EMOTIONAL BRAIN-COMPUTER INTERFACES

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OUTLINE

- Brain-computer interfaces
- Electrophysiological sources of control in BCI
- Emotions
- EEG correlates of emotion
- Emotions and BCI operation
- Emotive BCI operation
- Research agenda
A BCI detects the presence of specific patterns in a person’s ongoing brain activity that relates to the person’s intention to initiate control. The BCI translates these patterns into meaningful commands.

**Brain activity monitoring in BCI**

- Functional Magnetic Resonance Imaging (fMRI)
- Positron Emission Tomography (PET)
- Near-infrared brain (NIR) monitoring
- Magnetoencephalography (MEG)
- Invasive techniques (EECoG)
- Electroencephalography (EEG)
The appearance of EEG rhythmic activity results from the coordinated activation of neuron groups, whose summed synaptic events become sufficiently large.

Neuronal oscillators are composed of neurons that can coordinate their activity through excitatory and inhibitory connections in such a manner that they constitute a network with pacemaker properties.
## Mental Activities to Control a BCI

<table>
<thead>
<tr>
<th>Neuromechanism</th>
<th>Description</th>
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</table>
| **Sensorimotor activity**           | Changes in brain rhythms ($\mu, \beta$) ERD/ERS  
Mu and beta rhythms (8-12 Hz & 13-30 Hz) in the sensorimotor cortex are more prominent when a person is not engaged in processing sensorimotor inputs or in producing motor outputs. A voluntary movement results in a circumscribed desynchronization in the mu and lower beta bands. This desynchronization, event related desynchronization (ERD), begins in the contralateral rolandic region ~2 s prior to the onset of a movement and becomes bilateral before execution of movement. After the movement, the power in the brain rhythm increases (event related resynchronization, ERS). Motor imagery elicits similar patterns of activity. |
| **Visual evoked potentials (VEPs)** | VEPs are small changes in the ongoing EEG (more prominent in the occipital cortex) generated in response to visual stimuli (e.g. flashing lights). If a visual stimulus is presented repetitively at a rate > 5 Hz, a continuous oscillatory response is elicited in the visual pathways. This response is termed steady-state visual evoked potential (SSVEP). |

## Mental Activities to Control a BCI

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<tr>
<td><strong>P300</strong></td>
<td>Infrequent or particularly significant auditory, visual, or somatosensory stimuli, when interspersed with frequent or routine stimuli, typically evoke in the EEG over the parietal cortex a positive peak at about 300 milliseconds after the stimulus presentation. This peak is called P300.</td>
</tr>
<tr>
<td><strong>Slow Cortical potentials (SCPs)</strong></td>
<td>SCPs are slow, non-movement potential changes generated by the subject. They reflect changes in cortical polarization of the EEG lasting from 300 ms up to several seconds.</td>
</tr>
<tr>
<td><strong>Response to mental tasks</strong></td>
<td>BCI systems based on non-movement mental tasks assume that different mental tasks (e.g., solving a multiplication problem, imagining a 3D object, and mental counting) lead to distinct, task-specific distributions of EEG frequency patterns over the scalp</td>
</tr>
</tbody>
</table>
**Most current BCIs utilize:**

- **Sensorimotor activity (mainly motor imagery)**
- **Visual Evoked Potentials**
- **P300**

![BCI Neuromechanisms](image)

**ERD/ERS**

Term coined by Pfurtscheller and Aranibar 1977 “Event-related cortical desynchronization detected by power measurements of scalp EEG”

<table>
<thead>
<tr>
<th>% of change</th>
<th>Hypothetical curve: Prior ERD &amp; Posterior ERS</th>
</tr>
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<tbody>
<tr>
<td>(usually power in a certain freq. band)</td>
<td></td>
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</table>

Zero level

![Graph](image)

Reference interval

t=0 (relevant event)
These curves result from averaging over various trials.

SSVEP

The response to a repetitive visual stimulus is an oscillatory component, at the same frequency/harmonics of the stimulus. The SSVEP is more prominent at occipital sites.
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**EMOTIONS**

- Emotions are psycho-physiological phenomena associated with a wide variety of expressed subjective feelings, observable behaviors and changes in autonomic body state.

<table>
<thead>
<tr>
<th>Discrete perspective</th>
<th>Dimensional perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>James</td>
<td>Plutchik</td>
</tr>
<tr>
<td>Fear</td>
<td>Acceptance</td>
</tr>
<tr>
<td>Grief</td>
<td>Anger</td>
</tr>
<tr>
<td>Love</td>
<td>Anticipation</td>
</tr>
<tr>
<td>Rage</td>
<td>Disgust</td>
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- Emotional states can be plotted along the dimensions of valence and arousal:

  - **Valence** (positive-negative)
  - **Arousal** (calm-activated)

  - Boredom
  - Satisfaction
  - Content
  - Serenity
EMOTION ELICITATION

- Standardized emotional stimuli
  - pictures, films, audio

- Imagination techniques
  - guided imagery, autobiographic recall

- Preset social interactions
  - games

- Directed Facial Action Task

- Drugs

MEASURING EMOTIONS

- Subjective methods
  - Self-report instruments
  - Can accommodate any set of emotions
  - Measure only conscious emotions

