NEUROMUSE: TRAINING YOUR BRAIN THROUGH MUSICAL INTERACTION

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ABSTRACT

Human aural system is arguably one of the most refined sensor we posess. It is sensitive to such highly complex stimuli as conversations or musical pieces. Be it a speaking voice or a band playing live, we are able to easily perceive relaxed or agitated states in an auditory stream. In turn, our own state of agitation can now be detected via electroencephalography technologies. In this paper we propose to explore both ideas in the form of a framework for conscious learning of relaxation through sonic feedback. After presenting the general paradigm of neurofeedback, we describe a set of tools to analyze electroencephalogram (EEG) data in real-time and we introduce a carefully designed, perceptually-grounded interactive music feedback system that helps the listener keeping track of and modulate her agitation state as measured by EEG.

1. INTRODUCTION

Music is generally acknowledged to be a powerful carrier of emotions and mood regulator, and as such has become omnipresent in our day to day life. Many stores now use energetic dance music to instill a festive atmosphere during our shopping hours. Moreover, with the advent of new human-computer interaction technologies, it has now become possible to derive some information about our emotional or mental state from physiological data. As a matter of fact, certain specific activity patterns of our brain, measurable by electroencephalography, correlate with different state of anxiety, tranquility or concentration. In parallel, the developments of music technology and psychoacoustics now allow for the generation of “affective” parametric and synthetic sounds in real-time. This paves the way for a new type of application that takes advantage of real-time physiology analysis and musical feedback and interaction to understand and learn to control better our mental states. With this work, we propose a framework for training our brain to learn to reach a relaxing state by relying on a perceptually-grounded interactive music system.

2. BACKGROUND

2.1. Electroencephalography

Electroencephalography (EEG) devices measure the summed activity of post-synaptic currents in the brain. The electrical voltage of an individual neuron can't be detected by an EEG electrode placed on the scalp, but a surface EEG reading is the summation of the synchronous activity of thousands of neurons. If a group of neurons fire in synchrony, the activity will result in the measurement of a large signal whereas asynchronous firing will trigger a smaller irregular signal. Scalp EEG activity can oscillate at different frequencies representing specific rhythmic, synchronized activity: the brain waves [1].

2.2. Brain Waves

The rhythmic activity describing the EEG is divided into bands by frequency, and most of the cerebral signal observed in the scalp EEG falls into the range 1-20 Hz. Brainwaves are usually categorized into the bands known as delta, theta, alpha and beta which have been shown to correlate with different mental states [1].

Delta wave (0-4 Hz) is the slowest and is associated with deep sleep and can be measured frontally. It is the dominant wave rhythm in infants.

Theta wave (4-8 Hz) is associated with dream sleep, meditation and creative inspiration and is strong in children with attention deficit disorders.

Alpha wave (8-12 Hz) can be measured from the posterior regions of the head and is associated with a relaxed state. Only closing one's eyes increases the generation of alpha waves.

Beta wave (12-30 Hz) is most evident frontally and is associated with an alert state of mind, anxiety, concentration and mental activity.

Gamma waves (30-80Hz) correlate with higher mental processes, perception and consciousness. High frequency waves (alpha, beta and gamma) dominate during wakefulness.

Since different brain-waves activities correlate with different states, it is possible to imagine various protocols to enhance the activity of brainwaves that are related to soothing states. This is the main goal of a type of biofeedback called neurofeedback.

2.3. Neurofeedback

Neurofeedback is a technique that makes use of real-time feedback on brainwave activity. The goal is to teach people how to control their brainwave activity and limit it to a certain frequency range, representative of a characteristic mental state. A typical application is to control stress-related conditions by learning to increase alpha wave activity, which correspond to a relaxed state [1]. The feedback information allows people being monitored to better understand the process and gain some conscious control over the generation of different brain waves. Interestingly enough EEG studies of Yogis and Zen Masters, showed that high levels of alpha could be observed during meditation[2]. It is generally admitted that this increased alpha activity leads to less anxiety, improved attention and enhanced cognitive functioning [3].

