Musical Mandala Mindfulness: A Generative Biofeedback Experience

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Abstract

Music and art therapy have long been used to treat anxiety disorders, yet their efficacy is limited by a lack of intratreatment monitoring. The integration of EEG monitoring with generative music and art opens the possibility to a new form of more effective and accessible therapies. In this paper, we introduce Myndala, an EEG-driven immersive auditory and VR experience that assists subjects in reaching a relaxed mental state. Myndala was exhibited to broad audiences as part of Night of Ideas "Facing Our Times: The City of The Future" at the San Francisco Public Library. In addition to discussing Myndala and the exhibition, we propose directions for future work that arise from the integration of EEG with generative music and art.

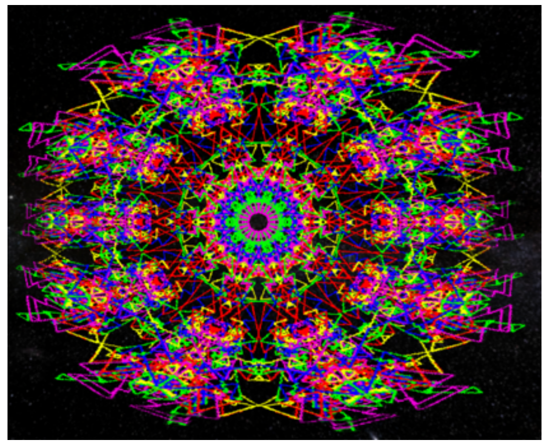

Figure 1: A screenshot of the visual component of Myndala. See `https://youtu.be/jpB-IuRb4HM` for a 2D version of the full experience.

Introduction

Music and art therapy have been shown to effectively treat anxiety (Gutirrez and Camarena 2015) and post-traumatic stress disorder (Bensimon, Amir, and Wolf 2008), provide pain management (Bernatzky et al. 2011), and have the potential to improve the quality of life for neurotypical individuals. While music and art therapy are evidence-driven, quantitative measures tend to deal with efficacy of the treatment by comparing measures before and after treatment but less so through the use of intratreatment monitoring. This limits the degree to which the efficacy of these therapeutic methods can be proven (Kelly et al. 2015), limiting their acceptance in mainstream medicine.

Intratreatment monitoring has the potential to offer deeper understanding into the impact of music and art therapy, which can bolster consideration and acceptance of these approaches. Perhaps the most effective means of intratreatment monitoring involves direct feedback from the subject's brain signals. Cost and complexity previously precluded the widespread application of EEG devices to art and music therapy. Recently, a number lightweight, affordable EEG devices entered the market, including Interaxon[1] with their Muse EEG headband. These units provide not only raw EEG data, but also preprocessed data, such as absolute band powers. Using these headbands, it is possible to receive the EEG (and other preprocessed signals), record and/or analyze the signals.

This opens up the possibility of creating audio and visualizations that convey meaningful information about the user's brain state, allowing subjects to gain real-time, accurate insight into the efficacy of a therapeutic process. Furthermore, music and art can also be customized in real-time to help guide the user to a desired mental state.

Using computational methods to integrate art and music therapy with EEG, the user can reap the therapeutic benefits without the monetary costs required for traditional neurofeedback therapies, which can require a minimum of 20 sessions over as many weeks (Vernon, Frick, and Gruzelier 2004). Additionally, an integrated approach can potentially increase users' involvement in their own therapy, which can lend a sense of empowerment and control over their treatment. The availability and affordability of intratreatment monitoring via EEG, combined with computational and creative approaches for meaningfully representing data, open the door to new, accessible, data-driven art and music therapies.

[1] https://choosemuse.com/

Meditation has been shown to help support some traditional forms of therapy for anxiety, such as cognitive behavior therapy (CBT), by addressing residual symptoms (Evans et al. 2008). In some instances, meditation can reduce anxiety levels (Zeidan et al. 2013), and is comparable to CBT in improving mood, functionality, and quality of life (Koszycki et al. 2007).

Inspired by meditative practices, the objective of our system, Myndala, is to create an immersive, EEG-controlled generative experience that is designed to help subjects reach a state of calm, focused attention. Myndala generates a mandala (see Figure 1) and meditative soundscape in virtual reality, which simultaneously reflects the user's state of mind and helps them reach a relaxed state. A video of the Myndala experience can be found at `https://youtu.be/jpB-IuRb4HM`.

