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An investigation of the use of EEG data for the purposes of sonification and visualisation in a creative environment

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Abstract

This work demonstrates a currently available method for measuring human brain-waves in order to generate electronic music, visualisation and an elementary neurofeedback software. The aim of the project is (1) to use Electroencephalographs (EEG) to alter visuals and sound and (2) to gain a better understanding of the software Max/MSP, SuperCollider and of Digital Signal Processing.

Acknowledgment

I would like to acknowledge the help and assistance of the following people: Firstly for all who helped me on “cycling74” and on the “SuperCollider Nabble” internet forum. Anna and Roger Merenyi who helped me with the English language. John Martin for his help with English and technical issues. James Christopher whose knowledge of biomedical signal processing was essential to understand EEG protocols and Dharmachari Vajrapriya who helped me understand the basics of the Fourier transform. Masahiro Kahata who helped me with the technical side of the EEG device. I also wish to thank Dr. Tom Hall for his encouragement in the use of SuperCollider.

This dissertation could not have been written without Dr. Richard Hoadley who not only served as my supervisor but also supported and challenged me throughout my project and the course.

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"Fallom closed her eyes, The note was softer now and under firmer control. The flute played by itself, manoeuvred by no fingers, but moved by distant energy, transduced through the still immature lobes of Fallom's brain. The notes which began as almost random settled into a musical succession and now everyone in the hall had gathered around Hiroko and Fallom, as Hiroko held the flute gently with thumb and forefinger at either end, and Fallom, eyes closed, directed the current of air and the movement of the keys." (Asimov, 1986)

Introduction

This work surveys a currently available method for measuring human brain-waves in order to generate electronic music, visualisation and an elementary neurofeedback software. I am investigating the use of Electroencephalography (later EEG) as altered states of mind always spellbound me. I will attempt to give a short insight into the early and recent use of brain-wave data in the fields of music and how I employ some of these in my portfolio.

When we look at the evolution of music and the way in which people perceived music we can see that as far back as the Greek philosophers, people were aware of its therapeutic effects (Henson, 1977). The study of how music is generally agreed to cause increased arousal in listeners, can be found in "Music and the Mind" by Antony Storr (2005). He describes this arousal as a condition of heightened alertness, awareness, interest and excitement where arousal can manifest itself in various psychological changes, many of which can be measured (Storr, 2005).

How we comprehend music is very complex*:* it has subjective and objective factors. Under some circumstances loud, fast music is arousing, whilst soft, slow music is relaxing. Researches have shown that infants are attracted to certain pitch and timbre changes and to simple repetitive rhythms - which can be called a *primitive response* (Sloboda, 1993). The other responses depend on the following factors:

(1) *listening to music in general* (cultural differences, simple and open harmonies, major key, general rhythmic impetus),

(2) *emotional significance* of the circumstances in which the music happens to be heard,

(3) *musical background* and

(4) the *mental state* of the listener (Sloboda, 1993).

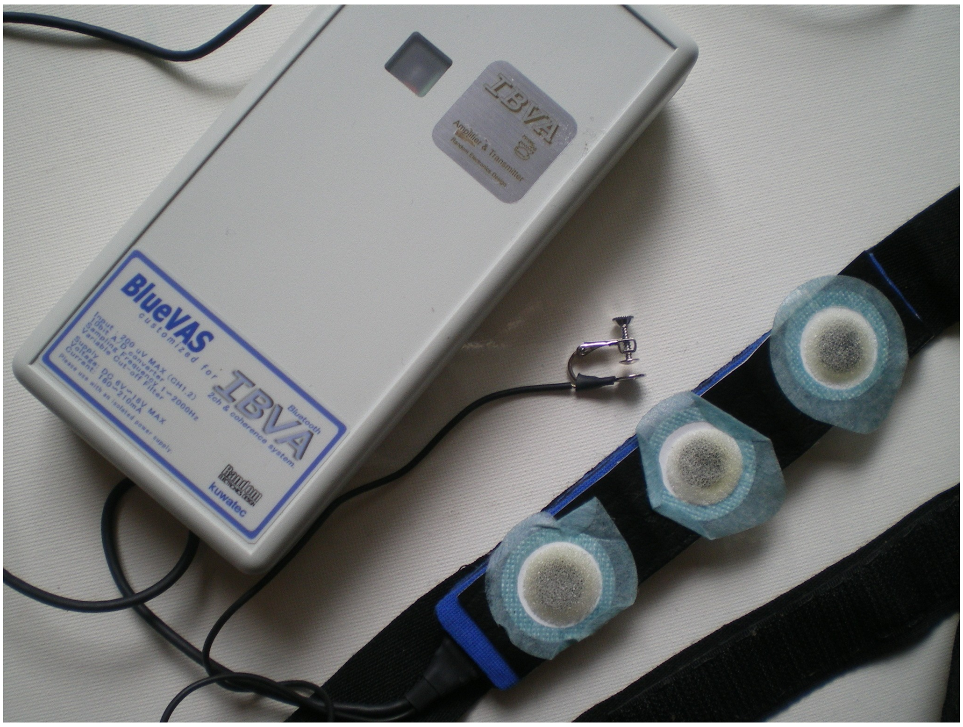
For my work, most of the times I recorded brain-waves I used some sort of music on the clients which was either relaxation or trance music. I also used EEG recordings of meditation.

