PA199
Advanced Game Design

Lecture 8

Brain Computer Interfaces and Games

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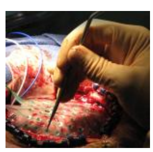
13th April 2017

Introduction

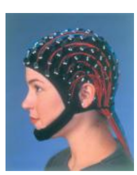
Brain–Computer Interface (BCI) or Brain–Machine Interface (BMI), is a direct way of communication between the brain and a computer system.

Types of BCI's

Invasive



Non-invasive



Types of BCI systems

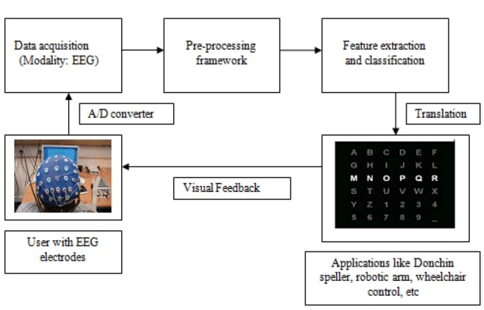

fMRI


fNIRS

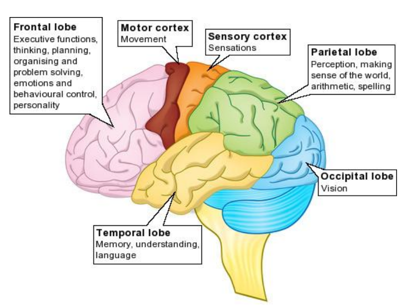

MEG


EEG

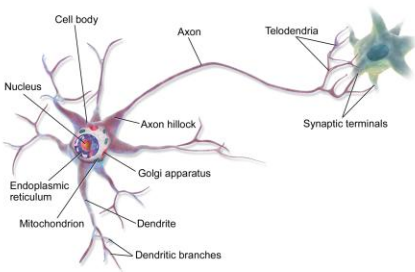
BCI pipeline



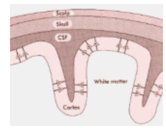
Principles of EEG

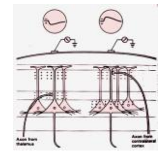


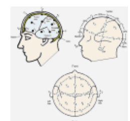
Principles of EEG

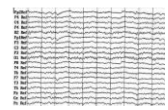


Principles of EEG


section of the skull


Representation of cortex


Electrode placement


EEG signal

Type	Frequency	Location	Use
Delta (δ)	<4 Hz	Everywhere	Occur during sleep, coma
Theta (θ)	4-7 Hz	Temporal and parietal	Emotional stress (frustration & disappointment)
Alpha (α)	8-12 Hz	Occipital and parietal	Sensory stimulation or mental imagery
Beta (β)	12-36 Hz	Parietal and frontal	Intense mental activity
Mu (μ)	9-11 Hz	Frontal (motor cortex)	Intention of movement

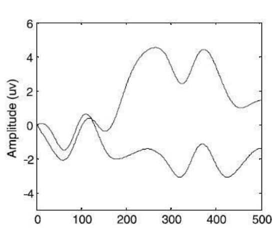
EEG-based BCI paradigm

Event-related (P300)

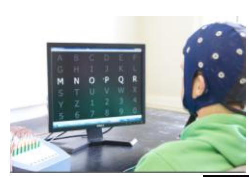
Sensorimotor rhythms

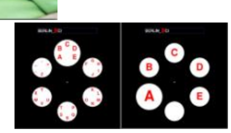
Steady State Visually Evoked Potentials (SSVEP)

Event-related (P300)

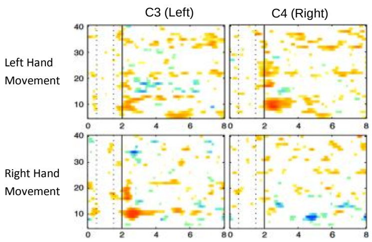


P300 spellers

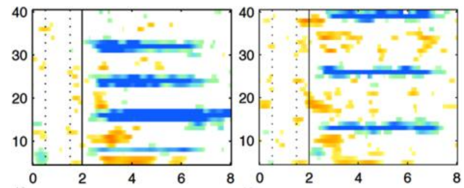




Sensorimotor rhythms



SSVEP



Commercial BCI Headsets

- Non-invasive BCI's most commonly use EEG:
  - Portability, low set-up cost, easy of use
- Low-cost BCI headsets are used the last 5-7 years

Initial Work

- Two non-invasive BCI headsets have been used to control
  - Lego Mindstroms NXT Robot
  - A simple computer game
- Two prototypes
  - First Prototype was based on the Neurosky Mindset
  - Second Prototype was based on the Emotiv Epoc headset