Both the soundscape and visuals are directly impacted by the EEG readings in real-time. The auditory component provides feedback through volume modulations of certain components, such as the "om" sound that repeats in regular intervals. Similarly, the mandala's transparency increases as the user relaxes. The user's goal in this generative meditative experience is to quieten the "om" sounds and fade out the mandala.

Excessive feedback, however, has the potential to cause biofeedback anxiety, which is when the user's anticipation of the feedback signal causes anxiety. Mindfulness practice is most effective when the subject does not strive to relax or control their thoughts, but rather observe what is happening moment by moment without judgement (Baer 2003). In our context, striving may occur when the user tries too hard to control the biofeedback, which can result in frustration and a loss of control over the feedback.

The integration of feedforward techniques can alleviate some of the shortcomings of feedback. Using feedforwards, the system guides the user towards the desired target state, in our case, through the creation of an immersive environment that promotes relaxation.

Figure 2 describes the canonical neurofeedback loop in which the user is connected to an EEG device. The absolute alpha wave powers are extracted from the analysis and transformed into the control signals for the mandala and soundscape. The system then applies the control signal, modulating the control parameters and thus changing the audio and visual components that the user experiences. Finally, the user reacts to the change in the audio and visual components and the feedback loop continues.

Myndala aims to fulfill the need for both aesthetics and self-regulation through a cohesive, immersive experience. It aesthetically represents to the user the user's own internal state in a way that facilitates and enhances the user's understanding and ability to control it.

Following a summary of related previous work, the remainder of the paper describes the Myndala system, its exhibition at the Night of Ideas in the San Francisco Public Library, concluding with a discussion of future work.

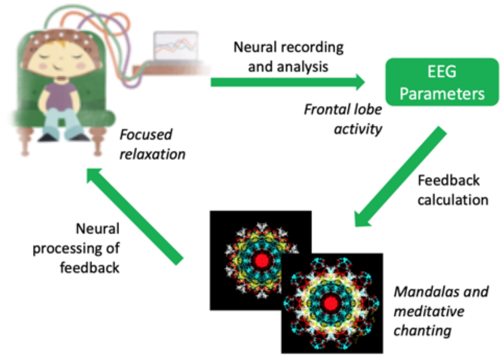

Figure 2: The neurofeedback musical mandala experience flow diagram.

Previous work

The application of EEG to music and art generation spans a range of applications, from purely artistic, often aesthetically or conceptually pleasing, to therapeutic goals.

One of the earliest examples on the artistic end of the spectrum is the work of Alvin Lucier, who amplified his EEG signals to create an experimental composition (Lutters and Koehler 2016). Another interesting artistic use of EEG signals includes the work of (Mealla et al. 2011), who use brain signals to filter white-noise as the base oscillator for a synthesizer (which can viewed as a brain signal-sonification method).

Therapeutic applications at the intersection of EEG and art include work that aims to allow disabled individuals to engage in creative tasks that are otherwise inaccessible. For instance, (Miranda, Durrant, and Anders 2008) created a EEG-based music-generator, with the goal of enabling brain-based composition for those who cannot otherwise engage in this creative endeavor.

(Muenssinger et al. 2010) gave back creative capabilities to ALS and paralytic patients. They showed that using EEG signals can allow paralyzed and healthy individuals alike to have a meaningful painting experience using devices such as the P300-Brain Painting Application.

(Ramirez et al. 2015) created a music-based system to alleviate depression in elderly people. Participants listened to music, preselected according to their preferences, and were encouraged to increase the loudness and tempo of the music to aim for a desired state. Models were created based on EEG readings and user-made music manipulations.

Other work in the therapeutic space includes the work of (Tokunaga and Lyons 2013), who aimed to provide feedback as to whether a meditative state was attained, via simple visual stimuli. Audio was used to try to elicit desired mental states, but without feedback.

Concurrently with our research, (Ehrlich et al. 2019) created an EEG-controlled music generator that guides users towards a desired mental state through feedforward methodology. Their approach differs from ours in several ways, including EEG signal analysis and the manner in which the music is created. Our focus here is to create an immersive audiovisual meditative experience, that incorporates binaural beats, and relies on a combination of easily-identifiable feedback and feedback mechanisms.

System Overview

Myndala can be divided into three primary components: the data/IO, the VR, and audio subsystems. The data/IO subsystem receives EEG data, transforms it, and outputs it to the VR and audio subsystems, whose parameters are then updated according to the transformed data.