2.4. EEG-based Music Composition

One of the first attempts to use brainwaves to generate music was the piece “Music for solo performer” composed by Alvin Lucier in 1965 [4] where he used brainwaves as a generative source for the whole piece. In this piece the EEG signal from the performer was amplified and relayed to a set of loudspeakers coupled with percussion instruments.

In the seventies, the composer David Rosenboom, started to systematically use EEG output as a means to create or enhance performance art and music. He used biofeedback devices such as EEG to allow performers to create sounds and music using their own brainwaves [5].

More recent research has attempted to create complex musical interaction between particular brainwaves and corresponding sound events where the listener EEG control a music generator imitating the style of a previously listened sample [6].

Data sonification in general and EEG sonification in particular has been the subject of recent studies [7] showing the ability of the human auditory system to deal with and understand highly complex sonic representation of data.

In the present work, we describe a unified framework where the user can learn to actively control her alpha-wave activity through interactive musical feedback. The musical parameters the user can control via her brainwave activity are based on psychoacoustics studies. They are designed to be perceptually salient in order to enhance the understanding of the interaction.

3. THE EEG SYSTEM

3.1. Hardware

3.1.1. *ENOBIO: a dry electrode wireless device*

Nowadays most of the scalp EEG use a conductive gel or paste applied on the scalp to reduce impedance and obtain clean recordings of the signal from the electrodes. With the advent of new technologies such as carbon nanotubes, it has now become possible to penetrate the outer layer of the skin and have an improved electrical contact with dry electrodes.

We used such a dry electrode wireless system called ENOBIO from Starlab, Barcelona [8]. ENOBIO is a wearable, wireless, 4-channel, all-digital electrophysiology recording system that has been optimised for dry electrodes (Figure1). The cables allow any combination of EEG (Electroencephalogram - brain activity), EOG (Electrooculogram - eye movement) and ECG (Electrocardiogram - heart activity) in a single wearable system without loss of signal quality.

For the purpose of this paper we focused on EEG signals only.

3.1.2. *Electrode Placement*

Following the international 10-20 system for EEG scalp electrode location, the signal from FP1 and FP2 are usually used for measuring beta channel whereas O1 and O2 give higher amplitudes in the alpha range[1]. Nevertheless, hair reduces considerably the sensitiviy of ENOBIO's dry electrodes, which excludes the possibility to use O1 and O2 locations in our setup. The advantage of the ENOBIO system though is that it can be easily usable in many different contexts (such as performances, relaxation sessions, etc.) since (dis)connecting is as easy as putting the cap on or off (no gel to put or specific preparation). We opted for the FP1, FP2 only and the ground reference is clipped to the left earlobe. Even if the overall amplitude of alpha waves in the FP area is not optimal, it is still possible to measure the relative increase of energy in the alpha range compared to the beta range.

Figure 1: The ENOBIO is a wearable wireless dry electrode electrophysiology recording system.

3.2. Software

3.2.1. *A Client-Server Architecture*

The ENOBIO device is not provided with any standard data analyis tools yet, but it transfers binary-encoded stream of data via a TCP-IP server called JENOBIO. We implemented a set of TCP client/decoder threaded externals in C for Max-MSP [9]and PD [10] to easily communicate with the JENOBIO server and decode the stream of bytes into the 4 different channels in real-time.[1].

3.2.2. *Filtering*

For each channel we implemented a suite of standard signal processing Max-MSP modules to extract each brainwave information as accurately as possible. The raw signal is first high-passed with a cutoff frequency of 0 Hz and low-passed with a cutoff frequency of 35 Hz to avoid ambient noise from the system. We then designed a set of bandpass butterworth filters with center frequency of 10 Hz and 22 Hz and bandwidth of 4Hz and 8Hz respectively for the alpha and beta brainwave specification.

