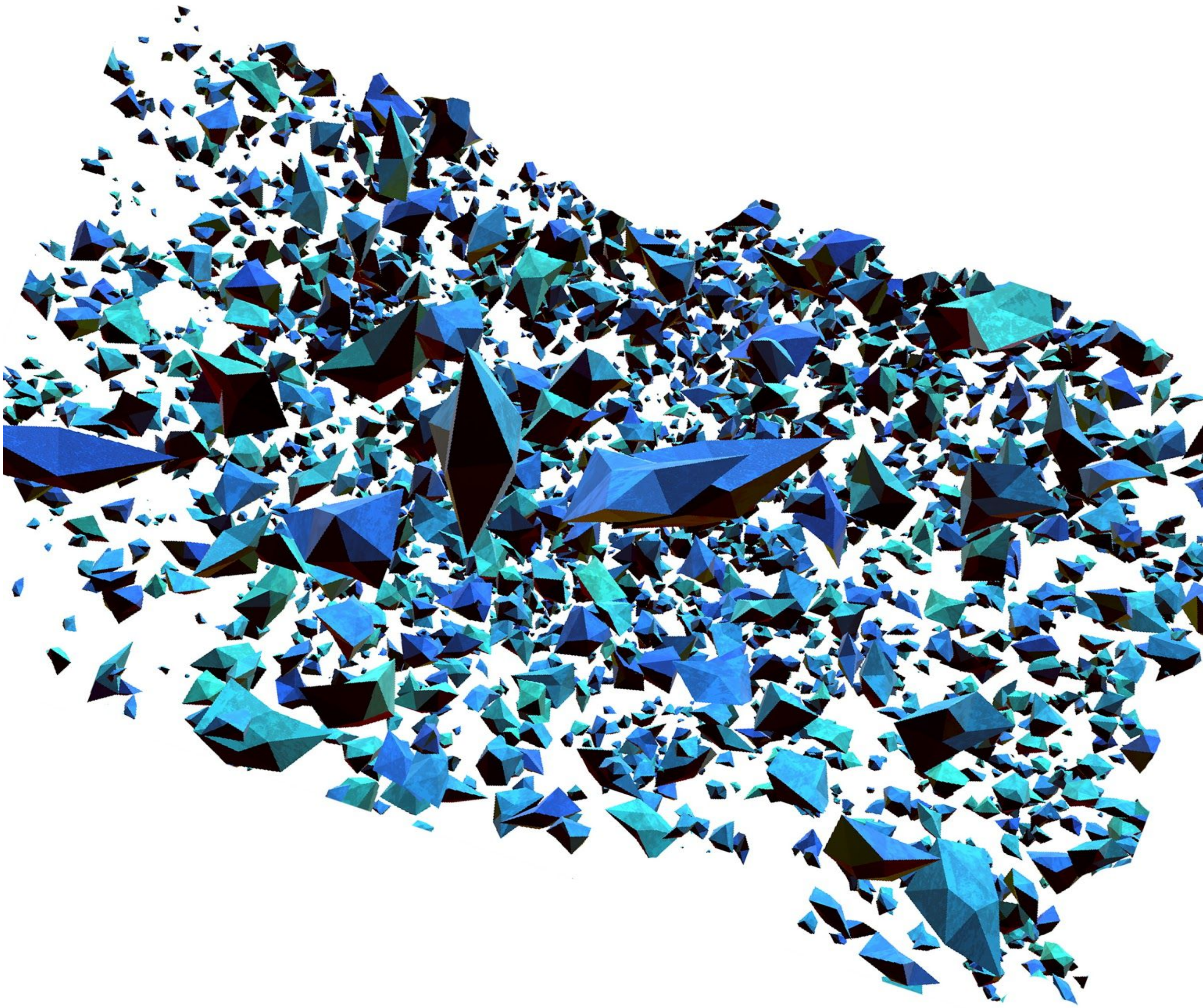
The asteroid field of your mind

Examine neurofeedback effects in an interactive art installation



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Abstract

Recent technological developments allowed Brain Computer Interfaces to be embedded in small, portable headsets, making them appropriate for usage in casual consumer applications. Data derived from brain computer interfaces can seem rather abstract to users. This paper addresses the need for visualisations, that can help making interacting with brain computer interfaces a more comprehensive and enjoyable experience. An interactive visualisation of brain states has been conceptualised and developed for the purpose. Furthermore, this project provides insights from psychology regarding visual perception and emotions to enhance user understanding of their brain activities as a part of feedback mechanism for entertainment applications. First, an exploration of visual methods and technological readiness has been performed. Further, game mechanics appropriate for brain computer interaction were created in order to observe the proposed visualisation in context. To confirm the validity of the product an early testing with first time users was used to define the initial specification of the project, such as reaction time, learning curve and other general input. Further a proposed shape was evaluated by comparing it to the provided default visualisation method and more finally, a user evaluation in game environment was conducted to verify their appropriateness for interactive entertainment experience. These evaluations showed that the proposed solution was aesthetically pleasant, however the comprehensiveness and entertainment value could be improved upon.

1 | Introduction

The document at hand is the final project for the Bachelor's program Creative Technology at the University of Twente. The study focused on bringing existing technology to users hands in a new innovative and creative ways. In this project, the goal is to create an interactive experience using devices capable of reading brain signals and detecting brainwaves, called neuroheadsets. Nowadays, Advancements in EEG (electroencephalography), allowed commercially available BCI neuroheadsets to make its ways to the consumer market. Devices capable of reading brain activities are accessible for regular users today with prices being more accessible with each generation.

This project is created under the guidance of Human Media Interaction (HMI) group at University of Twente, which conducts research on multi-modal interaction, from Brain-Computer Interfaces (BCI) to social robots. The group is focused on working towards novel forms of human-computer interaction. It was decided early in the proposition of this project, to focus on visualisation of brain states and in particular how it can be utilised to develop interactive experiences for entertainment applications for healthy users.

Beside technological and scientific interest, the topics of emotional intelligence and mindfulness increased popularity rapidly in past years and even without the technology available regular, healthy people are considered with their states of mind on daily basis. Those are indications for health benefit from the commercial brain-computer interfaces. Control over daily states of mind are now quantifiable in real time and could provide significant health benefits given the right tools, used to utilised in future.

1.1 Motivation

Once strictly part of the science fiction, Brain-Computer Interface was somewhat futuristic applications that is enabled in today's world of consumer technologies. Further rise of non-intrusive devices in a form of wearable headsets such as Emotiv[1], MUSE[2] and openBCI[3] can read and send brain signals to computer, providing brain signal interaction. Today developers and scientists can produce applications, which can provide interaction based on the input of brain activities in real life and digital systems.

It was author's motivation to create an immersive interactive experience and examine users' ability to compose their mental states in a neurofeedback loop. The approach to BCI on important aspect of solving multiple problems of a new technology being introduced, how people interact with it and specifically the possibility for health and well-being benefits. Human always strive for better living and now we have another important vector to quantify, assess and improve on their brain.

1.2 Goals and Challenges

Brain-Computer interaction is a novel method and for the majority of regular people, it is unfamiliar technology. Users are not aware the general purpose, use and benefits of such devices. This present challenge is to adequately create an interactive experience to demonstrate the technology for the general public. User expectations are yet to be formed with the entry of BCI into our daily lives, we are in early stages of forming what is to be accepted user experience. While this current stage presents opportunities for artistic, scientific and creative applications, it also presents challenges for

[1] *Wearable for your brain* www.emotiv.com
[2] *Meditation made easy,* www.choosemuse.com
[3] *Open Source Biosensing tools* www.openbci.com

developing an complete, pleasant experience for end-users.

Despite being the early stage of user expectations, several parties from commercial neuroheadsets brands to open-source community have multiple types of BCI interaction methods. We seek to have interactive experience for all types of first time users and comparing and choosing appropriate interaction method would present another challenge given availability of time and information.

From a scientific viewpoint, the classification of brain would present challenge given the information available to the public, including but not limited to source code, system supports and documentations. User testing would be needed to determine the system in use and main interaction method for neurofeedback.

Furthermore, design challenges are present in display and visualisation of the interaction method. Balancing speed, precision and ease of use of the interactive system on one hand and smooth, understandable and coherent user experience on the other could present challenging. The visuals should be informative, which crosses data visualisation methods and art.

Last but not least, some technical challenges of the project includes user readability of the real time interaction and smooth technical performance during user testing. Having to build our own system to choose which classification methods to use interaction and construct experience suitable for first time users.
The goal of this project is to design an interactive experience for representing brain states, which includes the following challenges:

- First, to define what brain states are, how those states would be detected. This includes research and testing on current classification methods for brain states and possible others methods for BCI inter- action.
- Second, to decide which of those interactive methods are most suitable for first time users and real-time interaction with BCI.
- Third, the visualisation of the given brain states and users perceived experience.

1.3 Research statement

We seek to develop an interactive experience which uses EEG signals detected with consumer grade, non-invasive neuroheadsets. Participants are expected to compose their brain states in real-time interaction with visualisation. The participants should be able to understand better the human ability to compose current brain states and hence controlling their emotions.

The final designed prototype aims to measure the learning effects on users adaptation for bio-feedback as input method, measured over the power spectrum of the given brain states.

1.3.1 Main Research Question

How can we design an interactive experience for observing composed brain states based on EEG readings ?

In order to answer this question to following sub-questions need to be addressed:

1.3.2 Sub-question: Interactive Experience

What constitutes an interactive experience for BCI ?

To design an interactive experience for BCI, we need first to understand what the contributing factors there are to be considered. In order to do so and to answer this sub-question, we consult related works and state of the art from literature, artistic sources and default provided functionality from the BCI devices and other supporting materials.

1.3.3 Sub-question: Control Of Brain States

Can users control their brain states at will ?

This sub-question is addressed in multiple ways: first, literature is consulted to explore the general ability of humans to compose their brain states when given instructions. Then, we dig deeper by looking at the conditions under which this control can happen in the evaluation.

1.3.4 Sub-question: Learning

How learnability plays role in the context of BCI interaction?

The factors that contribute to learning control over brain states are indicated in literature, and are further extended through the evaluation. This sub-question is therefore answered based on both of these sources. We look at human learnability level of the users during the experiment.

1.4 Methodology

The research method used in this bachelor thesis starts with an extensive analysis of relevant literature and projects. The design of a prototype and evaluation is guided by Creative Technology method, described by Mader and Eggink (Mader et. al, 2014). The method at hand is used for the design process, which would drive the solution for this project. The process consists of four phases: Ideation, Specification, Realisation and Evaluation.

Ideation is an investigation into related work, research, currently available technologies and approaches and formation of our own set of creative ideas. In this stage, we consider user needs and explore different interaction ideas in thinking sessions as part of creative explorations. As result of this stage, we form specification and concept to be realised in the realisation stages. The series of partial prototypes are produced and evaluated regarding functionality and experience. These prototypes might be improved, merged or discarded.

In the Realisation phase, a final prototype is developed based on specification. During this stage the primary focus is on decomposition of the designed system into building blocks, which acts as sub-systems. Realisation of these building blocks and their final integration results into a final prototype. Lastly, we have a functional testing to make sure everything works according to specifications.

Evaluation is the final stage of this project. We evaluate the prototype with participants and perform statistical tests over the findings. After which we discuss the results and, in the end, we draw conclusions and recommendations for future work.

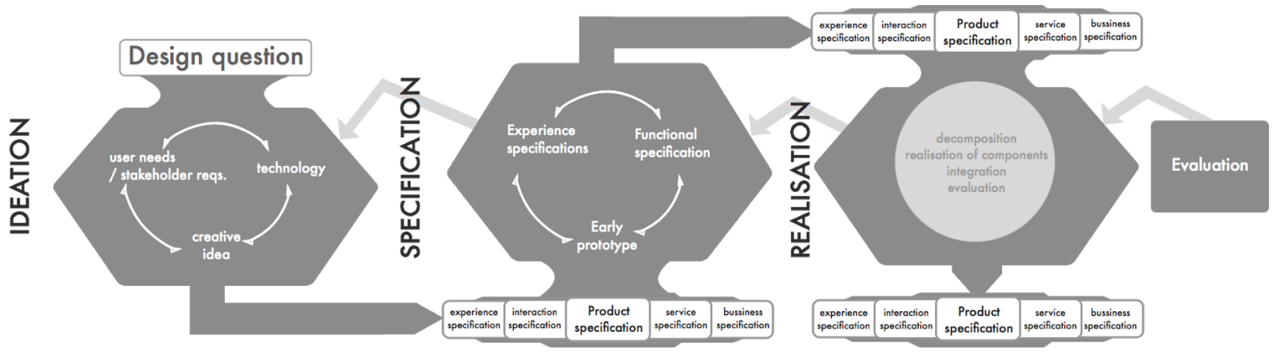

Figure 1: Creative Technology method (Mader et. al, 2014)

1.5 Report Organisation

- Chapter 1 starts with background of the research, motivation and design questions, followed by the method used for creating the final prototype and this experiment.
- Chapter 2 represent the analysis in related work and inspiration.
- Chapter 3 we look at interactive experience with a few technical tinkering sessions, creative ideas and overall ideation, before forming our first final prototype.
- Chapter 4 describes in-depth specification for the design choices taken.
- Chapter 5, describes the decomposition and realisation of those components.
- Chapter 6 we see the evaluation of the final prototype, followed by an analysis of the results.
- Chapter 7 we discuss the findings and results.
- Chapter 8 is the conclusion of this project.

2 | Theoretical Analysis

In this chapter, we start our research by looking into related work to Brain-Computer Interaction (BCI). Covering some of the core understanding in the context of the project, the relationship between input signals for interaction and underlying mental states. After that, we look at what neurofeedback is and how can we benefit from this approach by learning and control over those mental states.

2.1 Background

The topic of combining technology and brain functions has been of great interest in the science fiction (sci-fi) community starting in the 1970s going on to present days. Brain-Computer Interfaces handling various tasks such as health monitoring (Star Trek TGN 3x25; 7x08; VOY3x22, 1990), controlling space ships (VOY:7x25, 2010) or communicating telepathically (Clark, 1998), are just a few of popular sci-fi work with reach over 100s of millions. The image of BCI in science fiction is characterised by fast interaction, control over objects and health monitoring, all of which is paving a way for future real world applications.

Figure 2: Spock with BCI, Star Trek original, 1968 [4]

By measuring current brain activities and present states over time, we can have quantified data for human brain actives outside medical and laboratory environment. Some of the more recent examples of real world applications are of users controlling video games (Leceyer et al., 2008), wheelchair (A.R.Satti, 2011) or even the international space station itself (L.Rossini, 2009). Furthermore, art-science works described in sub-section 2.2 are illustrating the artistic interest in BCI, making the case for inspiring BCI applications.

Despite the long way since the early discovery of electromagnetic properties of the brain and sci-fi real, the technology is yet to achieve its mass adoption. According to Gartner's hype cycle (Figure A1), BCI is located in the Innovation Trigger Stage, which indicates more than ten years till it reaches full potential with the majority of the public not currently being familiar with the

[4] "**Spock's Brain**" *Star Trek: The Original Series* episode

technology. The current technological stage can create an opportunity for creative applications which can shape the new technology paradigm.

This project was executed under the guidance of Creative Technology method (Mader, 2014), (subsection 1.4), with a complete loop from ideation to prototyping and user evaluation. We create real-time interactive neurofeedback visualisation in 3D environment and investigate how to design an interactive experience that facilitates learning control over brain states. Motivated by a large-scale art-science installation My Virtual Dream (Kovacevic et al., 2015), and the virtual brain project (Larsen et al. 2001), which are collective brain interaction experiences with focus to explore participants' ability to learn rapidly to control their brain states in a complex environment.

2.2 Classification Of Brain States

As an electrochemical organ the brain is emitting electrical power, which in according to more conservative estimation is somewhere between five millionths to 50 millionths of a volt (mV). Despite the power being limited, it occurs in a very specific pattern which characterise the human brain. Those electrical activities are most commonly visualised in a form of brainwaves (Teplan, 2002). Brainwaves could be used to classify brainstates as each wave band is dominating in one state while there is constant fluctuation of the different waves. Each of those brain states, defined by the wavebands, describes some feeling and state of mind. This is one of the earliest methods for classification of brain waves and generalising brainstates, however many approaches exist and commercial devices provide their own more precise classifications for emotional states. We look at those methods and construct our own system for brainwaves classification and interpretation of the given brain states.

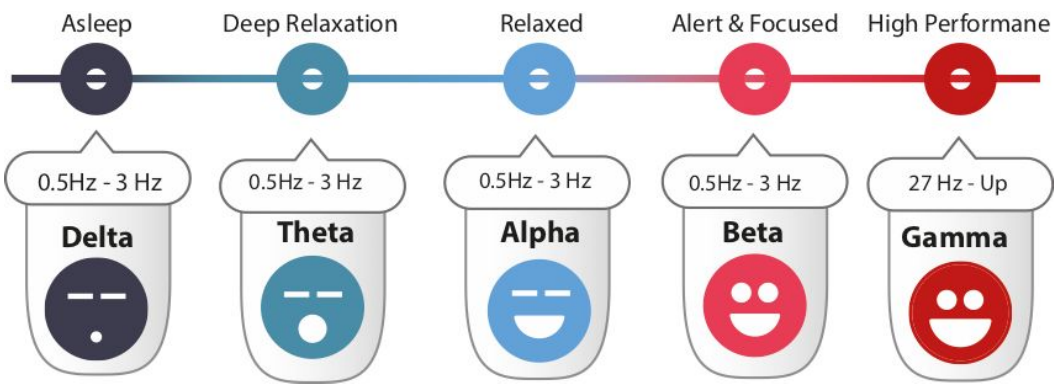

Figure 3: Brainwave bands and brain states

Advancements in commercialisation EEG advancements present a new paradigm for interaction, experimentation and application outside the traditionally controlled laboratory conditions and this opportunity allows for new insights into brain function in a complex environment of the real world (Hasson et al., 2012), (Vernon, D et al. 2003), (Griffiths et al. 2005).

