PA198
Augmented Reality Interfaces

Lecture 7

Brain Computer Interfaces for Virtual and Augmented Reality

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Gizmodo BCI Video

http://www.gizmodo.in/science/Watch-This-Beautiful-10-Minute-Film-on-the-Current-State-of-Neuroscience/articleshow/49272231.cms

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

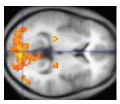
fNIRS

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

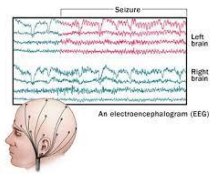
Magnetoencephalography (MEG)

- 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



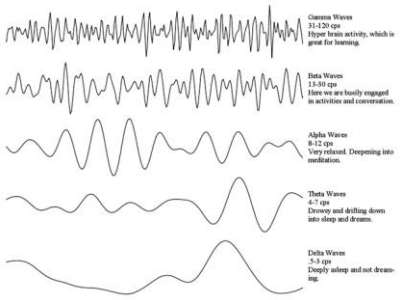
Brainwaves and EEG

- 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

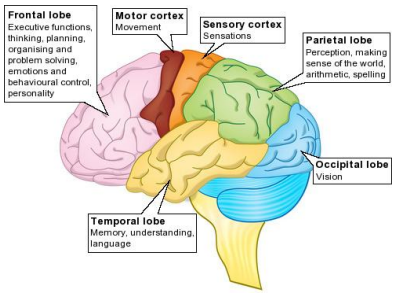
Type	Frequency	Location	Use
Delta (δ)	<4 Hz	Everywhere	Occur during sleep, coma
Theta (θ)	4-7 Hz	Temporal and parietal	Emotional stress (frustration & disappointment)
Alpha (α)	8-12 Hz	Occipital and parietal	Sensory stimulation or mental imagery
Beta (β)	12-36 Hz	Parietal and frontal	Intense mental activity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

Brainwaves Graph



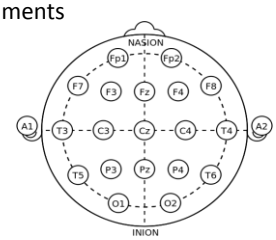
http://braintrainers.net/

Principles of EEG



The 10-20 System

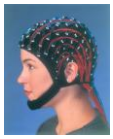
- The international 10-20 system describes the electrode placement on the scalp for EEG tests or experiments



Types of BCIs

Invasive BCI, implanted surgically

Partially-Invasive BCI, implanted inside the scalp



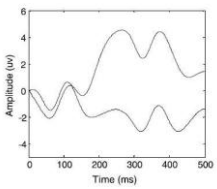
Non-Invasive BCI, using electrode cap

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
- The subcomponents are the novelty P3, or P3a, and the classic 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

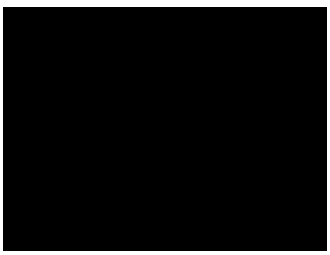
- P3b has a positive-going amplitude that peaks at around 300 ms, and the peak will vary in latency from 250-500 ms or more depending upon the task
  - Amplitudes are typically highest on the scalp over parietal brain areas
- Used to study cognitive processes
  - Especially psychology research on information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

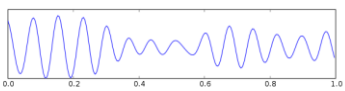
P300 Speller Video



https://www.youtube.com/watch?v=y3IGJVn5Ssg

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

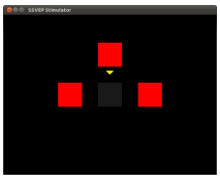
Steady State Visually Evoked Potentials (SSVEP)

- 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

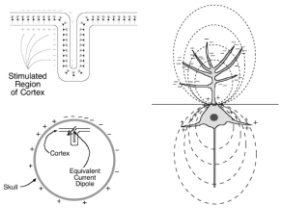
https://www.youtube.com/watch?v=spIVPw7XbCs

