PA199
Advanced Game Design

Lecture 7

Brain Computer Interfaces

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Introduction

Introduction

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

BCI Categories


fMRI

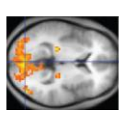

fNIRS


MEG


EEG

Functional Magnetic Resonance Imaging (fMRI)

- fMRI measures brain activity by detecting changes associated with blood flow
  - Relies on the fact that cerebral blood flow and neuronal activation are coupled
  - When an area of the brain is in use, blood flow to that region also increases
- High spatial resolution
  - Tells you what is the smallest feature you can see based on your detector



https://en.wikipedia.org/wiki/Functional_magnetic_resonance_imaging

Functional Near-Infrared Spectroscopy (fNIRS)

- fNIRS is a non-invasive imaging method for measuring brain activity through hemodynamic responses associated with neuron behavior
- fNIR and fMRI are sensitive to similar physiologic changes and are often comparative methods
- Studies relating fMRI and fNIR show highly correlated results in cognitive tasks

https://en.wikipedia.org/wiki/Functional_near-infrared_spectroscopy

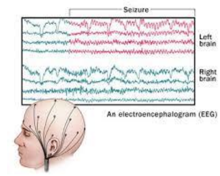
Magnetoencephalography (MEG)

- MEG is a functional neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain
  - Using very sensitive magnetometers
- High temporal resolution
  - Tells you how quickly you can measure things

https://en.wikipedia.org/wiki/Magnetoencephalography

The Electroencephalogram (EEG)

- An (EEG) is a measure of the brain's voltage fluctuations as detected from scalp electrodes
- It is an approximation of the cumulative electrical activity of the neurons
- High temporal resolution



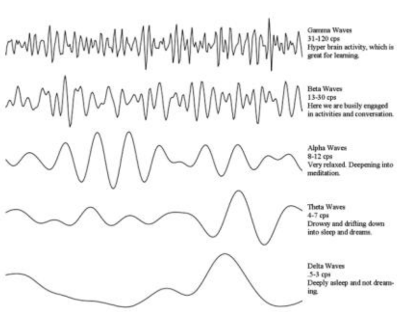
Brainwaves and EEG

- The human brain is made up of billions of interconnected neurons
- The patterns of interaction between these neurons are represented as thoughts and emotional states

EEG Frequencies

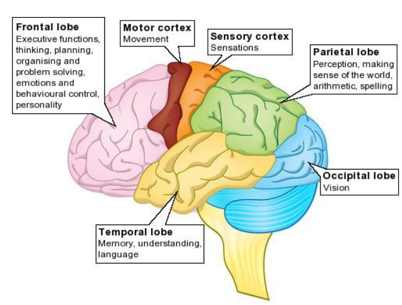
Type	Frequency	Location	Use
Delta (δ)	<4 Hz	Everywhere	Occur during sleep, coma
Theta (θ)	4-7 Hz	Temporal and parietal	Emotional stress (frustration & disappointment)
Alpha (α)	8-12 Hz	Occipital and parietal	Sensory stimulation or mental imagery
Beta (β)	12-36 Hz	Parietal and frontal	Intense mental activity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

Brainwaves Graph



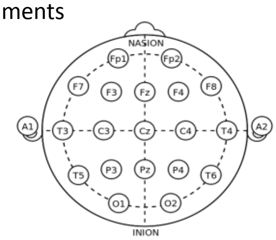
http://braintrainers.net/

Principles of EEG



The 10-20 System

- The international 10-20 system describes the electrode placement on the scalp for EEG tests or experiments



Types of BCIs

Invasive BCI, implanted surgically

Partially-Invasive BCI, implanted inside the scalp

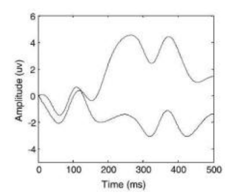
Non-Invasive BCI, using electrode cap

EEG-based BCI paradigm

- Three types:
  - Event related potential (P300)
  - Sensorimotor rhythms (SMR)
  - Steady State Visually Evoked Potentials (SSVEP)

Event Related Potential (P300)

- The P300 is thought to reflect processes involved in stimulus evaluation or categorization
- When recorded by EEG, P300 surfaces as a positive deflection in voltage with a latency of roughly 250 to 500 ms
  - The signal is typically measured by the electrodes covering the parietal lobe



https://en.wikipedia.org/wiki/P300_(neuroscience)

P300

- The presence, magnitude, topography and timing of this signal are often used as metrics of cognitive function in decision making processes
- While the neural substrates of this ERP component still remain hazy, the reproducibility and ubiquity of this signal makes it a common choice for psychological tests in both the clinic and laboratory

https://en.wikipedia.org/wiki/P300_(neuroscience)

P3a and P3b

- Since the initial discovery of the P300, research has shown that the P300 has two subcomponents
  - P3 or P3a
  - P300 which has since been renamed P3b

https://en.wikipedia.org/wiki/P300_(neuroscience)