Brain pattern could be extract from activities with non-invasive methods such as functional MRI/fMRI (graphical image based 3D scan) and electroencephalography (EEG, signal waveform), non-intrusive methods for observing mental states (Haynes, 2006). Commercial devices are based on EEG because of its' cheaper technology price and mobility. Non-intrusive sensors are placed on the head and the activities of the brain are mapped with anywhere between 4 and 32 for commercial devices and 64-128 and above for scientific and medical devices, which defines the resolution of the brain signal, where more sensors mean more accurate reading.

2.2.1 Brainwaves

One of the earliest and most used classifications of EEG is brainwaves (Tudor et al., 2004). Those includes: Alpha, Beta, Delta, Theta and Gamma band waves, since each one is readable on corresponding wavebands and often seen as brain states. It is believed that only one state is dominant, but all the others are present at any given time (Herrmann, 1997). Other methods of classifications do exist by now, such as the Emotiv's custom closed-source algorithms for more precise feelings classification such as frustration, concentration and boredom.

α Alpha (7.5 -14 Hz)	State of deep relaxation and associated with meditation
β Beta (14-40Hz)	Dominant state of daily human activity, alertness and consciousness
ϑ Theta (5-8Hz)	Typical for a person who takes time off an intense task or daydreaming
δ Delta (1.5-4 Hz)	Usually associated with sleep and dreaming
Emotiv Affective Suite	Now performance metrics of engagement, boredom, excitement

Table 1: Brainwaves frequency and associated mental state. (Herrmann, 1997)

There are different variations of the frequencies defining the brainwaves. Sometimes, in more precise studies, the given waves (e.g. Alpha, Beta) are divided on upper and lower frequency bands (e.g. upper Alpha, lower Alpha etc.). In this project we later redefine the waves, before choosing the exact band for the final prototype.

2.2.2 Brain States And Emotions

Developments in neuroscience show that emotions, experiences, moods, beliefs, a dreams, disturbances and habits are all produced by the brain. Improving brain function is logical consequence of working on brain and mental states (Doidge, 2007). Gaining control over one's brain activity can have a profound impact on well-being, (Brown, 2003) and is considered to be achievable by anyone (Brenninkmeijer, 2010) as it is a natural ability of human. The brain is as flexible and trainable as a muscle (Doidge, 2007). This lead to the rise of products that targeting training of control for brain state, such as previously mentioned MUSE, 'personal meditation assistance' device.

The two most dominant brainwaves in human daily activities are Alpha and Beta, which are associated with the states of relaxation and concentration respectively. Beta waves are typical for an adult human and are present during daily activities such as walking, reading etc. On the other hand alpha waves are commonly accounted for in relaxation, medication, deep concentration and light sleep/nap. While those brainwaves are important for effective day function, they might also translate to streets, anxiety and restlessness levels (Herrmann, 1997).

2.2.3 Neurofeedback

Neurofeedback is a type of biofeedback in which users observe real-time displays of their brain activities. This type of feedback loop has a number of medical application such as intervention for ADHD (Pope, 2001) and well-documented benefits, including increased attention, memory, intelligence and mood (Gruzelier, 2014a). Further studies have shown improvement on creativity of novice and advanced musicians (Vernon, 2005), communication and presentation techniques of school children (Gruzelier, 2014b), among others. Vernon (2005) pointed out that while there seems to be a performance increase through neurofeedback on a variety of tasks in sport, cognitive and artistic applications, a general failure to elicit unambiguous changes in baseline EEG activity may pose a limitation to these results. The health benefits of neurofeedback on control of brainwaves are recognised (Vernon et al, 2003), but the effects depends on individuals.

2.2.4 Natural Ability To Control Mental States

People do tend to have natural control over their state of mind, current moods and feelings. Neuroheadsets do introduce a window and provide us with quantified information about the brain. Naturally, human is an adaptive species and it is our believe that observing brain activities in real time, will trigger desire to improve or change any given state of mind. While the idea of enabling observation of one's brain states is novel for many users, but those headsets and technology have potential to make it possible for users to learn how to exercise control over their mind. This process of observation is called neurofeedback and can have a high impact on people's health and day-to-day life. Such findings are documented for decades in the medical environment, but we are yet to see it in normal daily use for healthy users. This creates an opportunity to make a positive difference in people's health and user adoption at this stage is crucial for achieving those higher goals.

2.2.5 Health Benefits

Besides technological and scientific benefits, one of the biggest opportunity is for the user to have a window into their mind, a topic fascinating for a vast amount of people around the world. This technology has been already to benefit for users with health and mental problems, but today's commercialisation opens it to everybody, healthy or not (Blankertz et al. 2010). This opportunity allows user to quantify, reflect and keep a healthy mental state of mind.

2.3 Learnability And Control Of Brain-states

Learning in general is associated with functional and structural changes in the brain when a given user is presented with new (to him/her) information (Bangert, 2001), (Reinacher, 2009). On neurological level changes happen continuously on synaptic scale, but long term effects require more time to manifest. Changes on structural level can be detected nowadays with non-invasive BCI devices after 45 min of neurofeedback training. When it comes to cognitive performance, significant changes however can be noticed after one session (Ros, 2012), (Reiner, 2014). Many specific applications for enhancing learnability with different BCI neurofeedback methods prove this in relation to attention, music and creativity (Gruzelier, 2014) and illustrate the possibility for enhanced learning. In this project we attempt to make an to probe into peoples naturally ability to learn control over their brainwaves given real-time neurofeedback process.

Concerning BCI, there are separated forms of training (Bos et al., 2010):

- *Interface training*: training the user right mental task to control the experience
- *User training*: training the user to reliably perform the mental tasks
- *System training*: training the system to recognise user specifically

2.3.1 Learnability And Brain-states.

In the context of this report, learnability is defined when high alpha over beta brain- wave is presented in tutorial stage. Control over the associated mental states is achieved when a user is able to change the given state of mind (concentration and relaxation). Studies have shown that users of BCI can gain some control over particular aspects of their EEG readings using neurofeedback

(Vernon et al., 2003). This aligns with findings from the 1970s, where research, showed that people can control their alpha activity, and that auditory feedback can assist with gaining control (Nowlis and Kamiya, 1970). In those cases users demonstrated that control over brain states could be learned with the help of feedback. Those findings clearly indicate that it is a human ability to control mental states on demand and in the same line of thought people can learn to perform tasks better when they observe their brain activities.

2.3.2 Identifying Learners

Identifying learners in a short term experiment is rather difficult. In the case of My Virtual Dream (Kovacevic, 2015), the authors defined two groups of high alpha and low alpha present during the tutorial stage in order to facilitate the processes of identifying learnability groups. In their experiment, a sample of 500 has been used with a requirement of 200 people minimal for identification for learners and non-learners. In our scaled down version of the experiment, we group users as high and low alpha to represent the similar characteristics of the original two groups.

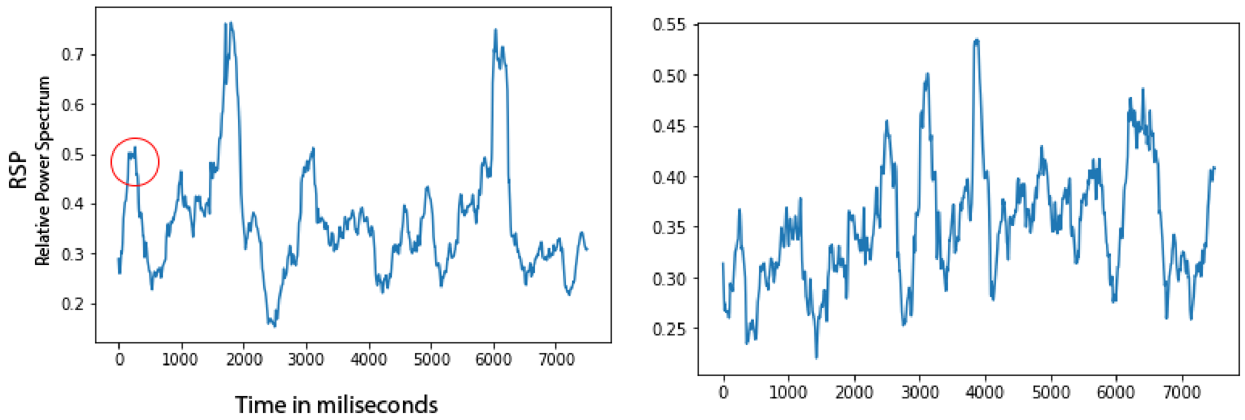

Figure 4: Left: example of identified learner, an spike occurs in the first couple of seconds. Right: Example of non-learner with small spike at around 16th second.

To identify the two groups, we perform a manual classification for high alpha readings during the tutorial stage. We examine the levels of alpha band wave, which is associated with learning style and we expected to detect high alpha levels during the first minute of interaction (Kovacevic et al, 2015),(Sigala et al, 2014), (W.Feng et al, 2014). Similar to MVD, (Kovacevic, 2015) we are going to look into significant changes in alpha and beta performance between the baseline case and the experiment stages.

2.3.3 Neurofeedback And Self-regulation

Neurofeedback utilises real-time displays of brain activity to teach self-regulation of brain function. Studies have shown that neurofeedback can have a range of health and well-being benefits. These include increased attention and memory, intelligence, mood and well-being (Gruzelier, 2014a). Neurofeedback can further benefit novice and advanced musicians for creative performance.

Another study, conducted with school children, indicated impact on creativity, communication/presentation and technique (Gruzelier, 2014b). Vernon (2005) pointed out that while there seems to be an impact on performance enhancement through neurofeedback on a variety of tasks in sport, cognitive and artistic applications, a general failure to elicit unambiguous changes in baseline EEG activity may pose a limitation to these results. Nevertheless, the benefits of neurofeedback on control of brainwaves is recognised (Vernon et al, 2003).

There have been limited efforts to include neurofeedback into entertainment applications to reap the benefits while delivering a pleasant user experience (Pope, 2001). Initial explorations showed that benefits, at least related to attention disorders, can be achieved in such a manner.

2.4 Psychology Of Audio-visuals

When it comes to the aforementioned categories of value encoding attributes, research from the field of psychology can contribute to a better understanding of appropriate visual elements. In particular the branch Gestalt psychology has intensively researched this field. In the following subsections a first selection of some widely accepted psychological principles on visual perception is performed. This is followed by a more in-depth research on visuals perception and emotions.

2.4.1 Gestalt Psychology

The Gestalt psychology is dealing with how people perceive visual components as organised patterns or wholes, instead of many different parts. While the grid approach can serve as good base for creation of shapes and forms (similar to the marvel of a sculptor), the Gestalt Laws of Organisation guide those shapes introduced an organised pattern. According to the theory six main factors are taking into consideration when dealing with visual systems, grouped into patterns: proximity, similarity, closure, common fate (i.e. common motion) and continuity. (Arnheim, 1971), (Marcoli, 2015).

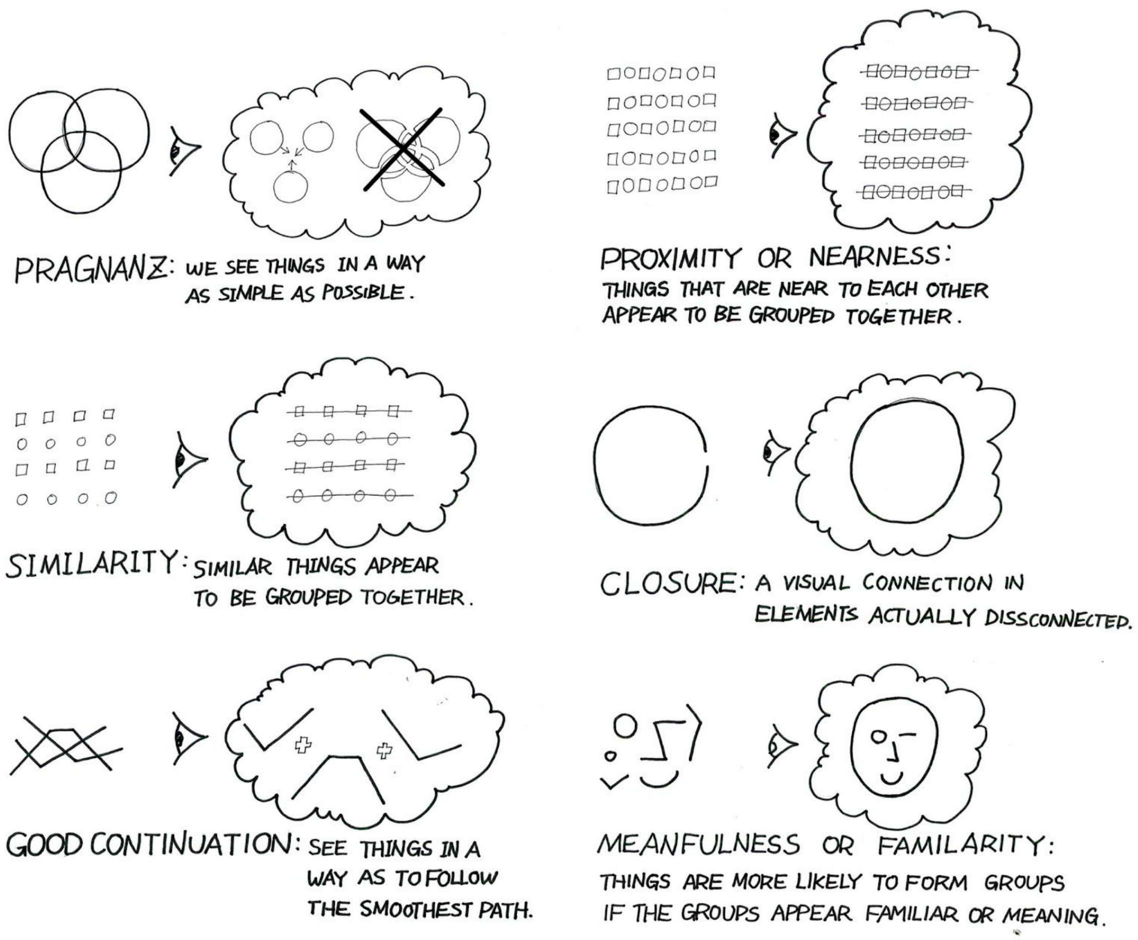

Figure 5: Gestalt principles visualised, Theory of Architecture, Unit 2, Ar. Thulasi Gopal, SRM University

As established in Section 2.2.2, the data collected via neuroheadsets can be linked to emotional states. It thus seemed interesting to investigate whether there are visual elements that also relate to these emotional states. Fortunately, there is a good amount of research on shapes, forms and their influence on emotions. In the paper "Humans prefer curved visual objects", curved contours are associated with positive emotions while more complex sharp and angular objects are considered to provoke negative bias (Bar M. 2006). Further, (Lu, 2012), documents different natural pictures and their shape characteristics. Parameters for roundness and angularity are further investigated with in-depth statistical analysis in order to understand the relationships between emotion and shapes. Shapes and Emotions are going to be used for the base of designing the final experience, since the requirements of this projects are framing the future interaction.

2.4.2 Shape And Emotions

There is a good amount of research on shapes, forms and their influence on emotions. In the paper Humans prefer curved visual objects, curved contours are associated with positive emotions while more complex sharp and angular objects are considered to provoke negative bias (X. Lu, 2012).

Further on emotion and shapes in (X. Lu, 2012), different natural pictures are taken and their shape characteristics are documented. Parameters for roundness and angularity are further investigated with in-depth statistical analysis in order to understand the relationships between emotion and shapes. We are going to use this findings in Ideation phase to construct our visual shapes.

2.4.3 Sound

It is known that music has influence over the overall experience (Yuan Q, 2000). This effect varies from individual to individual. Hence the music in the audio-visual experience should accommodate the stages and emotions which the given stage focuses on. While sound can be made also interactive, as Brain-Computer interaction is suitable for it, we will leave it outside the scope of this project and use sound as ambient element.

2.5 Interactive Experience With EEG

Interacting with EEG technology when it comes to BCI, is one of the prime methods in this current stage of development. Several EEG-based interactive experiences have been developed in the past, each with their own focus and storyline. This section, which can be seen as 'state of the art', describes them.

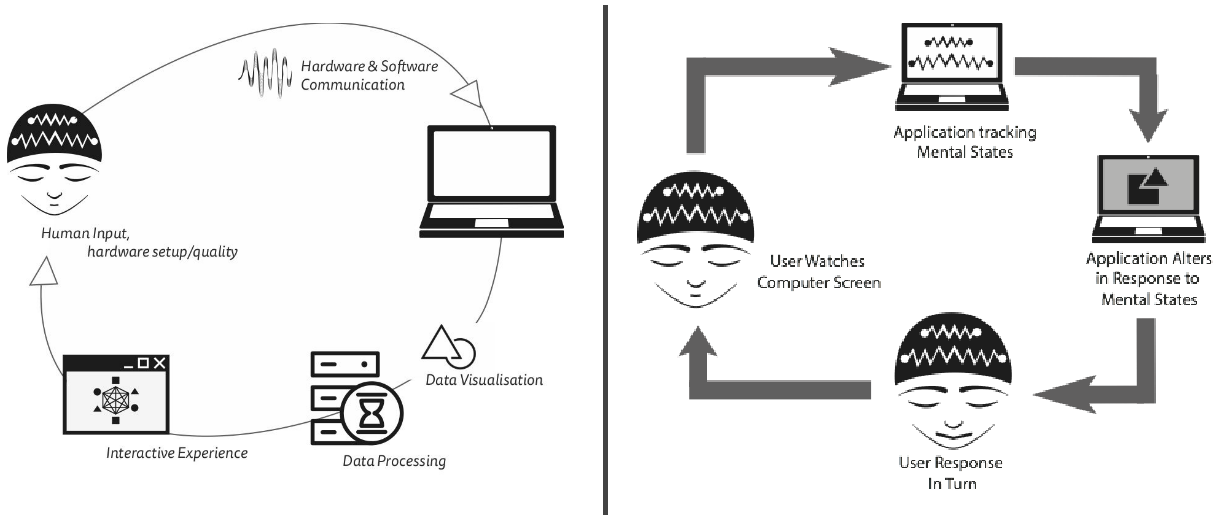

Figure 6: Interactive experience

My Virtual Dream (MVD) by Natasha Kovacevic et al., 2014

My Virtual Dream[5] is serving as inspiration for our work on the project at hand. The installation is immersive multimedia science-art experiment, figure 3, conducted as large scale BCI explorative experiment. The study, which took place in a single night event, is measuring the alpha and beta frequency range to detect mental states of relaxation and concentration. The project measures the learning outcomes of people's ability to control their emotion states by measuring EEG signals and make classifications based on spectral power patterns for the two states. During this experiment, the individuals signals were combined to create a multi-brain interaction, and represent a visual experience in a form of one big virtual dream (Kovacevic et al., 2015).

