University of Glasgow

School of Engineering

Brain Computer Interfaces for Neurorehabilitation of Sensory and Motor Functions

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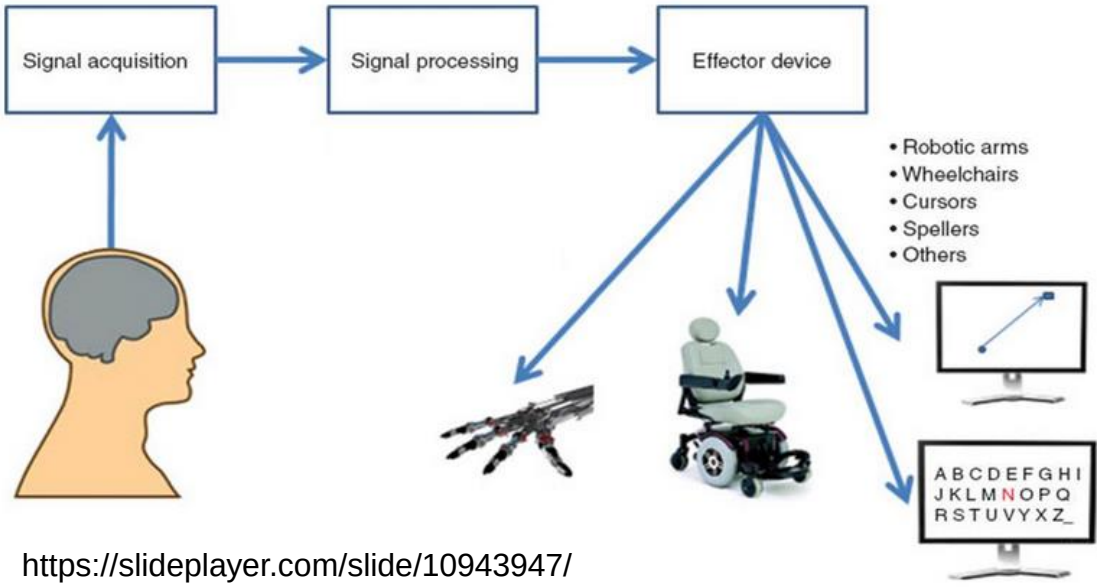
Technologies for Brain Health and Dementia Prevention Workshop

Brain Computer Interfaces

Brain-Computer Interface (BCI) is a hardware and software communication system that permits cerebral activity alone to control computers or external devices



https://slideplayer.com/slide/10943947/

Applications of Brain Computer Interfaces

Replace
- BCI control of a speller
- BCI control of a wheelchair

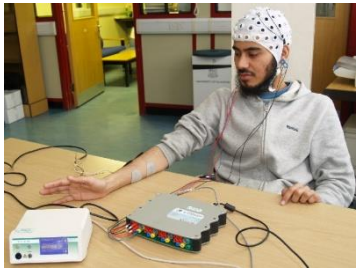
Restore
- BCI control of hand orthosis

Improve
- Neurorehabilitation of motor function
- Reduction of chronic pain
- Improvement of cognitive functions

Enhance
- Automatic error detection in spaceship control
- Enhanced gaming experience
- Detection of lapses in concentration

Research
- Study brain functions in dynamic conditions

Brain Computer Interfaces

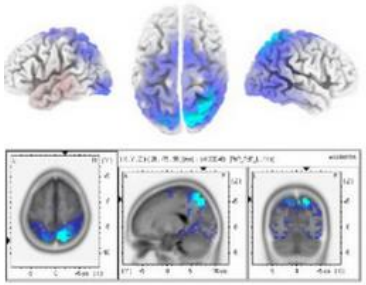


Improve

- **Neurorehabilitation of motor function**
- **Reduction of chronic pain**
- **Improvement of cognitive functions**

Enhance

- **Enhanced gaming experience**



Research

- **Study brain functions in dynamic conditions**

Communication though BCI inevitably requires neuromodulation

- Neuromodulation to control an external device where a lasting effect on brain activity is not the goal of the BCI application
  - Speller
  - Wheelchair control