P3a

- P3a has a positive-going amplitude that displays maximum amplitude over frontal/central electrode sites and has a peak latency in the range of 250-280 ms
- Associated with:
  - Brain activity related to the engagement of attention (especially the orienting, involuntary shifts to changes in the environment)
  - Processing of novelty

https://en.wikipedia.org/wiki/P300_(neuroscience)

P3b

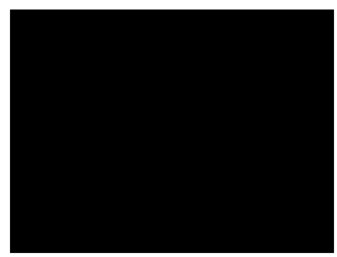
- P3b has a positive-going amplitude that peaks at around 300 ms, and the peak will vary in latency from 250-500 ms or more depending upon the task
  - Amplitudes are typically highest on the scalp over parietal brain areas
- Used to study cognitive processes
  - Especially psychology research on information processing
- The P3b can also be used to measure how demanding a task is on cognitive workload

https://en.wikipedia.org/wiki/P300_(neuroscience)

P300 Spellers

- Very popular nowadays

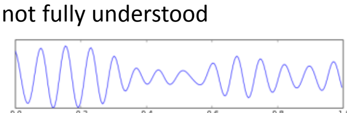
P300 Speller Video



https://www.youtube.com/watch?v=y3IGJVnSSsg

Sensorimotor Rhythms (SMR)

- SMR is an oscillatory idle rhythm of synchronized electromagnetic brain activity
  - It appears in spindles in recordings of EEG, MEG, and ECoG over the sensorimotor cortex
- The frequency is in the range of 13 to 15 Hz
- SMR is not fully understood



https://en.wikipedia.org/wiki/Sensorimotor_rhythm

How SMR Works

- Brain is producing a stronger SMR amplitude when the corresponding sensorimotor areas are idle:
  - During states of immobility, thus often mixed up with alpha waves
- SMR typically decrease in amplitude when the corresponding sensory or motor areas are activated
  - i.e. during motor tasks and even during motor imagery
- SMR is very difficult to detect as it is usually superimposed by the stronger occipital alpha waves
- The feline SMR has been noted as being analogous to the human mu rhythm

https://en.wikipedia.org/wiki/Sensorimotor_rhythm

SMR Neurofeedback

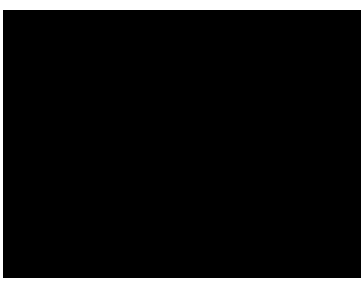
- Neurofeedback training can be used to gain control over the SMR activity
  - This feedback enables the subject to learn the regulation of their own SMR
  - Some patients may benefit from an increase in SMR activity via neurofeedback
    - i.e. learning difficulties, ADHD, epilepsy and autism
- In BCIs, the SMR amplitude during motor imagery can be used to control external applications

https://en.wikipedia.org/wiki/Sensorimotor_rhythm

SMR Speller Video

https://www.youtube.com/watch?v=R-tNE-y2QU0

Two-Dimensional BCI Control



https://www.youtube.com/watch?v=KMxop6xzsKM

Mu Waves

- Mu waves (known as mu rhythms, or sensorimotor rhythms) are synchronized patterns of electrical activity involving large numbers of neurons in the part of the brain that controls voluntary movement
  - These patterns repeat at a frequency of 7.5–12.5 (and primarily 9–11) Hz
  - Most prominent when the body is physically at rest
- Measured by:
  - Electroencephalography (EEG)
  - Magnetoencephalography (MEG)
  - Electrocorticography (ECoG)

https://en.wikipedia.org/wiki/Mu_wave

Mu Waves .

- Unlike the alpha wave, which occurs at a similar frequency over the resting visual cortex at the back of the scalp, the mu wave is found over the motor cortex, in a band approximately from ear to ear
- A person suppresses mu wave patterns when he/she performs a motor action or, with practice, when he or she visualizes performing a motor action
  - This is called desynchronization of the wave because EEG wave forms are caused by large numbers of neurons firing in synchrony

https://en.wikipedia.org/wiki/Mu_wave

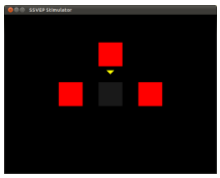
Steady State Visually Evoked Potentials (SSVEP)

- SSVEP are signals that are natural responses to visual stimulation at specific frequencies
- When the retina is excited by a visual stimulus ranging from 3.5 Hz to 75 Hz, the brain generates electrical activity at the same (or multiples of) frequency of the visual stimulus

https://en.wikipedia.org/wiki/Steady_state_visually_evoked_potential

SSVEP Usage

- This technique is used widely with electroencephalographic research regarding vision
- SSVEP's are useful in research because of the excellent signal-to-noise ratio and relative immunity to artifacts