Neurosky Headset

- NeuroSky MindWave is a simplified version of the traditional EEG technology
- The MindSet monitors:
  - Electrical potential between the sensing electrode
    - Positioned on the forehead
  - Reference electrodes
    - Positioned on the left earlobe

Neurosky Advantages

- Very easy to use
- No calibration is required
  - Plug and play!
- Good support is provided
  - SDK

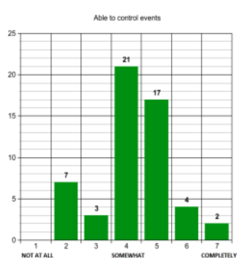
First prototype - Neurosky

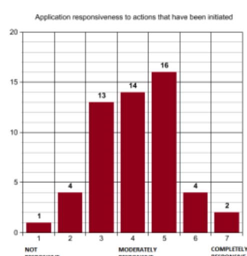
- *Attention* and *Meditation* levels are used
- Values from the headset are passed to the robot
  - Through the dedicated computer
- The robot is instructed to accelerate based on the attention levels of the user

Neurosky Drawbacks

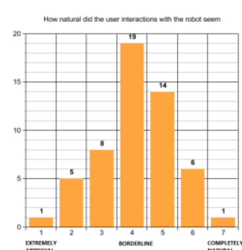
- Since there is only one sensor in place, separating brainwaves becomes a challenge
- Because the headset is not fastened to the head, pronounced muscle movements, such as yawning, facial expressions may result in a momentary decrease in signal quality

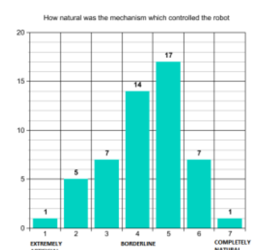
Initial User Evaluation





Initial User Evaluation .



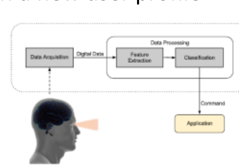


Recorded Feedback

Positive	Negative
• Interesting concept • Could be very useful • Lots of potential • Can help increase peoples concentration level • Can help improve disabled peoples lives • Can help for brain rehabilitation by triggering the motor cortex of the brain • The feel of controlling it with my mind was awesome.	• Not being able to move left/right • Need some indication on the PC as to the level of thought • Needed less distractions • Difficult to keep the robot stationary • Too many outside stimuli • Hard to remain calm

Second Prototype - Emotiv

- The system relies on a combination of Cognitive and Facial/Muscular functions
- The Emotiv Development Kit was used to create and train a new user profile

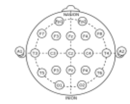


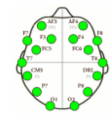
Emotiv Epoc Headset

- Emotiv Epoc Headset has 14 wet sensors (and 2 reference sensors) detecting brain signals and facial expressions

Emotiv Epoc Headset .

- Sensors are placed on the international 10-20 system, which describes the electrode placement on the scalp for EEG tests or experiments





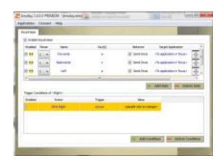
User Training

- Emotiv needs a unique user profile to be trained to map users' brain-activity

Control Panel

User Training .

- In a training session no more than 1 min, user's skills are increasing approximately from 45%-70% for the "push" action

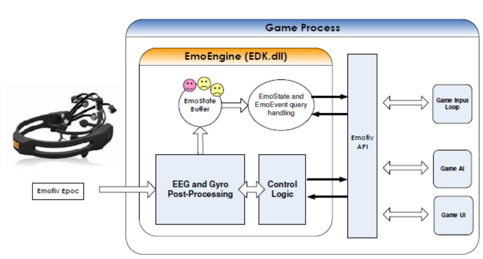


EmoKey

Game Control

- Each trained thought from the BCI headset is treated as a keystoke
- That communicates with Emotiv EmoEngine as a third-party application by using the Emotiv API
- The Emotiv EmoEngine refers to the logical abstraction of the functionality that Emotiv provides in edk.dll

BCIs and Computer Games

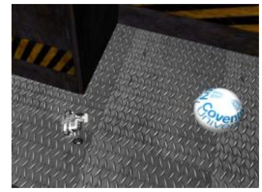


Methodology

- Profile training using Control Panel for 60s (push/pull actions plus blink calibration)
  - Navigating the 3D robot inside the maze to a pre-defined waypoint (increasing users cognitive workload)
- A second training session of 60s
  - Interacting with RomaNova
- Evaluation form completion and feedback interview