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=1Ir4CjtGtvg

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/

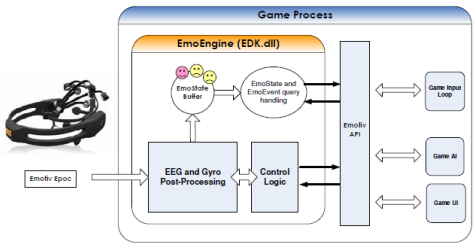
Case Studies

BCIs and Robots

- Main idea
  - Move a robot

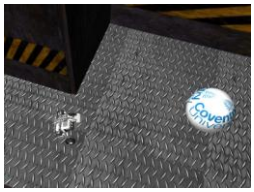
BCIs and Robots

BCIs and Computer Games



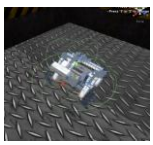
3D Maze Game

- 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

Roma Nova Video

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 brainwaves 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 more accurately the player's intentions

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 of games and it can be combined with other techniques
  - Such as other natural interaction 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

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

Cerebral Palsy User Case

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

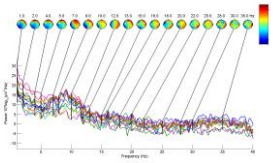
Results

- 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

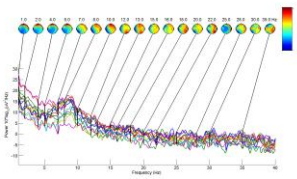
Results .

- 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 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

BCI Tetris

- Focus on determining the relationship between user experience enhancement and cheap commercial BCIs in games
- Aims were two examine:
  - Whether a plug-and-play BCI device as an additional component of the existing interaction metaphor can be an effective mechanism for games
  - If the gaming experience can be enhanced

System Overview

- A laptop equipped with a 32-bit Intel Core 2 Duo processor P7350 at 2.0 GHz and 3.00 GB of RAM were utilized in conjunction with the inexpensive non-invasive commercial BCI device
- In particular, the NeuroSky Mindset headset was used for this is the only device that can be used for game interaction without prior calibration since it is based on a single dry sensor

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Tetris Game

- 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

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Tetris Game .

- The speed of the current falling brick is determined by the number of milliseconds required for the shape to traverse one line
  - The bigger this time value is, the slower the brick will fall
- The step time will be 150 milliseconds
  - Which the double of the current meditation level is added
- As the game progresses, the number of lines cleared multiplied by 5 is subtracted from the step time
  - Whereas for the "non BCI input" mode, the current meditation value defaults to half of its full potential (50%)

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BCI Tetris 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%

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Qualitative Feedback

- The overall experience was described as interesting, enjoyable and relaxing
- The BCI mode was generally seen as more challenging and entertaining
  - Compared to the non-BCI mode
- They expressed their confidence that this type of novel gaming experience has a lot of potential for becoming industry standard in the near future

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Positive Remarks

- The BCI mode was welcomed as a unique and fascinating concept
- The ability to control the speed of the level in some instances made the game easier to play (for some)
- The meditation progress bar helpful and a key part of the experience which they could use to their advantage
- Users not noticing much fluctuation in the speed of the shapes during the two modes

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Negative Remarks

- User focus shifts from shape control accuracy to speed only halfway through the game
- Users noticed an increase in speed when becoming annoyed and impatient
- Some preferred the standard mode as they discerned a lower speed and allowed more time left for decision making and made the goal easier to reach
- The BCI-mode could not be fully experienced by participants who were tired

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Recommendations

- Fully control the game using a BCI device
- Expansion of BCIs in competitive multiplayer environments
- Focus on studying how meditation is controlled in a multitasking scenario
- Make more use of sound
  - i.e. Use sound as an indicator of speed instead of a progress bar
- Use of more accurate BCI device
- Alternative input methods
  - i.e. Voice, eye tracking, etc

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Results from non-BCI Tetris mode

