# Mix-it-yourself with a brain-computer music interface

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## ABSTRACT

This paper is a follow up from the work presented at the ICDVRAT 2006 conference in Esbjerg, where the first author introduced a Brain-Computer Music Interface (BCMI) to control a generative music system. Here we introduce a new musical application for the BCMI (an EEG-controlled music mixer) and report on efforts to make our BCMI system cheaper to implement, more portable and easier for users to operate. We also comment on a new method that we are developing to generate melodies from the topological behaviour of the EEG.

## 1. INTRODUCTION

Despite advances in technology, opportunities for active participation in music making are limited for people with differentiated physical and mental abilities, especially those with severe complex disability. At present, access music tutors use gesture devices and adapted accessible technology to make this possible, which achieve great results in most cases. For people with severe physical disabilities, however, having the ability to interact with the environment created for them by the facilitator can sometimes be difficult. This prevents them from engaging in the many emerging community initiatives, which may provide opportunities for recreational music-making including performance, composition and creative workshops. A brain-computer interface for music recreation and therapy could be the only option for many with disability to have a musical voice and thus benefit from more active participation in recreational and therapeutic music opportunities.

At the ICDVRAT 2006 conference in Esbjerg, the first author introduced a proof-of-concept Brain-Computer Music Interface (BCMI) to control a generative music system (Miranda 2006). The BCMI was programmed to look for information in the EEG signal and matched the findings with assigned generative musical processes corresponding to different musical styles. It activated generative rules for two different styles of piano music (e.g., Satie-like and Beethoven-like), depending on whether the EEG indicated salient low-frequency or high-frequency components in the spectrum of the EEG. Every time it had to produce a bar of music, it checked the power spectrum of the EEG at that moment and activated the generative rules accordingly. Subjects were able to lean to control the EEG in order to voluntarily produce high power in the low- or high-frequency bands of the EEG's spectrum. Therefore, they were able to actively steer the system to generate Satie-like or Beethoven-like of music. Because at the time we were more interested in implementing an experimental proof-of-concept system, we did not consider issues concerning the usage of the system in real-world applications. The system comprised expensive EEG equipment, three computers and a myriad of different software, some of which were not entirely compatible with each other, and had to be hacked.

In this paper we introduce a new musical application for the BCMI: an EEG-controlled music mixer. We also report on continuing efforts to make the BCMI system cheaper to produce, more portable, more stable and easier for users to operate. Finally, we briefly introduce a new technique that we are developing to produce music from the topological behaviour of the EEG signal.

## 2. TECHNICAL BACKGROUND

Human brainwaves were first measured in the early 1920s by Hans Berger. He termed these measured brain electrical signals the electroencephalogram (literally "brain electricity writing"). Berger first published his


 ISBN 07 049 15 00 6

brainwave results in an article entitled "*Über das Elektrenkephalogramm des Menschen*" (*On the Electroencephalogram of Man*) (Berger 1929). The English translation would not appear until the end of the 1960s (Berger 1969). He had a lifelong obsession with finding scientific proof of a causal linkage between the psychical world of human consciousness and the physiological world of neurological electrical signals.

The EEG is measured as the voltage difference between two or more electrodes on the surface of the scalp, one of which is taken as a reference. The standard convention for placing electrodes on the scalp uses electrodes placed at positions that are measured at 10% and 20% of the head circumference (Figure 1). The terminology for referring to the position of the electrodes uses a key letter that indicates a region on the scalp and a number: F = frontal, Fp = frontopolar, C = central, T = temporal, P = parietal, O = occipital and A = auricular (the ear lobe; not shown in Figure 1). Odd numbers are for electrodes on the left side of the head and even numbers are for those on the right side. The set of electrodes being recorded at one time is called a montage.