Communication though BCI inevitably requires neuromodulation

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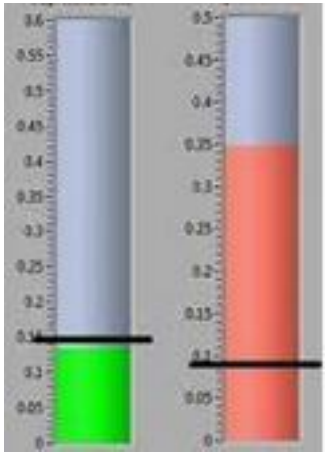
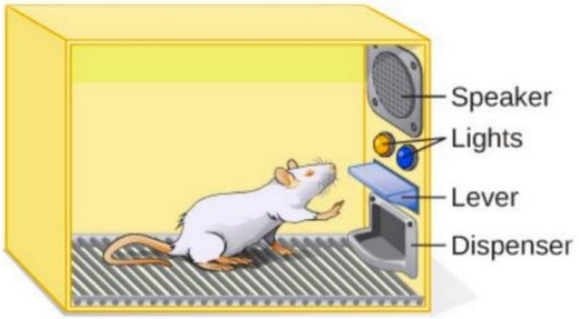
  - Speller
  - Wheelchair control
- Neuromodulation to control an external device where a lasting effect on brain activity is the goal of the BCI application
  - Verbalised strategy e.g. motor rehabilitation
  - Non verbalised strategy - operant conditioning e.g. neurofeedback

Neurofeedback Through Operant Conditioning

- **Operant conditioning process by which humans and animals learn to behave in such a way as to obtain rewards and avoid punishments (Skinner)**
- **In operant conditioning, a person associates a voluntary behaviour and a consequence**





Neurofeedback is a subtype of biofeedback through which a person learns how to regulate selected features of brain activity at will.

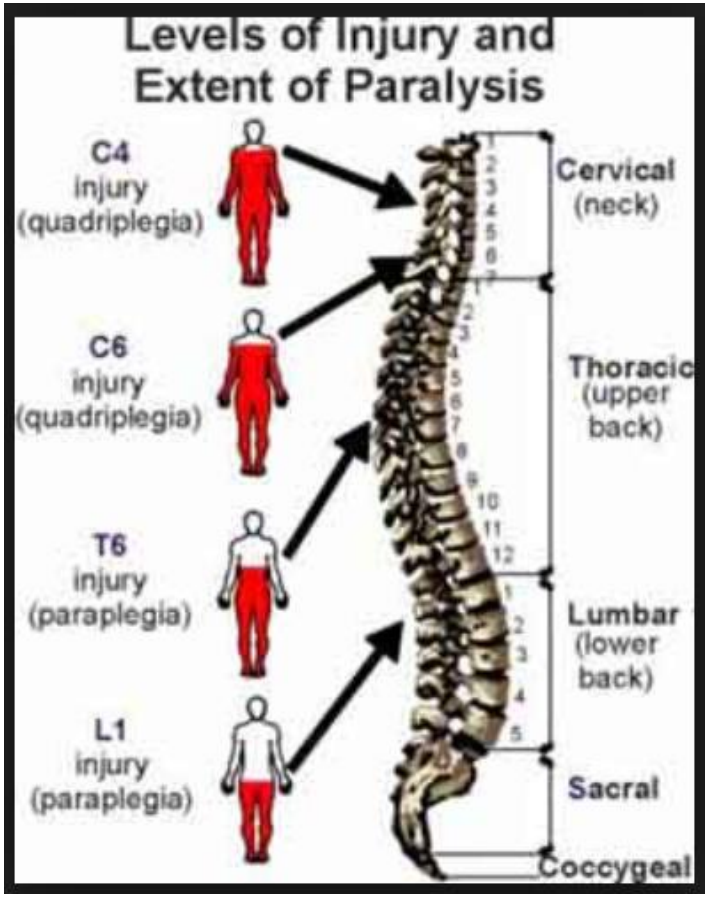
Neurofeedback Applications

- **Attention Deficit Hyperactivity Disorder**
- **Epilepsy**
- **Chronic pain**
- **Insomnia**
- **Depression**
- **Memory**
- **“Peak functions” in healthy people**

