Kara: a BCI approach to composition

Rodrigo F. Cádiz
Center for Research in Audio Technologies
Music Institute
Pontificia Universidad Católica de Chile
rcadiz@uc.cl

Patricio de la Cuadra
Center for Research in Audio Technologies
Music Institute
Pontificia Universidad Católica de Chile
pcuadra@uc.cl

ABSTRACT

Kara is a greek word that could be translated as head. In the *Kara* series of pieces, the musicians wear brain-computer interfaces (BCI) in order to capture their EEG waves while performing. The information from these waves is sent to a computer, where it is processed in order to generate a real-time score, computer generated sounds and a visual display of the data. A closed-loop is formed between the musicians mental activity and the music they generate. As they perform the real-time score generated by their EEG waves, more mental activity is generated, which in turn generates the next portion of the score, and so on. This loop continues for the whole piece, although the score generation algorithms vary along different sections of the musical discourse. This article is presented for the piece+paper modality.

1. INTRODUCTION

A brain-computer interface (BCI) is a physiological computing system, specialised and designed to operate based on brain activity [1]. Human brainwaves were first measured in 1924 by Hans Berger, who termed these measured brain electrical signals the electroencephalogram (EEG), literally "brain electricity writing" [2]. Using electrodes arranged around the scalp, voltage fluctuations resulting from ionic current flows within the brains neurons can be detected and measured. The change in these voltages over time are usually displayed visually as wave patterns. Neural activity often possesses a repetitive rhythmic quality, and these rhythms are classified as alpha, beta, theta or delta [3]. Today, the EEG has become one of the most useful tools in the diagnosis of epilepsy and other neurological disorders [2].

The fact that a machine can read signals from the brain has boosted the imaginations of musicians, engineers, scientists, artists and other enthusiasts, and EEG has made its way into applications in several realms, including music [2]. Many musicians and researchers dream with a day when musical ideas could be transmitted by simply making musical thought audible, an ideal performance without any physical limitations, where the performer plays with the expressiveness imagined in his mind [4]. In 1949, Raymond Scott wrote: "Perhaps within the next hundred years, science will perfect a process of thought transference from composer to listener. The composer will sit alone on the concert stage and merely think his idealized conception of his music. Instead of recordings of actual music sound, recordings will carry the brainwaves of the composer directly to the mind of the listener" [5]. Now, nearly a century after Berger's discovery, these dreams are becoming a reality [6].

As explained in [3], there are two ways to access the activity in the human brain with an EEG. One way involves invasive methods involving inserting electrodes directly into the brain. The second method involves non-invasive methods such as the attachment of electrodes to the scalp, which is the method used for all musical purposes.

Miranda writes about the difficulties in measuring EEG signals on the scalp: "It takes many thousands of underlying neurons, activated together, to generate EEG signals that can be detected on the scalp. The amplitude of the EEG signal strongly depends on how synchronous is the activity of the underlying neurons. The EEG is a difficult signal to handle because it is filtered by the meninges (the membranes that separate the cortex from the skull), the skull, and the scalp before it reaches the electrodes. Furthermore, the signals arriving at the electrodes are sums of signals arising from many possible sources, including artifacts like the heartbeat and eye blinks" [2].

Traditionally BCI systems have been associated with medical research due to the high costs involved and the therapeutic benefits offered to individuals with motor disabilities [7]. Fortunately, non-invasive BCI approaches are becoming much more accesible and common nowadays. Low-cost BCI hardware such as the Emotiv EPOC headset [1] or NeuroSky's MindWave heaset [2] are rapidly finding their way into musical applications.

2. BRAIN-COMPUTER INTERFACES

A brain-computer interface (BCI) allows for direct brain-computer communication without using the muscular activity. To date, most efforts of BCI research have been aimed at developing technologies to help people commu-

[1] http://www.emotiv.com
[2] http://www.neurosky.com

nicate with computer systems or control mechanical tools, such as a wheelchair or a prosthetic organ [8].

As Gurkok and Nijholt notice, "BCIs are not yet capable of transforming a scene that we imagine in our head into shapes and colours; or a melody into notes. They cannot create art on our behalf. However, BCIs can make a significant contribution to the arts with the inner state information they provide" [1].