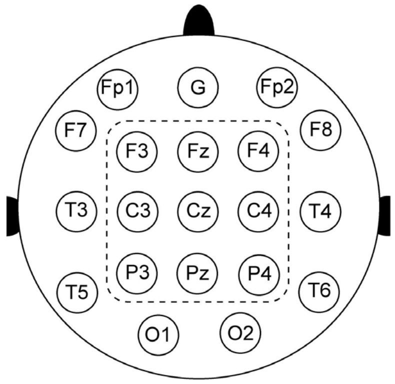


**Figure 1.** *The EEG is detected with electrodes placed on the scalp at positions measured at 10% and 20% of the head circumference. The terminology for referring to the position of the electrodes uses a key letter that indicates a region on the scalp and a number.*

The EEG expresses the overall activity of millions of neurons in the brain in terms of charge movement, but the electrodes can detect this only in the most superficial regions of the cerebral cortex (Misulis 1997). Today, the EEG has become one of the most useful tools in the diagnosis of epilepsy and other neurological disorders. Further, the fact that a machine can read signals from the brain has sparked the imaginations of scientists, artists and other enthusiasts, and EEG has made its way into a myriad of other applications.

A brain-computer interface uses information extracted from the EEG to control devices, such as a wheelchair or a computer cursor (Dornhege et al. 2007). Although most current efforts into BCI research focus on EEG, other techniques for measuring brain activity have been attempted; for example, near-infrared spectroscopy and magnetoencephalography (MEG). In the case of the EEG, it takes many thousands of underlying neurons, activated together, to generate signals that can be detected. The amplitude of the signal strongly depends on how synchronous is the activity of the underlying neurons. The EEG is a difficult signal to deal with. It is filtered by the meninges (the membranes that separate the cortex from the skull), the skull and the scalp. There are a number of approaches to EEG analysis, such as power spectrum, spectral centroid, Hjorth, event-related potential (ERP), principal component analysis (PCI) and correlation, to cite but a few (Niedermeyer and da Silva 1987). Although powerful mathematical tools for analysing the EEG already exist, we still lack a good understanding of their analytical semantics in relation to musical cognition.

In the work presented in this paper we have used power spectrum analysis. Power spectrum analysis is derived from techniques of Fourier analysis, such as the Discrete Fourier Transform (DFT). In short, DFT analysis breaks the EEG signal into different frequency bands and reveals the distribution of power between them. This is useful because the distribution of power in the spectrum of the EEG can reflect certain brain states. For example, spectra with salient low-frequency components are known to be associated with a state of drowsiness, whereas spectra with salient high-frequency components are normally associated with a state of alertness. There are five recognised frequency bands of EEG activity, also referred to as EEG rhythms, each of which is associated with specific brain states referred to as delta, theta, alpha, low beta and high beta rhythms. They certainly indicate different brain states, but there is, however, some controversy as to the exact boundaries of these bands and the states with which they are associated. It is often said in the literature that alpha rhythms (conveyed by frequency components ranging from 8Hz to 13Hz) indicate inattention and relaxed, almost drowsy, state of mind. The beta rhythms (conveyed by frequencies ranging from 13Hz to about 40Hz or so) seem to indicate active thinking, active attention and solving concrete problems (e.g., calculations, planning).

## 3. THE BCMI MIXER

The BCMI mixer system controls the faders of a music mixer. For instance, assume a piece of music recorded into 3 tracks: the first track contains the beat, which has a constant rhythm (bass and drums). The second and the third tracks main contain piano and guitar solos, respectively. Instead of activating generative rules for two different styles of music (as we have done previously), here we use the activity of the EEG to control the faders for the second and third tracks: the power (or amplitude) of the beta rhythms controls the fader for track 2 and the power of the alpha rhythms controls the fader for track 3 (Figure 2). Therefore, if the system detects prominent alpha rhythms in the EEG, then the guitar solo sounds louder. Conversely, if the system detects prominent beta rhythms, then the piano solo sounds louder.

In contrast to our previous system which comprised expensive 32-channel EEG medical equipment, three computers and hacked software, the BCMI mixer runs on a single personal computer and uses an affordable 4-channel EEG amplifier manufactured by MindPeak, USA (Figure 3). Although the accuracy of the latter lags behind the accuracy of our previous EEG amplifier, we believe that it is satisfactory enough for recreational, and even therapeutic, purposes. Moreover, the BCMI controls an off-the-shelf relatively easy to use music production software (Reason, manufacturer by Propelerhead, Sweden), which makes the whole system much more user-friendly to operate and customise.