That emotional and perceptual musical experience changes functions in the human body has been known for many years (G. Harrer and H. Harrer, 1977). Music, amongst other things changes pulse rate, blood pressure, respiration, the psycho-galvanic (see Glossary) reflex and other autonomic functions. For instance, experiments have shown that by listening to African drumming the body reacts (Rouget, 1985). Most of our body functions are operated from the brain (G. Harrer and H. Harrer, 1977). To follow from this, music affects the way of thinking, therefore music can be used for various purposes like healing, enjoyment and even for propaganda.

My portfolio seeks to demonstrate my simple knowledge of the use of EEG in both: obtaining profitable data and of its utilisation to entertain the human senses. On the DVD attached the reader will find various patches for SuperCollider, MaxMSP and Arduino, and as some of the work cannot be used without the EEG device I also include video and audio demonstrations.

1. Literature reference

The activity of nerve cells has an electrochemical basis and it is possible to record them with sensitive instruments (Scott, 1976). The device I am using to measure and record EEG is called IBVA (www.ibva.co.uk, appendix a). It has two channels, one for the left and the other for monitoring the right hemisphere. The headband has 4 sensors: 3 sensitive medical electrodes measuring electrical activity in the front lobe and one ear-clip for ground. It is a bipolar recording system which means that the output for one of the channels is the difference between the middle (reference) and the electrode in question (active). These fluctuations in the brain are rather small, much less then 1 millivolt and therefore they need to be amplified.



[Figure 1. - IBVA bluetooth device]

There are several ways of using brain-data for musical purposes. The most commonly used ones involve the Fast / Discrete Fourier Transform (later FFT/DFT), the Hjorth and Barlow analysis (Miranda, 2007) and techniques where the "simple" raw data is monitored to find Event Related Potentials (later ERP, see Glossary for explanation) (Miranda, 2006).

My initial plans were much more ambitious than I could practically realise with my software. Bearing in mind the complications of working with brain-data, I had to prioritise the features of the project I was to work on:

(1) to be able to receive the two raw data (Left Ch, Right Ch) in Max/MSP and in SuperCollider,

(2) to get a deeper understanding of the process behind power spectrum analysis so

(3) I can make my own patches/codes which are able to provide me with the same data as the IBVA software and the [IbvaGet] object (Max/MSP) does,

