

# Mind the Music: Towards Thought-Controlled Music Systems

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## Abstract

We are investigating whether electroencephalogram (EEG) patterns can be detected and classified according to different auditory stimuli. We explore advanced multichannel signal processing techniques to perform pattern classification on the EEG data. This paper outlines our research methods and describes the ongoing experimental work which uses a 128-channel dense array EEG recording system. This is the first step in our attempt to explore ways of allowing people to control a musical environment with their mind.

## 1. Introduction

The ultimate goal of this research project is to develop a system whereby people can create music simply by thinking. It is too much of a leap in the dark to foresee the particulars of such a system at this stage, but it is not inconceivable to imagine a situation in which one could actively listen to a type of musical composition that actually changes its course, rhythm, mood, style, etc. according to the brainwave signals of the listener. An even more ambitious goal would be a system that could actually synthesise the sounds (or music, for that matter) one is thinking of (Figure 1).

We envisage a system in which a wearable bio-feedback device, furnished with a neuro-compatible interface, would produce some sort of raw 'musical signal' that gets shaped (or 'composed') by the mind of the listener. Specific types of compositions could then be devised for particular cases; for example, for a music therapy context, where the music is created in response to particular brain signals that causes either or both, relief of stress or states of arousal. This is a dream waiting to be realised, and the inspiration behind our research project, in which we believe a great number of benefits exist such as: making music creation accessible to a broader population (including people with impaired muscular abilities), adding to the understanding of music and mind, and promoting the development

of thought-controlled systems. The medical sciences will also benefit, as the quantitative analysis of the EEG is becoming more common in the research of medical conditions.

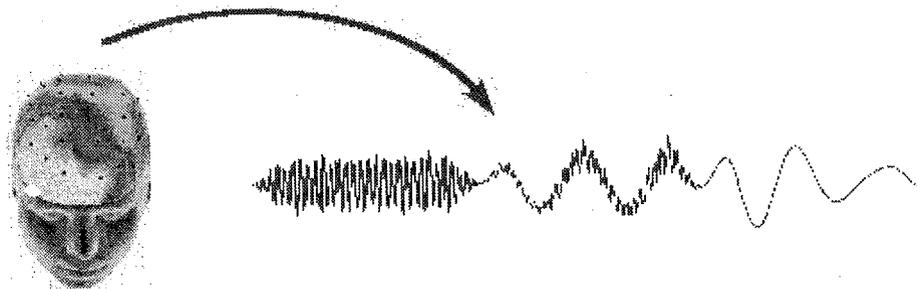


Figure 1: *Imagine if it were possible to play music simply by thinking.*

One of the key features that distinguish humans from other animals is the fact that we are intrinsically musical. Music is generally associated with the expression of emotions [Harrer and Harrer, 1977], but it is also common sense that the intellect plays an important role in musical activities [Deutsch, 1977]. All the same, music requires the ability to recognise and imagine patterns of sounds; it requires sophisticated memory mechanisms, involving both conscious manipulation of concepts and subconscious access to millions of networked neurological bonds [Miranda, 1997].

Our understanding of the behaviour of the brain when we engage in any type of musical activity (e.g. playing an instrument or simply imagining a melody) is merely the tip of an iceberg. A variety of methods to measure the activity of the brain have brought to light important issues that have helped researchers uncover the tip of the iceberg. The electroencephalogram method (EEG), for example, has been particularly useful to demonstrate that the brain expects sequences of stimuli that conform to established circumstances. For instance, if you hear the sentence "A musician composes the music", the electrical activity of your brain will tend to run fairly steadily. But if you hear the sentence "A musician composes the dog", the activity of your brain will display significant negative electrical response immediately after the word "dog". The human brain seems to respond similarly to musical events. This aspect of the brain activity is one of the main motivations of our research.

## 2 Measurements of brain activity

"The human brain produces a complex, multidimensional, pulsating, electromagnetic field resulting from the electrochemical behaviour of masses of neurones acting in small to very

large groups" [Rosenboom, 1990]. The EEG is the mixed frequency electrical signal produced by this activity, and it is measured from electrodes placed on the scalp. We found a few encouraging references in both musical and non-musical research fields that confirm that the EEG provides a rich source of information about our thought (musical) processes: [Birbaumer, 1994]; [Janata, 1994], [Makeig, 1997] and [Saiwaki, 1997].