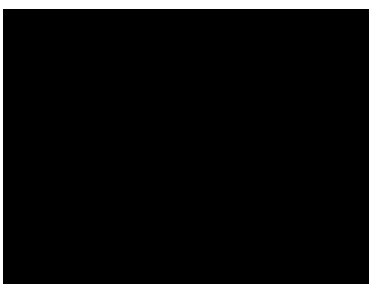
Open Vibe

https://en.wikipedia.org/wiki/Steady_state_visually_evoked_potential

SSVEP-based Mindspeller

https://www.youtube.com/watch?v=ZupEt1uvcls

SSVEP Chess Video



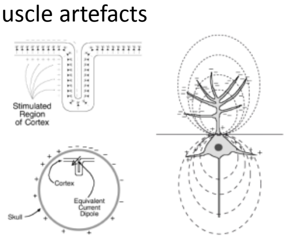
https://www.youtube.com/watch?v=splVPw7XbCs

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 improve BCI illiteracy
  - Understand neurophysiological-basis of BCI illiteracy
  - Build better BCI systems

Classification Issues

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



How to Improve BCI Illiteracy

- Improve classification accuracy
- Change paradigm
- Change neuroimaging technique
- Combine neuroimaging techniques
- Combine paradigms

EEG Devices

Cheap 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 10 years

Neurosky Headset

- NeuroSky MindWave is a simplified version of the traditional EEG technology
- Attention and Meditation levels are calculated from raw brainwaves by monitoring:
  - Electrical potential between the sensing electrode
    - Positioned on the forehead
  - Reference electrodes
    - Positioned on the left earlobe

http://neurosky.com/

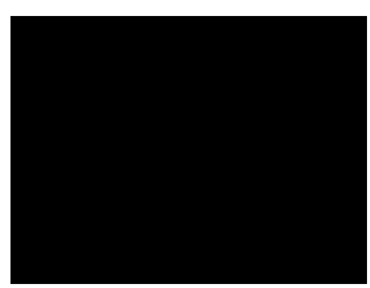
Neurosky Advantages

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

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

Neurosky MindWave Video



https://www.youtube.com/watch?v=1tr4CjtGtvg

Emotiv Epoc Headset

- Emotiv Epoc Headset has 14 wet sensors (and 2 reference sensors) detecting brain signals and facial expressions
- Emotiv requires a unique user profile to be trained to map users' brain-activity

Control Panel

https://emotiv.com/

Emotiv Epoc Wheelchair

https://www.youtube.com/watch?v=0at3NzNRySg

gMOBIlab

- gMOBIlab from g.tec
- Available in two versions:
  - 8 channel EEG
  - Multi-purpose version
- Multiplatform
  - Windows and Linux
- Integration
  - C or Matlab

http://www.gtec.at/Products/Hardware-and-Accessories/g.MOBIlab-Specs-Features

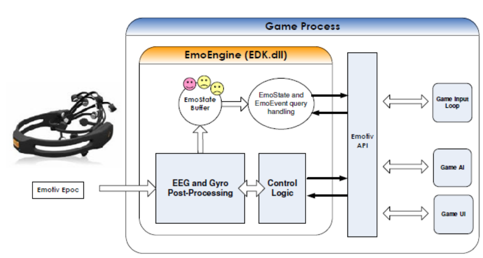
Enobio BCI

- Wireless, lightweight, comfortable
- Comes in 8, 20 and 32 channels
- Bandwidth: 0 (DC) to 125 Hz
- Sampling rate: 500 SPS
- Resolution: 24 bits – 0,05 microvolt (uV)
- Triaxial accelerometer data
  - For artifact removal

http://www.neuroelectrics.com/products/enobio/enobio-32/

Case Studies

BCIs and Computer Games



Methodology

- Interaction
  - Cognitive functions (brainwaves) are used to move the forwards/backwards
  - Expressive functions are used to steer left/right
    - When the user blinks accordingly
- 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)
- Evaluation with 30 users

Videos

3D Maze Game

RomaNova Game

Liarokapis, F., Debattista, K., Vourvopoulos, A., Petridis, P., Ene, A., Comparing interaction techniques for serious games through brain-computer interfaces: A user perception evaluation study, Entertainment Computing, Elsevier, 5(4): 391-399, 2014.

Comparison of Questionnaires

- No significant differences for the ability to control, responsiveness, interaction and naturality of experience were found
  - Can be explained by the similar difficulty of the BCI task

Variable	Robot	Roma Nova	T-test(df)	Sig.
Ability to control	3.452	3.129	t(30) = 1.976	0.057
Responsiveness	3.226	3.581	t(30) = -1.688	0.102
Interaction	3.323	3.032	t(30) = 1.393	0.174
Naturality	3.484	3.290	t(30) = 0.862	0.395

Comparison of Questionnaire & EEG

- Questionnaire
  - 16/31 (51%) users have reported through their answers that they were engaged to the game
- EEG
  - 9 out 31 users found with increased Beta activity
  - That's 29% of the users that scored high on the engagement related questions
- This could mean that whatever the users think about their status is different on what actually was recorded through the EEG
  - Taking in good fain that the headset measured accurately