Data/IO

The data/IO subsystem is responsible for obtaining the EEG data stream from the Muse EEG headband, obtaining a baseline reading, and transforming the EEG data into a suitable signal for the VR and music subsystems.

The Muse headband is a wireless 4-electrode EEG measuring at AF7 AF8, TP9, and TP10 locations with Fpz used as a reference.

Muse Direct is a utility included in the software suite provided by Interaxon which interacts with the Muse headband and sends data using the Open Sound Control protocol.

We utilized Open Sound Control (OSC), a protocol optimized for modern networking technology enabling communication among computers, sound synthesizers, as well as other multimedia devices. It allows multiple types of data to be sent to the same port with each type of data being associated with an address which uses a directory path-style naming convention. While the ChucK[2] language automatically provides OSC functionality, third party packages for Unity (extOSC) and Python (python-osc) were used.

Unity[3] is a cross-platform game engine equipped with a high performance graphical interface, an integrated physics engine, an object oriented designing scheme, and an asset store. Unity allows developers to create two and three-Dimensional simulations, various texture compression options, and resolution settings whilst also providing support for bump mapping, reflection mapping, parallax mapping, dynamic lighting and shadow maps, render-to-texture and post-processing effects.

Using Muse and OSC, along with Unity and Chuck, we made a custom built shader object featuring a transparent texture, rendering custom vertices with backwards light projection in guided segments. The parameters guiding the light segments respond to the users brain signals in real-time using the Muse headset, traveling via the extOSC system.

Data workflow

After establishing a connection between the headband and computer via Bluetooth, we configure Muse Direct to retrieve data from the Muse headband and output absolute alpha power data for each electrode over OSC at an emission rate of 10 samples per second.

Preprocessing Unity receives the OSC message and recovers the data from it, isolating data from only the AF7 and AF8 electrodes. The readings from TP9 and TP10 are highly affected by sound and music, making them less reliable for determining whether the user is in the target state. The sample is then smoothed using a sliding exponential moving average parameterized by a history length and a ratio for determining the weighting scheme. For some operator-defined number of samples, a subsystem in Unity retrieves the samples and calculates the mean and standard deviation for each electrode to establish a baseline. For each subsequent sample after the baseline is calculated, it then shifts and scales the samples by the means and deviations, respectively, to derive a score representing the users performance relative to the baseline taken at the beginning. This yields a z-score scaled by the easiness factor.

For each sample, the scaled z-scores from AF7 and AF8 are averaged, scaled by an easiness factor (defined below), and fed into a sigmoid function (the cumulative distribution function for a normal distribution) whose outputs are all in the interval (0,1). The easiness factor helps to artificially increase the score, thus making smaller changes in input have larger effects on the output and increasing perceptibility of those changes when the user is close to the baseline. The aim of the easiness factor is to make the process more encouraging for a novice users. The final score is sent via OSC to the ChucK program and passed internally to the rendering portion of the Unity script.

Generating Myndala's Audio

The audio is composed of binaural beats, a music track, and a set of monk chants.

Binaural beats Binaural beats are an aural illusion that is based on the interference between two waves of similar frequency. Given two waves with frequencies f_1 and f_2 and constant amplitude, when played together they compose a third wave with a perceived frequency $f_{composite}$ and beat frequency f_{beat} defined as

$$f_{composite} = \frac{f_1 + f_2}{2}$$

and

$$f_{beat} = f_1 - f_2$$

.

Pairs of sine wave oscillators are used to generate the binaural beats using the SinOsc Unit Generator. Sine waves are used because they are extremely well localized in the frequency domain, yielding better control over the binaural beats. However, this is unaltered form, sine waves can be said to sound clinical. We circumvent this by adding an additional pair of sine wave oscillators whose average is exactly double the average of the first pair and whose difference is equal to the difference of the first, thus adding a second voice one octave up but with the same beat frequency characteristics. This leads to a more aesthetically pleasing result.

Music track The music track is a recording made by Karl Verkade called Crystalline (Water in C) and released on Bandcamp October 24, 2012.

[2]https://chuck.cs.princeton.edu/

[3]`https://unity.com/`

Monk chants The monk chants are a recording made by user Lamat on `freesound.org`. The chants are centered around 528 Hz.

