MindMusic: Brain-Controlled Musical Improvisation

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Abstract

In this paper, we explore a new form of creative expression through brain controlled musical improvisation. Using EEG technology and a musical improviser system, Impro-Visor (Keller 2018), MindMusic engages users in musical improvisation sessions controlled with their brainwaves. Brain-controlled musical improvisation offers a unique blend of mindfulness meditation, EEG biofeedback, and real-time music generation, and stands to assist with stress reduction and widen access to musical creativity.

Background and Motivation

Musical self-expression and meditation offer two complementary approaches to improving mental health and well-being. Musical improvisation has been shown to activate the sensorimotor and language areas of the brain that otherwise remain dormant during the performance of predetermined melodies (Lopez-Gonzlez and Limb 2012). Furthermore, brain regions that manage executive functions such as planning, abstract reasoning, and working memory were found to be deactivated, which also occurs during meditation and dreaming.

In this work, we explore a new terrain of musical creative expression by cutting out all intermediaries and controlling musical improvisation directly through brain signals. This form of expression requires no training or musical expertise, is more widely accessible than traditional musical instruments, and stands to offer a variety of mental health benefits. In particular, we utilize the lightweight EEG headband, Muse[1], to access the user's EEG data, which is subsequently used to drive musical improvisation, incorporated within the musical improvisation system, Impro-Visor.[2]

Real-time feedback allows the user to gauge their mental state through changes in the music, which informs the user of their mental state in regular intervals. *Biofeedback* uses instruments to provide information on one's physiological function to allow greater awareness of that function. It has been shown to be an effective way to control one's mental state (deCharms et al. 2005). By becoming aware of one's mental state in an explicit, yet pleasantly communicated manner, the user is placed in a better position to transition to a healthier state of mind.

Direct EEG feedback is complemented through an alternate improvisation driver by allowing the user's head tilts to affect the music. The Muse device can detect head position, identifying whether the user tilts their head left or right, or keeps it centered. Head position subsequently controls the durations of notes played in the improvisation. This more easily controlled form of feedback can provide musical expression to those who cannot play musical instruments due to paralysis or other disorders.

Figure 1: Andy Vainauskas (left) and Rachel Goldstein (right) showcasing MindMusic for the Santa Clara University newspaper. Shown here wearing the Muse EEG headbands.

This paper shares early stage attempts at mind-controlled musical improvisation, whereby durations of notes in computer improvised music are effected through alpha waves and, more intentionally, head tilts. Future work will ex-

[1]https://choosemuse.com

[2]https://www.cs.hmc.edu/ keller/jazz/improvisor/

plore additional layers of interaction, as well as study the impact of this novel form of brain-computer interface (BCI) on mental health and the potential to improve access to musical self-expression for paralyzed individuals.

Previous Work

Combining EEG signals with music generation offers a variety of benefits. Alvin Lucier was one of the first to transform brainwaves into sound by amplifying his EEG signals to generate music, which offered a way for creative expression to be conducted by one's brain activity (Lutters and Koehler 2016). Loudspeakers were placed near percussive instruments to resonate when frequencies outside the human range of hearing were generated.

(Eaton, Williams, and Miranda 2015) identified that brain waves provide means of passive control in a BCMI, to allow for mental states to be approximated and mapped to relative musical phrases (Eaton, Williams, and Miranda 2015). In regards to therapeutic applications, (Keune Ne Muenssinger et al. 2010) expanded upon Brain-Computer Interfaces (BCIs) to enable creative expression for patients with ALS. Their P300-Brain Painting BCI produced meaningful experiences for both healthy and paralyzed individuals.

Effects of Mindfulness Meditation and Music on the Brain

Mindfulness meditation has been shown to reduce stress and improve mental states. When compared to relaxation meditation, mindfulness meditation can better improve focus and quiet distracting thoughts (Jain et al. 2007). Mindfulness meditation has also been shown to reduce anxiety in both a broad range of clinical patients and patients suffering from generalized social anxiety disorder (Koszycki et al. 2007). Additionally, research suggests that mindfulness-based cognitive therapy significantly reduces relapse and recurrence in patients suffering from major depression (Teasdale et al. 2000).

Music is fundamentally relaxing, especially when the listener finds the music pleasurable to listen to (Stratton and Zalanowski 1984). One study, which investigated the effects that drumming had on six soldiers combating PTSD, found a reduction in some of their symptoms after playing the instrument (Bensimon, Amir, and Wolf 2008). Another study found that not only does listening to music reduce the perception of pain, but when combined with traditional pain-management techniques, music therapy can enhance the effectiveness of pain-management for patients recovering from surgery (Bernatzky et al. 2011).