Cross-Currents in Water-Based Performance by Lisa Park (2013-2014)[6]

Lisa Park's performance work uses the medium of water to distinct a message of ideas and emotions. In 2013, she did Eunoia performance in which she monitor 5 emotions: sadness, anger, desire, happiness, and hatred, one per plate. In 2014, Eunoia II was outfitted with 48 vibration pools and inspired by Baruch Spinoza's work, the full spectrum of emotions outlined in his books, such as: frustration, excitement, engagement, and meditation. The use of water as physical medium and the sound created is fascinating because the installation moves out of the digital world out to natural and appealing to the audience (Rothbart, 2015).

MindArt: Generative sound Visualisations of real EEG data (2011)

The art installation is a demonstration of visuals for EEG data, an early example demonstrated during BCCN2011. The authors and participants observed clear influence of music over brain states. In relevance to this exploration, the importance of music as element of art installation, could have also influence on the users' input as well (Matthies, 2011).[7]

Brainlight 2015

The installation Brainlight, combines biology and illumination design into an interactive sculpture, which lights up in response to changing brain activity transmitted from an EEG headset. In this work the authors gives insight into users brain activity allowing them to flourishing intrigue to understand one's own mind. [8]

The Octave of Visible Light: A Meditation Nightclub

In this installation the artist is putting the human in 'the spotlight', literally, as the installation is using EEG biofeedback, representing users emotion state with texture, colour and sound, which are projected around the user. Similar to Mood Sweater, this installation is aiming to expose individuals emotions as a part of new medium, as somewhat define by Sensoree as extimacy[9] - externalised intimacy.

Anti-Apocalypse

The project is a project which explores how the embodiment of memory in networked media influences how re-/co-/create our worlds and our selves. As described by the authors, the immersive digital cinema, with the help of EEG BCI, digital video database and custom software, to composite

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[5] My Virtual Dream homepage http://myvirtualdream.ca
[6] Lisa Park official website, http://www.thelisapark.com/eunoia/, accessed: 2017
[7] MindArt - visualizations of real EEG data for BC 2011, youtube, accessed: 2017 https://www.youtube.com/watch?v=CO7PE9fEguQ
[8] Brainlight homepage, 2015, http://www.brainlight.com.au
[9] Sensoree: therapeutic biomedia is bioresponsive design for *extimacy* http://sensoree.com/about/

experience by remixing media and animated loops.Oscillating between visual perception and mental observation, the viewer navigates a labyrinth of multiple, discontinuous, collective memories, exploring the disorienting and transformative liminal spaces between these virtual records, their material manifestations and psychic traces.

The element of digital storytelling in new media is widely open for debate, however from the previous examples we see an similar approaches for interaction with the storyline itself used in MVD as background visuals of dream and Anti-Apocalypse. In both cases libraries of images and animations were combined together based on the input from EEG of the individual users.

Mutual Gaze

Marina Abramovic, experimenting on consciousness through art/science experiment involving real-time brain installation. In this installation, volunteers engage in silent mutual gaze while their brain activity is displayed in real time, giving in the mutual experience. The installation was performed at The Museum of Modern Art, New York during a three-month period. The installation has been described on many occasions by participants as unique experience and probably the confirmation for that can be found in the data. It is however not accessible for the public and no findings can be backed up by published paper. The scientific intend is very inspiring as the topic of gaze is interesting in the context of virtual worlds. This level of mutual perception is fascinating as it does happen natural between the two users. The project is great illustration of the power of mind and connectedness of individuals (Abramovic, 2012).

Mood Sweater

This installation is aiming to expose individuals emotions as a part of new medium, as somewhat define by Sensoree as extimacy - externalised intimacy.[10] Sensoree is describing itself as bio-media and has various conceptual projects for that concept, including brain animated fashion, heart sync and get mood sweater.

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[10] *The Octave of Visible Light: A Meditation Nightclub, Lia Chavez, artist in residency* www.liachavez.com/the-octave-of-visible-light-a-meditation-nightclub/

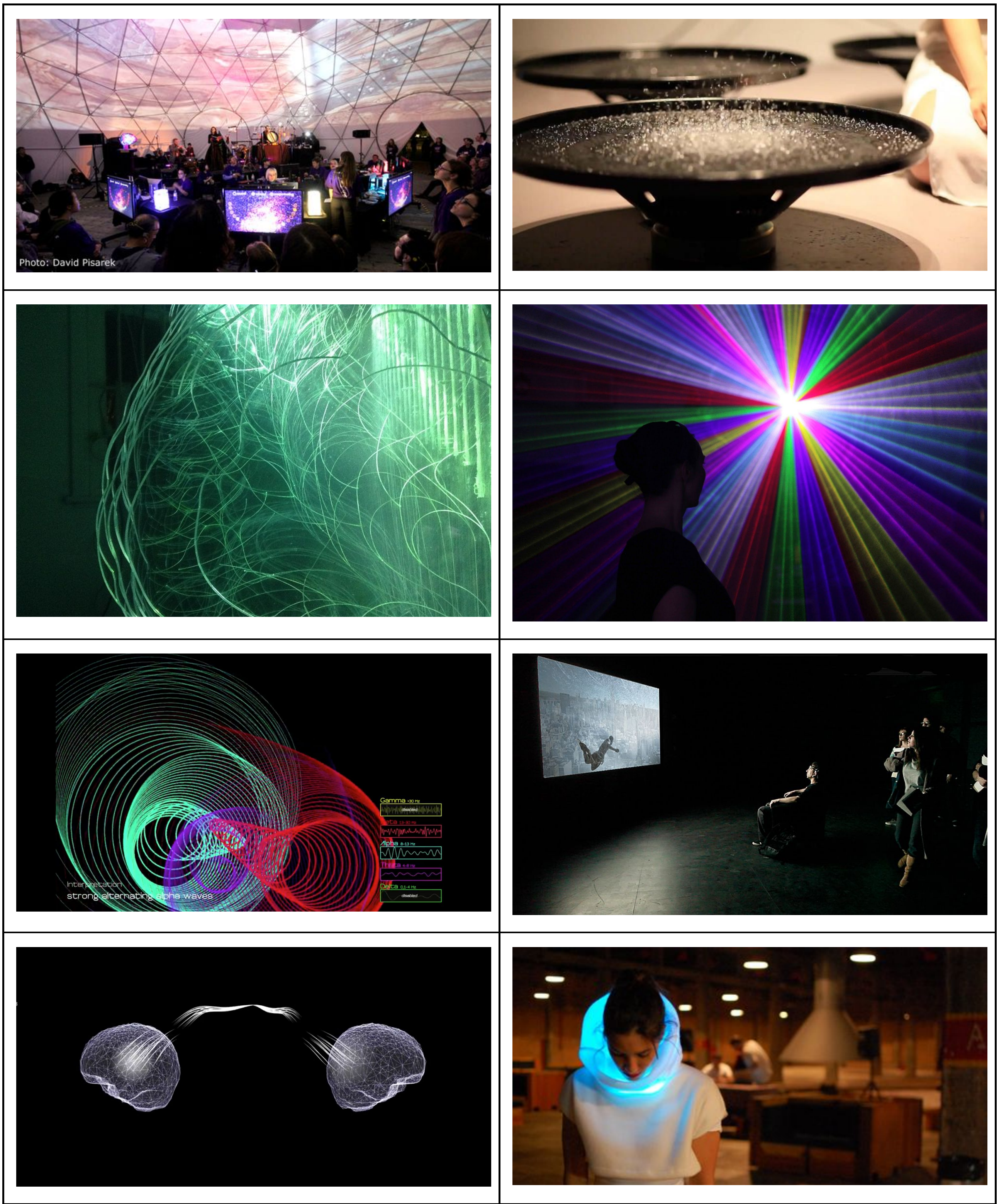


Figure 7: Screenshots from described projects. From top left to bottom right: My Virtual Dream, Cross-Currents in Water Performance, MindArt, Brainlight, The Octave of Visible Light, Anti-Apocalypse, Abramovic's Mutual Gaze, Sensoree's Mood Sweater

2.7 Requirements

In this section the final requirements for the interactive experience are stated. Those requirements are build based on the previous research and the goals of the project. In the upcoming chapter 3

Ideation, we use those requirements to filter and make design choices for our final prototype. The list and assign points to each of the requirements using must, could, should (MoSCoW) method.

#	Requirement	Points	MoSCoW
1	The application must be interactive with BCI	3	Must
2	The application must be real-time		
3	Active or Passive BCI Interaction		
4	The user must feel that he/she is providing the interactivity		
5	The user experience should have coherent flow		
6	The experience must provide insights into brain activities		
7	The data visualisation of the brain activities must be understandable for the user		
8	It should target first time users		
9	Should utilise psychology methods for visuals	2	Should
10	Visuals should enhanced conveyed emotions		
11	Should use ambient music		
12	The application could utilise machine learning for cleaning data	1	Could
13	The application could use shaders and high computational methods for visualisations		
14	The application could have multiplayer/brain experience		
15	The application could be suitable for Virtual Reality		

Table 2: Requirements with MoSCoW method

3 | Ideation

In Chapter 2 we outlined related work, which helps us define the design choices in the subsequent section of the project. In the first part of the development, we described some flashes of inspiration, live sessions with users and technology thinking. In the end, we outline the concept based on the insights gathered.

3.1 Users Needs

Identifying users needs is one of the first points of interest when it comes to BCI, due to the novelty of the technology and availability. With the goal of obtaining insights into the user experience, we used two different commercially available headsets, Figure 9. We observe the interaction during some open session with first-time users. Followed up we looked into those insights and start with technology tinkering.

The first sessions for obtaining insights were during an event called *Try and Play*. During it we observed the interactive experience of first-time users, playing a game *Spiriting Mountain*[11]. The game was developed to demonstrate the complete range of input methods for Emotiv headsets, described in *Section 3.2*, *table 2* After the completion of the game, which is around 10 to 15 minutes of gameplay, users shared their thoughts and feeling about the technology and more specifically the input methods in term of control. Some of the key learnings are:

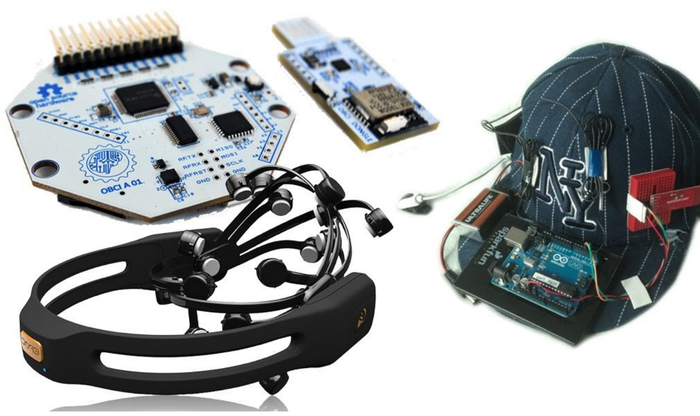
- Explicit training of interaction is difficult
- Trained commands isolate the interaction
- Mouse and keyboard lower the excitement level

3.2 Technology Tinkering

We looked at basic understanding of BCI at section 2.1 and got introduced to the concept of neurofeedback loop. The process of technology thinking take a deeper look into interaction methods, classification and visualisations. We explore the two BCI devices at hand and the available options for development. Finally, in this section, we look into visualisation and user interaction.

3.2.1 Hardware

The two devices at hand have similarities but also differences. Both provide EEG signals and come with software development tools. However, Emotiv is representing the best out of the commercial world last years, with company focus on perpetual algorithms for classification of emotions, while openBCI is representing the other spectrum with complete open approach suitable for makers and electronics hobbies.



[11] *Emotiv promotional video,Mind Control/Brain Control, Youtube Video https://www.youtube.com/watch?v=eVX7c_eviB8, ~20s-40s*

3.2.2 Processing Brain signals (EEG)

Processing the brain signal, the data provided by the devices, is essential part of the interactive experience. In contrast with more traditional input, such as keyboard, the software needs to interpret the signal in order to be used as input for this installation. As we previously learned in sub-section 2.1, we are left with few choices for classifications: to work with the raw EEG signal and make our own brain states classification, or use some of the pre-defined input methods provided by the makers of the devices, see Table 1 for complete list.

In the case of Emotiv, each suit represents different types of interaction, such as face expressions, trained thoughts, and different emotional states. We previously experienced all of those with first-time users and the provided by the companies software, see section 3.1. Considering feedback from those first time users and literature review, we choose Affective Suite and Raw EEG / Brainwaves the two methods for this Ideation stage. The data provided from Affective suite is already pre-processed and classified. The reason for that was mainly the setup up time, as the two methods represent interaction without the need for the system to learn/adapt to the users before the interaction starts, as the Cognitive suit requires. It was noted out by the majority of the users, that such interaction decrees the 'wow'-effect of the technology and adds up unnecessary additional setup up time.

Affective suite, is a great option in theory, however the absence of detailed information on the inside workings of the algorithms makes it difficult for us to assess or adjust it to our needs. Nevertheless, before drawing that conclusion we perform field tests on that input method. Brainwaves, as we mentioned before is one of the oldest methods for classification for brain signals. This input method is included in openBCI's provided software and is also further possible to achieve through custom classification on raw EEG signals.

Input method	Description	Platform
Cognitive	Pre-recorded, trained interaction	Emotiv
Brainwaves	widely known brain signals frequencies	openBCI
Custom Filters	various methods implemented from raw EEG signal	all
Expressive	face expressions	Emotiv
Affective	Classification of emotions: Frustration, relaxation and concentration	Emotiv

Table 3: Classifications of brainwaves

3.3 Prototypes

Now when we have understanding of underlying inputs, devices at hand and some experience with users, we can proceed to the visuals of the installation. While the classification decision is still to be made at that stage, we probe those different input methods in series of tinkering sessions called *hacks and explorations.* During those sessions we program and design an limited interactive BCI applications with focus on one major element at a time. The result is more than 15 developed applications, divided in three exploitative groups.

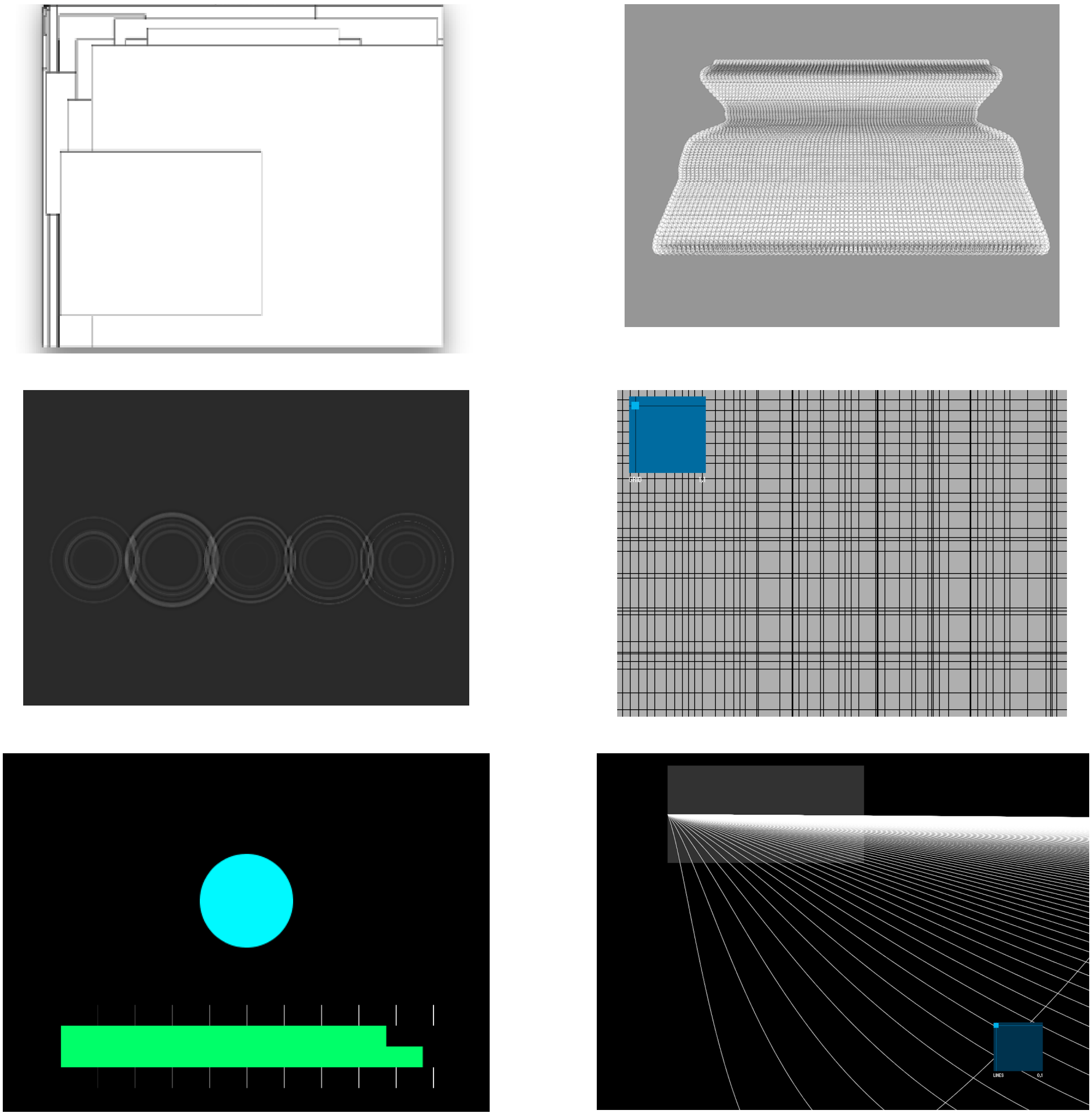


Figure 8: Early prototypes in processing

The communication between the hardware and the application is of a secondary priority, but of a importance considering latency of the signal and overall experience. This communication is possible with two methods: local network with Open-Source Sound Controller (OSC) and direct access with Software Development Kit (SDK). Different implementations of both were tested during the hacks and explorations. We concluded that the most suitable method for this project is OSC for both devices and SDK for openBCI, since Emotiv's SDK is presenting series of challenges related to backwards computability, software documentation and examples code functionality. This leads to successful prototyping with OSC and was later used in the final prototype, even though in theory SDK implementation should be the correct choice for end-user product, given it is considered the proper way of constructing derivative application and eliminates the need of multiple applications.