Connecting to EEG The audio is mixed based on the values received by ChucK script from the Unity script via OSC. Each voice of the binaural beats has a constant gain. The remainder of the headroom is divided between the music track and monk chant. To find the ratio between the music track and monk chant, ChucK periodically accumulates and averages samples. Once the ratio is determined, the chant is triggered to play and the volume of the music track smoothly transitions to its new level to prevent pops.

Generating Myndala's Visuals

The Scene The scene is comprised of a lighting system, a user object equipped with some limited movement capabilities, and a large spherical subject with various customization. See Figure 1 for a 2D illustration of this VR experience. A milky way galaxy cubic map background fills the sky-box. The directional lighting system is setup such that no shadows or color interference should divert the users attention from the target.

The spherical target is equipped with a custom shader object cutting out z-testing and z-writing in order to project a transparent base. An embedded subshader layers on top of the base shader to render 2D colors on the 3D transparent base canvas.

Parameters A plethora of customizable parameters are exposed for tuning the experience including: color palette, brush size, brush shape, speed controls, and minor stylistic options. One of the most important settings is the number of reflections, controlling to the number of rotational symmetries seen in the mandala image.

Generation The generated shape resembles that of a mandala made of colored light as it wraps around the user's foreground view. Modulating the brightness of these lights has the effect of modulating the transparency, as dimming these lights will ultimately revert to the transparent base object. Utilizing this feature, we mapped the incoming preprocessed OSC messages to affect the visual intensity and visual transparency of the 3-Dimensional foreground experience. As the full material shader can be very efficiently controlled without the need for pixel-level detail, this allows the manipulation of the full target painting without compromising processing power from an otherwise demanding system.

The system will keep developing and expanding the mandala until it reaches a user selected radius threshold. After exceeding this setting, the painting will continue from the center. This may repeat indefinitely, allowing the creative development to continually change and restructure itself throughout a session. A session's duration may be arbitrary and does not have to be decided beforehand. However if the user has a designated meditation time in mind, the mandalas lights will fade out as the simulation comes to an ending.

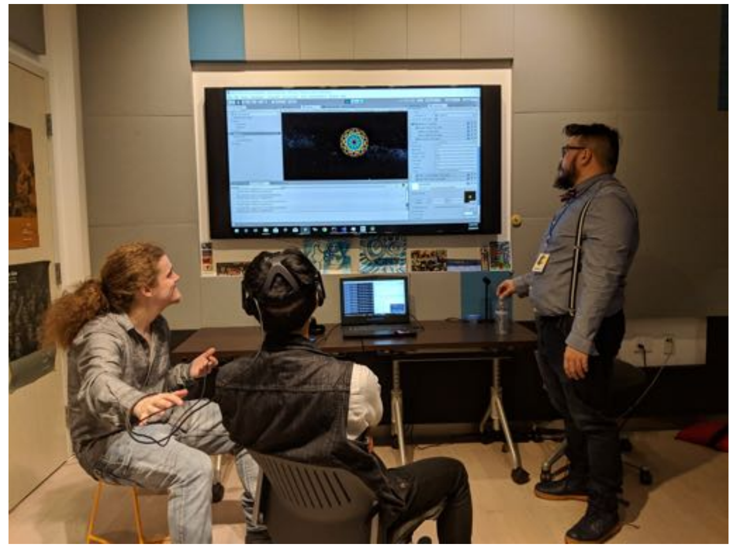

Figure 3: Andreas Adolfsson (left) and Jon Bernal (right) demonstrating Myndala to a museum guest (center).

Exhibition

Myndala was presented as part of Night of Ideas "Facing Our Times: The City of The Future" in San Francisco at the San Francisco Public Library (SFPL) on February 2nd, 2019.[4] The exibit was titled "Mandala Flow State: Relaxing Neurofeedback VR Experience"[5]

We installed Myndala in a sound isolated room at The Mix, the teen center at the SFPL, in order to facilitate a quiet, one-on-one immersive experience with the system. This was important because of the loud music and festive atmosphere at the event. During the three hour exhibition we received 76 reservations, with many more eagerly waiting to sign up, until we became aware of time constraints and stopped accepting additional reservations.

The overwhelming public interest in our research had caught us by surprise. Choosing not to compromise the experience by reducing the time allotted per person too much, we completed 38 one-on-one demos over the three hours of the exhibition. Additionally, 53 people have asked to be informed of future events or to participate in a research study on the project. [6]

Conclusions and Future Work

In this paper we introduced Myndala, an immersive 3D visual and musical experience influenced by the subject's brain wave stream. The experience promotes relaxation with goal-directed stimuli, easily followed by the user.