EEG data have been categorised into four main components [Rosenboom, 1990]:

- (a) a random-seeming background signal
- (b) long-term coherent waves
- (c) short-term transient waves
- (d) complex ongoing waves

The random-seeming background signal is the residue observed after all known methods of waveform decomposition are exhausted; very little is known about this signal. Long-term coherent waves are the well-known *alpha*, *beta*, *delta*, and *theta* rhythms, which range from approximately 1 to 30 Hertz. They are often associated with certain states of consciousness, such as alertness and sleep. Short-term transient waves reflect the 'singular experience' associated with an external stimulus and up to now they have been accessible only by Event Related Potential (ERP) analysis. ERPs are derived by taking the average of many EEG recordings, where the person is subjected to the same stimulus repeatedly. The reason for averaging is to remove noise caused by other uncorrelated brainwave activities. ERP analysis has played an important part in developing the theory of music cognition, as authors like Rosenboom [Rosenboom, 1990] and others have shown. Finally, it is suggested that a non-random complex component exist, whose ever changing pattern comes from the build up of baseline activation's from the vast neuronal masses within the brain. This pattern is expected to be the result of the ongoing, self-organisation of information during a person's own life experience. If these patterns could be successfully measured, and sense made of them, we might witness the mechanisms of higher level thought processes.

Another measurement of brain activity is the magnetoencephalogram (MEG), which uses super-conducting sensors to measure the fluctuation and topographic distribution of the magnetic fields associated with the discharge of neural action potentials, and electrochemical activity within the brain. The advantages of MEG over the EEG are twofold: (a) signals associated with highly spatial-localised activity are more readily detected; and (b) the sensing equipment does not require direct contact with the head, thus making it more comfortable. MEG technology is, however, still very expensive

Other methods of measuring brain activity, such as Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET), provide a mapping of the activation of individual cortical areas. They can contribute to the understanding of the spatiotemporal

activity of the brain under certain conditions; for example, PET scans have shown that listening to music and imagining listening to music 'activate' different parts of the brain. Unfortunately, both MRI and PET require extremely expensive and ergonomically restrictive equipment.

Mainly due to its temporal resolution, EEG technology is currently favourable for methods that might lead to 'expert-thought-systems', that is, those mind-controlled.

### 3 An overview of the ongoing research work

At present we are developing technology to detect features of brain activity that represent the sounds one thinks of. However, it seems logical that a primary aim might be to isolate general sonic-thought features, from the other ongoing mental activities; i.e. to extract information about musical thoughts from the brainwaves. We have chosen, at least for now, to focus on exploring methods of EEG analysis. We are also investigating methods to map brainwave signals to the parameters of a computer sound synthesis system [Miranda, 1998].

We currently are investigating whether spatiotemporal frequency patterning could be achieved by EEG analysis using a combination of auto-correlation (to segment EEG time series data), auto-regression (as an alternative to Fourier methods), and directed coherence analysis techniques, which form a type of statistical information flow method. Work of this nature has shown that there is a relationship between EEG and music cognition [Saiwaki, 1997] but these techniques still need to be much refined and adapted to suit our purposes.

Statistical time-domain methods such as, Independent Component Analysis (ICA) and Principal Components Analysis (PCA) are currently being used to look for evidence of voluntary musical thought in EEG. ICA, for example, has already been successfully used to segment auditory-stimulated ERPs into separate components [Makeig, 1997]. The strengths of these components were found to be related to specific features of the human cognitive process, involved in the detection of specific aspects of auditory stimulation. ICA can separate  $N$  statistically separate inputs, which have been mixed linearly at  $N$  outputs, therefore, the number of components equals the number of electrodes. We are currently assessing whether ICA can be effectively used as a pre-processing tool for further statistical pattern recognition methods, or as inputs to artificial neural networks (ANNs) [Hertz et al., 1991].

We believe that the application of ANNs for extracting musical thought features from pre-processed EEG signals might be the best approach to the problem (Figure 2), as they have been successfully applied in other similar problems; e.g. for the recognition of epileptic seizures [Weng and Khorasani, 1996].

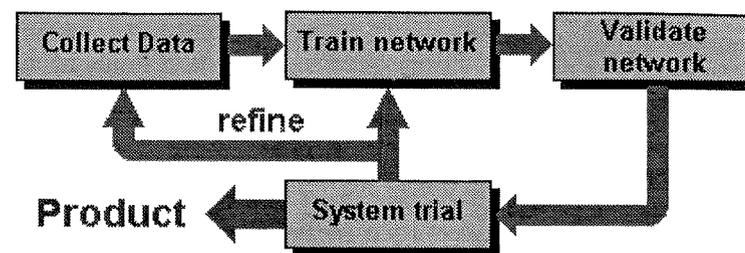


Figure 2: An artificial neural network system, to 'represent' the brain activity generated when one thinks of sounds, is under development

### 4 Measuring musical thoughts: our approach to the problem

*We are running a number of experiments to test the hypothesis that we can distinguish between the EEG of a subject when s/he is hearing a simple musical sound or not, with a view to further experiments that incorporate imagined musical events as well.*

*A group of subjects are presented with an auditory stimulus. During the experiment, the subjects listen to a short audio track, presented through loudspeakers. The audio track consists of a repeated recording of a sound, spaced by random moments of silence. Each subject is presented with the same audio track several times.*

*The EEG equipment records a synchronisation pulse generated by the stimulus device to ensure that the EEG data is 'marked' according to the exact time the sounds are presented.*

*Most of the work to date that involves EEG analysis use the time-averaged Event Related Potential technique (ERP). However, we adopted a different approach: we treat the data set as a multichannel time series, and make as few a priori assumptions as possible.*

The five main stages of our experiments are discussed below.