Neurofeedback for Neuropathic Pain Treatment in People with Spinal Cord Inquiry

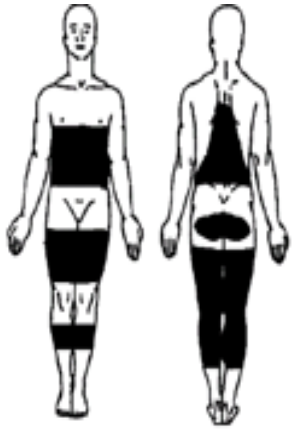
Background: Spinal Cord Injury

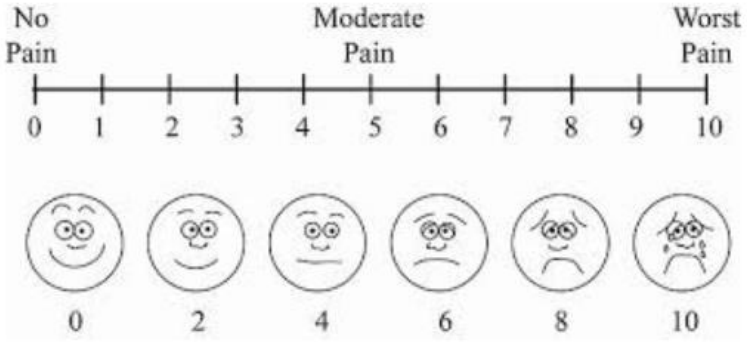
- **Paraplegia and tetraplegia**
- **Injury affects both spinal cord and brain**
- **Loss of motor functions is a primary consequence of SCI**
- **Central neuropathic pain is a secondary consequence of SCI**



Central Neuropathic Pain (CNP)

- **Central Neuropathic Pain (CNP) is caused by a lesion or a disease of the somatosensory system (*Jensen et al. 2011 Pain*)**
- **NP develops some time (even years) after the injury**
- **Feels as if coming from the body, generated in the brain (phantom pain)**

