Sonification of Brain Activity Using EEG for an Audio-Reactive Installation

To what extent can an audio-reactive system driven by EEG signals create a meaningful representation of a user's emotional states, and how does this impact the user's subjective experience of emotion?

Project Overview

This project explores the intersection of brain-computer interfaces (BCI) and generative music, aiming to create an audio-reactive system that converts neural activity detected from an EEG headset into a dynamic musical interface. The goal is to develop an interactive musical installation where a participant's real-time brain activity directly influences a musical composition. Drawing from research on electroencephalography (EEG) and brainwave analysis, this project investigates how sound and music modulate brain activity and emotional states, offering both artistic and scientific insights into neurofeedback-driven music generation.

Studies on musical emotions reveal that music engages neural circuits associated with pleasure, motivation, and emotional processing, particularly within the limbic system. Pleasant and unpleasant sounds engage with different areas of the human cortex, generating responses influenced by personal characteristics. Whether some music or a sound is enjoyable also depends on the audience's culture, age and musical experience[1]. Familiarity with a piece of music also plays a key role in influencing emotional responses, as familiar music activates reward-related brain regions more intensely than unfamiliar music. Additionally, EEG research supports the asymmetry hypothesis, suggesting that positive emotions are predominantly processed in the left frontal cortex, while negative emotions are more lateralized to the right hemisphere.[2]

Understanding these neural mechanisms is critical to designing an EEG-driven generative music system that can accurately reflect the emotional states of its users. These profound findings emphasize the core question of this research proposal.
The primary hypothesis guiding this project is that specific patterns of neural activity, which correlate with distinct emotional and cognitive states, can be meaningfully expressed through generative soundscapes. By mapping real-time EEG data to a generative music engine, the system will allow users to experience music as a reflection of their own mental state, opening up possibilities for applications in music therapy, cognitive enhancement, immersive art installations, and neuroscientific

[1] (Gaser, "Brain structures differ between musicians and non-musicians", 1)
[2] (Almudena, "Electroencephalography," ch. 2)

research. EEG has become an essential tool for studying the neural basis of musical affect, and another interesting case of study arises from these reflections. What is the role of sound and music in modulating brain activity and emotional states of a user? This work seeks to deepen our understanding of how music influences cognition and emotion, while also pioneering new forms of interactive, brain-driven musical experiences.

Background history and research

Electrical signals generated in the human body were first identified in 1840 by Emil Heinrich du Bois-Reymond from human muscles.[3] For nearly two centuries, the electrical nature of life has been well established. Research in the field has continued ever since, leading to significant advancements in the detection and usage of these biosignals. One of the most intriguing developments in recent decades has been the emergence of technological interfaces designed to interact with such signals. A biosignal interface bridges biology and technology, harnessing electrical activity from the brain, muscles, and nerves to control and communicate with external systems. These signals are measured using electrodes, amplifiers, and computational methods to extract meaningful patterns. By capturing and analysing biosignals, modern systems enable applications ranging from medical diagnostics to creative fields like music, where they translate physiological states into dynamic outputs.[4]

Electroencephalography (EEG) is a method for measuring brain activity by detecting the electrical signals generated by cortical neurons. These signals, originating from millions of neurons firing, create minute voltage fluctuations on the scalp that can be captured by electrodes placed in specific configurations. Typically, EEG electrodes are arranged in the internationally standardised 10-20 system, strategically positioned to record electrical activity from various brain regions. The collected signals are then amplified, filtered and processed using techniques like Fourier transforms or machine learning algorithms to extract meaningful features while

[3] (Miranda, “New digital musical instruments”, 173)
[4] (Miranda, “New digital musical instruments”, 173)

removing noise.[5] The measured data is often associated with different mental states. The frequency variations of these electric fields are usually categorised into five specific bands that reflect such states:

Alpha waves (8-13 Hz) – Relaxation and meditation.
Beta waves (13-30 Hz) – Active thinking and concentration.
Gamma waves (>30 Hz) – Stress or high cognitive load.
Theta waves (4-8 Hz) – Drowsiness and creativity.
Delta waves (0.5-4 Hz) – Deep sleep and unconscious processing.[6]

As a non-invasive and portable method, EEG has been extensively used in clinical and experimental settings. It has applications in neurology, cognitive research, and even brain-computer interfaces (BCIs).