3.3.1 Initial data visualisations

We started our exploration by looking into the traditional data visualisations such as, bar, charts, line graphs and colours. Next, we look at generative structures and scenes in virtual worlds for a more modern visual approach. Both simple and complex scenes were constructed and tested with emotional parameters such as *frustration* or *relaxation* for example. An overview of better outputs of the exploration can be seen in *figure 10.*

On first look, the two provided software dashboards provided by the two companies do already include some basic visualisations. The signals are represented by line graphs and some of the classified information in the form of bar charts.

When we started developing sketches for visuals we tried to build further than basic data visualisations, as we have a more artistic approach. In *fig. 9* we have two sketches resonating on different emotions. In the top example we have the five readable in Emotion Suit. The resulted animation of fading circles reminds somewhat to the Eunoia performance from *subsection 2.4.2*. In the bottom example the centre circle as a response to the dominant brainwave and the bar charts below are corresponding to the recorded power spectrum of that four brainwaves. This setup demonstrate a switch between emotional states with focus on one visual object, while tracking various others. The pulse rate and the colour of the circle are changing depending on which states comes on top of the others.

Further, we looked at *colours* as defining factor of visuals and emotions, *fig. 9*. We used different shades of red, green and blue to represent positive and negative emotions. In the top example we see two different states of early sketch where each box shows recorded values for previous moments. This was a first experiment with randomness, but quickly discarded since the EEG data was dynamic enough and adding randomness is not needed. We again tried the concept of one dominant colour for the dominant brain state. On the bottom sketch we see an overview of a Emo painting' with *concentration*, *relaxation* and *frustration.* The brushes in that case were 1 pixel height lines, which we accumulated in real time and hold ~30 sec. of recorded data.

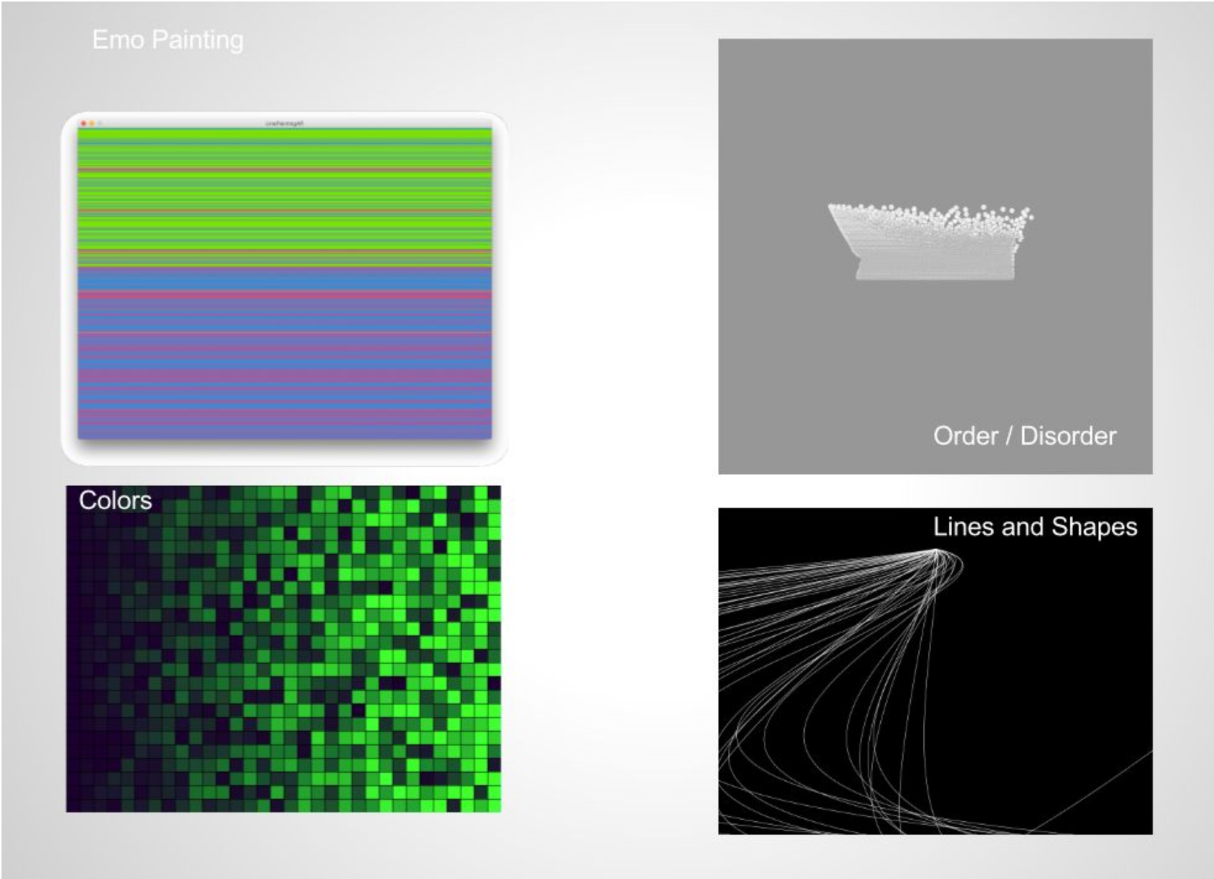


Figure 9: Categorised early prototypes

After having some basic views on different inputs, visualisation methods and quality of interaction, we wanted to try something more artistic and yet still basic concepts. We looked at the concept of *chaos* and balance between *order and disorder.* This was motivated by authors acquaintance with mindfulness movements and their contrasting ideas that the mind could be completely empty, or being in a constant state. In *fig. 9* Lines and Shapes is the outputs of various grids interpretations and patterns. This concept was extended by making various objects navigate through the previous grids. The size of the object was representing the power spectrum of the emotions, while the order/disorder was corresponding to the balance of contrasting emotions, such as *frustration* and *relaxation*.

Our final experiment from the basic session was also delivered from the concept of chaos and order. In this experiment we curved the grid lines between a vector point of origin and multiple other vectors. The visualisation transit from complete randomness when emotions of frustrations have maximum recording to well spaced, grid-alike composition when relaxation is at maximum. This sketch was pointed out from multiple test users as exciting directions and the concept of applying external forces to existing visuals was separated for more detailed exploration.

3.3.2 Advance Exploration

Advance explorations was the second approach used with focus on 3D scenes and complex composition. Multiple parameters at a time were tested as well as parameters dependencies, for example relaxation and concentration. We experimented with various colours, shapes and scenery and their relation to emotional states.

First we tried some using force to cluster on objects, as seen in *Fig 10*. The cluster is having a harmonic motion related to the long term readings of emotions from Emotiv Affective Suite and the force is applied if a significant difference is detected in the current moment. This setup was used for other visuals and different emotions as the one in the figure is considered the best one. In this sketch we use relaxation and focus as emotional input parameters.

The next idea with tried in visual form was inspired by 3D MRI scans of the brain[12] and the idea of being downsized to an small enough size to feel the vastness of the human brain. For our next sketch we used an particle system wrapped around invisible sphere, where the number of particles depends on the power readings of an emotion. The triangles, as an edgy shape is related to negative emotions and was used for visuals for frustration. On that stage it was clear that if we want to use multiple emotions in to further look at differentials than colour alone (*Figure 10*).

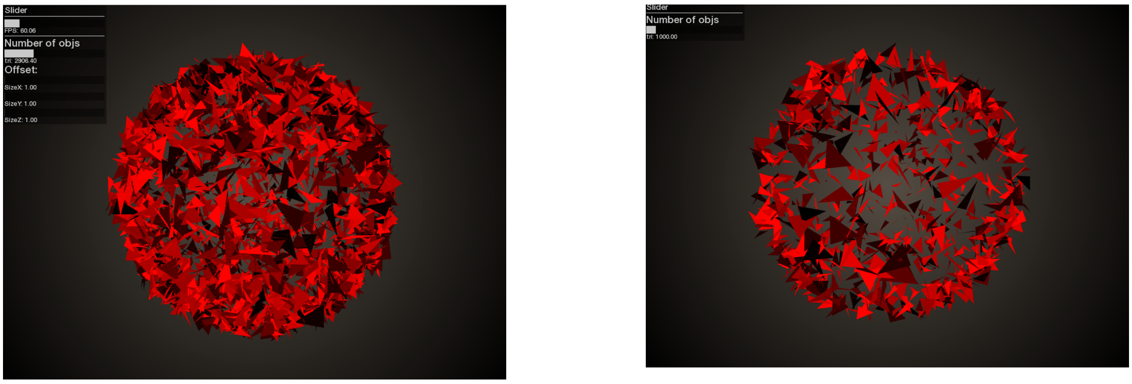


Figure 10: Advance prototype, sphere representing power intensity of brain signals

Our last exploration was an deeper look into shapes and emotions. We look into approaches for creating 3D shapes and manipulating their form based on EEG readings (*Figure 11)*. We used shaders to generate and manipulate different shapes, from rounded to downward pointing triangles and inverted sides, which were associated with feelings of frustration, concentration and focus.

Last, but not least we tried direct input for a game with the controls corresponding to brain states. For that test we used a basic runner concept, as in popular mobile apps. The advantage of this game mechanic is that the actions were rather limited, partially duo to the portability of the platform, to time based reactions. For the purpose of our exploration, the only action which the user had to preform was jump over or under and the control was designed to respond to relaxation and concentration correspondingly (*Figure 12*).

Figure 11: Shapes transformations experiments, relaxation as more rounded shapes, concentration and frustration more edgy, complex shapes.

[12] https://www.sciencedaily.com/releases/2011/01/110105194850.htm, Major advance in MRI allows much faster brain scans

Figure 12: Infinity Runner by Born Free Labs on Unity Assets Store

3.3 Experiment

The project experiment of this thesis work was a scaled-down version of the My Virtual Dream experiment, using the same methodology and experiment setup. The key difference between the two is the number of participants at a time. The project had a single user at a time in, instead of 20 divided into four group at a given time. In both experiment setups, the neurofeedback targeting modulation of relative spectral power in alpha and beta frequency range were used as input. The full procedure of the experiment can be found in *sub chapter 6.1.2.*

The procedure for the experiment hence is described in more details in *subchapter 6.1.* Scaling down the experiment also meant to exclude the multiplayer aspect and the comparison in-between users. We measure the relative spectrum power (*subchapter 6.2.2*) in alpha and beta band-waves for measurements of relaxation and concentration.

For our version of the experiment, we also use public space, but we lean more with *Hasson et al., 2012* and try look for more home alike venue. While participants and visitors were not explicitly separated, all visitors had to agree to some basic rules: *No new visitors were allowed during a running session, Visitor cannot participate in the experiment, users of the experiment cannot be visitors before taking part.* We also ask the participants, supporters and visitors to limit their interaction to freestyle stage**,** which was not part of the experiment.

3.4 Conclusion: Interaction Idea

Based on the insights from the Ideation phase and the background work in *subsection 2.5*, an interactive experience constitutes of an real time interaction with brain states in a form of neurofeedback loop. In this Ideation stage, we are extending the feedback loop to include more sub-system as well as the different inputs provided by the divides at hand. Those sub-systems yet to be more clear defined in the coming Realisation chapter, nevertheless hacks and explorations lead to following sub-system: *Communication, Data Logger, Classification and Graphics*.

The expectation of users to able "*to simply put on a magical helmet which would read their mind",* which is currently not yet realistic. However, we can take into consideration some of the elements which can give better user experience, no time consuming calibrating actions. By experiencing development and user testing with all methods for reading and classifying brainwaves into brain states, we make an educated choice. The users expectation rules out the Cognitive Suite as interaction method, despite years of being marketed as main feature in Emotiv's interaction toolkit. During exploration of the input methods, brainwaves was identified as the one most suitable for designing an interaction which adapts to the users states.

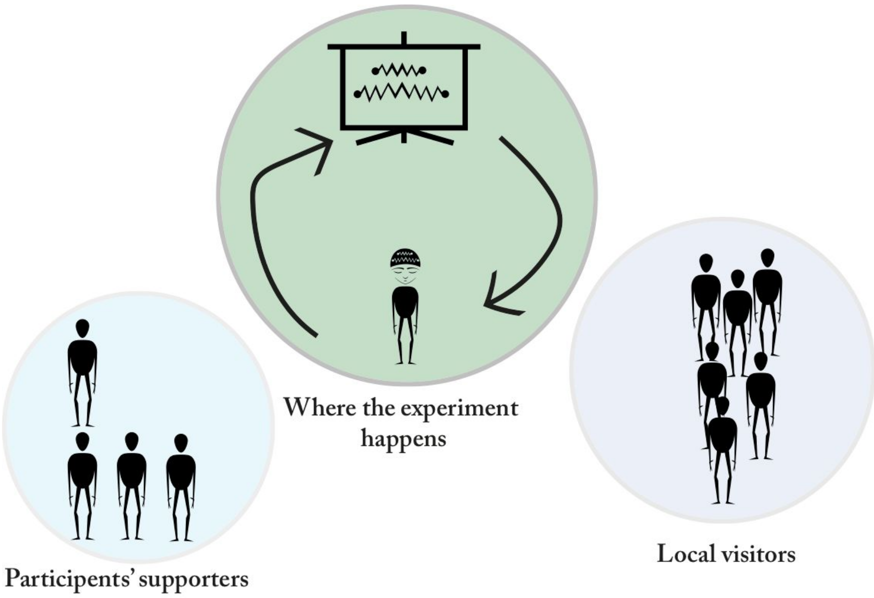


Figure 13: Experiment audience setup

By applying humans natural ability to control brain states, the interaction should represent an extension of power of the brain. To represent and amplified the feeling real time interaction with brain states, we choose to give the feeling of control over complex scene. This feeling of control is represented into closed simulated environment, in which the interaction is the system adaptation to different feelings. The visualisation and the rules of that close system are both depending on users levels of alpha and beta as the input changes colours, shapes and gravitation. This idea of interaction is rather new for the public and gives somewhat never seen before experience. Manipulation of heavy objects, such as tons of rocks and asteroids as easy as relaxing or concentrating.

Last but not least, we settle on shapes and colours for the implementation of the final visualisation. From the advance exploration methods in 3.3.2 we conclude that edginess and roundness are associated with negative and positive emotions. Hence a transition between the two can be used for element of interaction for two emotions. A group or composition can represent the emotions over time. Same relation could be applied for colours, were we choose variations of blue, green and red for relaxation and concentration.

Key Points

- **Users' needs to match the availability of technological and implementation methods**
- **Objects and general design of the scene could be used to convey user's BCI input i.e. Shapes and Colors changing according to mood.**
- **There are several visible approaches for interaction, they need to be appropriated to users' needs.**
- **Complex interactive scenes can convey the complexity of human brain too.**

4 | Specification

In this chapter we are going to translate the Ideation phase into specification before developing the final prototype. This specification stage aims to support the realisation of the final prototype and the evaluation as much as possible by providing guidelines for execution of the project. Look at requirement for basic setup, user experience as well as functional.

4.1. Use case scenario

To further translate the Ideation phase into development of the final experiment, we envision the following use case scenarios:

1. Home, office or another well *known physical environment* for the user
2. The user having a *feel of mental heaviness* and want to take a short break
3. Users choose to use guided mindfulness method with the help of computer or mobile device
4. As alternative to meditation they *choose to use a BCI device* and *try neurofeedback*
5. Their *brainwaves are detected* and the visualisation *adjust to the corresponding feelings*
6. Users changes brain states influenced by visual representation
7. The application responses to brain states in each second providing real time visual feedback

4.2 Brain States Interaction study

In this subsection we transform our findings Ideation into defined design decisions by taking all the elements from the ideation, concepts and what we learned during development of previous prototypes to create an design specification for interaction study ahead. we describe the study performed to answer sub question 1.2.2 and *1.2.3 " Can users control their brain at will ?* ", *"How can learning in this context be stimulated?"*. As we already know from Chapter 2 and especially sub-chapter 2.3, we need to create a neurofeedback for which we need to decide on classification methods and interactive visuals.

4.2.1 Neurofeedback

As outlined in the previous chapter, we tested both Emotive and OpenBCI devices and related SDKs. **OpenBCI** is the preferred choice, as it provides benefits in terms of technology, accessibility of raw data, documentation, an active and supportive community as well as the open source nature the device. However, most of the commercial available headsets should be suitable with different readings depending on the number of sensors.

For our experiment we decided to use **two mental inputs**, represented by **two brainwaves readings**. While the mental input could again vary from device to device being used, brainwaves is a universal method, which could be classified with any EEG device, hence providing a multi-platform approach. In addition to being one of the most understandable classifications we tried out, mainly because the majority of the people have been hearing the term more than once, brainwaves is the preferred universal approach for reading brain signals, for which the system doesn't need to adapt or setup for extended period of time. We had an extended look into different brainwaves readings and their readiness level for interaction and we came to conclusion that the readings in alpha and beta band waves are indeed the most readable once. This conclusion aligns with *Kovacevic et al. 2015.*

Last but not least we settle on design choices, related to the visualisation of the neurofeedback loop. Guided by the objectives of *My Virtual Dream* project for a visualisation, which rewards the users for high performance and/or learnability element. In *subsection 3.5*, we already mentioned our final idea for the concept for an interactive space, which amplified the mental states and their recorded spectrum power as a interaction input for influence over the visual scene in an empowering manner.

