20 bits/min, affected by level of severity, SMR- modulations in sensorimotor rhythms synchronized to motor activities, needs training and ITR 3-35 bits/min, SCP- Slow voltages shift in the brain signals, needs training and ITR 5-12 bits/min.

- Future BCIs-oriented studies must focus on BCI reliability and value for many different motor-impaired people, of all levels of severity, by testing BCI systems in real-life circumstance.
Discussion (III)

- **Self-regulation Problem**: Studies tried to reduce the time is needed for training:
  - low ITR 2.2–3.8 hits/min and showed that participants’ performance improved with more training (H. Jeon & Shin, 2015; Kauhanen et al., 2007).
  - Training is necessary to gain successful self-control of SMR.

- **P300**: performance of motor-impaired participants was worse than this of able-bodied (Nam et al., 2012; Gabriel Pires et al., 2012) in terms of ITR (Nam et al., 2012; Vaughan et al., 2011), or proved to be unable to respond to the experiment’s demands (Mauro et al., 2011).

- The most severely paralyzed participants seem not being able to operate successfully the EEG based BCI system (Pasqualotto et al., 2015; Gabriel Pires et al., 2012).
  - i) P300 may be affected by level of severity,
  - ii) participants have worse performance during the sessions due to a “habitual effect”. 

The latest advances in BCI research suggest that innovative multimodal developments may be forthcoming in the near future. Future and ongoing studies should try to address that EEG patterns may need many changes according to the patient’s learning progress and many adaptations. BCI s which use SMR for system operation relying on motor imagery of upper and lower limbs and have not been tested with individuals who never experienced voluntary control of their movements (e.g., congenital motor impairment). More research is necessary to best candidates so as to improve the efficiency of signal detection and decoding for better and promising outcomes. (Thomas, 1977): “BCIs are not yet able to fly airplanes and are not likely to be doing so anytime soon.”
THANK YOU FOR YOUR ATTENTION

RELAX