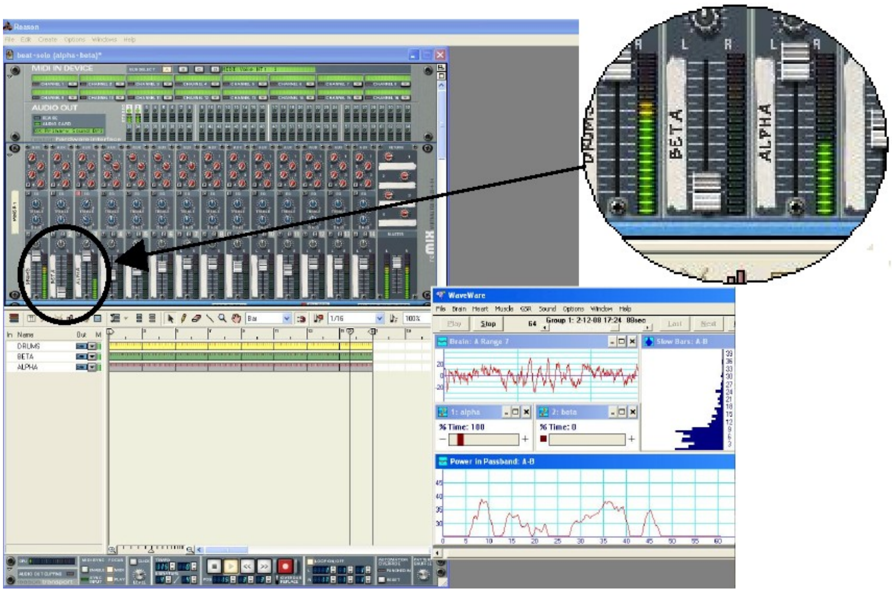


**Figure 2.** *The BCMI music mixer controls the faders of the mixer of a music production program called Reason, manufactured by Propellerhead, Sweden.*

**Figure 3.** *The BCMI mixer system uses an ordinary PC, affordable EEG equipment with serial or USB connection and off-the-shelf software, making it user-friendly and easy to operate.*

## 4. TOWARDS MORE SOPHISTICATION

We are currently experimenting with a new method to generate music with the EEG, which requires more sophistication with respect to the analysis of the signal and understanding of its meaning.

Besides the information conveyed by the overall activity of different frequency bands, the EEG signal certainly conveys a number of other types of information, which might be significant for music control. We are currently looking at the topological behaviour of the EEG as it varies across different regions of the cortex. Instead of analysing the overall EEG resulting from the summation of the signals from all electrodes simultaneously, we consider the signal of each individual electrode separately. Figure 4 plots an extract of the individual signals from 14 different electrodes organised as shown in Table 1.

**Table 1.** *The montage of 14 electrodes used in our experiments.*

| Electrode number | Electrode name as shown in Figure 1 |
|---|---|
| 1 | Fp1 |
| 2 | Fp2 |
| 3 | F7 |
| 4 | F5 |
| 5 | F4 |
| 6 | F8 |
| 7 | T3 |
| 8 | T4 |
| 9 | T5 |
| 10 | P3 |
| 11 | P4 |
| 12 | T6 |
| 13 | O1 |
| 14 | O2 |

We extract information from the signals of each electrode in order to infer possible trajectories of specific types of information across the montage. For instance, in Figure 5 we demonstrate how the power of the signals shown in Figure 4 has varied on the scalp in 5 steps. The area with the highest EEG power moved from electrode 2 (Fp2) to 1 (Fp1), then 5 (F4) and then 6 (F8), where it remained for two steps. The length of the window used to analyse the power of signals defines the number of steps. (The length of the window is arbitrary.)