#### 4.1 Bio-sensing

The bio-signal we are measuring comes from the EEG equipment and the data that are collected form a multichannel time series. This time series can be thought of as a multidimensional pattern space.

The EEG equipment we are using is the state-of-the-art 128-channel *Geodesics Sensor Net*, by Electrical Geodesics. The Geodesic Sensor Net is composed of 128 plastic sensor housings, interconnected by durable polyurethane elastomer threads that form the tension

lines of an icosahedron. Each sensor housing contains a low drift, custom-made electrode embedded in an electrolytic sponge. As the sensor net is stretched over the head, the electrodes make contact with the scalp via the sponges and are held firmly by the geodesic tension network (Figure 3).

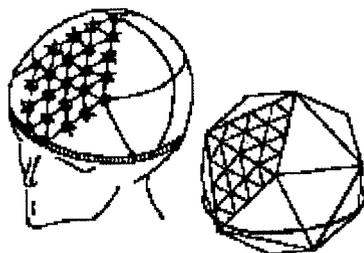


Figure 3: With a 2.8 cm intersensor distance, the Geodesic Sensor Net provides adequate means for the characterisation of the electrical fields on the scalp.

#### 4.2 Pattern localisation and normalisation

Once the raw EEG data has been collected, some initial pre-processing is required to remove unwanted 'contamination', such as muscular and eye movement artefacts. A simple amplitude threshold test can achieve this [Jung et al., 1997]. At this stage, the data also require additional pre-processing operations, such as normalisation and scaling, zero padding and windowing.

#### 4.3 Feature extraction and selection

Both non-transformed signal characteristics, such as parametric modelling, and transformed characteristics, such as auto-regression and Fourier analysis, are options for the extraction of features from the pattern space. Here, statistical reasoning plays an important role in the selection of the best features for classification purposes.

#### 4.4 Property formation and clustering

Statistical techniques, such as Principal Components Analysis (PCA), Independent Component Analysis (ICA), distance classifiers and clustering, combined with connectionist methods such as Kohonen networks (Figure 4), are among the methods we are investigating for the selection and property formation stages of the problem.

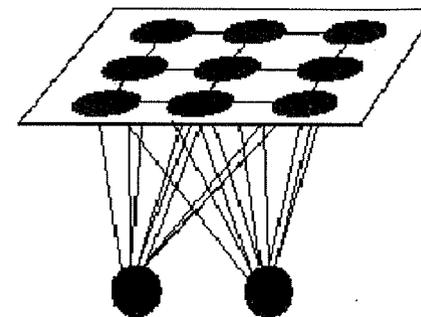


Figure 4: A Kohonen network is able to classify data by grouping them into clusters containing similar features.

#### 4.5 Classification

For classification methods, we are investigating both statistical and connectionist (i.e. artificial neural networks) techniques, as both have shown to be effective in work by other authors. For example, neural networks have done successful detection of epileptic seizure patterns in EEG, where the network was trained with a known seizure EEG data-set [Weng and Khorasani, 1996]. Radial Basis Functions (RBF) is one of the techniques under investigation. RBF is a supervised feedforward neural network that combines linear and non-linear functions. RBF is suited for classifying data highly corrupted with noise.

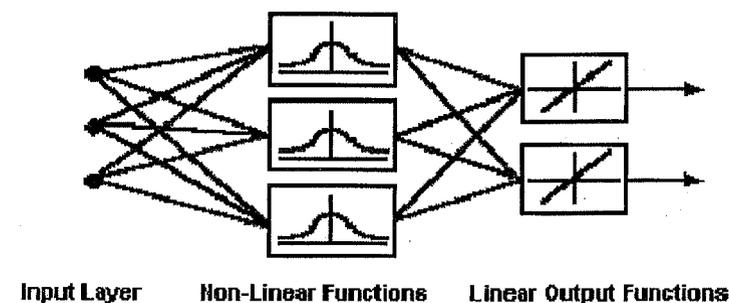


Figure 5: Radial Basis Functions is a supervised feedforward neural network that combines non-linear and linear functions.

## 5 Conclusion

The work outlined in this paper is the first step towards our long term goal of developing thought-controlled musical systems. It is our hope that sufficient information representing thought processes are present in the EEG, otherwise we may be searching for the impossible.

So far, we have learned that the design of suitable experiments is far from trivial, and possibly controversial. However, we have attempted to keep our first experiments simple and rigorous, with the hope that they lead to confidence and experience in handling multichannel time series EEG data. There are still many issues to explore, such as choosing the best analysis techniques, and developing the means to evaluate their success.

The EEG signals are very small and are immersed in an ocean of background noise. Also, the EEG signals appear to be variable between different subjects. We believe that analysis methods used in radio astronomy and sonar systems may help to provide clues as to the analysis methods we investigate; these systems also deal with highly noisy signals.

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