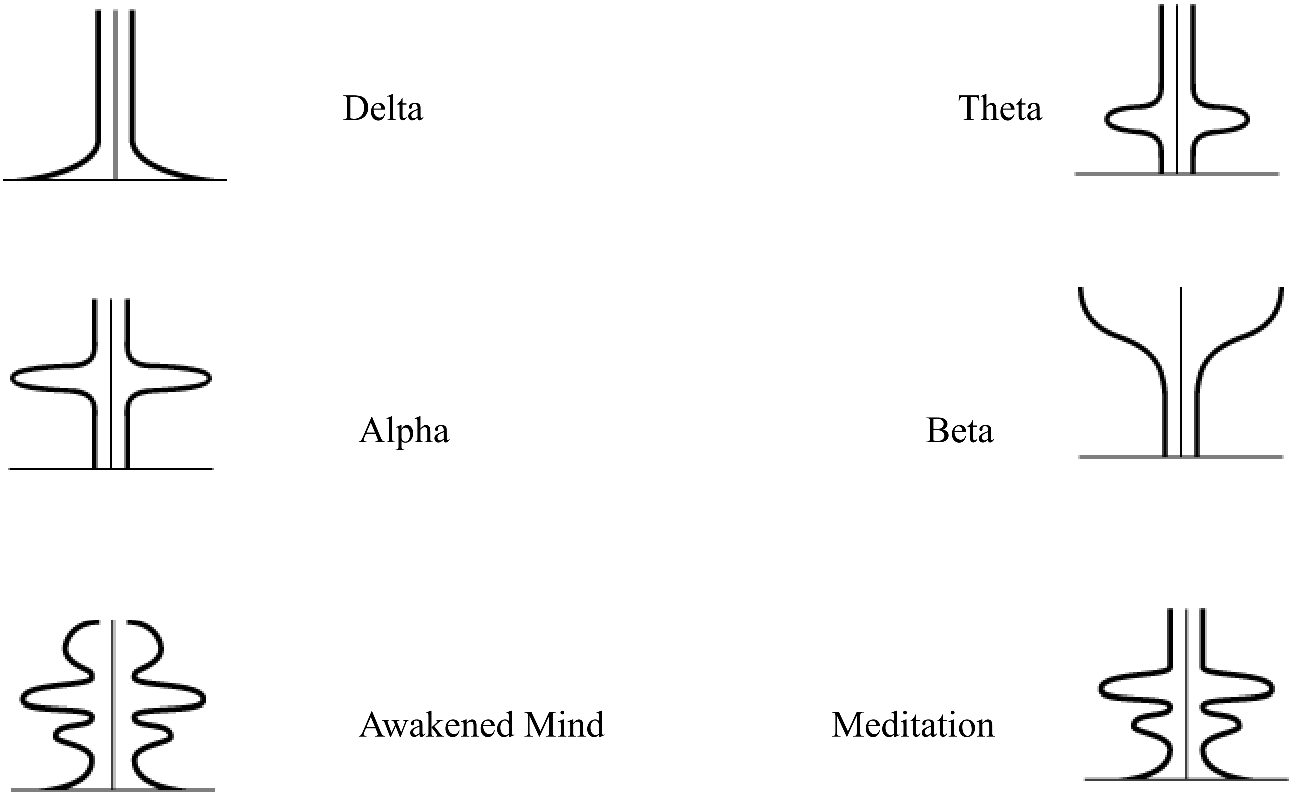
(4) read EEG data from text files into the audio software,

(5) be able to distinguish thoughts manifested with thinking of a certain musical note (use of ERPs) and lastly

(6) to generate an interesting soundscape which has characteristic parameters of the person's mental state, the brain's electrical activity I recorded.

I work on the grass-root level with EEG technology but to understand the way I created my patches I will write a few lines about brain-wave rhythms and what their pattern can represent. The waves recorded on the scalp are the result of the brain's electrical activity conducted through the brain tissue. The distinct configuration of power distribution in the spectrum of the EEG signal (FFT/DFT) is useful to indicate different "states of mind". In other words, with power spectrum analysis we deconstruct the signal into partials and determine their relative amplitudes and frequencies within windows (FFT bin) (Scott, 1976).

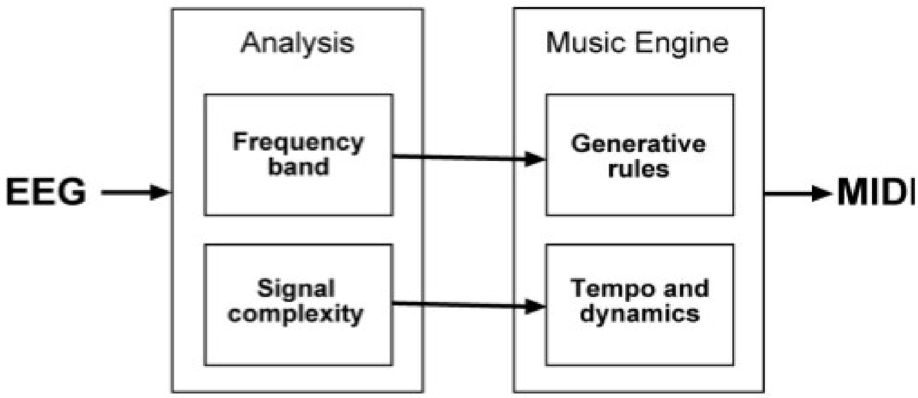
Delta (0 - 4Hz), *Theta* (4 - 8 Hz), *Alpha* (8 – 13 Hz) and *Beta* (13 – 30 Hz) are the bands of EEG activity. *Delta* rhythms are associated with sleep; *Theta* with drowsiness, trance, deep relaxation or meditation and hypnosis; *Alpha* with relaxed wakefulness and *Beta* alertness, intense mental activity or stress (Miranda, 2006). This is a complex topic therefore a full explanation falls outside of the scope of this essay.



[Figure 2. – 2D representations of brain-rhythms and mental states by Anna Wise.
Power spectrum of EEG data with both hemispheres. Horizontal axis represents amplitude.
Vertical axis is frequency from 0hz growing exponentially from bottom to 30hz.]