4.2.2 Experiment Setup

We already know a big part of the experiment, since we created a scaled down version of the experiment performed during the interactive installation of My Virtual Dream project, with similar but different visuals objective and experiment designed for single user experience.

One of the factors mentioned by several authors of prior work is the amazing opportunity to bring BCI out in a real world environment. It was therefore decided that the installation should be placed in such an environment as well. Desired location, would be one in which the user feels comfortable and in familiar place, such as social clubs, frequently visited public spaces or home environment. The time of the day is also important factor, as this experiment is focus on stress free, work time hours.

Beside the visuals and number of participants at a time, we also had to consider that our experiment is concluded in much smaller space and less assistance to navigate it. Therefore, as describe in *subsection 3.3*, we tried to make set of rules which will ease the experience and avoid interruptions of the experiment.

4.2.3 Functional Specifications

The functional specification is aiming to provide an overview of the elements needed for the smooth technical experience. We need to take into consideration *what brain measurements we take*, what and *how the data is recorded* as well as *processing the signals* into *classifications* and *parameters*, which can be used in visual neurofeedback installation.

- **Device capable of reading EEG brain signals** such as openBCI or Emotiv's EPOC.
- **Measuring brainwaves** is the form in which the brain signals needs to be classified and mapped to a power spectrum for comparison and interaction.
- **Data Logging** of the raw EEG signal, should be recorded in their pre-classified form, in order to be used later on for data cleaning and independent from the interactive experiment brainwaves classification.
- **Interaction Parameters** should be extracted from classified brainwaves in a form of post-processing method of *normalisation (Bos, 2012)*.

On the other hand we have the visualisation specification which include *elements*, *style* and how users interact with them.

- **Elements** should be modelled in 3D and with representative sharp or edgy contour. Those elements should be grouped together depending on the reading and represent a set of recorded/detected mental states over time.
- **Style** of the visuals should be somewhat futuristic scene in which amplified emotional states and should provides the feeling of power over the interaction. The style of the classified mental states should be designed with GESTALT principles in mind. *(Section 2.3.1)*
- **Interaction** should be smooth and in real as possible time, providing the user a seamless experience between mental changes and visualisation.

All of those elements need to be dealt with software systems, which needs to be implemented into a coherent experience with the visualisation for the neurofeedback to be complete and designed for the needs of this experiment. The system should be able to read, classified and visualise mental changes in users brain signals and react to those changes in a matter of *couple seconds* to *under 500 milliseconds*, *but in no case above 3 seconds* as we know from the hacks and explorations in the Ideation stage.

The visual feedback has to be representation of the emotional states of the users and the corresponding brainwaves. An indication for their current performance needs to be part of the visualisation and to be clear for users that their mental input is corresponding with the visualisation at any given time during the interaction.

4.2.3 Headband and sensors

Given the choice for OpenBCI, it was necessary to construct a custom headset, as the OpenBCI comes in the form of an Arduino-like shield and a set of electrodes. While there are 3D printing options for headsets matching the platform available, we decided to produce a soft headset for increased user comfort. The headset was constructed from elastic band and Velcro. We produced a first version ourselves, and gave it to a fashion designer to produce a more advanced version. It can be seen in Figure 15.

The placement of the sensors for this experiments is demonstrated in the Fig #. We have sensors placed in frontal regions in proximity to location of Fp1, Fp2 as well as two reference closed to the ears. The rest are used as electrical reference. A getting started guide for the rest of the setup could be found in an article from Autodidacts webpage[13].

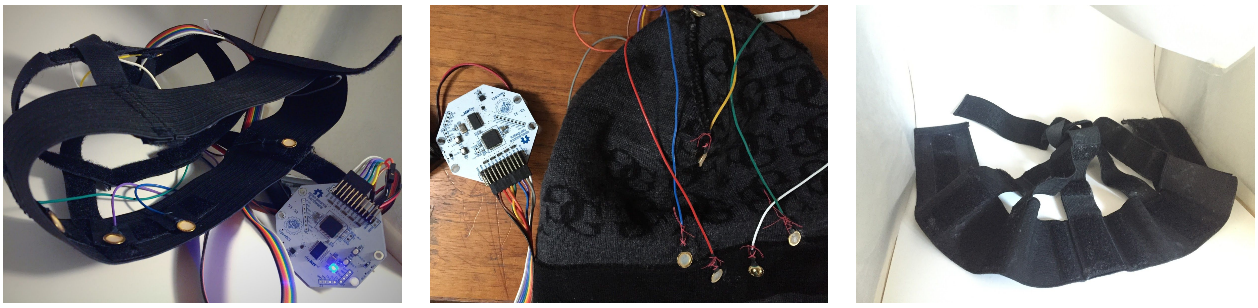


Figure 14: Different stages of prototyping headband with sensors

[13]*Getting Started with openBCI by Curiositry, Jan 7th 2015*
http://www.autodidacts.io/getting-started-with-openbci-a-tutorial-on-testing-troubleshooting-and-recording-ekg/

5 | REALISATION

For this final stage of research and development we focus on the realisation of the project. First we describe the various sub-systems and their realisation. We take into consideration all we have learned and the specifications which we construct. We look at the different modules and incorporate them into subsystems, which works together as an Interactive Installation, with all functional specification.

5.1 Neuromore Studio

While many different methods were experimented with for various platforms during the Ideation phase, we decided to use for the realisation of this project Neuromore Studio[14]. We do not diverge from the previously explored various subsystems and the software toolkit allowed us to smoothly translate from initial prototypes to their platform. The Studio includes graph programming interface, which made quick switches possible, without the need to reprogram the data logger and the classification modules. We further used it for signal processing, thus reading the incoming data from the OpenBCI, filtering of wavebands, detecting and sending it to the visualisation engine via OSC network protocol. The full setup and corresponding sub-systems can be seen in Figure #

EEG device is our case openBCI, but by using Neuromore, we can use several of more popular BCI devices, including Emotiv and Muse, which we previously mentioned. By exchanging just the Device node we can flip the setup to a different device and keep the setup.

Data Logger is handled by file writing node, which was produces an CSV file, with columns for each available sensor. The software also offers Cloud synchronisation, but that was not valuable option for experiment like that.

Filtering is the first subsystems, which are addressing has more than one node. We know from previous literature review and exploration, how to do the filtering to obtain the RPS of alpha and beta brainwaves. First two filter nodes are low pass (below 0.5 Hz) and high pass filter (above 50Hz) and the output signal goes to Fast Fourier Transformation. We used FFT in order of 7 and Hann function. At this point we need to filter alpha and beta. Because of the variations of humans, those readings were filtered in corresponding bands *(8 to 12 Hz and 16 to 30 Hz)* as well as corresponding background *(6 to 8 Hz and 12 to 14 Hz).* We then produce two variables for Alpha over Background and Beta over Background, which represent the two spectrum. The final step of the filtering is to adapt the signal over 30 seconds and subtract that with the current reading for a readings over time.

Post-processing is done with the next few nodes, which are statistical mean of the adapted signals for interval of 1 second. If the resulted value is positive that means, strong alpha or beta detected. Beside from the detected value we can also measured the absolute values of the RSP. We then *remap* the values to interval *between 0 and 1*, for more suitable use in the Visualisation engine. We know that the remap values are having 0.5 as strong RSP detection minimum.

OSC output is the protocol with tested with highest degree of success in the Ideation and it is also part of node graph. We broadcast the mapped values after the post-processing into two separate streams one for alpha and one for beta.

[14] *Software for biosensors, Neuromore Studio, https://www.neuromore.com/*

Last but not least we utilised the Session function, which made it easy to separate the levels and the band waves into series of files for each user, could be start, stop and paused, hence making the recordings on the precise and making the data cleaning process afterwards one-step easier.

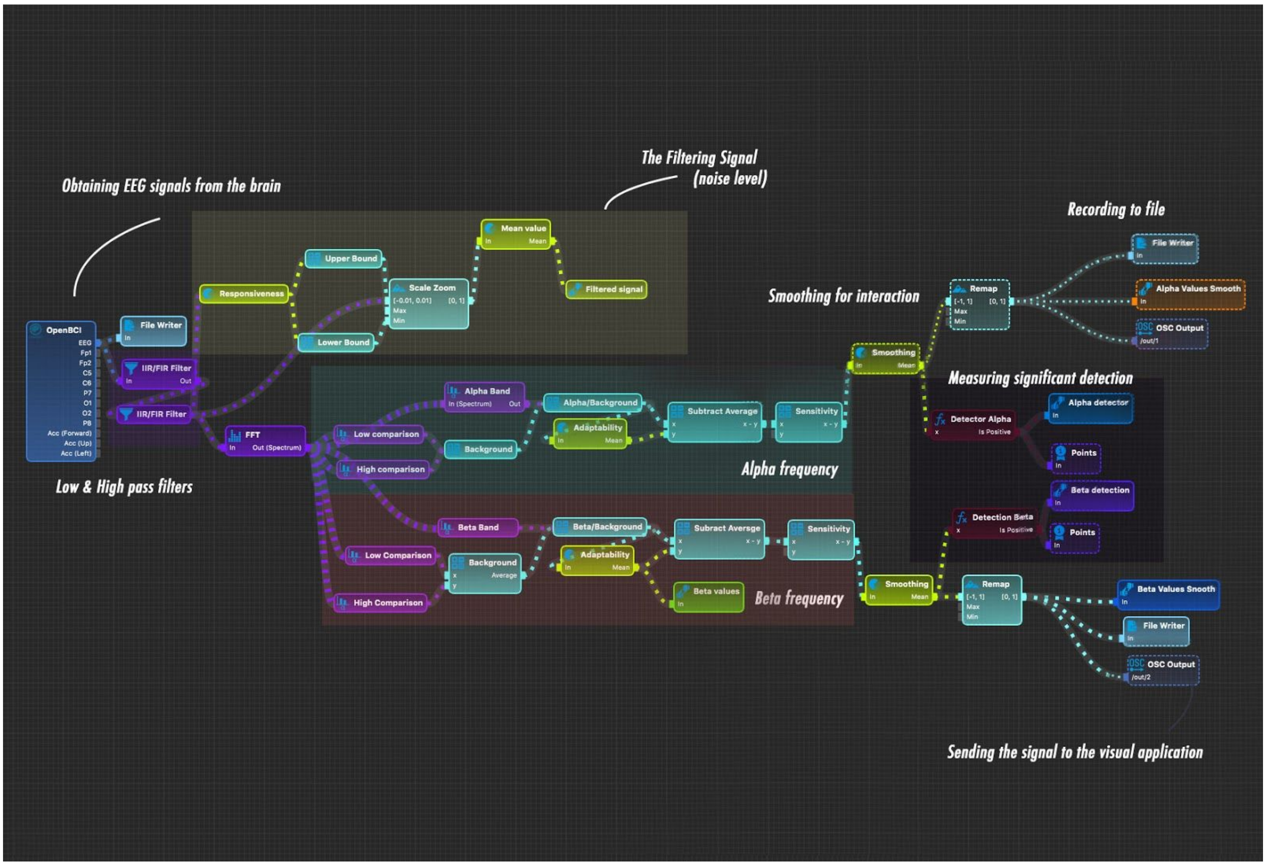


Figure 15: Subsystems implemented in NeuromoreStudio graph interface

5.2 Visualisation Engine

The visualisation was implemented in Unity3D game engine which enables us to design and manipulate an environment in three dimensions. We receive the signals from Neuromore via the network using the OSC protocol and a client side inside Unity. Alpha and Beta waves, respectively, are translated into an asteroid field. The type of wave determines the colour of the asteroids, and the number of objects and spread are controlled by the power spectrum of the waves. This design was derived from the order and chaos and irregular pattern prototypes, as described in ideation.

OSC is considering of two software pieces, server and client side. The server side is already handled by Neuromore, and we need to create the client side inside the Unity engine, in order to receive the signals broadcasted with OSC. Fortunately, the popularity of the protocol resonates in many implementation for majority of popular platforms. For Unity3D, there are *UnityOSC*[15],

[15] https://github.com/jorgegarcia/UnityOSC

Unity-osc-receiver[16] as well as commercial packages *UniOSC*[17], which offers extended functionality on a reasonable price and excellent ratings.

The **main visualisation** of the project is driven by those two normalised inputs for alpha and beta delivered from OSC. We use those parameters as variables into the scene simulation of space asteroid field. The class which handling particle system with variables for number of particles, *Emitter, Velocity*, *Turbulent* and *Shapes* based on KvantSpray[18] instancing animation system. The full diagram of the class could be found in Appendix 2.

In addition we used some **filmography techniques** for the look of the visualisation, such as video boom, Vignette and Ambient Obscurant. We attached those as scripts to the camera and attached it to a pivot gameObject, which we can use for navigating in similar manner to cinema techniques. The associated scripts and scenes can be found in the repository of the project.

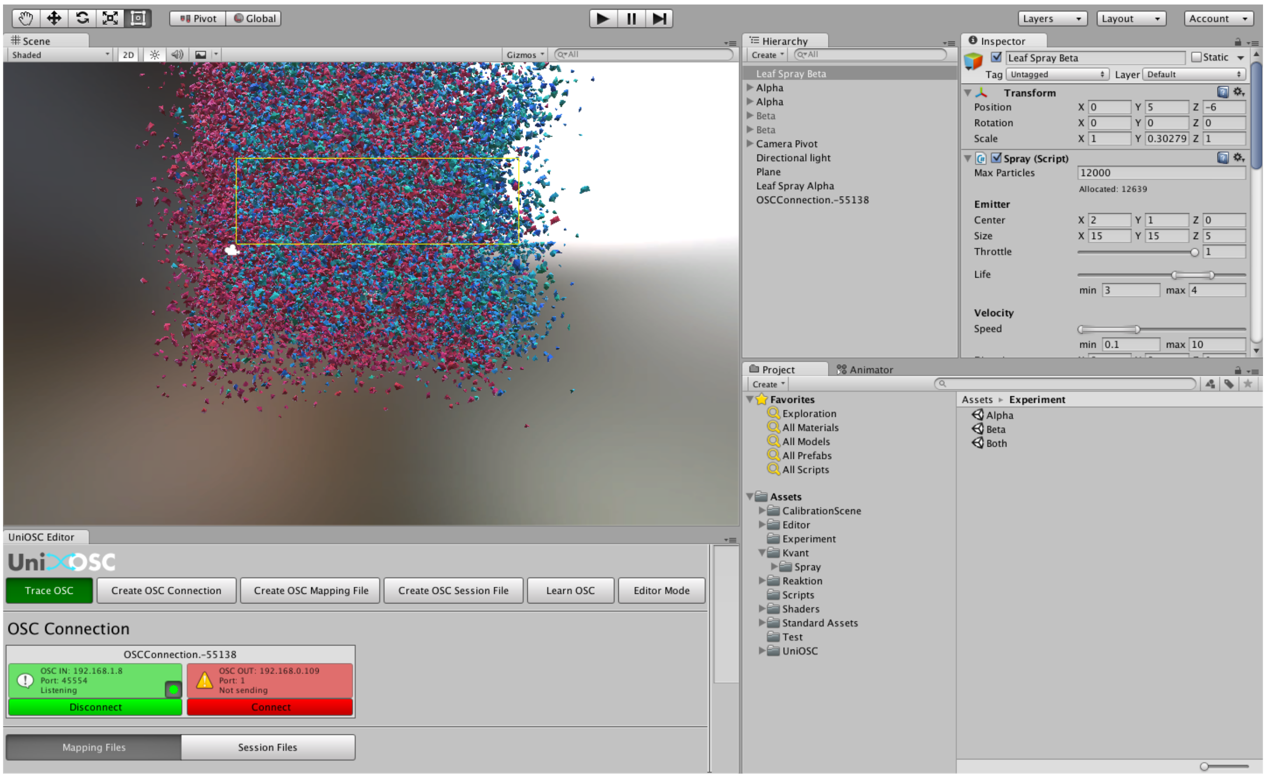


Figure 16: Development in Unity3D

5.3 Ambient music

As part of complete audio-visual experience, lastly we added music to the experience. While music has influence on the overall experiment (Yuan Q, 2000), it does have an effect which varies from individual to individual. The music in our installation probably will influence the alpha and theta

[16] https://github.com/heaversm/unity-osc-receiver
[17] https://www.assetstore.unity3d.com/en/#!/content/17658
[18] https://github.com/keijiro/KvantSpray

readings, but we considered it a vital part of real life environments. Bottomline, changes in the spectrum because of music are closely related to users' emotions and their personal preference of style, topic and etc. e.g. For the scope of this experiment we are using ambient music related to the emotions of relaxation and concentration. We filter the chosen soundtracks based on popular human-curated playlists (sources Youtube and Spotify) which include in their descriptions and popular comments the series of words such as "Concentration, Intense Concentration, Relaxation, Deep Relaxation" and other relevant terms. During the experiment randomly selected 2 songs were used in all cases.