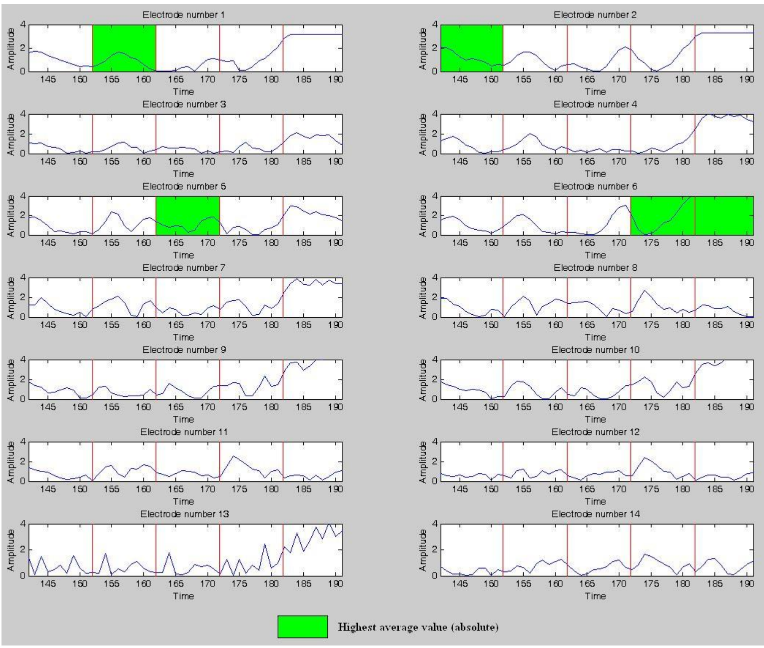


**Figure 4.** *An extract of the individual raw EEG signals of 14 electrodes.*


Proc. 7th ICDVRAT with ArtAbilitation, Maia, Portugal, 2008

A number of analyses could be performed here. For instance, one could analyse the trajectory of alpha rhythms (Figures 7 and Figure 5 on the right) or beta rhythms (or both simultaneously), correlation between electrodes or sets of them, synchronisation between one or more electrodes, and so on (Giannitrapani 1985). Much research is needed to establish the meaning of the trajectories in terms of cognition or state of mind, particularly with respect to music cognition.

**Table 2.** *Associations between musical notes and the electrodes of a given montage.*

| Electrode number | Electrode name as shown in Figure 1 | Musical note |
|---|---|---|
| 1 | Fp1 | A4 |
| 2 | Fp2 | A4# |
| 3 | F7 | B4 |
| 4 | F5 | C5 |
| 5 | F4 | C5# |
| 6 | F8 | D5 |
| 7 | T3 | D5# |
| 8 | T4 | E5 |
| 9 | T5 | F5 |
| 10 | P3 | F5# |
| 11 | P4 | G5 |
| 12 | T6 | G5# |
| 13 | O1 | A6 |
| 14 | O2 | A6# |

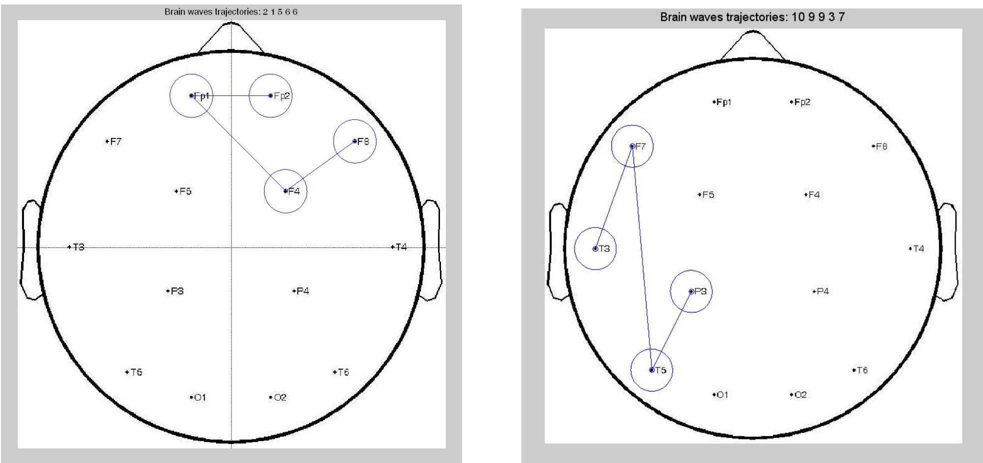


**Figure 5.** *(Left) The trajectory of EEG power information on the scalp in 5 steps. (Right) The trajectory of alpha rhythm information on the scalp in 5 steps.*