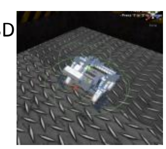
3D Maze Game

- The 3D environment has been designed using the 'Unity 3D' game engine with a 3D reconstruction of the robot and a simple 3D maze

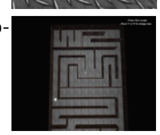


Game Elements

- 3D Robot
  - The LEGO NXT Mindstorms Robot 3D model has been used with a simple wheel animation, interacting with basic physics



- Maze walls
  - The maze is made by a set of hetero-sized blocks



Roma Nova Project

- Seeking to advance information transfer through immersive 'living background'
- Partners:
  - Serious Games Institute
  - University of Toulouse

Brain Computer Interactions

- The Cognitive functions (brainwaves) are used to move the robot forwards/backwards
- The Expressive functions are used to steer the robot left/right when the user blinks accordingly

Initial Evaluation

- An evaluation session has been conducted with five participants in a laboratory environment
- Feedback was received in direct reply to the questions, as well as by raising additional issues
- All participants had no previous experience with BCIs so some time was given to familiarise with the technology

Initial Evaluation .

- Since all users interacted with a virtual object using their brain activity for the first time, it was necessary to perform repeatable profile training
  - So players managed to familiarise with the prototype system
- At this stage, the system extracts and classifies the player's intentions more accurately

Initial Evaluation ..

- All participants had to complete a small task
  - 5 to 10 minutes
- The task was to
  - Move an avatar inside the Roma Nova
  - Interact with the agents using just brainwaves and facial expressions

Positive Feedback

- All participants mentioned that it was a unique experience to interact with the game through brainwaves
- Even if it was 'slower' to interact with the game they reported that this way of interaction is far more enjoyable
  - Compared to standard input devices such as the mouse and the keyboard

Positive Feedback .

- All users enjoyed the graphics quality of the game
  - As well as the 'clever' dialogues with the intelligent agents
- The majority of the players mentioned that the brain computer technologies can be very useful for interaction in games and it can be combined with other techniques

Negative Feedback

- Some users found it hard to adapt in taking control of the agent straight away
  - They got distracted by external stimuli
- Some mentioned that it was not easy to concentrate in the game and they would prefer a more immersive environment
  - Even if through time they started to get control and adapt to the prototype system

Negative Feedback .

- Finally, some participants found the BCI technology not as accurate as standard input devices
  - Even if in this particular game there were no significant requirements on accuracy in navigation, in other computer games that could be problematic

End User Evaluation

- 31 users have been evaluated the hybrid BCI architecture providing feedback by interacting with the two games
- Each user had to complete a set of tasks to evaluate efficiently the system and the overall interaction
- EEG data from two mental tasks of the user (push, pull) had been recorded and stored in order to be analysed and processed

Cerebral Palsy User Case

- Cerebral palsy (CP) is a motor condition that causes physical disability in human development in various areas of body movement
- A user with Cerebral Palsy had been interacted successfully with the system, being able to move the virtual objects despite being affected by spastic hemiplegia

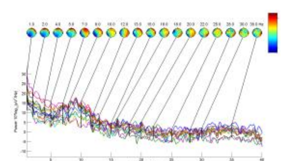
Results

- 16/31 (51%) users have reported through their answers that they were engaged to the game
- EEG analysis had been performed to see if their answers matches their brain activity

4.55	4.35	4.23	4.35	5	3.9	5.19	4.51
5	5	5	5	6	4	6	5.14
5	4	6	3	6	5	5	4.85
5	6	5	5	6	5	6	5.42
5	3	5	3	3	5	4	4
4	4	4	3	3	5	6	4.14
4	1	3	7	6	2	5	4
5	3	3	5	5	2	1	3.428571
5	4	6	5	4	2	5	4.428571
5	4	5	5	4	5	5	4.714286
5	5	5	5	7	7	6	5.714286
5	4	3	3	6	3	5	4.142857
5	5	5	4	7	5	7	5.428571
5	3	3	4	4	3	7	4.142857
4	4	3	3	7	3	6	4.285714
4	6	5	4	5	5	5	4.857143
4	3	3	3	4	1	4	3.142857
5	5	5	6	5	4	4	4.857143
5	3	3	2	3	2	3	3
5	4	3	6	5	5	6	4.857143
4	4	4	5	5	2	4	4
5	5	6	6	7	1	7	5.285714
5	4	1	1	3	3	5	3.142857
5	5	4	3	4	1	4	3.714286
5	6	7	6	6	6	7	6.142857
4	5	3	5	7	5	5	4.857143
3	6	5	5	5	6	6	5.142857
4	5	5	6	5	6	6	5.285714
4	5	4	4	5	4	5	4.428571
4	5	4	4	5	5	5	4.571429
5	4	3	4	3	4	5	4
3	5	5	5	4	5	6	4.714286

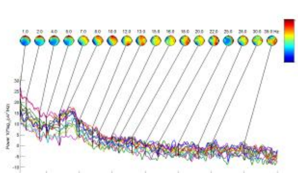
Results .