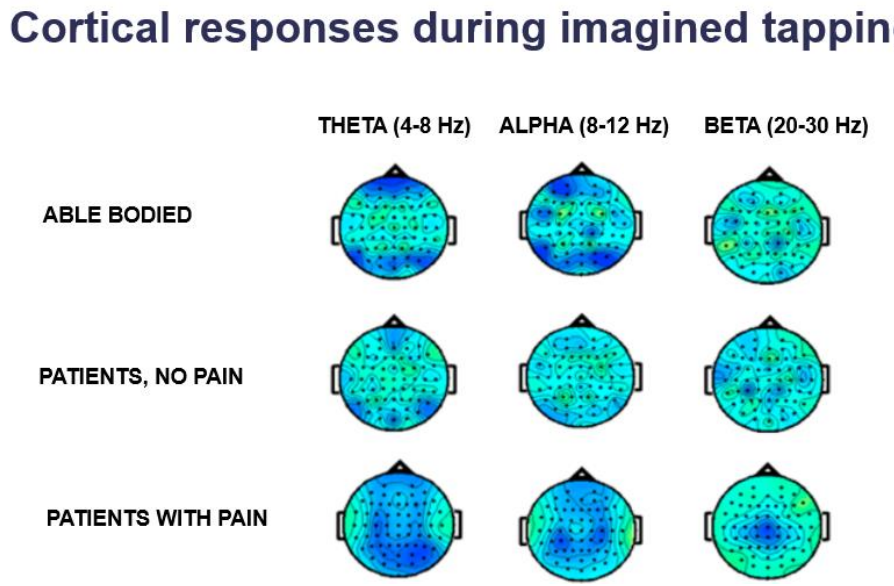




EEG markers of Central Neuropathic Pain

Spinal Cord Injured patients with CNP have

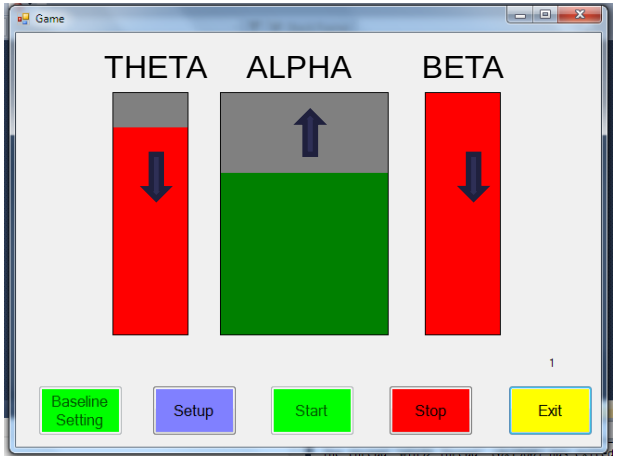
- Increased theta and beta band, decreased alpha band activity
- Dominant alpha frequency reduced, EO/EC reduced
- More intense ERD during imagined movements



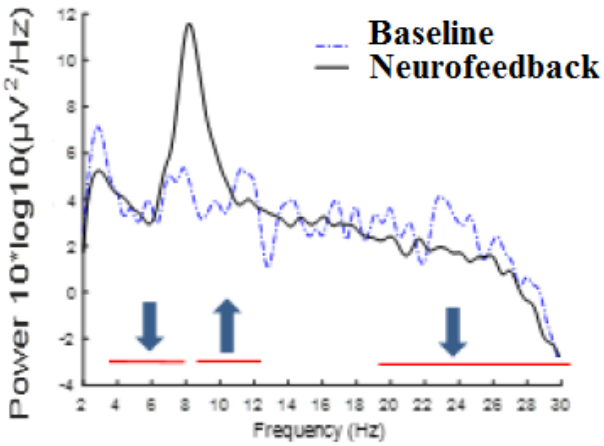
Vuckovic et al. J Pain 2014

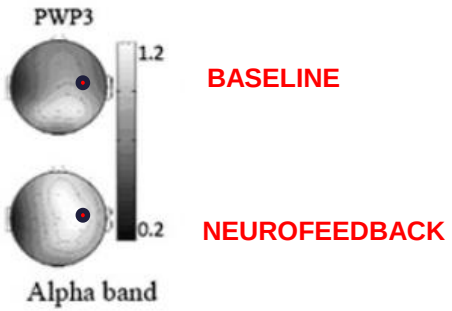
Neurofeedback Clinical Results

- **Two pilot studies with 20 people, one at clinic and other at patients' homes** ***(Clin Neurophsiol 2016, Front Neurosci 2018)***
- **75% patients significantly reduced pain**
- **In 40% clinically significant reduction of pain**
- **Could practice neurofeedback strategy without device**
- **Learning neurofeedback related to self-efficacy and affect**
  (Sci Report 2022 accepted)



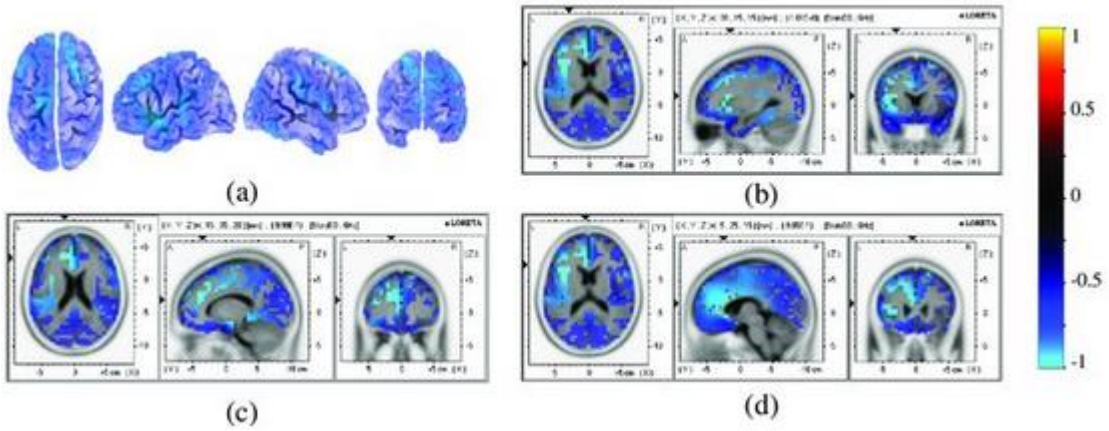
Modulation of EEG During Neurofeedback





- Training to increase alpha and decreased theta and beta band power from one electrode only (C4)
- Wide-spread increase of the alpha rhythm, over the sensory-motor area