Correlations

			Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration	Learnability	Satisfaction
Spearman's rho	Mental Demand	Correlation Coefficient	1.000	.583**	.382*	-.153	.340	.268	-.146	.062
		Sig. (2-tailed)	.	.001	.037	.419	.066	.151	.440	.743
		N	30	30	30	30	30	30	30	30
	Physical Demand	Correlation Coefficient	.583**	1.000	.472**	-.276	.458*	.519**	-.400*	-.047
		Sig. (2-tailed)	.001	.	.008	.139	.011	.003	.029	.805
		N	30	30	30	30	30	30	30	30
	Temporal Demand	Correlation Coefficient	.382*	.472**	1.000	-.484**	.662**	.488**	-.247	.126
		Sig. (2-tailed)	.037	.008	.	.007	.000	.006	.189	.506
		N	30	30	30	30	30	30	30	30
	Performance	Correlation Coefficient	-.153	-.276	-.484**	1.000	-.496**	-.254	.573**	-.152
		Sig. (2-tailed)	.419	.139	.007	.	.005	.175	.001	.423
		N	30	30	30	30	30	30	30	30
	Effort	Correlation Coefficient	.340	.458*	.662**	-.496**	1.000	.437*	-.231	.139
		Sig. (2-tailed)	.066	.011	.000	.005	.	.016	.220	.464
		N	30	30	30	30	30	30	30	30
	Frustration	Correlation Coefficient	.268	.519**	.488**	-.254	.437*	1.000	-.264	-.081
		Sig. (2-tailed)	.151	.003	.006	.175	.016	.	.158	.670
		N	30	30	30	30	30	30	30	30
	Learnability	Correlation Coefficient	-.146	-.400*	-.247	.573**	-.231	-.264	1.000	.144
		Sig. (2-tailed)	.440	.029	.189	.001	.220	.158	.	.447
		N	30	30	30	30	30	30	30	30
	Satisfaction	Correlation Coefficient	.062	-.047	.126	-.152	.139	-.081	.144	1.000
		Sig. (2-tailed)	.743	.805	.506	.423	.464	.670	.447	.
		N	30	30	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

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Results from BCI Tetris mode

Correlations

			Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration	Learnability	Satisfaction
Spearman's rho	Mental Demand	Correlation Coefficient	1.000	.374*	.174	-.095	.599**	-.057	-.207	-.090
		Sig. (2-tailed)	.	.042	.356	.619	.000	.765	.272	.636
		N	30	30	30	30	30	30	30	30
	Physical Demand	Correlation Coefficient	.374*	1.000	.460*	-.147	.369*	.168	-.422*	-.027
		Sig. (2-tailed)	.042	.	.010	.439	.045	.376	.020	.889
		N	30	30	30	30	30	30	30	30
	Temporal Demand	Correlation Coefficient	.174	.460*	1.000	-.400*	.226	.272	-.326	.304
		Sig. (2-tailed)	.356	.010	.	.029	.230	.145	.079	.102
		N	30	30	30	30	30	30	30	30
	Performance	Correlation Coefficient	-.095	-.147	-.400*	1.000	-.087	-.231	.092	-.124
		Sig. (2-tailed)	.619	.439	.029	.	.647	.219	.628	.514
		N	30	30	30	30	30	30	30	30
	Effort	Correlation Coefficient	.599**	.369*	.226	-.087	1.000	.167	-.323	-.026
		Sig. (2-tailed)	.000	.045	.230	.647	.	.376	.081	.893
		N	30	30	30	30	30	30	30	30
	Frustration	Correlation Coefficient	-.057	.168	.272	-.231	.167	1.000	-.627**	.051
		Sig. (2-tailed)	.765	.376	.145	.219	.376	.	.000	.791
		N	30	30	30	30	30	30	30	30
	Learnability	Correlation Coefficient	-.207	-.422*	-.326	.092	-.323	-.627**	1.000	-.029
		Sig. (2-tailed)	.272	.020	.079	.628	.081	.000	.	.916
		N	30	30	30	30	30	30	30	30
	Satisfaction	Correlation Coefficient	-.090	.027	.304	-.124	-.026	.051	-.029	1.000
		Sig. (2-tailed)	.636	.889	.102	.514	.893	.791	.916	.
		N	30	30	30	30	30	30	30	30

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

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Results Comparison

- 13/30 users thought that the mental demand quotient for each mode (non-BCI and BCI) should be of the same value
  - Whereas other 13 users saw the BCI controlled game version more mentally demanding (almost statistically significant, $p = 0.051$)
- Other statistically significant differences are for learnability ($p < 0.005$) and satisfaction ($p < 0.010$)

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Results Comparison .

- 36.6% thought that the meditation-controlled Tetris required more time to learn how to play it than the generic mode
- Satisfaction comparison reveals that the same percentage of participants considered the “BCI” Tetris mode to be much more enjoyable than the “non BCI” Tetris mode
- Perceived user performance remains unchanged from “non BCI” to “BCI”

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EEG Rhythms Log

- Significant correlations were found for attention
- For increased attention we can see decreasing Theta oscillations ($r = -0.2885$, $p < 0.05$)
- Theta is usually linked to inefficiency and daydreaming
  - In fact, the very lowest waves of theta represent the fine line between being awake or in a sleep

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EEG Rhythms Log .