- Delta and Theta rhythms (0.1-4-8Hz) are low-frequency EEG patterns that increase during sleep in the normal adult



Results ..

- Beta rhythms (12-30Hz) occur in individuals who are alert and attentive to external stimuli or exert specific mental effort



Results ...

- 9 out 31 users found with increased Beta activity
- That's 29% of the users that scored high on the engagement related questions

User No.	Increased Activity (Hz)	increased Beta Rythms(Y/N)
1	1-7Hz, 25-30Hz	Y
2	1-12Hz	N
3	2-22Hz	Y
9	4-28Hz	Y
10	8-18Hz, 28-35Hz	Y
12	1-5Hz	N
15	1-5Hz, 30Hz	N
17	1-5Hz	N
19	1-4Hz	N
21	1-4Hz, 35Hz	N
24	7-15Hz	Y
25	1-5Hz	Y
26	7-22Hz	Y
27	8-13Hz	Y
29	1-4Hz	N
31	7-16Hz, 18-22Hz	Y

General Finding

- This proves that user's experience may is different from what actually was recorded through the EEG
  - Taking in good faith that the headset measured accurately

Enobio

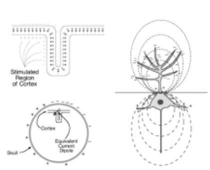
BCI illiteracy

Around 20 % of BCI users do not obtain reliable BCI control (Tan and Nijholt, 2010).

- Investigation of BCI illiteracy can lead to:
- Avoid unnecessary training sessions
- Develop co-adaptive learning strategies to 'cure' BCI illiteracy
- Understand neurophysiological-basis of BCI illiteracy
- ... and ultimately build better BCI systems!

Physical factors make classification difficult.

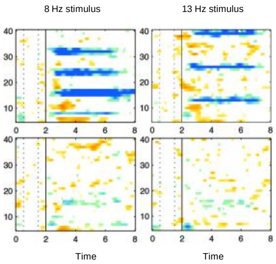
- Differences in brain anatomy may yield very variable signal quality
- Large muscle artefacts



BCI illiteracy has been shown in different paradigms.

- Steady-State VEP (SSVEP)
- Evoked Related Potentials (ERP)
- Sensory Motor Rhythms (SMR)

Illiteracy in SSVEP



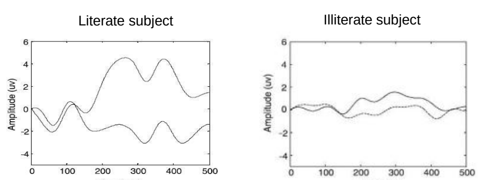
SSVEP-BCI illiteracy

Mostly demographic data:

- Age and gender may be important but not significant
- handedness
- vision correction
- tiredness
- time slept
- alcohol
- and caffeine
- computer work
- computer games.. .. had no effect.

(Allison et al., 2010; Volosyak et al., 2011).

Illiteracy in P300-based BCI



(Tan and Nijholt, 2010)

Illiteracy in P300-based BCI

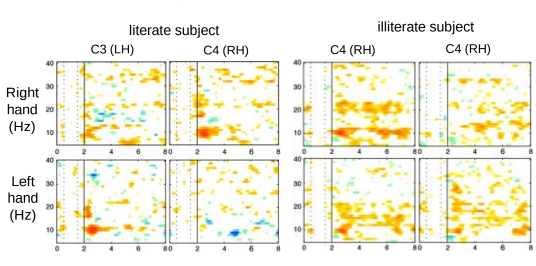
Gender, level of education, working duration and cigarette and coffee consumption did not show significant differences. Participants who slept less than 8 hours showed to perform better (Guger et al., 2009).

Table 1. Amplitudes, latencies and correlations thereof with BCI performance shown for N200 (minimal amplitude before latency of P300 on Cz), P300 (maximum between 250 and 700 ms on Cz) and late ERP component (maximum after P300 latency on POz).