Multimodal BCI Games

Liarokapis, F., Vourvopoulos, A., Ene, A. Examining User Experiences Through A Multimodal BCI Puzzle, Proc. of the 19th International Conference on Information Visualisation (IV 2015), IEEE Computer Society, Barcelona, Spain, 21-24 July, 488-493, 2015. (DOI: 10.1109/IV.2015.87)

Multimodal Games

- The game is multimodal, supporting a "BCI input" and a "no BCI input" mode
- In the latter, meditation is defaulted at 50% of its maximum possible value
  - Speed is only affected by the number of cleared lines
- An instance of the game depends on:
  - Name of the player
  - Log's creation timestamp
  - Meditation

Liarokapis, F., Vourvopoulos, A., Ene, A. Examining User Experiences Through A Multimodal BCI Puzzle, Proc. of the 19th International Conference on Information Visualisation (IV 2015), IEEE Computer Society, Barcelona, Spain, 21-24 July, 488-493, 2015.

Video

Evaluation Procedure

- Evaluated by 30 volunteers
  - Selected by random sampling
  - Duration was approximately 30 minutes
  - 73.33% males, 26.67% females
- The dominant age group is 18-25 with 80%
  - 10% only aged 26-33
- 83.3% participants reported using the computer to a very high degree in their daily activities
  - However, in terms of gaming experience the percentage drops to 23.33%

EEG Rhythms Log

- Significant correlations were found for attention
- Decreasing Theta ($r = -0.2885$, $p < 0.05$)
  - Theta is usually linked to inefficiency and daydreaming
- High Alpha ($r = -0.1841$, $p < 0.05$)
  - Alpha rhythms attenuate with drowsiness, concentration, stimulation or visual fixation
- High Gamma ($r = -0.1589$, $p < 0.05$)
  - High gamma oscillations have been observed in a variety of different purpose neuro-anatomical domains including information processing

Conclusions

- More experienced gamers did not notice the speed difference because they usually rushed the pace of the game
- No significant change in terms of meditation was observed from one game mode to the other
  - Participants can get considerably frustrated
- Significant correlations of EEG rhythms with attention showed that users could possibly be more concentrated during the session
  - Achieving a high degree of relaxation overall during non-BCI control

Prior Gaming Experience in MI

Vourvopoulos, A., Liarokapis, F., Chen, M.C. The Effect of Prior Gaming Experience in Motor Imagery Training for Brain-Computer Interfaces: A Pilot Study, Proc. of VS-Games 2015, IEEE Computer Society, Skovde, Sweden, 16-18 September, 139-146, 2015.

Video Games and the Brain

- People regularly exposed to video-games have improved :
  - Visual and spatial attention (C. S. Green, D. Bavelier, Nature, 2003)
  - Memory (J. Feng et al., Psychol. Sci., 2007)
  - Mental rotation abilities
  - Enhanced sensorimotor learning (D. G. Gozli, et al.,Hum. Mov. Sci., 2014)
- Extensive video-game practice has also been shown to improve the efficiency of:
  - Movement control brain networks
  - Visuomotor skills (J. A. Granek, et al., Nerv. Syst. Behav., 2010)

How Used in Current Mental Tasks?

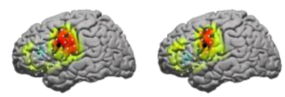
- Mental rotation
- Motor imagery
- Remembering familiar faces
- etc…

Important for using BCIs

Motor Imagery (MI)

- MI is a mental process by which an individual rehearses or simulates a given action
  - Implies that the subject feels herself/himself performing the action
  - MI is relying on the same brain systems that would be used for actual performance of the task (Miller et al., 2010)

Movement



Imagery

Miller, K. J., Schalk, G., Fetz, E. E., Nijs, M. den, Ojemann, J. G., & Rao, R. P. N. (2010). Cortical activity during motor execution and motor imagery. Proceedings of the National Academy of Sciences of the United States of America, 107(9),4430-5

Neurogaming & Brain-Controlled Virtual Environments

- BCI's used as primary input
- Excludes the use of traditional controllers

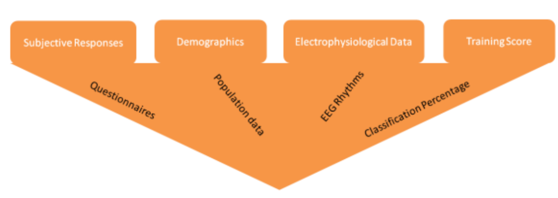
Current Limitations

- Long and repetitive training sessions can result in user fatigue and declining performance over time
- No relationship between videogame practice and BCI training

In this Study

- Neurophysiological correlates of gaming experience reflected in MI-BCI training
- Designed an experimental setup including:
  - A standard BCI training paradigm
  - Two different user groups based on their previous gaming experience