- High Alpha ($r = -0.1841$, $p < 0.05$) and high gamma ($r = -0.1589$, $p < 0.05$) oscillations are observed with increased attention
  - Alpha rhythms attenuate with drowsiness, concentration, stimulation or visual fixation
  - High gamma oscillations have been observed in a variety of different purpose neuroanatomical domains including information processing

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EEG Rhythms Log ..

- For the Non-BCI setup, Delta is almost three times higher, indicating deeper relaxation when the BCI device was not used as an input
  - Delta band is modulated the highest compared with the rest of the rhythms showing an overall deep relaxation

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Conclusions

- 30 participants tested a Tetris-based game in two modes, normal game play and BCI input
- It was observed that the more experienced gamers did not notice the speed difference because they usually rushed the pace of the game
- For the participants who actually managed to maintain high levels of meditation throughout the second mode, they were more inclined to notice the speed difference, achieve more and fully enjoy the experience
- It is also important to note that after long periods of use, the device increased user fatigue

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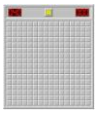
Games comparison using EEG data

TrackMania Nations

Quake 3



Minesweeper

Video

BCIs and Games

- The Effect of Prior Gaming Experience in Motor Imagery Training for Brain-Computer Interfaces: A Pilot Study

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)

Video Games and the Brain .

- 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)

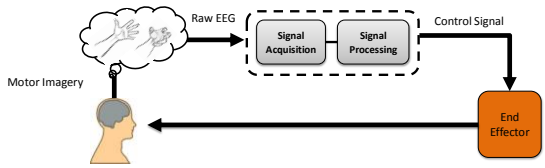
How Used in Current Mental Tasks?

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

} Important for using BCIs

Interfacing the Brain with the Computer

- BCIs are communication systems which translate brain activity into control signals in computers or external devices

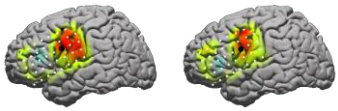


Motor Imagery

- Motor Imagery (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

Motor Imagery .

- 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

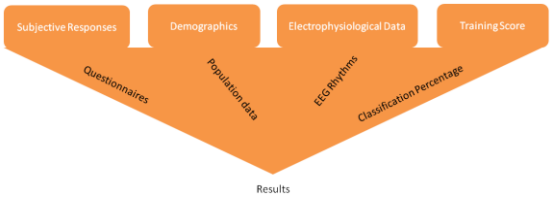
Current Limitations

- 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 and
  - Two different user groups based on their previous gaming experience

Types of Acquired Data

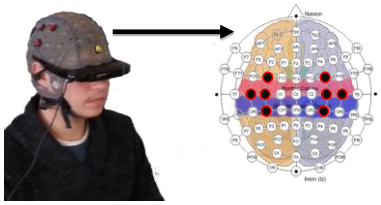


Methodology: Participants

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

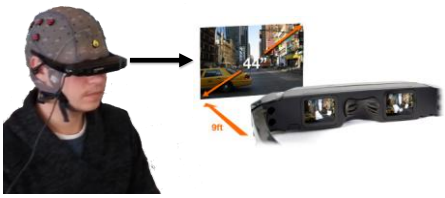
Methodology: Experimental Setup

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

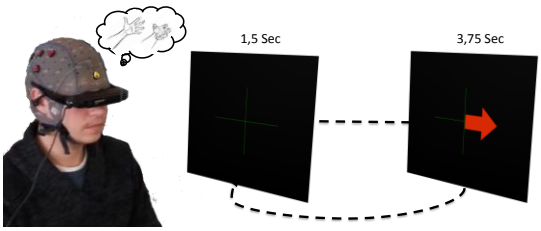


Methodology: Experimental Setup

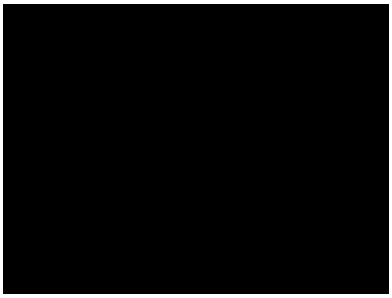
- Twin 640x480 LCD displays
- 32-degree FOV