As a final year Creative Music Technology student I became aware of being able to recognise the connection between art and social- and also formal-sciences. Although earlier music has been perceived as a way of making art with some algebraic knowledge and later with science (for instance analog synthesisers, sonifications of DNA, etc, ...), fields of study, it has only been possible over the previous two decades to receive music as a significant research focus in the brain sciences. “This came as a surprise to many artists and scientist alike; it was an unlikely development for music, as an aesthetic medium and art form, to become a focus of many serious scientists' major research efforts.” (Thaut, 2005)

While working on my project I made contact with artists, teachers of music technology, programmers and also with physiologists. One of them is Dr. Mick Grierson who is an experimental artist specialising in real-time interactive audiovisual research, with specific focus on cognition and perception and the other one is Eduardo R. Miranda, a Professor in Computer Music in the Faculty of Technology (University of Plymouth) and an active composer in his own right. Grierson's work *“Composing with Brainwaves: Minimal Trial P300 Recognition as an Indication of Subjective Preference for the Control of a Musical Instrument”* presents a system of the detection of P300 ERPs (see Glossary) with visual stimulation in a real-time environment. The study shows how the EEG of certain types of visual stimuli can be used to trigger indications of subjective preference, in this case MIDI notes in Max/MSP. *“Brain-Computer music interface for composition and performance”* is a project from Eduardo Reck Miranda (2006). Here he demonstrates the use of EEG data to control generative rules to compose and perform music. This BCI (brain-computer interface) among others monitors the subjects' brain-waves in real time and uses the activity of different frequency bands (*Delta*, *Theta*, *Alpha* and *Beta*) to steer musical scales for a MIDI piano. For the tempo and dynamic changes he used the signal's complexity, which was measured with the Hjorth analysis, a time-based amplitude analysis. The picture is from the article (Miranda, 2006). Both of their work was influential for my project.



[Figure 3. - Process of a BCI from Mirada's article]

2.0 Experimental work

As mentioned in the introduction, the EEG data I have used for the small projects were either live recordings of my nerves' discharges or brain activities of friends while listening to music or meditating. By opening different files you will hear or see different things happening as each brain-data is different.

IBVA FFT waterfall diagram with exported text files can be found on the attached DVD in [_IBVA exported data] folder.

All of the patches, video demonstrations and examples can be found on the attached DVD in [_demonstrations] folder.

After reading one section in the following text, please go straight to the relevant video demonstrations as they contain essential information to get the full picture of each project.

2.1 - [1] Max Read EEG

This patch reads an exported text file and uses the contained EEG raw signal to manipulate visuals. I look for data repetition and use these to alter volume, loop-points and rate of video extracts. The text file is made with the IBVA software – see www.psychiclab.net. (More information can be find in the relevant video demonstration.) The process is the following: First I check where “Left” and “Right” data start and end in the text file (line number), because I wanted to use the EEG data in the same tempo as it was recorded. Among others I used [regexp] to subtract the 2nd column into a [coll] object. The elapsed time between the lines is basically the same (0.133 – 0.134 sec), which means I could have used a [metro] as well, but to experiment and to get more precise triggers I built a clock like structure.

One line in the text contains 16 consecutive EEG data (microVolt). I read in all of them in exactly the same time and used their sum to recognise repeated patterns. The object used is [zl stream] in the [repetition] sub-patch. Repetitions found by the software trigger rules in the video and audio part of the patch.