Types of Acquired Data

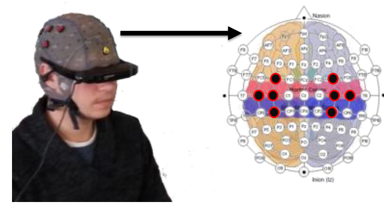


Methodology: Participants

- 12 participants
- Mean age of 28 yrs
- 8 male, 4 female
- 1 left handed

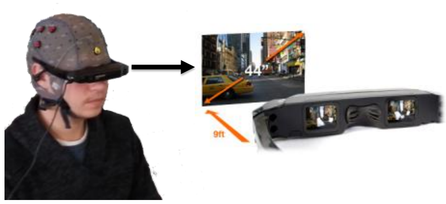
Methodology: Experimental Setup

- 8 Active Electrodes
  - Frontal-Central (FC3, FC4)
  - Central (C3, C4, C5, C6)
  - Central-Parietal (CP3, CP4)
- Frequency: 256Hz

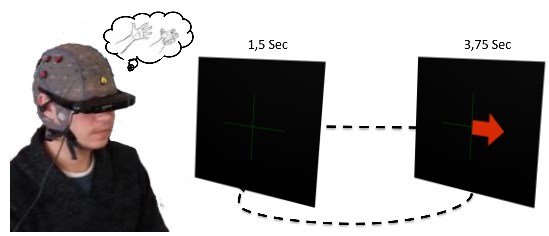


Methodology: Experimental Setup

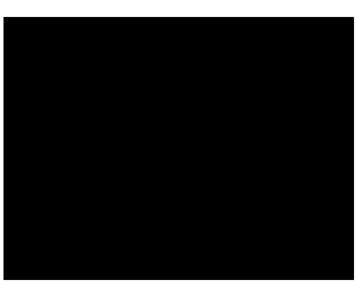
- Twin 640x480 LCD displays
- 32-degree FOV



Methodology: Experimental Setup



Video



Methodology: Questionnaires

Edinburgh Handedness Inventory
- left handed (-100% to -40%)
- ambidextrous (-40% to 40%)
- right handed (40% to 100%)

Vividness of Movement Imagery
- Kinaesthetic Imagery (KI)
  - 1 ('no kinesthetic sensation'/'no image')
  - 5 ('as clear as executing an action'/'image as clear as seeing')

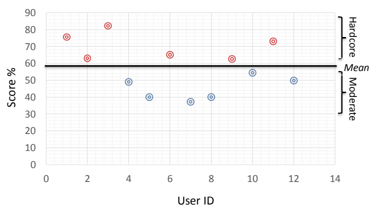
Game Addiction
- low: 0 – 20 points
- moderate: 21 – 40 points
- high: 41 – 60 points
- very high: 61-80

Gamer Dedication
- >30 non-gamers
- 30-45 casual
- 46-55 transitional/moderate
- 56-70 hardcore,
- >70 ultra-hardcore

Methodology: Grouping Players

- Clustering based on reported Gamer Dedication (GD)

$$GD = \frac{\sum_{j=1}^{n} w_j s_j}{\sum_{j=1}^{n} 5 w_j}$$

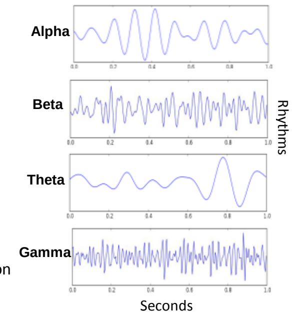


– where s = self-ranked score; w = weight

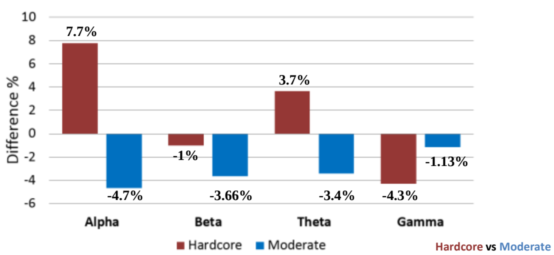
Ernest Adams, Barry Ip, From Casual to Core: A Statistical Mechanism for Studying Gamer Dedication, 2002.

Extracting the EEG Rhythms

- Drowsiness, Concentration, Visual fixation, Sensorimotor rhythms (J. M. Stern, 2005)
- Active thinking, Active attention, Sensorimotor rhythms (S. Sanei, J. A. Chambers, 2008)
- Meditative, Relaxed and Creative states (S. Sanei, J. A. Chambers, 2008)
- Visual, Auditory, Somatic and Olfactory perception, Attention (J. T. Cacioppo et al., 2007)



Can different gamer groups modulate different EEG patterns?

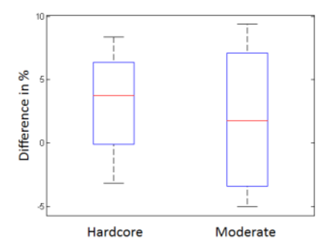


Hardcore vs Moderate

Alpha	+12.4%
Beta	+2.64%
Theta	+7.09%
Gamma	-3.17%

Can experienced gamers increase their performance faster?