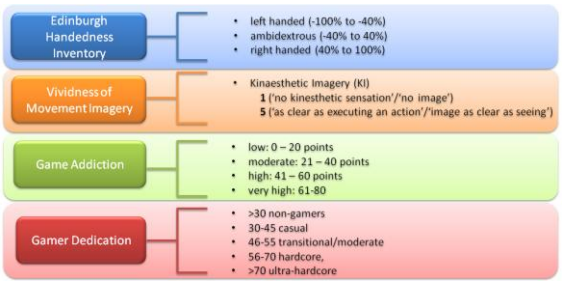
Methodology: Experimental Setup



Video



Methodology: Questionnaires



Methodology: Grouping Players

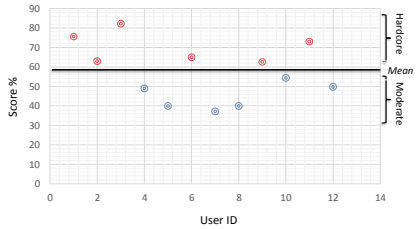
- Clustering users based on reported Gamer Dedication (GD)

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

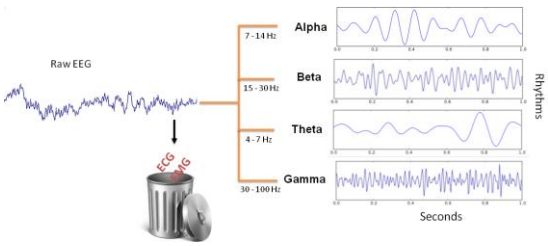
- where s = self-ranked score; w = weight

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

Grouping Players

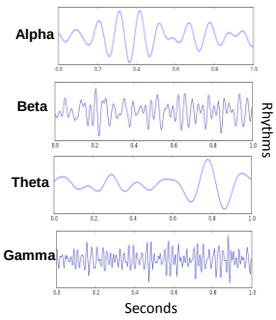


Extracting the EEG Rhythms

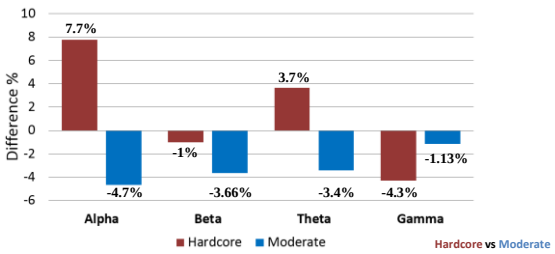


Extracting the EEG Rhythms

- 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?

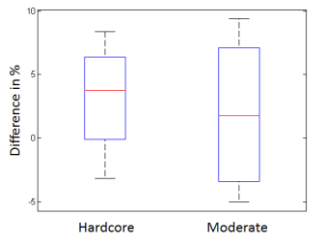


Hardcore vs Moderate

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

Can experienced gamers increase their performance faster?

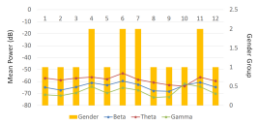
- Hardcore -> 3.16%
- Moderate ->1.53%



Relationship between demographics and EEG pattern modulation

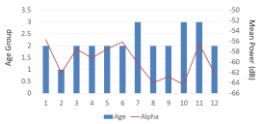
Gender

- **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

Summarizing: Alpha Activity

- Gaming experience leading to increased Alpha activity can be the reason that older participants had higher Alpha
- Gamers with favorite genre the Action games, had increased Alpha activity
- Increased in Hardcore group
- Past research showed positive correlations between good game performance (less time to complete a task) and, on average, the production of Alpha waves

Summarizing: Beta Activity

- Gamers that unsuccessfully tried to reduce the amount of time they play video games, and get headaches, red eyes, etc, have increased Beta activity.
- Participants with higher level of right-handedness and females had increased modulation.
- Decrease on Moderate group but more stable on Hardcore
- So far we know that, voluntary movement results in a desynchronization in alpha and beta band oscillations, localized over sensorimotor areas
- Therefore high levels of addiction could result into higher sensorimotor activation

Summarizing: Theta Activity

- Participants which play games over many long sessions have increased Theta modulation during training
- Increased in Hardcore group
- Cortical theta is observed frequently during meditative or relaxing states, but also it has been shown that the level of theta brainwave activity in the prefrontal cortex predicts whether people will be able to overcome ingrained biases - choosing an action that is counter to habit - when is required to achieve a goal