Improvisation in music has an interesting effect on the brain. A study looking at improvisation in professional jazz pianists that utilized functional MRI scans found that, when compared to well-rehearsed music, improvisation correlated to disassociated activity in the prefrontal cortex. This suggests that when engaging in improvisation, musicians are using fewer brain processes involved with self-monitoring, planning, and problem-solving and are instead using more areas of the brain associated with meditation and daydreaming (Limb and Braun 2008).

System Overview

MindMusic enables brain-driven musical improvisation. EEG signals are detected through the Muse device and a user's brain activity is then used to drive the real-time music generation. We built MindMusic within Impro-Visor (Keller 2018), a musical improvisation system by Robert M. Keller (see Figure 2).

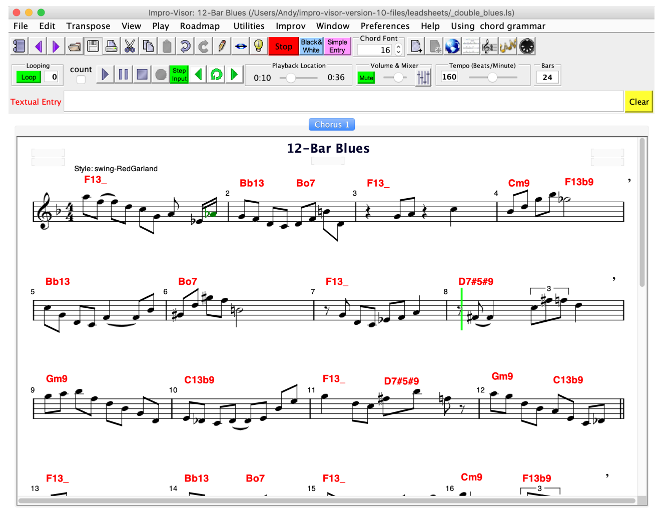

Figure 2: The Impro-Visor software displaying a lead sheet of a blues melody line.

The music created by MindMusic reflects your current brain activity, producing a musical expression based on your state of mind. By controlling the music with one's mental state, the user stands to benefit from both biofeedback and playing a musical instrument.

MindMusic comes in two modes: one for intentional musical influence and another for mindful feedback of one's brain activity (EEG). The first is a mode that enables notes to be intentionally made longer or shorter depending on which direction the user's head is tilted, allowing for the user to purposefully make adjustments as they desire.

In the head tilt mode, shorter notes are played when the user tilts their head to the left, longer notes for when the user tilts to the right, and when their head is in the middle, a mix of the two lengths are generated.

In the EEG mode, note durations reflect the current level of relaxation as measured by alpha waves, where longer durations correspond to deeper levels of relaxation.

These two modes were initially created to be used separately, however, future expansion could allow for them to be combined, with certain aspects of the music controlled with head tilts while others are reflective of brain data.

Architecture

The MindMusic architecture is shown in Figure 3. The Muse uses Bluetooth to connect to a device running the Impro-Visor software. Once Impro-Visor is initialized, an OSC server begins to listen for the data being sent from the Muse. During an improvisation session, Impro-Visor processes the

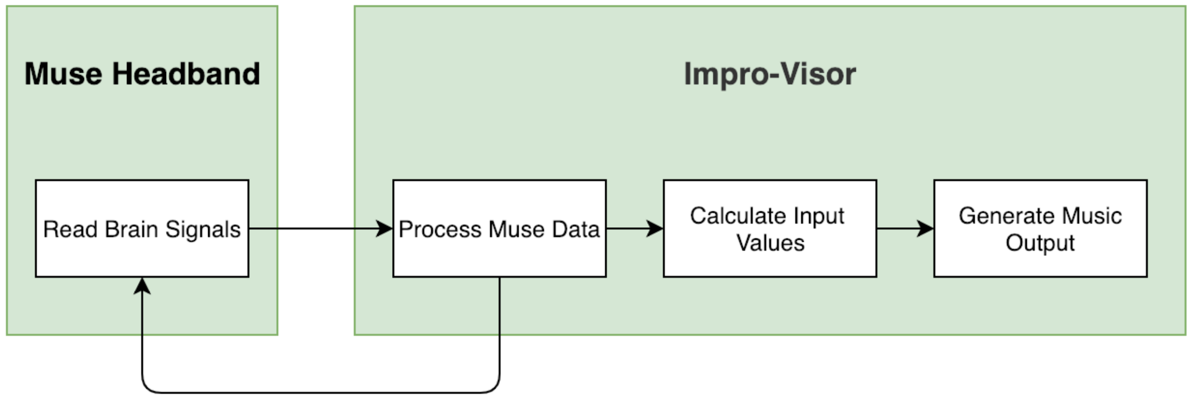

Figure 3: The MindMusic architectural diagram, which describes each individual system component.