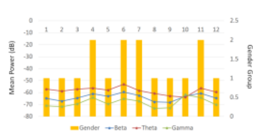
- Hardcore -> 3.16%
- Moderate ->1.53%



Relationship between demographics and EEG pattern modulation

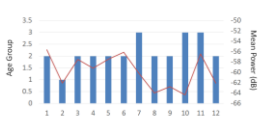
Gender

- Beta (r=0.7848)
- **Higher modulation -> women**
- Gamma (r=0.6302)



Age

- Alpha (r=-0.5642)
- **Higher modulation -> older people**



Relationship between subjective reports and brain activity

Alpha	Beta	Theta	Gamma
• **Game Genre** • **Gamer Dedication:** - Discuss games with friends/bulletin boards • **Game Addiction:** - Stay up late to play video games	• **Gender** • **Game Addiction :** - Unsuccessful reduction of video games duration - Eat meals while playing video games - Headaches, red eyes, etc. from playing video games • **Handedness**	• **Gamer Dedication:** - Play games over many long sessions	• **Game Addiction :** - Active member in activities or clubs • **Kinesthetic Imagery:** - Kicking a stone

Overall

- So far, with current results:
  - We can distinguish a trend between the two gamer groups
  - A strong gaming profile could possibly enhance the ability to use a BCI system
  - Differences between all EEG bands
  - Classification percentages increased performance faster over time for Hardcore users
- Enhanced sensorimotor capability of experienced gamers is partially reflected in MI-BCI training

Examining Brain Activity While Playing Computer Games

Bakaoukas, A., Florin, C., Liarokapis, F. Examining Brain Activity While Playing Computer Games, Journal on Multimodal Interfaces, Springer, 1-17, 2015. (DOI: 10.1007/s12193-015-0205-4).

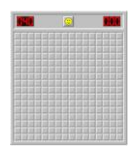
Aim

- Analyse data recorded while participants were engaged in playing popular computer games
- Contribution
  - Connection between activities in the brain and the different categories of computer games

Three Games

TrackMania Nations

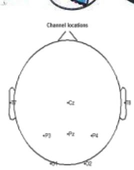
Quake 3



Minesweeper

Experiment

- gMOBIlab (g.tec) - 8 channels:
  - O1, O2, T7, P3, Cz, P4, T8, Pz
- 21 participants
  - 20 males (19 and 26 years old)
  - 10 located in a quiet environment
  - 11 located in a noisy environment



Different Conditions

Type of Environment	Quiet Environment	Noisy Environment
Location	Isolated laboratory	Games Technology Laboratory
Other Persons Presence	In this environment, only the subject and the person conducting the testing were present.	Alongside the subject and the person taking care of the recording apparatus, other peoples were engaged with their daily activities.
Sound	Sounds from the games (if available) and other sounds from the outside world (low volume).	Sounds from the games alongside other sounds from the nearby environment (people chatting, music, etc.).
Number of Samples	At least 5 samples for each game.	Generally 5 samples (considered as isolated cases, those when due to time restrictions fewer samples were recorded).
Time Allocated For Familiarising With The Game Controls	A couple of minutes allocated to understand the game controls and mechanics.	A couple of minutes allocated to understand the game controls and mechanics.

"Minesweeper"	"TrackMania"	"Quake 3"
Intermediate difficulty: a 16x26 maze with 40 mines.	Single Player Track Red – Endurance.	Map Q3DM17.
200% size centre of the screen.	Up, Down, Left and Right car controls.	W, A, S, D keyboard keys as movement controls, click for shooting, space key for jumping.
Game loaded from Minesweeperonline.com	The user is allowed to re-join at last checkpoint.	Opponents are 5 AI-controlled bots on an intermediate skills level.
No time limit.	No time limit.	No time limit.
User is allowed to restart the game at will.	User is allowed to restart the game at will.	Subject is allowed to use any in-game provided item available.

Results

- Focus on the Alpha and Beta rhythm waves
  - Frequencies range of 2–45 Hz
- Results revealed that the highest Alpha and Beta rhythm magnitude levels are obtained when engaging with the "Quake3" game
  - As expected
- No significant differences between noisy and quiet environments
  - But higher beta from noisy compared to quiet environment

Video

Understanding Body Ownership in VR/AR

Aim

- Examining the use of body ownership in real environment, virtual environment and augmented reality environment
- Make use of the rubber hand illusion
  - Future application in patients with schizophrenia

VR/AR Rubber Hand

- Compared to the classical experiment where a plastic rubber hand was used, a virtual 3D representation was chosen to create the same illusion this time in an immersive VR and AR environment

Participants & Evaluation

- Experiments were performed on 30 healthy volunteers, aged 19-49
  - 10 female
  - 20 male
- Two different questionnaires
  - Cognitive workload
    - NASA TLX questionnaire
  - Rubber Hand
    - Ownership, Agency, Ownership Control, Agency Control

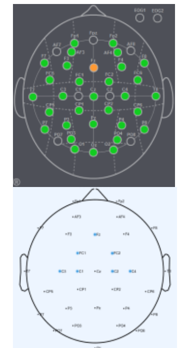
Experimental Setup: Hardware

- Visualisation (Wrap 1200DX AR)
  - Twin high-resolution 852 x 480 LCD displays
  - 35 degree diagonal FOV

- BCI (Enobio BCI)
  - 32 sensors
  - Sampling rate: 500 SPS
  - Resolution: 24 bits - 0,05 microvolt (uV)