Brain-computer Interfaces (BCIs) have a history that dates back to the mid-20th century and is deeply rooted in neuroscience and human-machine interaction. Initially developed for medical and assistive purposes, BCIs emerged from early electroencephalography (EEG) research in the 1920s and became a focal point of innovation in the 1970s, when researchers began to explore how brain signals could be used to control external devices. Over time, computing power and signal processing advancements led to more sophisticated BCIs, expanding their applications beyond clinical settings into creative domains, including music and sound design.

The exploration of brain-controlled music dates back to the late 20th century, when scientists and artists began experimenting with how EEG signals could influence sound generation. One of the pioneering projects in this space was *Brainwave Music* by composer and researcher David Rosenboom in the 1970s. Rosenboom's work demonstrated how EEG data could be mapped to musical parameters, allowing performers to shape sound using their brain activity. Another early effort was Alvin Lucier's *Music for Solo Performer* (1965). EEG signals were used to translate alpha waves from the performer's brain into vibrations that activated percussion

[5] (Miranda, "New digital musical instruments", 173)
[6] (Miranda, "New digital musical instruments", 184)

instruments, creating an experimental musical experience.[7] Richard Teitelbaum also expanded on these ideas in works like *Organ Music* (1968) and *In Tune* (1968), incorporating not only EEG but also heartbeat and breath sounds to influence electronic soundscapes. His approach emphasised the body's physiological rhythms as direct compositional elements, contributing to the broader field of live electronic and interactive music performance.[8]

As technology progressed into the 21st century, new projects that refined and expanded the use of BCIs in music emerged. In 2009, *Brain Computer Interface and Music* (BCMI), led by Eduardo Miranda at Plymouth University, developed systems that allowed users to generate music in real time using brain activity. The BCMI project pioneered applications for disabled musicians, offering individuals with severe motor impairments the ability to compose and perform music using thought alone.[9] Similarly, *Encephalophone*, developed at the University of Washington in 2017, enabled users to control musical instruments through brain signals, creating new avenues for musical expression, again, particularly for those with limited physical movement.[10]

Recent BCI music applications have also found their way into live performances and experimental sound design. For example, *Brain-Body Digital Musical Instrument* (BBDMI) is a currently developing research project by Atau Tanaka et al. I, aimed at creating a digital musical instrument that integrates physiological signals from the brain (EEG) and muscles (EMG) for musical performance and interaction. Open-source platforms such as EAVI Exg allow the acquisition and processing of EMG and EEG signals in real-time, which performers can use to control sound and music.[11][12]

Today, BCIs continue to push the boundaries of musical creativity, offering artists and researchers innovative ways to integrate biofeedback with sound, composition, and performance. These developments provide new forms of artistic expression, exploring embodied interaction and new forms of digital performance. As technology

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[7] (Straebel, “Alvin Lucier's music for solo performer”, 17-29)
[8] (Rosenboom, “The performing brain”, 48-66)
[9] (Eaton, “BCMI systems for musical performance”, 15-18)
[10] (Deue, “The Encephalophone,” 11)
[11] (Tanaka, “Brain-Body Digital Musical Instrument,” 1)
[12] (Tanaka, “The EAVI ExG Muscle/Brain Hybrid Physiological Sensing” 1)

advances, the future of music may increasingly be shaped by the direct connection between the mind and sound; the evolution of biosignal music challenges traditional boundaries between performer, instrument, and audience, paving the way for novel forms of musical interaction.

Context, audience goals and proof of concept

This project exists at the intersection of neuroscience, generative music, and interactive installations. Designed primarily for artistic applications, it also appeals to audiences interested in biofeedback, neurotechnology, and immersive sensory experiences. The main goal is to enable participants to explore their mental states through sound, allowing their emotions to shape an evolving musical environment simply by wearing an EEG headset. This connection creates a deeply personal and introspective experience, particularly intriguing in terms of feedback loops—where not only is the participant's brain activity represented, but the generated output also influences their state of mind, thereby modulating the sonic output in real-time.