Muse data, categorizes the current brain activity level, and generates music that is reflective of the user's current mental state.

Muse EEG Device and Data Communication

The Muse is a headband with seven EEG sensors, two on the forehead, two behind the ears, and three reference sensors.[3] It samples brainwave data at a rate of 10 Hz, and can connect to a device over Bluetooth. The Muse device offers a lightweight, affordable EEG solution for the broad consumer market.

Alpha Brainwaves

EEG brainwaves can be split into five frequency-based categories – delta, theta, alpha, beta, and gamma. At each moment, our brains have activity in each of these frequency ranges. We focus on the most prominent relaxation-related band, alpha brainwaves. There is more activity in the alpha frequency range when a person is alert but not actively concentrating or processing information. Alpha brainwaves are linked to feelings of calmness, relaxation, and tranquility while being conscious and non-drowsy.[4] For instance, these waves tend to be more active during meditation than during normal activity. Looking at the power spectral density function (PSD), higher readings within the alpha range indicate that a user is in an "alpha state." [5]

Brain Data Activity Categorization

To find the user's neutral state, MindMusic begins with a 22 second calibration stage. This phase allows MindMusic to assess what constitutes a relaxed or anxious state for different users. During this period, samples are taken of the user's alpha brainwaves. From that sampling, the user's average alpha, μ, and standard deviation, σ, are saved.

Following the calibration stage, we calculate the average of the user's alpha band using their most recent three seconds of alpha brainwave data. From there, the z-score of this new sampled alpha is calculated, using the following equation,

$$z = \frac{x - \mu}{\sigma}$$

where x is the average of the most recent read values, and μ and σ are the values saved from the user's calibration stage.

Using this z-score, these new alpha values can then be mapped to different activity states. We chose to have five different activity states: very low, low, medium, high, and very high. A z-score close to the user's average will be closer to 0 and categorized as a medium activity level, very high and low z scores are categorized as very low and very high activity levels, and those in-between are categorized as low and high. A higher alpha value read reflects that the brain has more brainwaves that fall into the alpha frequency range, and so the user can be seen as more calm and less active.

Musical Representation

Impro-Visor uses a collection of probabilistic context-free grammars to establish a set of rules that are used for music generation (Keller 2018). Two additional grammars were created to support MindMusic's functionality: head tilt and brainwave. These two grammars allow the user to engage in both intentional and reflective modes of musical creation, respectively.

For the head tilt grammar, if the user's head is tilted to the left, the grammar will execute a rule that returns notes that have longer durations, such as quarter notes. If their head is tilted to the right, notes with a shorter duration are generated, such as eighth notes. When the head is held upright, a mixture of short and long notes are generated.

The brainwave grammar uses alpha waves read by the Muse that have already been categorized into an activity level. If the level is "low" or "very low", then notes of a longer duration are generated (half or whole notes). If the level is "medium", this means that their current activity level is similar to what was measured during the calibration stage, so quarter notes are generated. If their activity level is "high" or "very high", then faster notes, such as eighth and sixteenth notes, are generated.

[3] https://choosemuse.com/how-it-works/

[4] https://nhahealth.com/brainwaves-the-language/

[5] https://musemonitor.com

To improve brain activity categorization, we tested MindMusic with several users to get their feedback on the accuracy of the musical representation of brain activity. Minor adjustments were made to the range calculations after discovering that achieving a "very low" or "very high" state occurred too often. Future work will include detailed user studies.

Conclusions and Future Work

We have initiated the exploration of mind-driven improvisation by effecting the note duration of a musical improvisation based on either head tilts or brain activity. There is significant potential to expand. Aspects such as pitches, volume, tempo, dynamics, note register, and note quality could also be influenced by brain data, and more advanced systems could reflect higher order concepts such as the musical tone and mood. By incorporating other waves (beta, theta, delta, gamma), a more complete picture of one's mental state could be captured and better reflected in the music.

Mindfulness meditation has been shown to reduce symptoms of major depression and anxiety, and music has been shown to alleviate pain. Through the integration of mindfulness and music, MindMusic has the potential to lead to more effective treatment options for those suffering from similar conditions. MindMusic gives healthy individuals an audible way to connect with their current mental state, and this approach may help people with disabilities engage in musical expression when they cannot engage in this creative activity through traditional instruments.

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