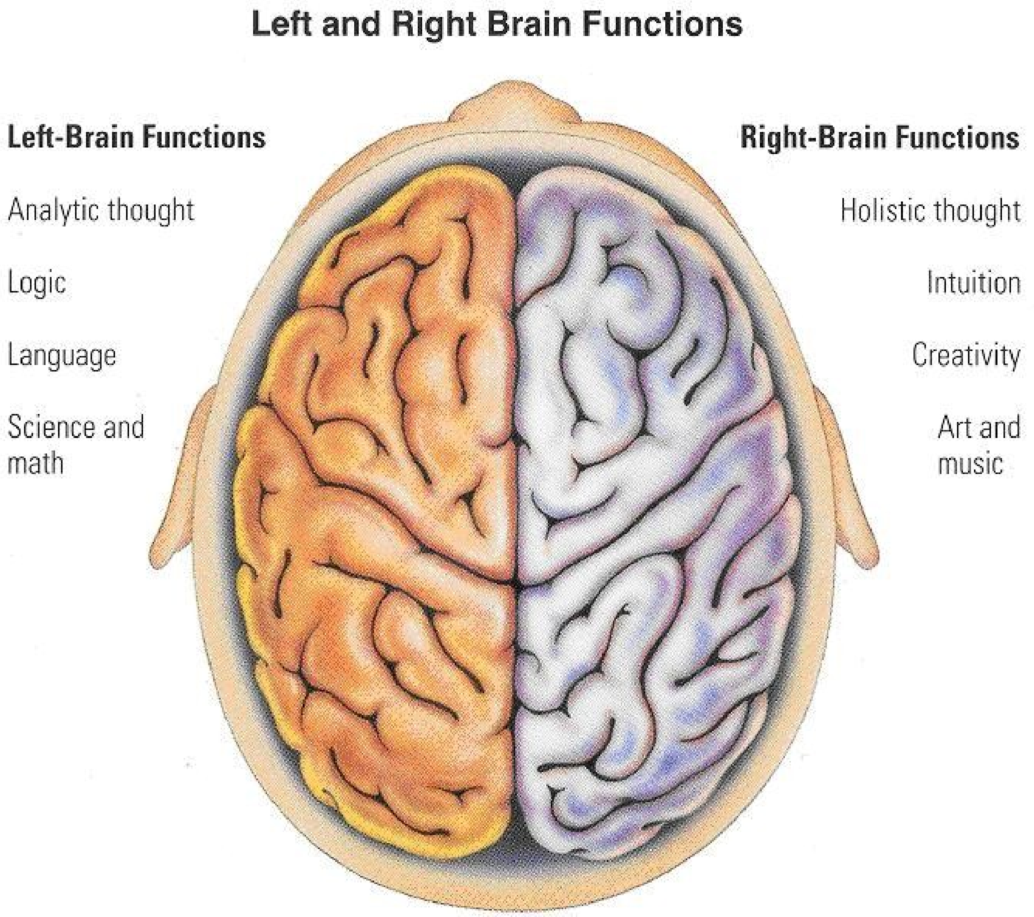
I have used a video extract from the last episode of *Twin Peaks1* written and produced by David Lynch (http://www.imdb.com). Here the main character gets trapped in a place beyond the logical. With the long movie file (15 min) I had to reject the object [spigot] as it copies the audio from the movies too slowly thus I used separate audio files with [groove].

2.2 - [2] SC Read EEG

This is a piece of code which reads text files into arrays. The text files contain

1 “Twin Peaks” is a TV series (1990 – 1991) by David Lynch

raw EEG signal data exported with the IBVA software (same as above in "**[1] Max Read EEG**"). In Max/MSP I found a way to use the original text file, here I had to trim the exported text file into two separate files, one for the right and the other for the left hemisphere's EEG data.



[Figure 4. How the hemispheres work - picture from http://brainchildco.wordpress.com/]

The idea behind the project is to sonify the nerves electrochemical discharges. The main benefit of this code for me is the better understanding of SuperCollider. My goal was to have control over each columns data, thus the code became very large. After assigning too many variables, the code did not start (error message in post window). This made me use the [arrays] with [vars] in them. After many long hours with this free software I realised for the first time the advantage of it over Max/MSP.

The SynthDefs I am using are not all made by me, some I have borrowed from the Nabble SuperCollider forum (http://www.nabble.com) and from the help files. I altered them so they can fit into the outcomes of the project.

The concept behind the code is hemisphere synchronisation, which is believed to be a comparison of waveforms or patterns rather than amplitude (Demos, 2005). To experiment, here I used the voltages of the raw signals. Whenever the sum of the 16 columns in one line of the Right hemisphere's EEG data gets closer to the other hemisphere's sum, in other words the difference is less, the background sounds change. Meditation experts say if both hemispheres work together, it can reward you with altered states of mind and more. Most of the commercial “hemisync” audio CDs use binaural beats, which can be easily created with two sine-wave oscillators [SinOsc.ar].

```
{ SinOsc.ar([200,204], 0, 0.5) }.play;
```

[Figure 5. - SuperCollider example of hemisphere synchronisation.]