Research into BCI for music is an interesting arena for the development of new possibilities in recreational and therapeutic devices for people with physical and neurological disabilities. Miranda refer to such systems as brain-computer music interfaces (BCMI) [2].

During the 1960s and 1970s biofeedback was incorporated in artistic applications, most notably within the context of experimental music such as in the compositions of Alvin Lucier and David Rosenboom [9]. Lucier's Music for Solo Performer, from 1965, was the first brainwave musical composition. This was a piece for percussion instruments made to resonate by the performers EEG waves [10]. Up to date, several artistic [1] [11], gaming [12], and musical applications have been proposed based on BCI technology. Most of them are attempts to sonify EEG signals directly [3] [8] [13] [14], but others have developed other approaches, such as the rendering of musical chords with organic nuances [4], real-time notation [15], networked musical performances [16], and the study of the differences between music imagery an music perception [17].

One of the key elements of BCMI systems for creating and performing music is the way in which the brain affects the relationship between music the user, and an audience [7]. Performing with BCMIs usually requires a performer to have wired electrodes placed on their scalp, connected to a computer. For highly accurate brain wave measurements the performer must remain very still to avoid electrode movement, which is musically non-natural, as involuntary movements can introduce noise to the signal. This is the main reason why a dry, single-based electrode device such as NeuroSky's Mindwave appear as a attractive alternative for BCMI-based music generation.

We now briefly describe the two low-cost BCI hardware for musical purposes that were used in the *Kara* series of pieces.

2.1 NeuroSky Mindwave

The NeuroSky Mindwave has been carefully reviewed in [18]. It is basically a bluetooth headset containing only one electrode that is capable of detecting EEG signals. The device can produce ten channels of data, including power readings of seven spectral bands, the time domain signal from the single electrode and two processed signals corresponding to the user's attention and meditation levels. The meditation signal correlates to the alpha levels, while the attention is not specified, however [18] reports a correlation between the user's attention and the signal provided by this device.

2.2 Emotiv EPOC

The Emotiv EPOC is described in [3]. This device is a wireless interface for the acquisition and processing of human EEG signals. It contains 14 saline electrodes meant to be placed directly on the scalp. The EPOC has a strong community of developers and researchers who have adapted the device for a variety of different purposes. According to Emotiv's website, "the EPOC uses a set of 14 sensors plus 2 references to tune into electric signals produced by the brain to detect the users thoughts, feelings and expressions in real time. The EPOC connects wirelessly to PCs running Windows, Linux, or MAC OS X". This device generates signals that measure the user's meditation, excitement, frustration and engagement levels. It can also provide signals that detect smiles, blinks, eyebrow and furrow movements, and spatial orientation by means of an embedded gyroscope.

3. KARA

Kara is a greek word that could be translated as head. There are currently two pieces of the Kara series: *Kara I* for flute, violoncello, BCI, computer music and visuals, and *Kara II*, for solo flute, BCI, computer music and visuals. In the *Kara* series, the musicians wear brain-computer interfaces (BCI) in order to capture their EEG waves while performing. The information from these waves is sent to a computer, where it is processed in order to generate a real-time score, computer generated sounds and a visual display of the data. A closed-loop is formed between the musician's mental activity and the music they generate. As they perform the real-time score generated by their EEG waves, more mental activity is generated, which in turn generates the next portion of the score, and so on. This loop continues for the whole piece, although the score generation algorithms vary along different sections of the musical discourse.

We decided to incorporate a visual counterpart to the piece. The main reason behind the addition of a visual score is that, as [19] notices, despite the claim that the BCI-based music is controlled from the brain activity, it is very hard for the audience to imagine what the performer is going through, what the brain is actually controlling and in what extent. As a consequence, the music produced is completely abstracted from any visible cause-effect relationship, leaving no cues for the audience to understand what is being controlled or how. We incorporated a visual respresentation of the EEG data so that the audience could visually relate some aspects of the mental processes of the performers to the overall performance. The visuals were done in Processing [3] , based on Elliot Larsons Fractal Batons code, released under Creative Commons. A still of the visuals can be seen in the background of figure 5.