We have developed a simple but nevertheless effective method to generate melodies from the trajectories of the type illustrate in Figure 5 on the left. Each electrode is associated with a musical note (Table 2), which is played when the respective electrode is the most active with respect to the EEG information in question. In the case of this example, the information is the power of the raw EEG signal. The associations between notes and electrodes are of course arbitrary. Considering the associations in Table 2, the trajectory shown in Figure 5 on the left would have generated the melody shown in Figure 6.

## 5. CONCLUSION

We tested the BCMI mixer on the same person (a member of our research team) who was trained to control our previous BCMI for generative music. After a few minutes, the colleague was able to control the mixer at his own will.

As the system is more portable and more user-friendly to operate than its predecessor was, we plan to take it out of the lab to be tested in real-world scenarios. One problem that we may encounter is that the EEG of a person with differentiated physical and mental abilities might behave differently. We need to provide straightforward means for calibrating of the system to cope with differentiated EEG signals.

**Figure 6.** *Generated melody from trajectory shown in Figure 5.*

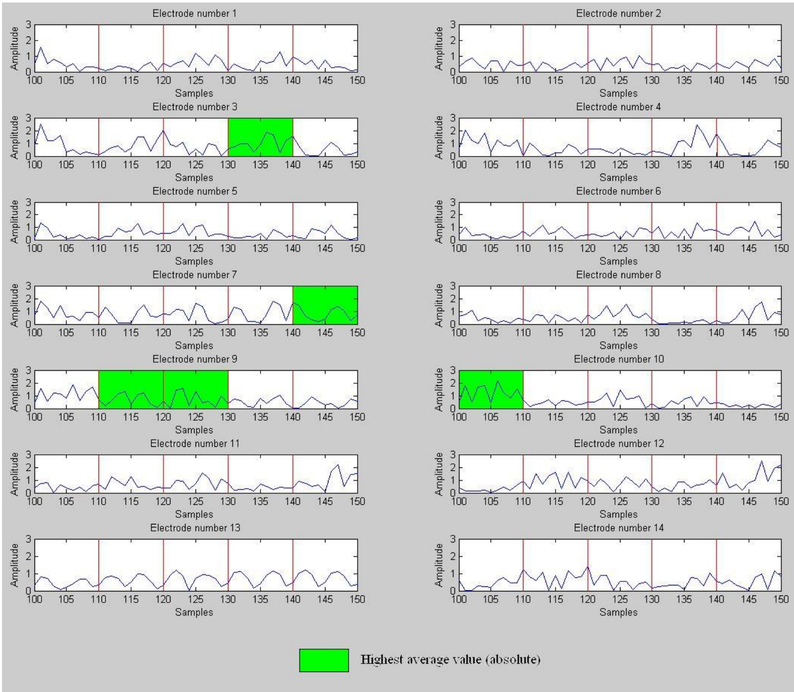


**Figure 7.** *An extract of the individual EEG analysis of 14 electrodes showing alpha rhythms.*

Although we have demonstrated that it is possible to produce inexpensive BCMI systems using off-the-shelf hardware and software, we acknowledge that there is a limit as to how far you can go with such approach to engineering and design. Because the EEG signal needs much amplification, the amplifiers and associated electronics need to be of the highest quality possible, and this comes at a price. It may not be possible to produce solutions like the one we proposed for the BCMI mixer, as we move towards more sophistication. For example, our new method for generating melody from the topological behaviour of the EEG necessarily requires a reasonably large number of EEG channels and bespoke software.

**Acknowledgements:** This work was supported by the EPSRC grant EPD063612-1. V.S. thanks the financial contribution from the University of Plymouth to attend the conference.

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