- Objective methods
  - Physiological manifestations
    - ANS: facial expression, voice, HR, GSR, temperature, respiration, etc.
    - CNS: EEG, fMRI, etc.
  - Possible difference in the physiological signals for the same emotion in different people
EEG CORRELATES OF EMOTION (1)
FRONTAL EEG ASYMMETRY

- Frontal asymmetry

<table>
<thead>
<tr>
<th>Approach</th>
<th>Avoidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater trait left frontal activity</td>
<td>Greater trait right frontal activity</td>
</tr>
</tbody>
</table>

- ERS/ERD
  - Valence effect
    - Greater left hemisphere theta-ERS for positive stimuli
    - Greater right hemisphere theta-ERS for negative stimuli
  - Arousal effect
    - Affective pictures induce larger amount of theta-ERS than neutral pictures in the 200-500 ms interval after stimuli presentation

EEG CORRELATES OF EMOTION (2)
STEADY-STATE VEPs (SSVEP)

- The SSVEP elicited by a repetitive visual stimulus (RVS) is modulated by the brain processes that occur concurrently
- Presentation of emotion eliciting pictures of the IAPS overlaid with a 13 Hz RVS influence the amplitude, latency and distribution of the corresponding SSVEP

<table>
<thead>
<tr>
<th>Negative valence</th>
<th>Positive valence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal amplitude increase</td>
<td>amplitude increase in the left temporal-parietal, posterior frontal, and right anterior temporal regions</td>
</tr>
<tr>
<td>Occipital amplitude decrease</td>
<td></td>
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</tbody>
</table>
EEG CORRELATES OF EMOTION (2)
EVENT RELATED POTENTIALS (ERP)

- Picture stimuli:
  - Valence effects at early latencies
  - Consistent arousal effects at later latencies
  - Task relevance in the P300 range
  - P3b component sensitive to both valence and arousal

- Utilization of the user’s emotional state to adapt the BCI classification algorithms

- We suggest 2 approaches:
  - Account for the user’s emotional state.
  - Enhancing BCI operation through emotion elicitation.

EMOTIONS AND BCI OPERATION
ACCOUNTING FOR THE USER'S EMOTIONAL STATE

- Proposed approaches:
  - Exhaustive training of the BCI classification algorithm under various emotional states.
  - On-line emotional adaptation of the classification algorithm.

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<th>BCI</th>
<th>Influence of emotions</th>
<th>Strategy</th>
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<tr>
<td>ERD/ERS</td>
<td>Changes in frontal $\alpha \rightarrow$ changes in sensorimotor $\mu$</td>
<td>Adapt the classifier coefficients corresponding to sensorimotor sites</td>
</tr>
<tr>
<td>P300</td>
<td>Amplitude changes after $\sim$200 ms after stimulus presentation</td>
<td>Adapt the classifier coefficients corresponding to samples expected to change with the emotional state</td>
</tr>
<tr>
<td>SSVEP</td>
<td>Scalp distribution, amplitude and latency of the SSVEP</td>
<td>Take such changes into account by modifying the spatial filters used to detect the SSVEP</td>
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</tbody>
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ENHANCING BCI OPERATION THROUGH EMOTION ELICITATION

- **P300 based BCI**
  - arousal amplifies activity in the parietal cortex.
  - the P3b amplitude is influenced by both valence and arousal when the pictures are task relevant.
  - oddball paradigm where the target is an image of positive arousal

- **SSVEP based BCI**
  - arousing pictures elicit higher SSVEP amplitudes in parietal regions
  - stimulation with flickering affectively salient pictures

- **ERD/ERS based BCI**
  - a relatively high resting level of the mu rhythm will entail a more pronounced ERD
  - relaxation techniques for eliciting a high mu level
EMOTIVE BCI OPERATION

- Active use of emotion to control BCI operation
- We consider 2 possibilities:
  - active user involvement and explicit user control
  - dynamic BCI adaptation to the user's emotional state

ACTIVE BCI OPERATION

- Current BCI algorithms:
  - May require long training
  - Their effectiveness depends on the ability of the users to voluntary and consistently control their brain activity.

- Active BCI can provide novel and more natural ways for control, e.g.:
  - Hemispheric asymmetry triggered by a recollection of a pleasant memory
  - Event related responses to emotionally loaded pictures, films and music
PASSIVE BCI operation

- Difficulty adjustment based on the level of interest or irritation of the user
- Satisfaction or frustration identification
  - error related potentials, N400
- Predict the user intentions and minimize the required interaction
  - model approach/avoidance responses
- Enrich communication

RESEARCH AGENDA

- Adapting the recognition algorithms in function of the emotional state of the user:
  - Requires the selection of (online) machine learning methods allowing the incorporation of application specific knowledge.
- Validating the prospect of advantageously utilizing the influence of emotions to enhance BCI operation:
  - Does a high alpha level prior to BCI operation enhance the (motor imagery) ERD?
  - Does the increase in P300 amplitude resulting from arousing pictures prevail in the long term?
- Researching how self-induced emotion can be utilized in a BCI paradigm:
  - Analysis of reproducibility of the corresponding EEG patterns throughout BCI training and operation.