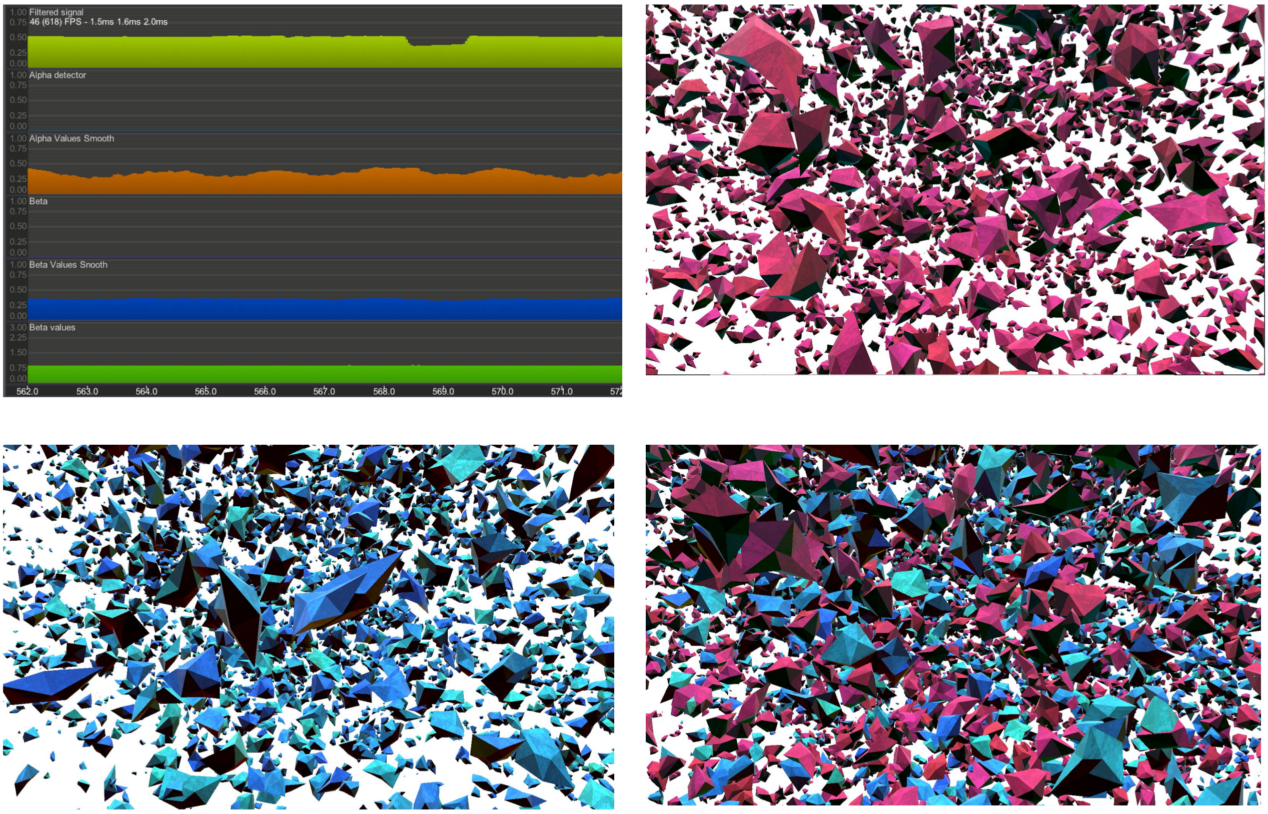


Figure 17: Different stages of the game: From top to bottom, right to left: Setup/Tutorial, Alpha, Beta and Freestyle

6 Evaluation

This chapter sets out to answer our Research Questions from 1.2.3 Can users control their brain states at will ? and sub-question 1.2.4 How learnability plays role in the context of BCI interaction ?

6.1 Method

In order to answer our research question and confirmed our hypothesis that people have the natural ability to control their emotional states, which is particularly visible with neurofeedback training, we look at experiment setup similar to My Virtual Dream. The interactive experience as well as the underlying variables for the experiment are related to relative spectrum power of alpha and beta brainwave pattern. We record the RSP and compare the variations difference based on the pre-recorded baseline for each individual users, because of the unique fingerprint-like properties of brainsingals.

6.1.1 Recruitment and organisation

The participants in this installation, had to pre-register and reserve a time slot. An assistant for the project was assigned to take care of the schedule and give conduct the post-questionnaire and recording any additional comments from the participants.

For recruiting the participants for the event, an extended invitation was created in the form of facebook events and posters in the venue. The majority of participants signed up in advance with an email or confirmed attendance in Facebook event. Given that some of the people did not come, further random visitors of the venue, were recruited to fill up the empty time slots before the experiment started. Duo to novelty of the interactive installation, many people were interested, but due to limitation of the time frame *(18:00 - 02:00)* we had to reject most of the requests after the event start. A total of 25 people participated in the experiment and on average the participants waited about 45 minutes to take part in the experiment.

Each session was conducted with one participant at a time, situated in the middle of the room facing a projection of the experiment. Four spaces for friends of the users were reserved and on the other side of the room another space was available for standing local visitors, as neither of the observers participated in the experiment. This decision for the experiment was taken based on the foundings in *subsection 2.2* and the outlined need for more BCI experiments in more natural for the user environment, the outside traditionally controlled laboratory conditions.The venue was open for regular visitors but the room of the experimenting (*the cinema room)* was exclusively reserved for the experiment. In total less than 10% of all venue space was occupied by us, which allowed us to inform every visitor and participants about the rules of conduct in the experiment before entering the experiment room.

The brain data was collected with wearable headset and directly streamed on to a computer. The streamed data was then processed and classified for interactive neurofeedback loop *as describe in subsection 5.1 and subsection 5.2*. The two software are running on the same computer, which is connected to a beamer and speakers and running and audio visual experiment.

6.1.2 Neurofeedback and interactive experience

The neurofeedback data stream was used with custom software, which respond to on relative spectral power (RSP) in alpha (8-12 Hz) and beta (13-30 Hz) bands. In first tutorial stage use the data of the new users to calibrate the behaviour of the installation i.e. to determine individuals thresholds for both bands of interest per individual user. Based on those individual thresholds, continues input messages were sent to the virtual environment: for each of the alpha and beta bands normalised feedback.

Screenshots from the different game stages are shown in Figure 18 and full in-game video capture is provided in video (Mov1) in the appendix. The game experience was decided into 6 stages:

1. EEG data observation. During this initial stage the users are equipped with headsets and verification of quality of the signal is performed. The researcher or an assistant corrects the placement of the headset if necessary. Once the basic setup processes is complete, users are encouraged to identify their own brain waves and emotional states. During this stage, users try to manipulated their brain states and observe the effects on the ongoing signal.
2. Welcome Message. Starting with welcoming the participants we also begin recording the EEG data. We are going to next use those ~5s of data for estimating baseline.
3. Tutorial. During this stage, two 20s intervals were initiated for both states relaxation and concentration. By measuring the corresponding bands and displaying those in form of graph(fig. #) and raw signal the users with positive 'energy points', when exhibit sustained increased power (above 0.5). The game display the current score in real time as value in top of the screen. When both stages end the gathered particles are released and vivid visualisations serves as a reward for the user.
4. Alpha stage was similar to the tutorial stage, but instead of 20s the time give is 2min30sec and visualisation of the appropriate signal.
5. Beta Stage same to Alpha stage, but with Beta waves detection.
6. Freestyle. In this final stage the users are given free time, which often lasted at least 90s and were provided with no guidelines, as a form of award for participating in the event. This level was not part of the data collected for the experiment.
7. Post-Experiment: At the end participants were send back a video playback of the individual experience if the users wanted to opt in.

Participants in the experiment are not disturbed during the stages 3-5. Observers in the room are other non-participants only, as they are allowed to interact with the participant during 1 and 6. Further, each participants were informed that their EEG data is recorded and given the option to opt out. Further as a part of the experiment users were asked if agreed to take part in the audio and visual recording during the experiment and provide additional feedback in the end of the experiment if applicable.

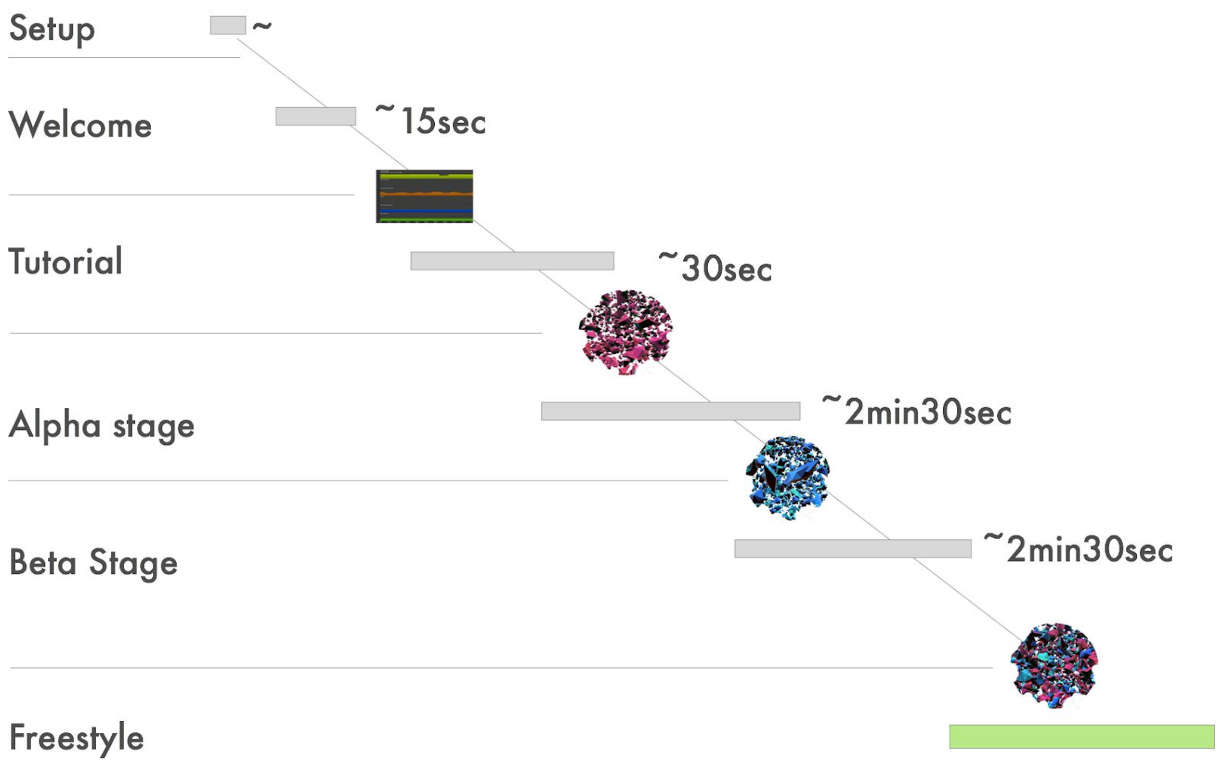


Figure 18: Timeline of the experiment and game stages

6.2 Measurements

6.2.1 Basic Information

Initially we collect some basic information for the users, such as their age, the time of the session start, if they are first time users and gander. Furthermore, we looked of associated Relative Power Spectrum for the given brainwave of the users accumulated during the experiment stages.

6.2.2 Relative spectral power(RSP)

The brain signals used in this neurofeedback experience were classified in real time in different brainwaves based on their frequency. Once segmented and classified we compare the different groups based on how strong the signal for each is. This is done in order to see which is the dominant brain wave at each given time. The classified data was used for interaction and recorded alongside the raw, pre-classified, EEG signal. For the result sections we used this recorded data to obtain RSP values independent from the one used for interaction in the experiment. This allowed us to analyse the signal after cleaning and have more precise overview on the situation. The formula of classifying brain signals in the complete (readable) spectrum power as followed:

$$Prel(i) = P(i) / \sum_{j=1}^{50} P(j)$$

The power spectrum readings of alpha and beta waves were classified in the three stages: tutorial, relaxation and concentration. To estimation the brain's RSP of each condition we measured the power spectrum in the 1-50Hz frequency range and extract relative power readings (P rel), where we calculate P for alpha and beta frequency range later *(Kovacevic, 2015)*. The final RSP was estimate of all sensors data recorded with the signals combined.

We look into observed RSP of the individual performance of the selected brainwaves during both stages of the experiment. We expected to see stronger power spectrum of Alpha waves during the experiment. Further, we expect to see the band waves of the given level to be dominant in that given stage.

6.2.3 Questionnaire

Last, but not least we have a questionnaire, which participants fill in after the experiment. The five questions are looking at users perceived level of control of the installation and the input. As the first one has been explained to participants as their input to the installation and the second the installation itself. We would like to see the perceived experience of both input and interaction.

Did you feel in control	1-5
Did you manage to control the brainwaves?	1-5
Did you find the experiment interesting?	1-5
Did you understand what it was expected?	1-5
Did you think the technology helped you control your emotions?	1-5

Table: Questionnaire

The third question is focusing on the level of interest and motivated by the novelty of the technology. Afterwards we have question about how understandable the visualisation was and the meaning. Finally, we have one question dealing with benefits of the technology on the well-being.

6.3 Pilot

The verify the study at hand and the performance of the installation, we conducted a pilot study with two participants. The pilot resulted in no changes to the envisioned methodology, but in technical adjustments to the method of brainwave wave detection. The range for interaction was also adjusted to prevent overlap of Alpha and Beta waves. The reason for those changes were to similarities of the interaction, provoked by the overlap of the reading, which have unexpected influence on the user experience.

Beta readings overall were quite low, resulting into little, to no interaction. For the final experiment we adjust the interaction values of both alpha and beta, to keep the relation between the two and in the same time make visible beta level readings for the users. Amplifying the beta had positive outcome on the interaction, but it needed to be normalised in the recorded data post-experiment.

After the pilot, the following changes were made to the software:

- Alpha’s upper limit was adjusted from 7.5-14 Hz to 9.4 - 14 Hz
- Beta’s upper limit was adjusted from 14-40Hz to 16 - 24Hz
- Alpha and Beta interaction parameters were amplified

6.4 Analysis

In order to gain insights into the human's natural ability to control emotion we look into performance of alpha waves over beta waves with statistical test in order to determine the dominant one for each of the level and compare those to the individual baseline. Furthermore we compare different groups of gender and time of the night as well as those with low (technical) readings and self-reported low experience score. To illustrate the process we look into step-by-step analysis of the pilot study. Later we apply the same processing to all of the experiment users and make further statistical test to confirm those findings. More details about the analysis and the tools required can be found in Appendix 3.

6.4.1 Epoching

The devices send the incoming EEG data to Neuromore Studio, where we have a session management which adds timestamps to the corresponding moments of the experiment stages, which allow us to identify and select the correct data points. The visual interface allowed us to defined the system easier and do the epoching with ease.

We define four conditions in corresponding to the interaction timeline from *sub-section 6.1.2, figure 18*. The conditions were as following: *Tutorial Alpha, Tutorial Beta, Relaxation and Concentration* each with alpha and beta RSP readings. The last *freestyle stage* was not a part of the experiment and hence not analysed, but used as reward for the participants. For those we look at alpha over beta and the individual baselines.

For each condition we sample the incoming brain signals on scale of 1000uV in a time window of 3 seconds. For tutorial stage our sample include 7,500 data points on 250Hz (30 seconds) and the following experiment stages 37,000 (02:30 seconds). A complete set of data is each of those stages for each users, which are used for gaining insides in the different groups.

6.4.2 Statistical Method

For statistical analysis we use a series of T-test to compare the mean RSP of differently selected groups: Gender, Time of the night, learners/non-learners. As well as the questionnaire and the technical readings of the recordings.

6.4.3 Global Effects

The global effects observed are related to general information collected such as the gender and time-of-night. We look at the difference of those reading grouped by respective condition. We expect to see different in both as previously documented in other experiments (Kovacevic et al., 2015).

6.4.4 Neurofeedback effects

The main **effects observed** in relation to the neurofeedback are related to Relaxation and Concentration in the corresponding stages. Another vector of observation is the measurements of neurofeedback performance in terms of signal quality and numerical completeness of the experience. We compare this to the users reported satisfaction rate to the quality of the signal and general technical quality of the recordings (e.g. number of active sensors at the time, level of noise).

6.5 Results

6.5.1 Experiment

In the experiment a total of 25 participants (10 female/12 male and 3 discarded samples). The participants range from 19 and 47 years old *(Std Dev: 6.87),* all first time users for BCI. The sample was collected during late afternoon (18:00) to early morning (02:00) and mean session time of 22 minutes. This includes setup and freestyle level, which were not included in the data used for RSP estimation or any other part of the experiment. While the time of interaction did vary in between users, the experiment duration was fixed.

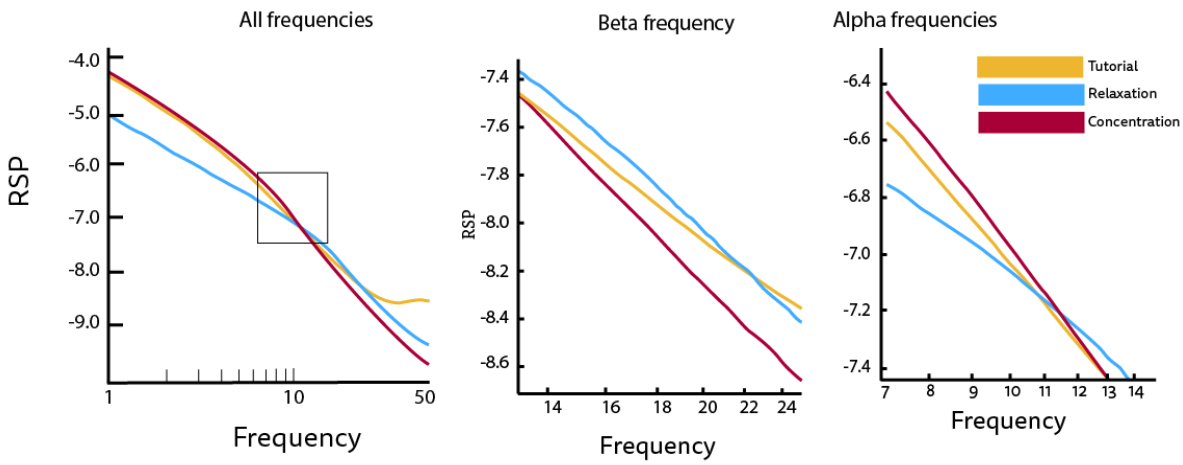


Figure 19: Overall results, all users

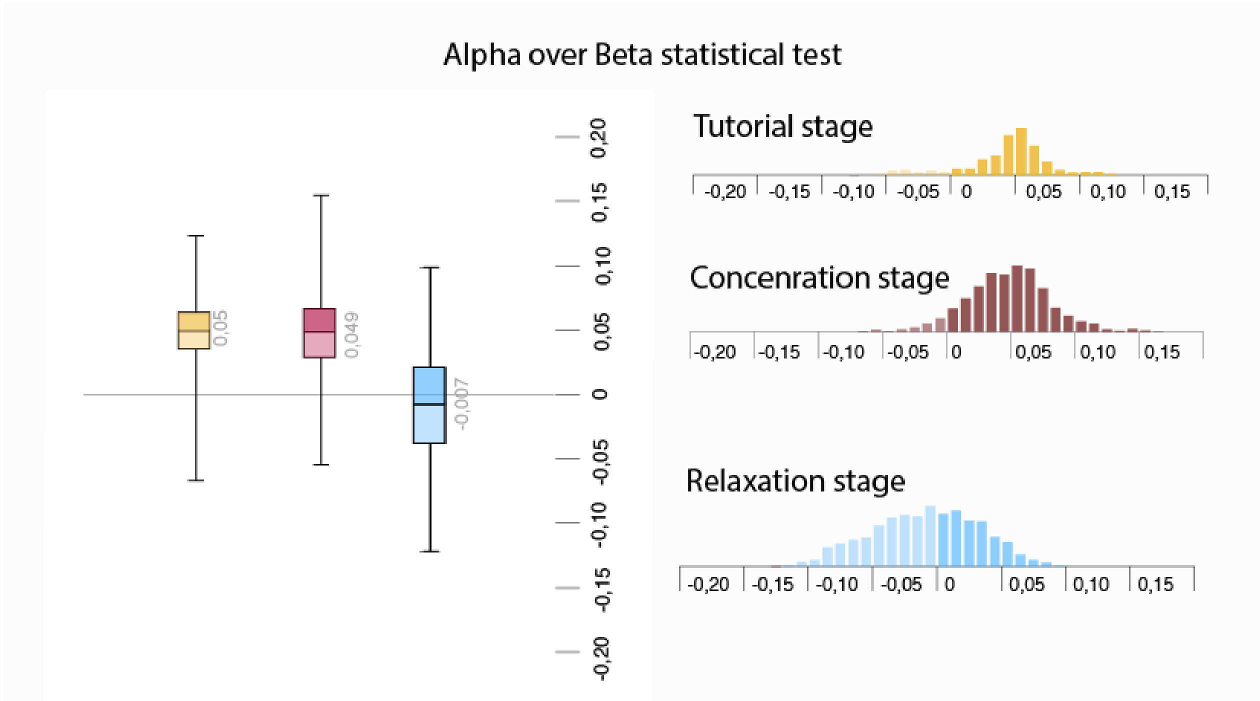
Our initial focus is at the overall performance during the Relaxation and Concentration levels, in which we expect the performance for the respective wave to be dominant in the given stage. Our results show that indeed in Concentration level, the performance for Alpha is higher than for Beta. In the Relaxation stage the reverse is also the case, but with less significant difference. These results could be seen in *Figure 19.*

Further we look at the individual performance of the users during the stages of the experiment. An table for each stage we consider in this experiment. When we take a look at table for the tutorial level, we can consider maximum alpha level as indication for learners (marked with green and dark green), as well as non-learners in Red. A value above 0.5 is considered detected “significant level”.