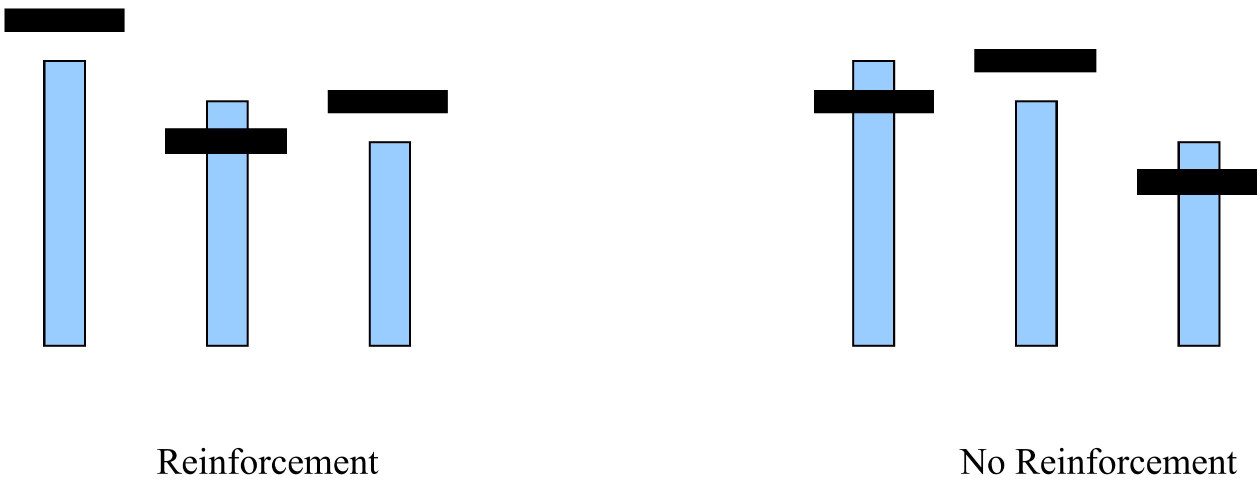
2.3 - [3] Max FFT EEG

In the patch I am using an external object [IbvaGet] which does FFT analysis to distinguish the power of the assigned bandwidths. The Max/MSP patch incorporates mainly two ideas: (1) sonifiaction and (2) neurofeedback training.

In (1) I updated one of my projects for ACMP (Advanced Creative Music Programming) from last semester and used it as a contribution to experimental music and as a tribute to John Cage. (John Cage used to work with EEG when he assisted David Rosenboom in his work “Ecology of the Skin” in 1970-1971, see - www.horizonzero.ca). We can choose between synthesised or audio samples to be trigged. They are played when there is a peak in the brain-rhythm. Two other component parts can be found here. In one the power of alpha (wave like motion) alters the audio loops' rates with the help of [groove] and in the other big changes in amplitude trigger audio samples (in the patch I detect eye movements).

This patch opened new perspectives for me: neurofeedback training (later NFT). Though the patch only contains a basic approach to a decent NFT, with some work and with Max/MSP's broad possibilities of signal processing and visualisation (Jitter), future work seems promising.

NFT is often aimed at changing the amplitude of a selected frequency bandwidth, its goal is to change an unhealthy (hyperactivity) EEG pattern into a healthy one (which is beneficial for the person). An example is BETA/SMR (sensorimotor: 12-15 Hz) training. This style includes only one reward filter combined with two inhibit filters (Norton, 2005).



[Figure 6. Threshold (black) on the selected bandwidths, explained below]

Beta is sandwiched by one lower and higher bandwidth. It only gives a reward feedback if the inhibit filters do not sense signals above the threshold and the reward filter reaches the threshold. In NFT both sounds and graphics are very important. “Most graphics tend to be boring and repetitive... there are only a few systems which can hold the clients attention unless they are highly motivated” (Norton, 2005). This means the field needs to be infused with some creativity. In other words I will seek employment in the NFT business.

2.4 - [4] Max Raw EEG

In this project my goal was to understand more about the technical part of EEG data transmission. I needed to get the raw data into Max/MSP as I wanted to have my own FFT analysis and to experiment with ERPs. First I could only do this with the help of a patch in Quartz Composer and OSC.

After a long time of communicating with IBVA users on EEG protocols, posting questions on the “Cycling74 forum” (www.cycling74.com) on the internet and studying the basics of Digital Signal Processing (DSP) I finally managed to get the EEG raw data in Max/MSP straight from the device. I thought this had been the hardest part, but I was wrong as using FFT in the software to see the amplitude (power) of the partials (brain-rhythms) is even more complicated (appendix b).

This project has not been finished yet. In the sub-patches and on the video examples you can see how much I achieved and what external objects I used to experiment on the signal.

2.5 - [5] Arduino

“The Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software” (www.arduino.cc). The idea here is to alter a servo motors spin with brain-waves. In the future I could add another bio-feedback element, which could use a piezo-disk to measure the heartbeat while the EEG device measures brain-waves. The relevant codes on the attached DVD are very basic, they just demonstrate one of the uses of EEG data.

3. Conclusion

The process is simple but a proper methodology is crucial to get a good result.

While working on the project I encountered some challenges.

(1) Understand the way the raw data has to be processed so I can see some good results;

(2) how to use this data in an artistic, aesthetic way, and ;

(3) balancing between how much time to spend on (1) and (2).