Sensor Placement

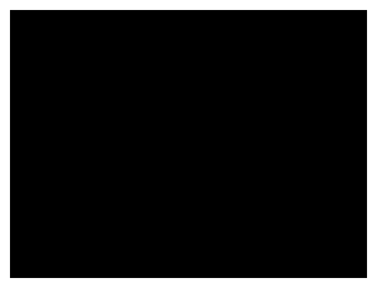
- Frontal (F3, F4, F7, F8)
- Temporal (T7, T8)
- Central (C3, C4)
- Parietal (P7, P3, P4, P8, P03, P04)
- Central-Parietal (CP1, CP2, CP5, CP6)
- Occipital (O1, O2)
- Frontal-Central (FC1, FC2, FC5, FC6)
- Frontal-Parietal (FP1, FP2)
- Intermediate (AF3, AF4)
- Mid Line (Oz, Pz, Cz, Fz)



Recordings

- EEG signals and head orientation of the individuals were recorded and stored for further processing
- Head orientation information is used to remove artifacts

Video



Qualitative Results

- Positive
  - It's fun and interesting
- Negative
  - HMD doesn't cover whole visual area
  - HMD has poor resolution, is heavy
  - Issues with the AR scene
  - Can't understand the questions
- Suggestions
  - "what would happen if…"

Results - Questionnaires

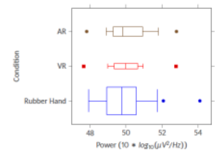
- ANOVA on questionnaires
- Difference for ownership statements
  - I felt as if I was looking at my own hand, sig. p=0.001
  - I felt as if the rubber hand was my hand, sig. p=0.034
- Best-accepted is the rubber hand in the physical world
- No other significant differences

Results - Analysis of correlations

- Beta and gamma bands correlate positively with questionnaire outputs
  - Pearson r correlation
  - Ownership and gamma: r=0.329, p=0.002
  - Agency and beta: r=0.346, p=0.001
  - More brain wave production for participants subjectively feeling the illusion

Immersion Results

- Ownership statement rating splits the subjects
- Immersed: 20 in reality, 14 in AR, 13 in VR
  - VR and AR ”worked” in less participants
  - AR not really different from VR
- AR and VR produced slightly more brain waves



Overall

- Correlation between questionnaires and EEG
  - Rubber hand was the preferred medium
  - AR subjectively comparable to VR
- Premotor cortex activity linked to higher gamma production during the illusion
- However AR and VR produced more brain activity for both gamma and beta waves

User Profiling for BCIs and Games

Vourvopoulos, A., Niforatos, E., Hlinka, M., Skola, F., Liarokapis, F. Investigating the Effect of User Profile during Training for BCI-based Games, Proc. of the 9th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games 2017), IEEE Computer Society, Athens, Greece, 6-8 September, 117-124, 2017. (ISBN: 978-1-5090-5812-9)

Overview

- This research illustrates the importance of:
  - User-related effect
  - Time-related effect
- The effect of reported workload immersion during game play
- Difference in training modalities

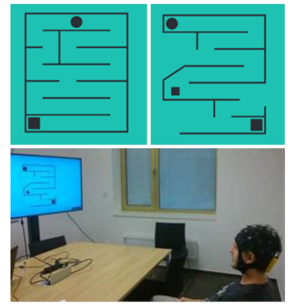
Experiment

- 34 Participants (17 males)
- 18-33 Age
- 32 EEG channels

Methods

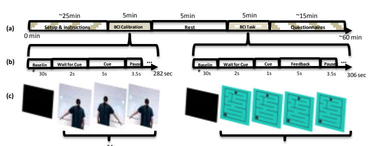
- BCI Training

BCI Game

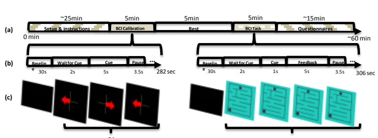


The Protocol

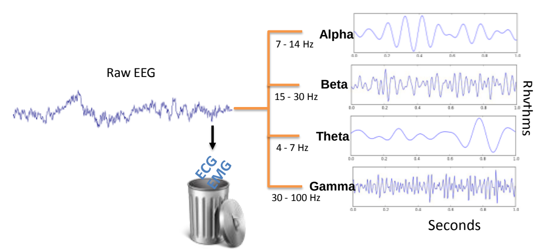
- Motor Observation



- Motor Imagery

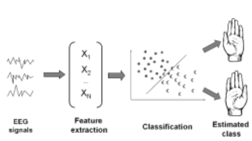


Extracting EEG features



EEG Data

- Alpha & Beta -> Classifier Input (Lotte, 2014)



- Beta/(Alpha+Theta) -> Engagement Index (A. T. Pope et al., Biol. Psychol., 1995)

Demographics & Questionnaires

- Demographics
  - Gender
  - Age
  - Role
- Subjective experience
  - Presence Questionnaire (PQ)
  - Workload (NASA TLX)
  - Flow (GEQ)

Results - Effect of Role

- Students vs Employees
- Differences in:
  - Reported Workload
  - Alpha, Theta bands
  - Engagement Index
- Employees -> increased engagement and decreased workload (mental, temporal demand)