3.2.3. *Power Band Spectrum*

For each channel the powerband spectrum was computed and averaged using a moving average filter of length 20 in order to obtain a relatively smooth representation of the alpha and beta bands that can be fed to the adaptive musical system. We also implemented a set of graphical interfaces and displays in Max-MSP that allow us to check in real-time the evolution of the signal for each channel.

4. THE MUSICAL SYSTEM

4.1. Macro Structure: I-Ching

The generation of a musical structure for this project was intentionally fairly simple. We based the real-time algorithmic composition process on the I-Ching principle used in works such as "Music of Changes" by John Cage [11]. The basic idea is to have real-time modulation of precomposed musical cells.

We devised a set of modules in Max that allow to score basic midi information such as Rhythm, Pitch, Velocity, Duration and

[1] http://www.iua.upf.edu/˜slegroux/download

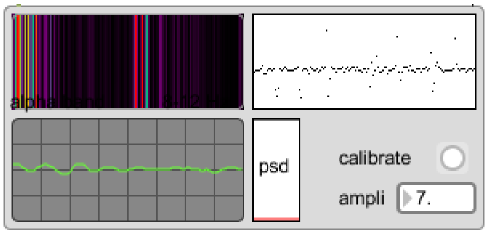

Figure 2: The upper display represents the spectrogram in the 8 to 12 Hz frequency range (alpha wave). The upper right side is the discrete byte information sent from the server. The bottom left side is the interpolated version of the data. The bottom right display shows the alpha wave power as a bar plot.

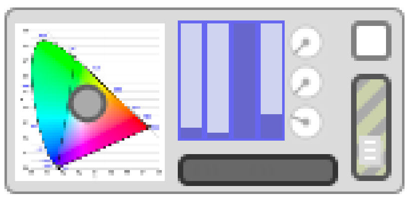

Figure 3: The tristimulus synthesizer allows control over tristimulus parameters, ADSR envelope, noisiness, loudness, inharmonicity and vibrato.

chose deterministic and probabilistic techniques to modulate this material. For this project we wanted to put the emphasis on the timbre modulation of the musical material, to obtain a minimalist, meditative musical atmosphere. The pitch sequence is based on the following indian scale That Todi: [C Db Eb F# G Ab Bb] that was chosen for its meditative mood. A 10 beat primitive rhythmic cell Jhaptal was defined as the following division of beat: [2+3+2+3]. The selection principle of each element (note or rhythmic entity) follows a serial music paradigm: in one run each element should be played only once in a random order. When all the elements of the list have been played once, the procedure starts again. For the velocity and duration parameters, we chose a random walk process with a velocity range between 10 and 120 on the midi scale and a note duration between 40 and 400 ms. This gives a distinct character to the piece since the scale is the same, but enough randomness is injected so that the piece is not completely predictable and boring.

4.2. Micro Structure: Perceptually Grounded Sound Generation Based on the Tristimulus Timbre Space

Here, we put the emphasis on studying a tristimulus synthesizer that allows the modulation of subtle timbral features that are perceptually relevant [12].

We implemented a polyphonic synthesizer with GUI-based interface (Figure3) in Max-MSP which relies on the tristimulus model of timbre [13, 14]. It provides us with a simple and intuitive interface to modulate relevant perceptual features such as brightness, noisiness, harmonicity, or odd/even ratio of an additive plus noise synthesis model

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The tristimulus analysis of timbre proposes to quantify timbre in terms of three coordinates (x, y, z) associated with band-

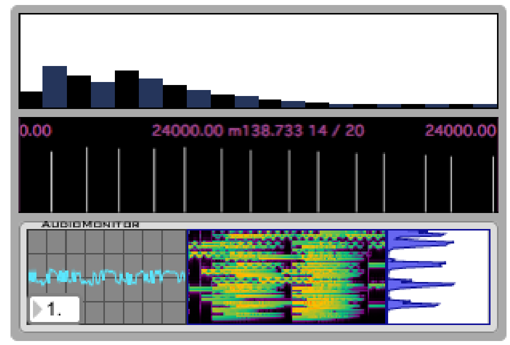

Figure 4: Spectral analysis of the TristimuluSynth: the upper display represents the weighting of the harmonics as defined by the tristimulus controller. The middle display represents the time varying harmonics after synthesis. The bottom display represents the audio signal as well as the spectrogram and spectral density.