As I wanted to have a project where the outcomes (sounds and visuals) can represent at least some characteristics of the mind being analysed I was tempted to work as much as possible on the technical side and keep the musical and pictorial sides for last. I could realise half of my goals: I could manage to get the raw data straight into Max/MSP, could read brain data from exported text files and could use the data to make an experimental soundscape. I was a bit ambitious with the rest, therefore I will postpone the understanding and the use of FFT and the work with Event Related Potentials (ERPs).

I started using IBVA just out of curiosity, then used it for a smaller project ("brain-control" - project for ACMP), for this Major Project and now I am thinking about digging deeper and keeping on working in the area. I used to be a percussionist and thus I am very interested in rhythm. We can find much research about how certain types of music change the mind (Rouget, 1985 and Thaut, 2005), but I am sure there will be some gaps to fill. In other words my plans are not certain yet, but I would definitely be interested in exploring further projects using Brain Computer Interfaces. My goal is to gain a better understanding of Neurofeedback training, the software SuperCollider and work on a 3D installation which has a shape of a tree as big as a man. The branches and the leaves would be controlled via the Arduino, and would receive messages from the software depending on the brain pattern.

When we attach electrodes to the scalp we are listening to a very complex organ. Since I started studying in England I went through a change. I used to be more idealistic and had nothing really in common with technology. I enrolled on the Creative Music Technology course without expecting to be working with such software like SuperCollider or Max/MSP. I believe the whole course and the EEG project was very beneficial for me as now I can imagine more what the Renaissance was about, where science met art. At meditation courses I have heard this to be expressed by the harmony between the brain and the heart. Working on the project has taught me to be more patient if I want to get to know myself, which was a hidden aim of the project.

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Glossary

[1] Psycho-galvanic Reflex (PGR):

A change in the electrical properties of the body (probably of the skin) following noxious stimulation, stimulation that produces emotional reaction, and, to some extent, stimulation that attracts the subject's attention and leads to an aroused alertness. The response appears as an increase in the electrical conductance of the skin (a decrease in resistance) across the palms of the hands or soles of the feet. It appears about two seconds after stimulation, as by a pinprick or threat of injury; it rises to a maximum after two to ten seconds and subsides at about the same rate.

http://www.britannica.com

[2] P300 Event Related Potential:

"Event Related Potentials (ERPs) are brain signals that occur in response to external stimuli. They can be detected through the processing of an Electroencephalograph (EEG) signal." (Miranda, 2005)

Appendix a

Hardware electric specification (as in IBVA manual).

The transmitter amplifier

Sensor jack:

Analogue side:

we used special balanced DC coupling op amp, total Gain = 50,000 to 50,458.
Amplifier differential impedance is 10 T ohm,
Input Bias current is ¬±1.2 PA .. ¬±2 PA.
10 M ohm to 100 M ohm resistance input coupling.

variable high cut frequency filter amplifier Max 900 Hz -3bd.
Low cut 0.16 Hz at -3bd.

Common mode noise is up to 110 dB at 0..40 Hz.
Input Noise:
voltage noise
fB = 10 Hz to 10 KHz -> 0.6 ¬µ Vrms .. 0.7 ¬µVrms
fB = 0.1 Hz to 10 Hz -> 1.2 ¬µ Vp-p .. 1.6 ¬µVp-p
Current noise:
fB = 0.1 Hz to 10 Hz -> 12 fAp-p .. 15 fAp-p.
*fo = 0.1 Hz to 20 KHz -> 0.6 fA/*Hz .. 0.8 fA/*Hz*
Input Noise that depend on source impedance at 10 Hz:
*10M ohm: 400 nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 7.5¬µ Vp-p*
*1 M ohm: 120 nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 2.4 ¬µ Vp-p*
*100 K ohm: 50n nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 1.2¬µ Vp-p*

Analog side:
total Gain = 50,000 to 50,458. --> 25,000 (24,240 to 26,664)
Input Bias current is ±1.2 PA .. ±2 PA. --> 4 PA (TYP)

variable high cut frequency filter amplifier Max 900 Hz -3bd. ==> 10% - 100% to sampling frequency -3db

Common mode noise is up to 110 dB at 0..40 Hz. --> Common-Mode Rejection Ratio ? OPA2107 is 94db.

But, this time,
Important side is TL062's value. It's 86db.
This adjustment is very effective.
This adjustment is not in old IBVA.

I am searching a better OPA (for replace TL062). If it changes, I inform to you. AD706 is 106db. But, AD706 is not good. (more 2.5mA per channnel is necessary for stability.)