Results - Effect of Gender

- Differences in:
  - EEG bands (Delta, Theta, Alpha, Beta)
  - GEQ: Females reported less concentration

Results - Effect of Hour of Day

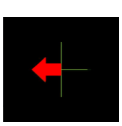
- Main effect of hour of day on:
  - Gamma
  - Engagement Index
- Higher at 15:00 than 19:00

Relationship of EEG data with Reported Experience

- Relationship of Alpha & Theta:
  - TLX: effort
  - GEQ: Feedback, Time, Experience
- Engagement Index
  - PQ: Adjustment in Experience

Motor Imagery vs Motor Observation

- No significant differences



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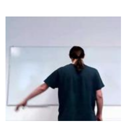


Summary

Demographic data have an effect in BCI training and interaction, being also inline with previous literature (*Davidson et al., Biol. Psychol., 1976; Kober and C. Neuper, Int. J. Psychophysiol., 2011; Vourvopoulos et al., Vis. Comput, 2016*)

Females reported less concentration in the task compared to male participants in overall

In Arrows condition, females reported significantly more natural control of movement during the game

Both genders in Arrows condition, reported **significantly higher loss of self consciousness** than they did in Video condition

Difference between user roles (students vs employees)

Employees had increased EI and decreased reported workload

Difference in hour of the day in terms of the extracted EI and the Gamma band*

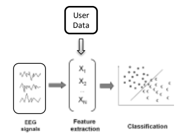
*Gamma is responsible for Visual, Auditory, Somatic perception, Attention (J. Bhattacharya, 2001, T. R. Schneider, 2008, J. T. Cacioppo et al., 2007)

Conclusions

- Overall, this study showcased that gender, role and time have a significant effect not only on EEG modulation but also on reported workload and loss of self-consciousness during the game play
- This demonstrates how sensitive BCI interaction can be, easily affected by insufficient attention due to user distraction or frustration

Future Work

- Include the analysis of specific electrode locations, during BCI training, and create models of user profiles that could be included in a personalized training together with the EEG data



Brain Chatting using Augmented Reality

Kerous, B., Liarokapis, F. BrainChat - A Collaborative Augmented Reality Brain Interface for Message Communication, Proc. of the International Symposium on Mixed and Augmented Reality (ISMAR 2017) Adjunct Proceedings, IEEE Computer Society, Nantes, France, 279-283, 2017. (DOI: 10.1109/ISMAR-Adjunct.2017.91)

New Communication Ways

- Nowadays we see a number of alternatives for communication
- May different applications exist
- Ubiquitous computing

Interaction Modalities

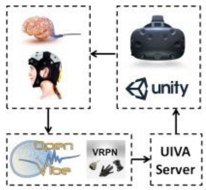
- Event Related Potentials

Advantages of ERP

- P300 recommended for mobile uses, as early as 2004 in based on error rates reported in 2003 BCI competition
- Evaluation of a P300 in a fully mobile environment
  - Moderate drop of performance between sitting and walking conditions
- The canonical presentation of a the stimuli is evolving in recent years

Proposed BCI pipeline

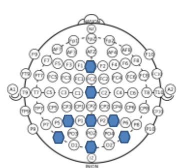
- Components:
  - Openvibe
  - UIVA
  - VRPN
  - Unity3D



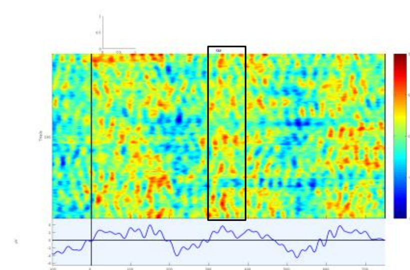
Calibration

- The calibration session was conducted by instructing the user to count the number of flashes of the target letter
- Calibration consisted of 10 randomly selected letters
- All rows and columns flashed in random order 12 times for each letter the user was instructed to spell, with one second delay between these 12 repetitions
- The flash duration was set at 0.2 seconds, preceded and followed by a 0.1 second delay
- The user was given 3 second delay before the next target letter block of flashes was initiated

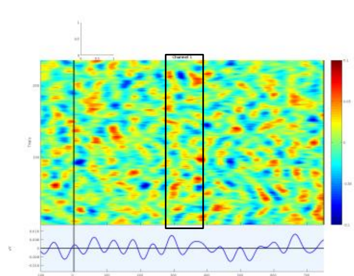
Experiment



Results – User 100% Accuracy



Results – User 25% Accuracy



Future Tasks

- Stimuli changes (motion, size, color, sound)
- Find ways to eliminate multiple layers for communication
- Embedding the stimuli in a context sensitive and unimposing way
- Combining more than two users in a shared or competitive task

Conclusions

- A lot of research is going on in this area
  - Bio-feedback: very experimental at this stage
  - EEG: ideal for patients and perception studies
- Won't see many commercial applications soon
  - Much more studies are required
  - Technology will get better and cheaper
  - Better algorithms for cleaning and classification are needed

Collaborators

- Alina Ene (Coventry University)
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Questions