BA13 orbitofrontal



BA34 superior temporal gyrus

BA23 posterior cingulate cortex

Changes in brain activity after 40 neurofeedback sessions (averaged over 5 participants)

Hassan et al. 2015 BMC Neurology

Conclusions and Future Work

- **Neurofeedback reduced pain with efficacy similar to gabapentin**
- **Potentially patient self-managed therapy**
- **Long term changes in brain activity**
- **Unlike medication, no side effect**
- **Non-curable condition**
- **Recent meta analysis support evidence of neurofeedback treatment of pain (Patel Eur Jour Pain 2020)**

Conclusions and Future Work

- Neurofeedback reduced pain with efficacy similar to gabapentin
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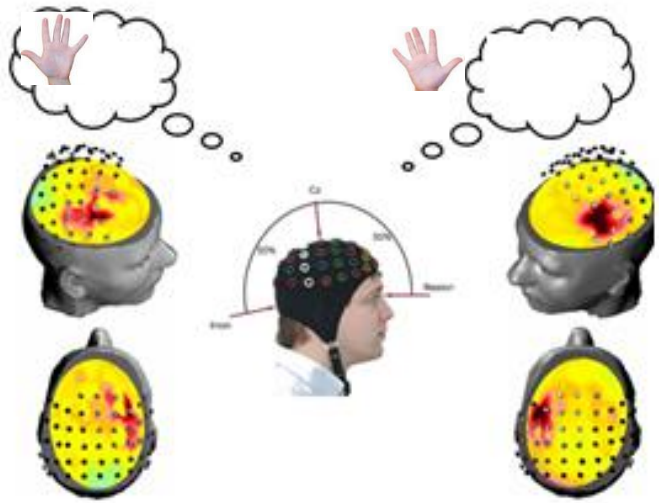
Future Work

- **Testing neurofeedback protocol on patients with different causes of neuropathic pain (collaboration with Singapore Institute of Technology)**
- **Combining neurofeedback with other neuromodulatory therapies of pain for closed loop systems for community use (MRC Neurotechnology Network grant)**
- **Neurofeedback for other neurological problems?**

Brain Computer Interface Controlled Functional Electrical Stimulation for Hand Therapy

BCI based on movement imagination/movement attempt

- **BCI detects brain wave features related to a specific movement using spatial-frequency-time information**
- **Real and imagined/attempted movements activate similar areas of the brain**