Input Noise:
voltage noise
fB = 10 Hz to 10 KHz -> 0.6 ―¬µ Vrms .. 0.7 ―¬µVrms --> 0.85 ―¬µ Vrms
fB = 0.1 Hz to 10 Hz -> 1.2 ―¬µ Vp-p .. 1.6 ―¬µVp-p --> 1.2 ―¬µ Vrms

Current noise:
fB = 0.1 Hz to 10 Hz -> 12 fAp-p .. 15 fAp-p. --> 23 fAp-p
fo = 0.1 Hz to 20 KHz -> 0.6 fA/*Hz .. 0.8 fA/*Hz --> 1.2 fA/*Hz

Input Noise that depend on source impedance at 10 Hz:
10M ohm: 400 nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 7.5―¬µ Vp-p --> There is not graph in pdf. 1 M ohm: 120 nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 2.4 ―¬µ Vp-p --> There is not graph in pdf.
100 K ohm: 50n nV/*Hz, fB = 0.1 Hz .. 10 Hz -> 1.2―¬µ Vp-p --> There is not graph in pdf.

variable high cut frequency filter amplifier Max 900 Hz -3bd. --

There is another hi-cut filter.
Amp's cut-off is about 1.5KHz (-3db), even in the case that there is not a variable filter.

Yes. 16V to 6V (5.6 is ok)

Digital side:
10 bit AD convertor 120 to 1960 sample par second.
minimum input 0 micro V p-p generate number 0.
max. input 200 micro V p-p generate number 1024.
minimum digital resolution is 200 micro V p-p / 1024 = 0.1953125 micro V p-p generate number 1.

Radio frequency: Bluetooth Interface class 2
2400 - 2483.5 MHz for USA/Europe/Japan
2446.5 to 2483.5 MHz France

Electrode side:
we can get good signal even if skin and electrode impedance changed between 0 to 100 K ohm then 0.4 micro V p-p out put noise. this mean we can use different electrode easily.

Power:
one 9V battery operate about 1 to 2 hours.
16 V to 6 V is works.

Appendix b

IBVA port (as in IBVA manual)

Activate Port = Auto Port Setup. : Need to use original port name that come with BlueVAS IBVA hardware.
sampling frequency is 120 Hz. Only one of this patch can make Port ON. Don't make Port ON with other IBVA4 patch in case make ON with this patch.

Input:
Output Update: This trigger update output. around 30 times par second is nice update speed. You can adjust this depend on your needs.
Port ON: Make Port ON / OFF.
Battery Trigger: Update Battery Monitor.

Output:
Port Active: Show port active state.
Sample Count: show sampling number since QC is start.
Time Monitor: show time since QC is start
Battery Monitor: Show battery power voltage.
IBVA4 Data String: Send Sampling brain wave data string directory from IBVA hardware. This can connect to other IBVA4 patch to re-analyze and display it. Use Inspector to select Settings shows IBVA4 Data string stream. Max buffer sampling size is one hour and recording is loop mode. Packet size is about 10 sampling, actuary depend on machine speed. This data is same as data come from IBVA hardware. In case trigger Battery then send Battery command and data also.

BlueVAS IBVA hardware data format :

10 bit : 000.. 3ff
direct out, no offset
000 is 0V input. -> -2.5 V input (- 100 micro V amp input)
3ff is 5V input. -> +2.5 V input (+ 100 micro V amp input)
200 is 2.5V input. -> 0 V input

/*
ex data

```
221   18f   12f   121
222   121   0b3   078
1b8   0f6   098   07a
```

```
181	0b3	07e	051
1ad	0fb	0d2	0b9
1de	144	11e	10c
20f	187	15f	14f
239	1ea	186	1f4
*/

/*
overflaw mesage


1ad	0fb	0d2	0b9
1de	144	11e	10c
ov
20f	187	15f	14f
239	1ea	186	1f4

*/

/*
send to get battery V
BL

then return
bl x

(hex)400 = 16V
(hex)200 = 8V


ex out

1ad	0fb	0d2	0b9
1de	144	11e	10c
bl 2a5
20f	187	15f	14f
239	1ea	186	1f4

*/
```

Appendix c (Additional information)

Information on hemispheres:

http://brainchildco.wordpress.com/

http://www.news.com.au/dailytelegraph/story/0,22049,22535838-5012895,00.html

Software information:

Max/MSP: www.cycling74.com

SuperCollider: http://www.audiosynth.com

IBVA: http://www.psychiclab.net,

http://www.ibva.co.uk

Game industry:

EMOTIVE

http://emotiv.com/

http://www.neurosky.com/

EEG sonification:

ICAD 2004

http://www.icad.org/websiteV2.0/Conferences/ICAD2004/concert.htm

John Cage and EEG

in HORIZON 0 : issue 15 – flow – new movements in digital music

http://www.horizonzero.ca/textsite/flow.php?file=7&is=15&tlang=0