6.5.2 Questionnaire

Perceived user experience was measured with post-questionnaire, see Appendix #. The questions were designed to record users self-evaluation on the their performance and views on the technology. We use the data from the questionnaire to further categories the experience of the users. We look at the first two questions about the perceived control and compare the self-reported to the experiment results.

Six users reported unsatisfactory experience with low-level of control. We compared the perceived controllability and pleasure with the recorded sample data in order to see if there is correlation between bad signal quality and perceived negative experience.



Graph 20: Results all users, segmented for each stage of the experiment

6.5.3 Learnability

When it comes to high and low learners, we look at the differences between the two groups on level based. We classify learners as users who shows an alpha spike in first milliseconds of the interaction in the tutorial stage. The classified learners and non learners is given as we know that the users is dealing with 'new information' to him/her. In our case we used the tutorial stage's baseline to define those groups. Out of the 22 participants, we successfully classified twelve of them, while the others were difficult to impossible to classify, probably because of mix reasons of technical signal and resolution of the device . Six fall into the learners category, the other six are non-learners. The remaining five participants could not be classified reliably given the data quality. When comparing learners to non-learners, it is visible that learners perform better in direct comparison, however the effect is vary slight.

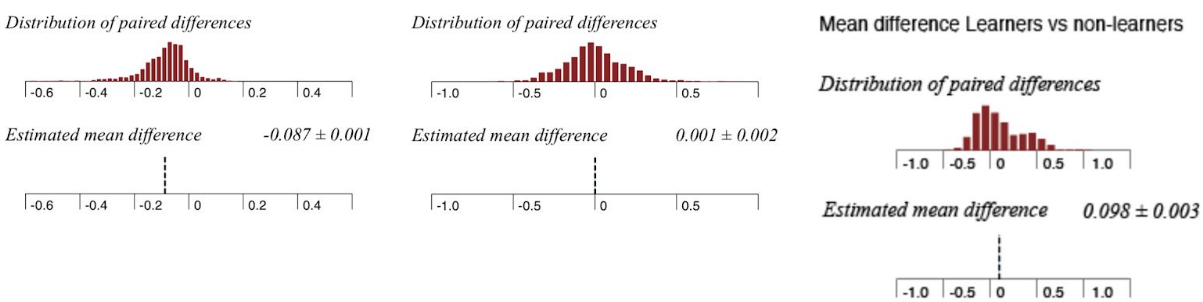


Figure 21: Mean difference between learners and non-learners, left to right: Tutorial, Concentration and Relaxation

7 Discussion and Recommendations

7.1 Discussion

Brain computer interfaces are extremely novel and an unknown technology to the general public. The information about implementation of different methods is still in pioneers hands and hence great discrepancy between technology expectations and what is available to the public. This is something we already anticipate and we saw in the Gartner Hype Cycle from chapter 2. We saw in the experiment that users were very inspired and yet confused of what a brainwave represent.

We took a glance look into what constitutes interactive experience for BCI in sub-chapter 2.5 and Chapter 3, which answered sub-question 1.3.2 for the scope of this experiment. This provided us with a view of what is well known in the field and have general acceptance level in science. This however, does not provide the complete picture and many more methods are available with less scientific significance (e.g. not published papers or know-hows on given methods) and yet being exciting methods for consumers. Huge sample size (e.g. above 200) and/or more long term, multi session, user focused experiment, both of which were outside the scope of this project.

To answer sub-question 1.3.3 we did notice that people are having different levels of control, which didn’t manifest in some users’ interactive experience. The issue here is that personalising experience, would require longer sessions and some people are having insignificant level of control which cannot be amplified in general fashion. The use of baseline helped so most of the people to have some experience, but for general consumer product, this is not an option. On the other hand, Neurofeedback is targeting that idea and users can benefit from multiple sessions and improve their own control instead of technology adaptation.

Audio-Visual stimulation can enhance neurofeedback for alpha and beta waves, as we noticed that in both cases the power spectrum was higher in the corresponding stimuli stage. The combination between audio and visuals as a stimuli for Alpha and Beta brainwaves was higher in the corresponding stages.

Time-of-night and gender influence power spectrum of readings. With the later hours the less strong of signal was noticed. Female also on general had lower readings, as expected (Kovacevic et al, 2015).

7.2 Future work

The concept of a framework for neurofeedback training is already existing in projects like MVD. The concept of collective neurofeedback could be used creating a framework for large scale experiment and rapid data retrieval. For this project, the accuracy could benefit from such a framework, but in the long term collective brain data would be a very valuable asset for research and developers.

Focus on learners and their abilities e.g. artists, actors. Some of those groups did indicate higher levels of flexibility of the mind. This could be due to extended training of adopting different personalities, but further study could reveal more interesting insights. Most of the people who showed mental flexibility were classified as learners.

Perceived health-benefits are very neglected factors for adopting the technology from user perspective. People’s main concern was that technology is not medical grade, but in today's world many bio trackers are widely used without being medical grade devices.

8 | Conclusion

Neurological headsets are going to be more and more available for consumers, with extremely high user excitement duo to long anticipation created by science fiction in the past decades. This however is not the only key factor, as the expectation and the given applications would be the key for the mass adoption. Such applications were strictly domain of science and now enter the commercial market. It is still unclear for users if Brain-Computer Interaction would be actually be including health benefits.

Created by unreasonable expectation of the current technology many users have unclear view of what could an such interaction be good for and yet we saw that majority of the users did have some kind of expectation of the superiority of the technology over their own understanding of the main. Given the resolution and the field of neuroscience it seems that the time is early for users to experience an comprehensive, medical like assessment on their brain. This expectation is problematic as majority of users did feel the upper limit of the technology and noted that beside the readings they don't feel like achieved the maximum of that given reading, emotion.

The use of Brain-Computer Interaction as a secondary input method is on clear path of success. This however contrast to the using the technology as the only source of input method and exclusive interaction. Furthermore, the health benefits are hard to identified for the users in a short term sessions and hence does not motivate the people enough to seek such application. However, new applications and devices are targeting specific well being element, such as sleep quality and enhanced learning, paving the way for health oriented applications. In the coming decade we will see how the adoption will shape, but at this current stage we need to raise awareness of the technology's possibility and create solutions which utilise that benefit and compete with more traditional methods such as meditation and mindfulness. It is yet unclear what the future of the technology would look like, but applications in both entertainment and well-being are going to be main vectors of the development.

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Software & Open-Source

Matlab & iPython notebook - for cleaning up the signal and visually expecting

Data Science Studio - for post processing of the data and iPython notebook

SPSS Statistics for analysis of the results

openFrameworks and Emotiv EPOC. openFrameowkrs version 8.4 and Emotiv SDK version 1.0.5 (C++) + Control Panel version 2.0 were used. oF provides a wide range of tools, like geometry buffering, camera and openGL graphics suitable for 3D applications. Being written on C++, speed and computability with very well respected libraries are further advantages of the platform.

Unity3D Game Engine. At this current stage, the Emotiv Unity3D plugin is available, however it does not include OS X or Linux support. alternatively OSC is used to communicate messages, available as open-source package.

Mind Your OSCs. The application provide accesses to non-eeg data from emotiv by directly connecting to the emotiv Engine. Working with Version 1.

EEG2OSC. Provide full access to the emotiv SDK, including raw EEG and conjoint commands with OSC. Works with Emotiv SDK version 2. The application is available as open-source and successfully builds with the current OS X 10.10 version.

FFTW+ Fast Fourier transformations library.

The code written for this project could be find as open-source on the following address: https://gitlab.com/VessoVit/vvEmotiveOF/tree/master released under Apache license v2 .

Graphics

Different Brainwaves: www.brainwave-meditation.net/what-are-brainwaves.html

Appendix 1

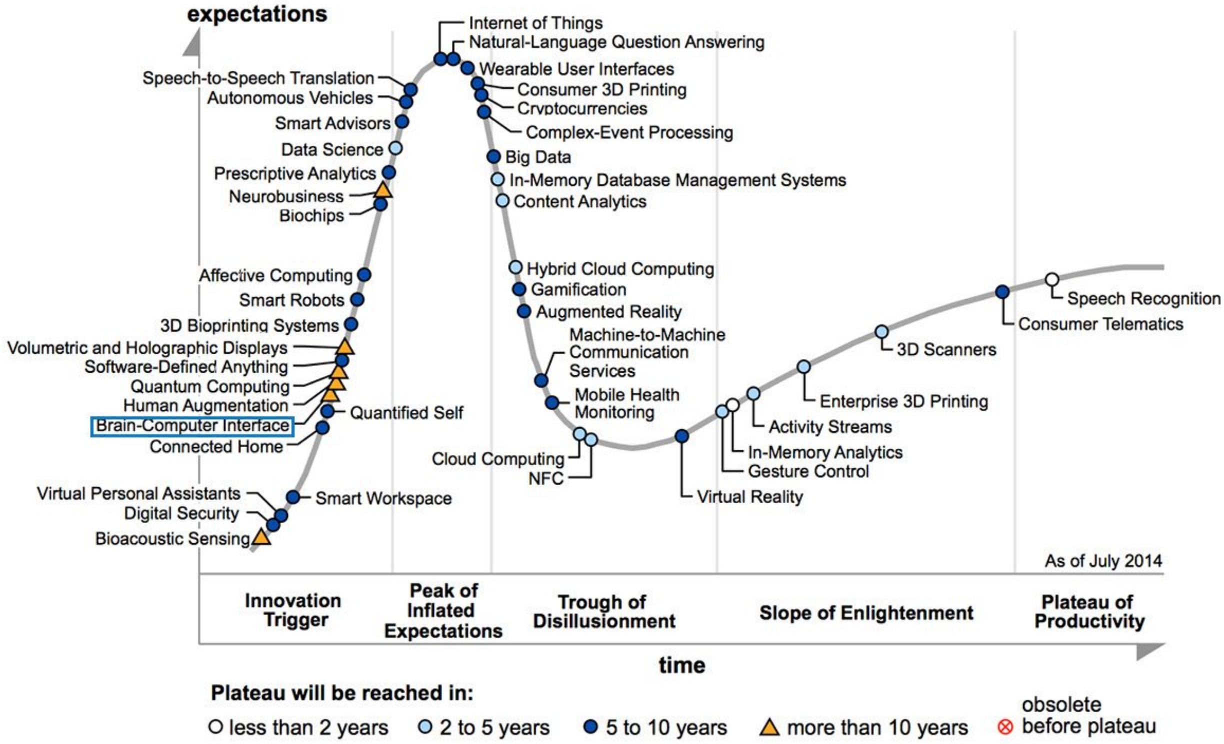

Figure A1: Gartner's hype cycle is representing the maturity , adoption and social specific developed for Informational Technology sector.

Appendix 2: System Diagram

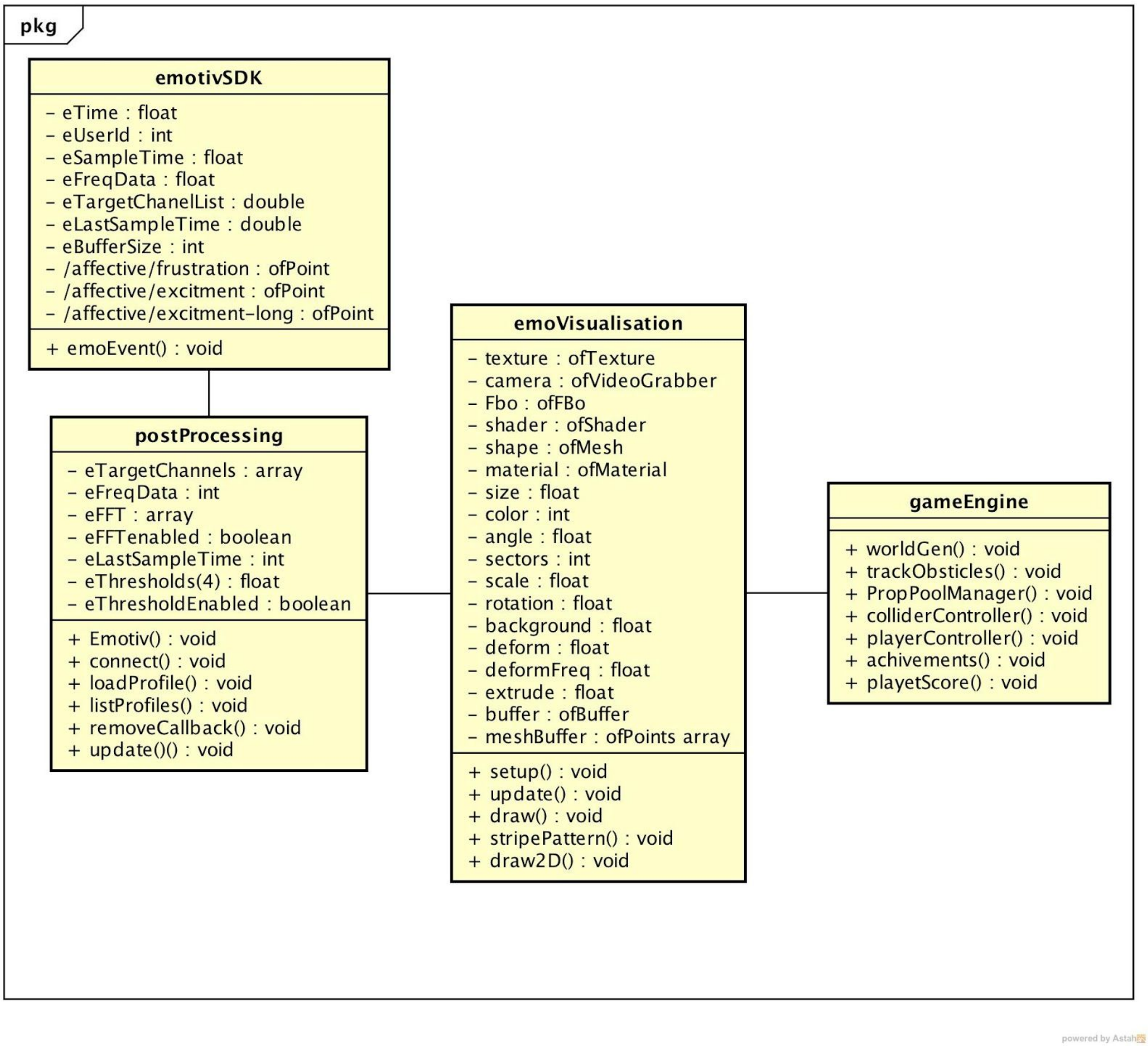

Figure A2-a: System diagram of the installation.