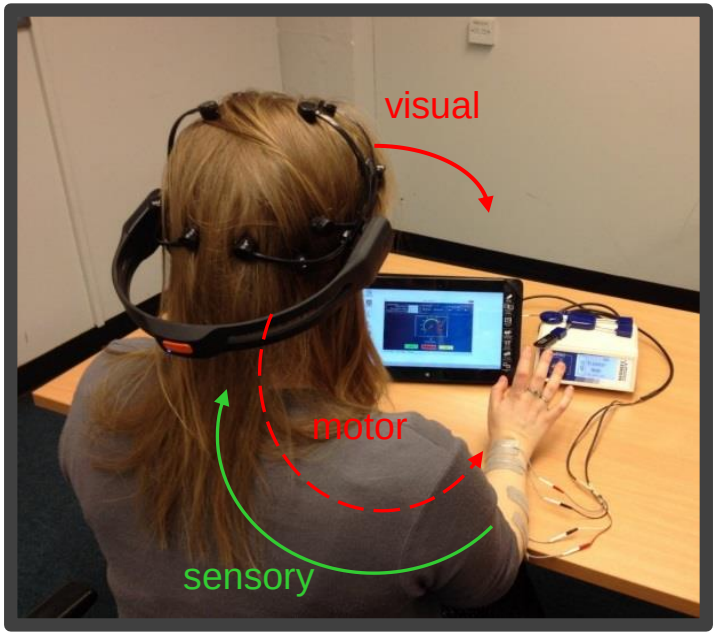


Source: TU Graz

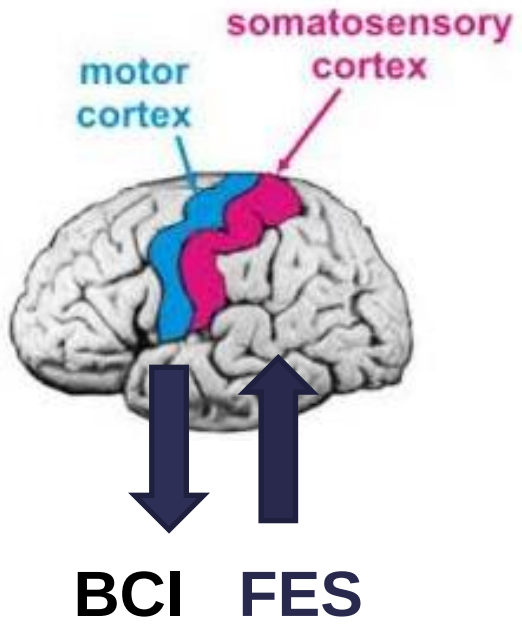
BCI-FES

- Thinking of movement results in characteristic EEG pattern that is recognised by BCI and used to activate hand muscles

- Closing sensory-motor loop results in strengthening of remaining motor pathways