Summarizing: Gamma Activity

- High addiction users produce higher Gamma
- Participants with high kinaesthetic imagery related with “kicking a stone” visualization, have increased Gamma activity
- Participants of the “Hardcore” group had decreased activity compared with the “Moderate” group
- Binding of different neurons together into a for carrying out a certain cognitive or motor function

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

How to Use Current Results

Stimulate the areas responsible for high motor control during training

Use electrophysiological + subjective data to classify gamers

BCIs and VR/AR

- Examining the use of real environment, virtual environment and augmented reality environment for body ownership

Filip Škola, Szymon Fiałek, Liarokapis, F. Augmenting the Rubber Hand Illusion, ERCIM News, ERCIM, 103, 25-26, 2015. (ISSN: 0926-4981)

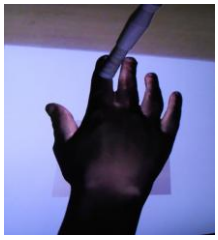
Classical Rubber Hand Illusion

- The traditional rubber hand experiment is a psychological experiment where participants are under the illusion that a rubber hand is part of their own body
- During the experiment, the rubber hand is positioned in front of the participant while their real hand is kept hidden from their view
- Synchronous touches are then applied to both their real hand and the rubber hand and within minutes participants get the illusion that the rubber hand is part of their body

Kalckert, A., Ehrsson, H.H. The moving rubber hand illusion revisited: Comparing movements and visuotactile stimulation to induce illusory ownership, Conscious Cogn. 26:117-32, 2014

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



3D Rubber Hand

- Based on photogrammetric techniques
  - 15 high definition images were taken
    - Processed using medical imaging software to produce the 3D mesh
  - Textures were also taken from the high definition images
- The resulted 3D model consists of 46611 vertices and 93218 triangles offering a very realistic model of a human hand

Participants

- Experiments were performed on 30 healthy volunteers, aged 20-35 years old
- Participants were asked to complete two different questionnaires, one measuring their cognitive workload (based on the standard NASA TLX questionnaire) and another one regarding their experience with the rubber hand illusion
- In addition, EEG signals of the individuals were recorded and stored for further processing

Finger Sequence & Sensor Placement

- Total: 38 brushes
- Time: 4 secs
- Total Time: 152 secs
- Sequence:
  - 3, 1, 4, 3, 1, 4, 1, 2, 1, 3
  - 1, 3, 4, 4, 2, 3, 1, 1, 4, 3
  - 2, 1, 4, 3, 4, 2, 1, 1, 4, 2
  - 1, 2, 1, 3, 2, 4, 3, 4

Video

Methodology

- Absolute numbers:
  - Average band power from 100 seconds of data in the later phase of the experiment
- Relative numbers:
  - (avg band power from the later phase of the experiment) minus (avg band power from the beginning)
  - Basically brain wave change for each band
    - Positive or negative

Overall Results - Absolute

- Ownership control vs Beta = 0.305, vs Gamma = 0.262
- Agency vs Beta, Gamma = positive correlations
- Ownership Control vs Beta = positive correlations
- Agency Control vs Alpha, Beta, Gamma Theta (Beta strongest) = positive correlations

- Positive TLX corr.:
  - TLX Mental vs Beta
  - TLX Physical vs Beta
  - TLX Temporal vs Gamma

Rubber Condition - Absolute

- Ownership vs Beta=0.31, Gamma=0.356
- Agency Control vs Beta = 0.554, Gamma=0.554 strong positive
- Other conditions from both TLX and RH questionnaire similar as overall

VR Condition - Absolute

- Strongest: Ownership vs Beta = 0.293; Gamma = 0.186, Delta = 0.368
- Ownership Control vs Theta
- Agency Control vs Beta

AR condition - Absolute

- Strongest: Ownership vs Beta = 0.396; vs Gamma = 0.313
- Ownership Control vs Beta = 0.448
- Agency Control vs Alpha, Beta
- Weaker Ownership vs Gamma
- also NEGATIVE ownership vs Delta

Overall Results - Relative

- strong correlations: Ownership vs Alpha = -0.254, Ownership vs Gamma = -0.23
- Owneship Control vs Delta = -0.224
- TLX Physical vs Alpha & TLX Physical vs Theta (0.211, 0.219)
- TLX Temporal vs Gamma = 0.256
- TLX Performace vs Alpha & TLX Performance vs Theta (0.22, 0.242)

Conclusions

- A lot of research is going on
- Wont see commercial applications very soon
- More studies are required
- Technology will get better and cheaper soon

Questions