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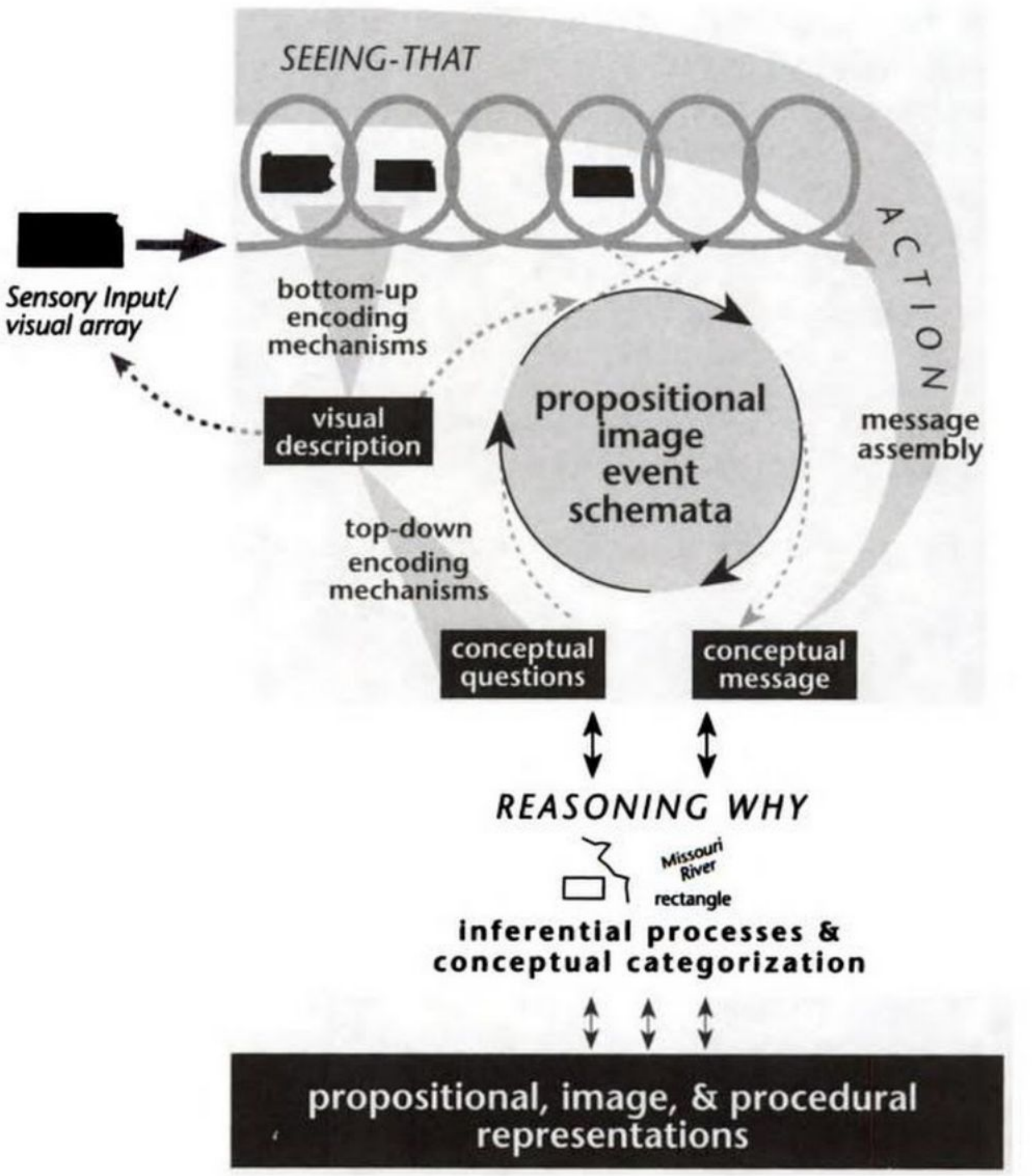

FIGURE 8.1. The feature ID model for map-based visualization, an extension of the original pattern-matching model to incorporate schema and category theories.

Figure A2-c: How Maps Work: Representation, Visualization, and Design, [Alan M. MacEachren](#), 2004
https://books.google.nl/books/about/How_Maps_Work.html?id=xhAvN3B0CkUC&redir_esc=y

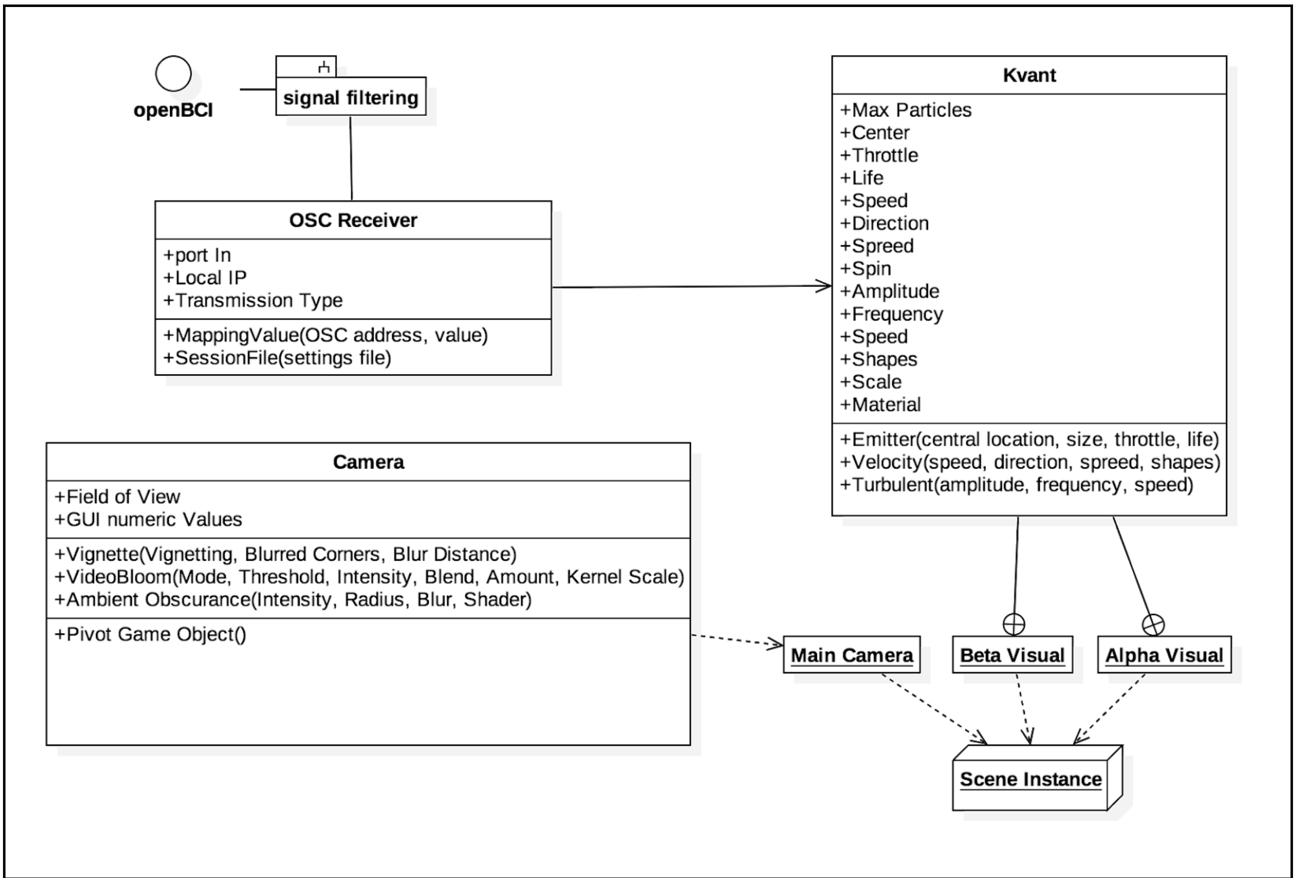

Figure A2-b: Unity systems design

Appendix 3: Analysis

1. Download Data Science Studio (DDS)[19] , including iPython Notebook and download Matlab. 17
2. We create new project and include all data files
3. For cleaning data: We use the data cleaning tools of DDS, with a recipes for cleaning records which are invalid, with the following set of rules: Drop the column if there is no deviation in the values and then select all rows which include extreme values, such as those resulted of technical noise. Visual indication of those could be seen on Fig A3, marked in red.
4. Combining the signals for detecting brainwaves (Classification). After cleaned and prepared all channels, we need to combine the signal and filter the desired band-waves. This was achieved is the help of Neuromore studio, which had playback option in the free tire of the product. This option is no longer available for free, but it worked by the time for this 'hack'. By using the new, filtered signals as a playback input, we can use the same setup of the experiment to detect the brainwaves and output that into new files. This was time consuming processes since it worked on the playback principle, where all the experiment samples had to replayed to produced the classified output files, similar to record tape coping. The end result it 3 files for each user, each one including alpha and beta readings with corresponding RSP in normalised format (0 to 1).
5. We now can run descriptive statistics for each user, on each level and each brainwave. The results could be add in the database, which includes the basic user information and the questionnaire results.
6. Next we look at learners and non-learns as different group of samples. By looking at first Tutorial stage we look for high spikes in alpha readings, such as the one in green on fig A3-B. Those users with high level of alpha readings are assigned to learners group, where users with low alpha readings during the tutorial stage we assigned to non-learners.
7. We take into consideration all factors and readings and we run an statistical analysis for all factors into consideration.

The record signal comes in Comma Separated Value (CSV), with 8 columns for each sensors readings. From there on we can repeat the same process for detecting brainwaves as we used for the live interaction during the experiment. The advantages of doing this analysis first before proceeding to statistical tests is to compensate for noise and inactive sensors, hence making the signal more suitable for analysis.

• First, we preselect channels. One of the channels is not reporting any important information, so we can automatically discard it. This happens sometimes for some of the sensors are we simply refer to it as technical malfunction. This could be traced down to bad positioning or interrupted contact.
• Second, we look at the plotted signal with the given frequency ranges, in order to extract the brainwaves . The resulted signals are two separated channels one for alpha and one for beta signal as deliverable of the 8 channels signal we got before. By normalising all the channels into single one for the given brainwaves, we proceed with data sets more suitable for our analysis.
• Third, the two bands of Alpha and Beta are represented in time domain for duration of each stage. The result is a single vector for each brainwave , which we further need to segment into a matrix of 6 different vectors for each stage and brainwave.
• Fourth, we extract the Total value of Relative Power Spectrum of the waves and perform descriptive statistics. This is also our value of interest as we going to conduct the comparison in between users and groups based on this RPS values.

[19] http://www.dataiku.com/dss/ Integrated development platform for data professionals to turn raw data into prediction

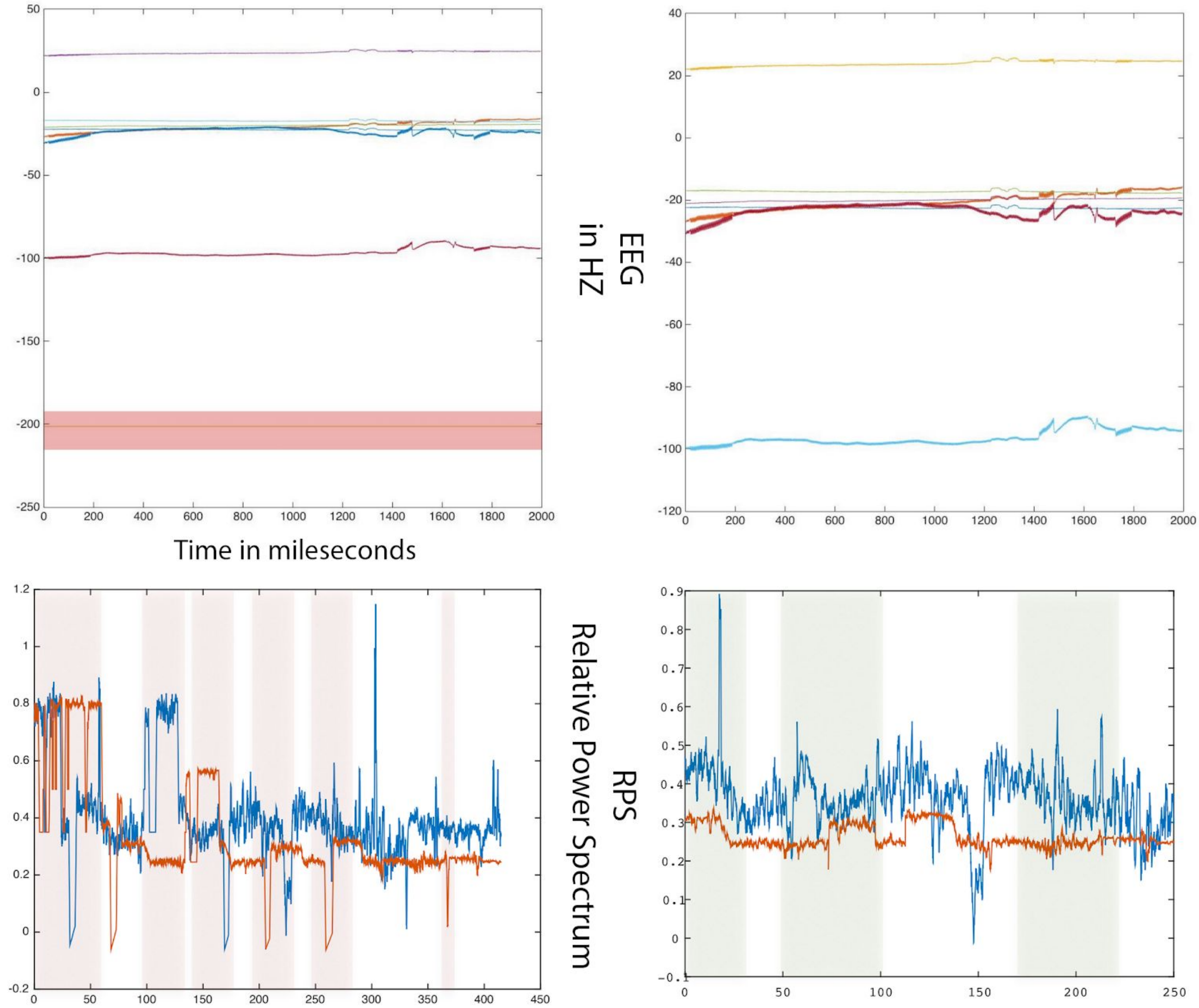

Fig A3: Random sample of raw data recorded for alpha and beta waves experiment.

Fig A3-b: The same raw data, cleaned and selected One sample areas out of the three.

Appendix 4: Post-experiment questionnaire:

Did you feel in control?	(1-5)
Did you manage to control the waves?	
Did you find the experiment interesting?	
Did you understand what it was expected?	
Do you think the technology helped you control your emotions?	
Appendix 4-a: Post-experiment qustionnaire	

N	20	20	20	20	20
Min	1	1	5	3	1
Max	5	5	5	5	5
Mean	3.1	3.4	5	4.5	3.4
Q1	2	3	5	4	3
Median	3	3	5	5	3.5
Q3	4	4	5	5	4
Std Div	1.986	0.9403	0	0.688	1.200
Variance	1.4368	0.8842	0	0.473	1.440
Std Error	0.2680	0.2102	0	0.153	0.268

Table A4-b: Questionnaire, Descriptive Statistics Outputs

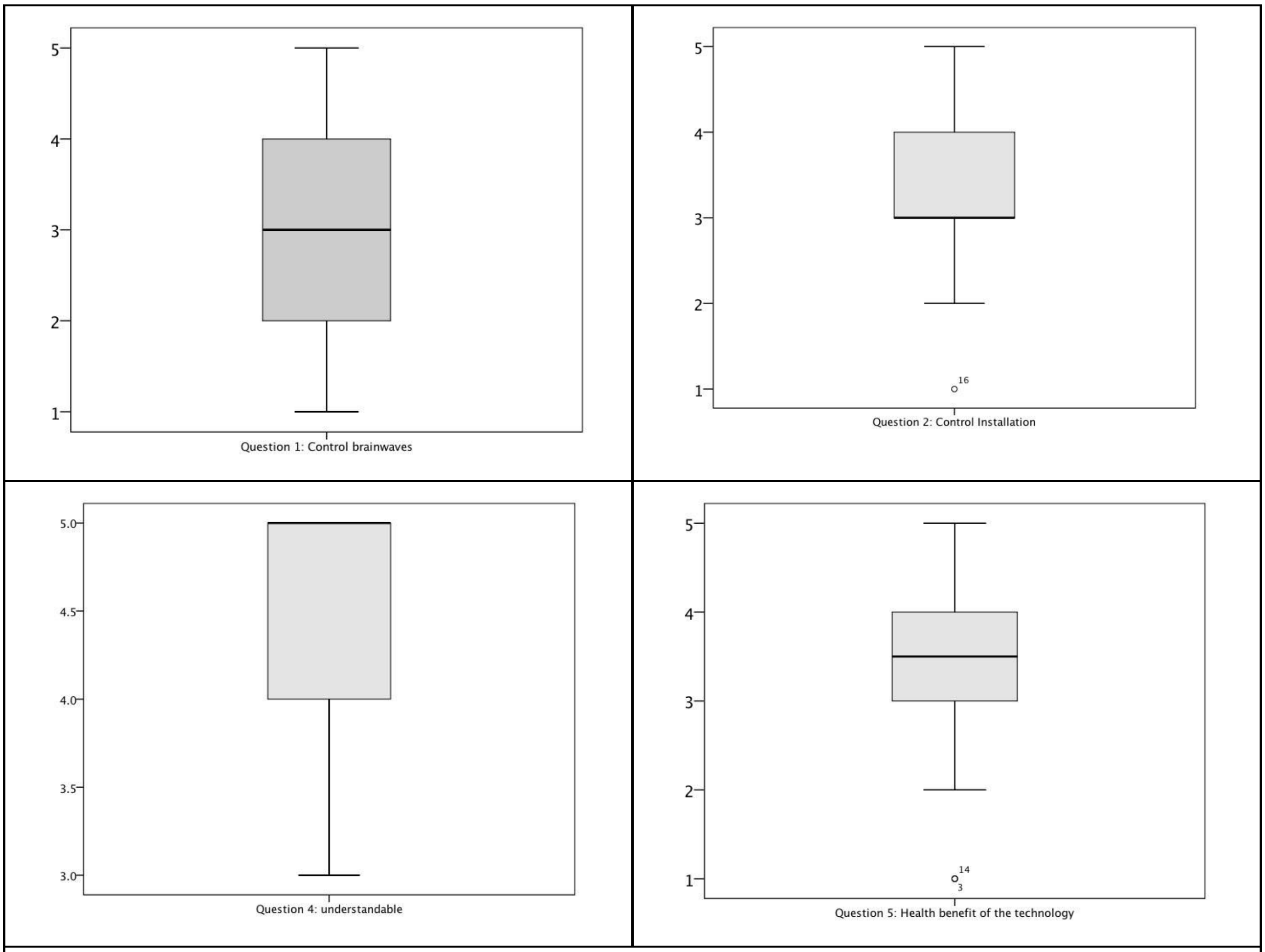

Figure A4-C: Questionnaire results in numeric representation.