All audio and score processing was done in MaxMSP. In *Kara*, the score is generated in real-time using the data captured by a EEG device. This is very similar to what is described in [15], where the authors provide brainwave control over a musical score in real time. Their approach

[3] http://www.processing.org

combines measuring EEG data with mappings to allow a user to influence a score presented to a musician in a compositional and/or performance setting. In our case, in contrast, the musician itself generates the next portion of the score by its own mental activity. *Kara I* in particular, requires two NeuroSkys MindWave BCIs. *Kara II* uses only one, and it can also utilize data from the Emotiv's EPOC device as an alternative.

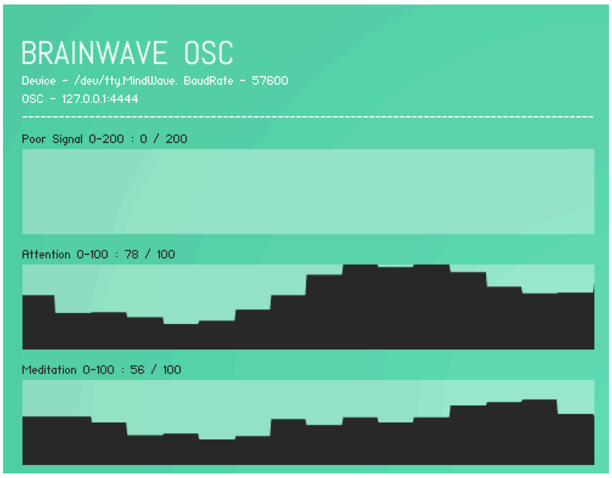

Figure 1. Screenshot of the BrainWave interface window, displaying the attention and meditation signals over a period of time. This data, along with the rest of EEG signals, is sent by this program over the network using the OSC protocol.

3.1 Kara I

We now provide a more detailed description of *Kara I*, as *Kara II* is a very similar piece that differs only in the instrumentation, but retains a lot of the characteristics of *Kara I*. It is probably worth mentioning that *Kara III*, a piece for BCI and computer music, with no instrumental performance, is currently on the early stages of composition.

In the case of *Kara I*, the EEG data captured by the headset is handled by the BrainWave OSC application [4] , built by Trent Brooks and George Khut. A screenshot of this application is displayed in figure 1. The OSC data is sent to a MaxMSP control patch built by the composer, shown in figure 2.

Kara I is structured in eight sections. As this piece uses the MindWave headsets, it takes advantage of the meditation and attention signals that this device provides. Each one of the sections emphasizes different aspects of the musical discourse based on these two signals and the a subset of the other EEG signals as well. For example, in the first two sections, the pitches and durations to be performed by the two musicians are derived exclusively from the meditation signals coming for both instruments, while in the middle sections, this material comes from the combination of one instrument's meditation signal and the other instrument's attention signal.

[4] `https://github.com/trentbrooks/BrainWaveOSC`

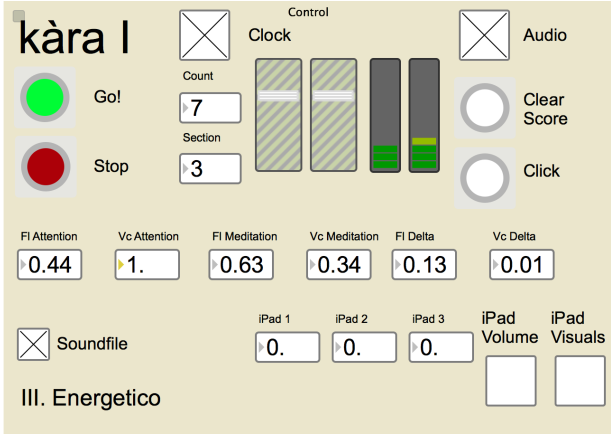

Figure 2. Main MaxMSP control patch. This patch receives the OSC data from the performer's headsets and realizes all the necessary algorithms and calculation to generate a score for the musicians to perform. This control panel allows to start and stop the piece, monitor the EEG data values, audio levels, and score progression, and allows remote control of the application from an iPad tablet.