loudness values. Inspired from the tristimulus theory of colour perception, it associates high values of x to dominant high-frequencies, high values of y to dominant mid-frequency components and high values of z to dominant fundamental frequency.

The sound is represented as a sum of weighted sinusoids at frequencies multiple of the fundamental frequency plus a noise factor [15].

In the synthesis model, the harmonics partials belong to three distinct frequency bands or tristimulus bands: $f_0(n)$ belongs to the first low frequency band, frequencies $f_{2...4}(n)$ belong to the second mid-frequency band, and the remaining partials $f_{5...N}(n)$ belong to the high-frequency band.

The relative intensities in the three bands can be visualized on a tristimulus triangular diagram where each corner represents a specific frequency band (Figure 4). With this model the brightness can be modulated by the position of a cursor in the tristimulus timbre space (cf. Figure 3), where the lower left corner of the triangle corresponds to the darkest class of sounds whereas lower right corner correspond to the brightest.

The noisy part of the sound was generated following the subtractive synthesis paradigm. We filtered a random noise generator with a bank of three passband filters centered at f_0, $3f_0$ and $9f_0$ respectively as suggested in [14] so that the noisy portion of the sound follows a tristimulus spectral distribution.

Noisiness is defined as the relative amplitude of the filtered noise generator. Inharmonicity relates to the factor by which successive partials deviate from the harmonic spectrum. Finally, we define the even partial attenuation factor as the relative amplitude level of even partials in the spectrum of the signal

.

The synthesizer allows the control of perceptually relevant sound parameters, which variation has been shown to correlate with different emotional states [12]. Our hope is that the differences in parameters are clear enough so that the listener will easily learn to make the distinction between different musical parameters that lead to different musical "moods".

5. NEUROFEEDBACK TRAINING WITH MUSIC

In our interactive paradigm, the user's goal should be to consciously control her brainwaves to stay in the alpha band. The music acts as an auditory feedback that helps the listener understand the process. The musical parameters are predefined and should clearly represent positive feedback if the EEG detects more energy in the alpha band, or negative feedback if the energy is principally in the beta band.

For this purpose we chose to use a set of parameters based on psychoacoustical studies that investigated the relation between musical feature and valence [12]. Noisy, inharmonic, bright (high tristimulus component) and loud sounds were associated to negative feedback whereas harmonic, dark (low tristimulus) component and mellow sounds were associated to positive feedback.

During a set of informal experiments done at the university, it appeared that listeners could practice and learn to gain control over their brainwave emission thanks to the auditory feedback component and that the experience was pleasant. Nevertheless the process was not completely obvious, and a more detailed and systematic study of the parametrization of the system is needed. First impressions were encouraging, but we will need further investigation and quantitative assessment of the neurofeedback paradigm.

6. CONCLUSION

We presented a unified framework for learning to control EEG signals through a perceptually-grounded interactive sonic feedback system. The technology works in real-time, and the hardware is mobile, wireless, and easy to setup, making the system suitable for diverse environments. We believe the sound parameters we chose were good at representing different state of agitation and helped the listener to understand better the interaction. However, the whole system needs to be robustly evaluated. In the near future we plan a series of controlled experiments and statistical analysis to assess the validity of the system. Different interactive scenario are also possible. We can imagine a machine learning algorithm searching the sound synthesis parameter space for the set of parameters that would maximize the power in the alpha band. In this scenario the listener is not consciously adapting anymore. The system does the learning and adaptation itself in order to induce a relaxed state in the listener.

7. REFERENCES

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