	Amplitude (μV)	R auditory	R visual	Latency (ms)	R auditory	R visual
N200 (Cz)	−3.25 (SD 2.25)	**0.37 (p = 0.02)**	**0.47 (p<0.01)**	229.05 (SD 42.57)	−0.22 (p = 0.18)	0.04 (p = 0.81)
P300 (Cz)	4.99 (SD 2.66)	0.04 (p = 0.81)	−0.05 (p = 0.75)	378.00 (SD 89.00)	**−0.32 (p<0.05)**	0.07 (p = 0.65)
Late ERP (POz)	3.61 (SD 2.10)	−0.26 (p = 0.12)	**−0.46 (p<0.01)**	548.65 (SD 168.55)	0.07 (p = 0.66)	0.19 (p = 0.25)

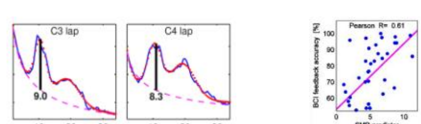
(Halder et al., 2013)

Imagined movements of right and left limbs may not elicit SMR.



Predicting BCI performance in SMR

- power spectrum density in alpha band in the (Blankertz et al., 2009)

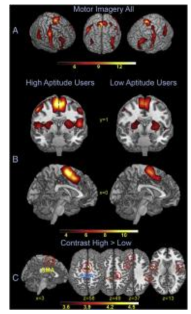


- motor imagery (Vuckovic, 2010)
- locus of control of reinforcement with (LOC) regard to dealing with technology (Burde and Blankertz, 2006)

Predicting BCI performance in SMR

- performance level (measured by Attitudes Towards Work test)
- two-hand coordination (Hammer et al., 2012)
- age and daily average amount of hand and arm movement (Randolph et al., 2006)
- mood and motivation (Nijboer et al., 2008)

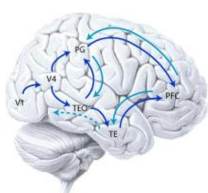
Predicting BCI performance in SMR



Participants with better SMR-BCI performance employ larger cortical area during motor imagery. The number of activated voxels during motor observation was significantly correlated with accuracy in the EEG-BCI task (r=0.53).(Halder et al., 2011)

Two types of attention

- Dorsal, top-down, network (light blue)
- Ventral, bottom-up, network (dark blue)



(Desimone & Duncan, 1995)

Does attention have an effect on BCI performance?

- Good SMR performers activated prefrontal cortex and supplementary motor area significantly more than bad performers which is involved in top-down attention (Halder et al., 2011).
- Attention (measured by block tapping task and digit span) correlated with ability to control slow cortical potentials (SCP)(Daum et al., 1993). Control of SCP relies on cortico-basal ganglia-circuits (Hinterberger et al., 2005).
- Meditation influences BCI performance:

I. Zen meditation improves control of EEG signal (Lo et al., 2004) and classification accuracy (Eskandari and Erfanian, 2008) .
II. Vipassana and Himalayan meditation resulted in higher peaks frequency in SSVEP (Karalis et al., 2011; Karalis et al., in press).
III. Mindfulness meditation training improves P300-based BCI performance (Lakey et al., 2011).

How to combat BCI illiteracy?

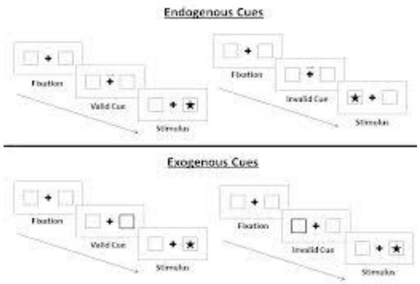
- improve classification accuracy
- change paradigm
- change neuroimaging technique
- combine neuroimaging techniques
- combine paradigms

Effects of attention on P300-based BCI performance

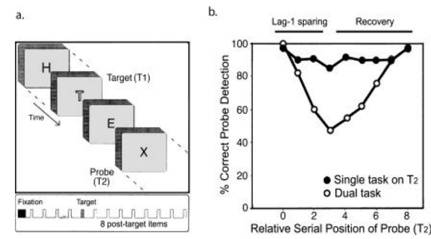
Three measures:

- Attentional blink
- Posner cueing task
- P300-bic task

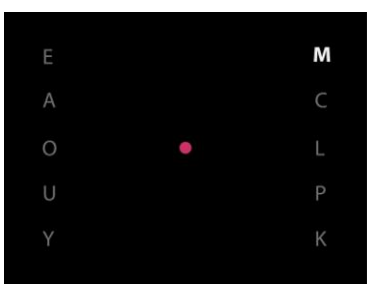
Posner cueing task



Attentional blink



P300 task



Thank you for your attention!

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