The evolution of the dynamics, shown in colors in the score, is calculated from a linear combination of the Delta and Low Gamma signals of both performers. There are two modes of operation for the durations of each section. The first mode fixes the duration of each section in approximately one minute, while the other allows for a real-time determination by the computer operator on stage.

The on-the-fly score is shown to the performers using a computer monitor on stage, as depicted in figure 3. As is it possible to observe on that figure, there are two staves for each performer containing the music that they must perform now and the music they should perform next. There are also general indications for the sections, shown in red, and more specific performance indications above each staff, shown in black. A gliding cursor indicates the current time and the note that each performer should be playing at the moment. The duration notation is proportional. Dynamics are shown in colors in real-time, from white to red. As the background gets more red, the performance should be louder.

There is also a computer music soundfile that accompanies the live performance. The intensity of this audio signal is also controlled by the musician's meditation and attention signals.

Figure 4 shows a picture of the premire of this piece at the Contemporary Music Festival of the Pontificia Universidad Católica de Chile on November 2013, in Santiago, Chile. Each performer wears a MindWave headset, connected wireless to the computer out of stage, monitored by the composer. Behind the performers there is a screen showing the visual score of the piece that the audience sees. The score is displayed in the computer monitor in front of the musicians, and it is not seen by the audience. A video of this performance can be seen on YouTube at the URL `https://www.youtube.com/watch?v=qjumX8J0jQE`.

Figure 3. Screenshot of *Kara I*'s real-time score as seen by the musicians on stage. The score is generated on the fly by the MaxMSP application. The score uses separate staves for the flute and violoncello. Intensity of the sound production (dynamics) is shown in red. Durations are proportional. A gliding cursor indicates the actual note to be performed. The section descriptor is shown at the top of the window and specific articulation instructions are shown above each staff.

3.2 Kara II

In the case of *Kara II*, the EEG can be provided by either NeuroSky's Mindwave or the Emotiv's EPOC headsets. In the latter case, data captured by the headset is handled by the MindYourOSCs application [5] and sent to MaxMSP over the network, and the meditation, excitement, frustration and engagement signals are used to generate the real-time score.

Figure 5 shows a picture of the premire of *Kara II* in May 2014 by Patricio de la Cuadra at the XIII Concierto GEMA, Sala Isidora Zegers, University of Chile, in Santiago, Chile. A video of the performance is available on YouTube at the URL `https://www.youtube.com/watch?v=pMwznnYi2Ig`.

4. CONCLUSIONS

We have presented *Kara*, a set of pieces that rely on BCI technology in order to generate musical in real-time. The EEG data is used to derive a musical score on-the-fly. A closed-loop is then formed between the musicians mental activity and the music they generate as they perform. As they play the real-time score generated by their EEG waves, more mental activity is generated, which in turn generates the next portion of the score. One of the most interesting aspects of these pieces is this kind of strange loop that lasts for the whole piece, although the score generation algorithms vary along different sections of the musical discourse. Another important conclusion is that current low-cost technology allows for the creation of very powerful and interesting musical applications based on the capture of EEG signals and the usage of BCI devices.

[5] `http://sourceforge.net/projects/mindyouroscs/`

Figure 4. Musicians Patricio de la Cuadra (flute) and María Gabriela Olivares (violoncello) performing *Kara I* wearing NeuroSky's MindWave headsets. The score is displayed in real-time in the computer monitor at the front.

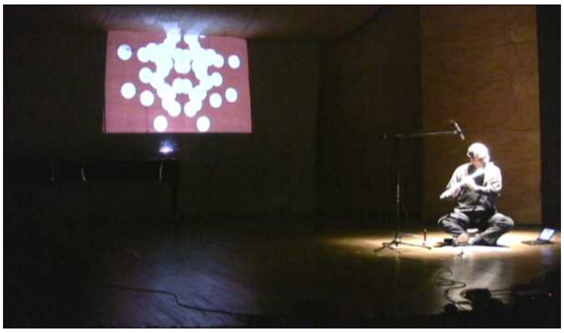

Figure 5. Patricio de la Cuadra (flute) performing *Kara II* wearing an Emotiv's EPOC headset. Behind the performer there is a screen showing the visual score of the piece that the audience sees.

Acknowledgments

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