This line of research offers many opportunities. We've chosen a relaxed, focused state as the desired mental state. However, similar methodology can be used to direct subjects

[4] https://www.nightofideassf.com/

[5] https://sf.funcheap.com/mandala-flow-state-vr-experience-sf-main-library/

[6] https://www.sfmoma.org/event/night-ideas/

towards other desired states, such as deep meditation or focus (eg. treatment of ADHD).

Further, the integration of EEG technology with generative music and art offers endless possibilities for providing feedback and feed-forward to support a desired mental state. EEG input may also be used to control additional aspects of the experience, and may benefit from additional biometric readings, such as heart rate monitoring.

The integration of generative music and art with EEG has the potential to create drug-free, effective treatments for anxiety and attention disorders, while offering greater mental control for neurotypicals.

References

Baer, R. A. 2003. Mindfulness training as a clinical intervention: A conceptual and empirical review. *Clinical Psychology: Science and Practice* 10(2):125–143.

Bensimon, M.; Amir, D.; and Wolf, Y. 2008. Drumming through trauma: Music therapy with post-traumatic soldiers. *The Arts in Psychotherapy* 35(1):34 – 48.

Bernatzky, G.; Presch, M.; Anderson, M.; and Panksepp, J. 2011. Emotional foundations of music as a non-pharmacological pain management tool in modern medicine. *Neuroscience & Biobehavioral Reviews* 35(9):1989 – 1999. Pioneering Research in Affective Neuroscience: Celebrating the Work of Dr. Jaak Panksepp.

Ehrlich, S. K.; Agres, K. R.; Guan, C.; and Cheng, G. 2019. A closed-loop, music-based brain-computer interface for emotion mediation. *PloS one* 14(3):e0213516.

Evans, S.; Ferrando, S.; Findler, M.; Stowell, C.; Smart, C.; and Haglin, D. 2008. Mindfulness-based cognitive therapy for generalized anxiety disorder. *Journal of Anxiety Disorders* 22(4):716 – 721.

Gutirrez, E. O. F., and Camarena, V. A. T. 2015. Music therapy in generalized anxiety disorder. *The Arts in Psychotherapy* 44:19 – 24.

Kelly, S.; Davies, L.; Harrop, D.; McClimens, A.; Peplow, D.; and Pollard, N. 2015. Reviewing art therapy research: A constructive critique.

Koszycki, D.; Benger, M.; Shlik, J.; and Bradwejn, J. 2007. Randomized trial of a meditation-based stress reduction program and cognitive behavior therapy in generalized social anxiety disorder. *Behaviour Research and Therapy* 45(10):2518 – 2526.

Lutters, B., and Koehler, P. J. 2016. Brainwaves in concert: the 20th century sonification of the electroencephalogram. *Brain* 139(10):2809–2814.

Mealla, S.; Väaljamäae, A.; Bosi, M.; and Jordà, S. 2011. Listening to your brain: Implicit interaction in collaborative music performances. In *NIME*, volume 11, 149–154.

Miranda, E. R.; Durrant, S.; and Anders, T. 2008. Towards brain-computer music interfaces: Progress and challenges. In *2008 First International Symposium on Applied Sciences on Biomedical and Communication Technologies*, 1–5.

Muenssinger, J. I.; Halder, S.; Kleih, S.; Furdea, A.; Raco, V.; Hoesle, A.; and Kubler, A. 2010. Brain painting: First evaluation of a new brain computer interface application with als-patients and healthy volunteers. *Frontiers in Neuroscience* 4:182.

Ramirez, R.; Palencia-Lefler, M.; Giraldo, S.; and Vamvakousis, Z. 2015. Musical neurofeedback for treating depression in elderly people. *Frontiers in neuroscience* 9:354.

Tokunaga, T., and Lyons, M. J. 2013. Enactive mandala: Audio-visualizing brain waves. In *NIME*.

Vernon, D.; Frick, A.; and Gruzelier, J. 2004. Neurofeedback as a treatment for adhd: A methodological review with implications for future research. *Journal of Neurotherapy* 8(2):53–82.

Zeidan, F.; Martucci, K. T.; Kraft, R. A.; McHaffie, J. G.; and Coghill, R. C. 2013. Neural correlates of mindfulness meditation-related anxiety relief. *Social Cognitive and Affective Neuroscience* 9(6):751–759.