BCI is conditioning the motor cortex prior to FES



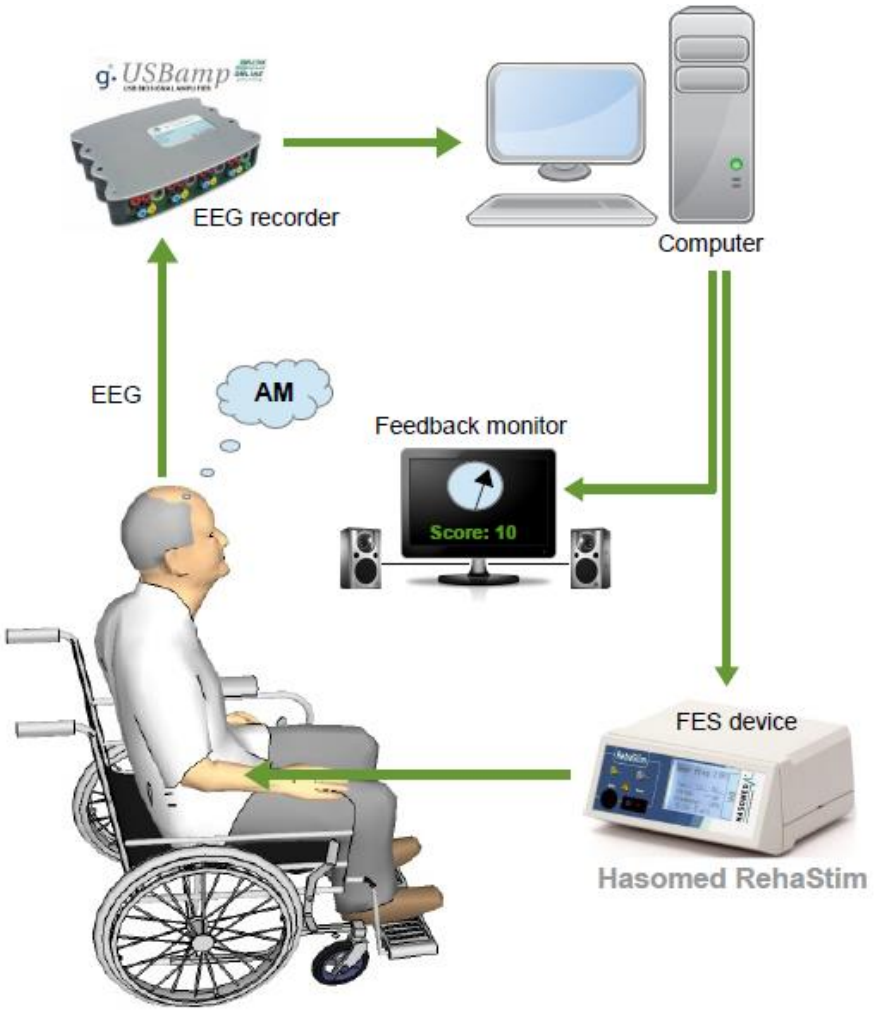
Therapy sessions

Active Group BCI&FES (N=7)

- Visual feedback
- Motor attempt controlled FES

Passive group FES only (N=5)

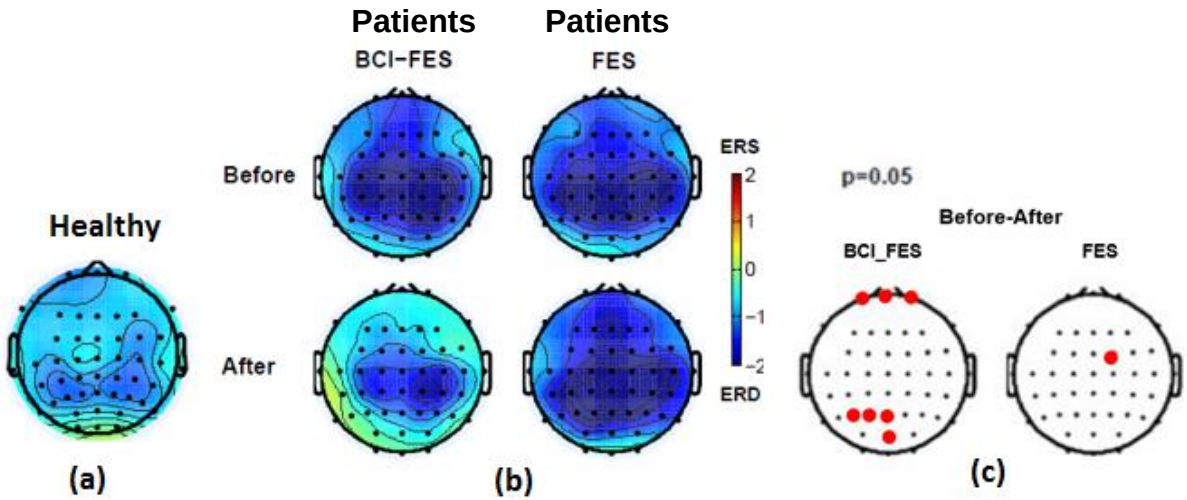
- Same amount of FES automatically activated



(Osuagwu et al. 2016 J Neural Eng)

Results: Neurological Recovery

- **Significant improvement in muscle strength in BCI-FES group only**
- **Event related desynchronisation (ERD) in BCI-FES group**
- Lateralisation;
- Normalisation of wide spread activity;
- Shift from parietal to central region;



ERS/ERD scalp maps, motor attempt of the left hand, 12-16 Hz

Related Studies

- **Usability study exploring transfer of knowledge (8 SCI patients& caregivers couples and 4 therapist)** ***(Neuro Eng Rehab 2021)***

- **Short-term priming effect of uni and bimanual BCI FES (10 stroke patients, 10 able-bodied older and 10 able-bodied younger volunteers)** ***(Clin Neurophysiol 2021)***

- **BCI –FES as priming therapy prior to physiotherapy (ongoing)**

Conclusions and Future Work

- **Motor imagination supported with BCI results in cortical reorganisation indicative of motor recovery**
- **BCI with FES has larger effect on muscle strength than FES alone**
- **Caregivers can learn to setup BCI-FES and deliver therapy**
- **Single 30 min BCI-FES session produces measurable changes in brain activity in stroke patients and healthy people**
- **Bimanual BCI-FES in stroke patients does not supress the activity of the affected side and could be used as a therapy**

Future

- **BCI-FES for rehabilitation of walking**

Acknowledgements

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