To develop an effective prototype of the installation, the first challenge is to establish a system that measures brain activity and translates it into sound. Neural electrical fields are extremely faint (on the order of microvolts) and require amplification for processing. EEG signals are complex as they pass through biological structures like membranes and the skull and are often mixed with noise from other sources, such as heartbeats and eye movements. Advanced signal processing is crucial to extract meaningful data from the raw voltage differences detected by the electrodes.[13]

Two primary approaches were considered for EEG measurement. The first option is to build a DIY headset, which offers advantages in terms of customization, affordability, and direct access to raw data, allowing for tailored signal processing and integration into specific projects. A custom amplifier setup can capture raw microvolt-level signals (-100 μV to +100 μV)[14], enabling frequency analysis, custom filtering, and diverse mappings to the sound engine. Open-source communities like OpenBCI and OpenEEG provide free resources to develop relatively simple EEG

[13] (Miranda, "New digital musical instruments", 184)
[14] (Sourceforge, "The OpenEEG project,")

devices[15]. However, DIY systems require extensive physical computing expertise and have significant safety concerns. Experimenting with electronic devices connected directly to the head must be cautiously approached, as any malfunction could have serious consequences. This installation will be open to the public, so these safety risks make the DIY approach less viable.

The second approach is to customize an existing commercial EEG headset. Many user-friendly EEG devices, such as those from Emotiv or Muse, offer reliable, pre-calibrated data with built-in signal processing. While they are easier to use, they provide less flexibility for in-depth analysis. These devices apply internal filtering, artefact removal, and signal enhancement before transmitting data, limiting access to fully raw EEG waveforms. Instead, they typically output band power values (Alpha, Beta, Theta, Gamma) as normalized figures rather than direct microvolt readings. Customising such devices requires reverse engineering to extract and integrate the necessary data. Using OSC protocols and Python, along with commercial headsets' Bluetooth capabilities, preliminary communication between the EEG device and a laptop should be relatively straightforward. Although commercial headsets provide a limited range of data readings, this can be compensated for through creative mappings and further signal processing.

Integrating Max/MSP with the Muse EEG headset will be central to developing a functional system that generates dynamic musical compositions in response to real-time neural activity. The muse-lsl Python library can stream brainwave activity from the headset to a laptop[16], where the data is redirected into Max/MSP to control pitch, harmony, dynamics, and spatial effects in a generative music system. For example, higher Alpha wave activity, associated with relaxation, could result in slower tempos, ambient textures, and gentle harmonics, while increased Beta or Gamma activity, linked to cognitive engagement or stress, could introduce rhythmic patterns, complex harmonies, or modulated effects. This phase will focus on creative exploration to develop an audio engine that generates diverse outputs based on different brain activity patterns.

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[15] (Sourceforge, “The OpenEEG project,”)
[16] (Barachant, “alexandrebarachant/muse-lsl,”)

Once a functional music-responsive system is established, the final development phase will refine the prototype and interaction model. Ideally, the installation will be entirely screen-free, relying solely on audio and environmental design. The Max/MSP patch could be translated to C++ and uploaded to a Raspberry Pi or Bela interface, removing the need for a laptop. At this stage, the communication system between the headset and the audio engine will also need to be adapted to the new interface.

After the system is fully operational, its effectiveness and impact will be analysed. This phase will involve testing the device in various conditions (e.g., while reading, moving, or relaxing) and gathering feedback from users of different age groups, musical backgrounds, and cultures. Collecting extensive feedback and analysing the results will be essential in refining the experience.
Dynamic lighting and some minimal furniture around the loudspeakers may further enhance the environment in which participants wear the headset. A brief set of instructions will also be provided to help guide participants through their experience, encouraging deep thought and focus. The ultimate goal is to create a sensory-driven journey into emotive soundscapes.

Development timeline

Use of generative AI tools

I acknowledge the use of ChatGPT (https://chat.openai.com/) to refine the academic language and accuracy of my own work. On 29th January 2025, I submitted my entire essay with the instructions to “Correct this text to make it clearer and more readable. Try to keep the style and word choice as close as possible to the original”. The output (Final Project Proposal) was then modified further to better represent my own tone and style of writing.

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