THE BRAINWAVE VIRTUAL INSTRUMENT: MUSICAL IMPROVISATION AND BRAINWAVE SONIFICATION VIA FAUST PROGRAMMING

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ABSTRACT

The Brainwave Virtual Instrument (BVI) is an open-source software synthesizer built in the programming language Faust. Its purpose is to facilitate the exploration of electroencephalogram (EEG) and other brain data through sonification. Pre-recorded data is translated as parameter controls of the instrument in the form of Open Source Control (OSC) messages that are generated and streamed by a small python program. The instrument can easily be distributed and compiled to different targets thanks to Faust's flexibility. Frequency Modulation synthesis provides a comprehensive approach to textural parameters of sounds, so that musical composition and improvisation based on a creative use of brain data become feasible. This is exemplified by the Brainwave Etudes (BE), a series of compositions inspired by measurements of brain activity during different states of mind. The BVI was created for two major purposes: on the one hand, to find musical structures that relate to each other in order to present an aesthetic proposal, and on the other, to create a tool that familiarizes scientists and researchers in the field of neuroscience with sonification techniques, and the exploration of brain activity through sound.

1. INTRODUCTION

Sonification is defined as "the use of non-speech audio to convey information. More specifically, sonification is the transformation of data relation into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation"[1]. Medicine, science and engineering have used sonic cues since the standardization of their practices in the 19th century, and some of these sonic skills are widely used until the present day[2]. For instance, medical auscultation remains a common diagnostic practice in medicine. Since 1992, the International Community for Auditory Display (ICAD) has held conferences where researchers from diverse backgrounds — such as medicine, science, arts and the humanities — work together in order to use sound and auditory cues for scientific and medical purposes[3].

Practices of translating data into sound are diverse. For example, audification is the practice of transposing data series to the human audible range, which usually results in frequency changes. In parameter mapping, sonic and musical attributes are mapped to synthesis parameters (e.g., musical pitches, duration, timbre, etc.). Model-based sonification, unlike the previous two, allows the interaction of the user with the input data for exploration and interaction.[1] The BVI is based on the latter approach.

[1] A more comprehensive theory and taxonomy of sonification can be found in [4]

Perspectives for brainwave sonification have been a topic in neuroscience ever since first EEG measurements were realized. EEG measure the electrical activity of the brain and return a raw signal of voltage fluctuations that can be processed to identify certain brain activity. More recent developments of computational power allow sound synthesis and data processing on personal computers, which renders sonification approaches feasible for large and diverse user groups. This includes the availability of software and devices specifically tailored towards EEG recordings, next to libraries and frameworks that facilitate data processing in an efficient way.

The particular allure of translating brain activity into sound has attracted musicians and artists alike. In the 1960s, experimental composers explored possibilities of brainwaves as musical material. Examples of musical pieces include Alvin Lucier's *Music for solo Performer* (1965), where the performer uses alpha brainwaves to manipulate motors attached to mallets hitting percussive instruments; and Richard Teitelbaum's *In tune* (1968), where EEG signals are used as Control Voltages (CV) to manipulate Moog analogue synthesizers, emphasizing the inherent relationship between electrical signals and acoustic signals. Contemporary contributions in the field of brainwave sonification have been made by Chris Chafe[5], Alberto de Campo[6], Thomas Deuel[7], and the AXNS Collective[8]. Their approaches cover diagnostic, therapeutic and artistic applications alike. In addition, projects have explored possibilities with multichannel spatial audio techniques, applied to datasets of multichannel EEG recordings [9].

Sonification of data presents a substantial challenge for the music composer and the sound artist, as it requires both a scientific and creative approach, in which aesthetic intention and data meaning are equally relevant. Our multidisciplinary approach invites artists, digital engineers, scientists and anyone interested in this topic to think "outside the box" and to expand perspectives of interest in these knowledge areas through sonification approaches.

Overall, this project is situated in a *Data Sonification Initiative*, in which institutions such as the Center for Computer Research in Music and Acoustics (e.g., [5]), the Hasso Plattner Institute for Digital Engineering at the University of Potsdam (e.g., [10] [11]), the Audio Communication Group at the Technical University of Berlin (e.g., [12]) and the Berlin University the of Arts (e.g., [13]) are involved so far. This initiative is anchored in technical developments that open up novel opportunities for data sonification, in neuroscientific research that seeks novel means to make sense of data, in design thinking creativity studies, and the emerging field of neurodesign [14][15] that combines neuroscience, engineering and creativity studies.

2. THE DATASET

To collect data for this project, we conducted EEG recordings with the medical device Mindfield BioEra Clinical Performance 1.10, using the software Mindfield MindStream 1.2. All recordings stem from one participant. Two electrodes were placed on the left side of the participant's head, on a frontal and a parietal position. Each electrode captures one signal conveys the rhythmic activity of the brain over time. Most signals range in a spectrum of 1–30 Hz.

The raw signal is processed through spectral analysis in order to gather more specific information about the brain activity. This allows to detect the relative amplitude in specific bandwidths. Often assessed EEG frequency bands include delta (< 4 Hz), theta (ca. 4-8 Hz), alpha (ca. 8-12 Hz), low beta (ca. 12-16 Hz), beta (ca. 16-20 Hz) and high beta (ca. 20-32 Hz). The amplitude shown in each of the gathered frequency bands is associated with different mental states [16][17]. For instance, high levels of delta activity occur during sleep. Theta indicates drowsiness in adults. Prominence of alpha activity obtains when subjects are relaxed, when they close their eyes and direct attention inwards, as well as when they are creative. Low beta activity shows calm concentration, while high beta is associated with intense concentration or even stress. The relative amplitude in each band can change drastically across different states of mind.

Our recordings lasted for ca. 15 minutes. During the recording, the participant was given different tasks to induce different states of mind. Each task was performed for ca. 2 minutes with brief breaks in between. The software analyses the raw signal automatically and returns four measurements per electrode: (i) theta, (ii) alpha, (iii) low beta and (iv) beta frequency bands. Since recordings were made with two electrodes, altogether eight measures (=2x4) are available per moment in time.

3. THE INSTRUMENT

The Brainwave Virtual Instrument was coded using the Faust programming language. Before opting for this implementation, we had created some prototypes with other musical software and programming languages. We chose FAUST thanks to the flexibility it offers regarding the building targets, which also allows us to distribute the BVI to a wider range of audiences. We believe that Faust is relatively intuitive to learn and it can help interdisciplinary teams of audio engineers, scientists, artists and other interested user groups to find a common language in the discussion and development of data sonification projects.

In the design of the BVI, the instrument synthesis approach was inspired by De Campo et al.[6], who used base Frequency Modulation to highlight deviations in data. Frequency Modulation (FM) synthesis has the advantage of being very versatile, and it is able to create a wide range of timbres and textures, making it suitable for sonic and musical exploration.

The BVI consists of eight parallel FM synthesizers that correspond to the eight measurements that we gather from our experiments (four frequency bands x two electrodes). The initial carrier and modulation frequencies are the same in each frequency band for both electrodes, while chosen frequencies mirror the relationship of different frequency bands in the EEG dataset, so that differences between EEG frequency bands now become audible. The numerical relationship between audible frequencies corresponds to numerical relationships in the recorded EEG frequency bands (see Table 1.)

Table 1: *EEG Channels and Frequency equivalents.*

$EEG\,Frequency$	$Freq\,(Hz)$	$FMFreq\,(Hz)$
$theta\,(electrode\,1+2)$	$4-8$	60
$alpha\,(electrode\,1+2)$	$8-12$	100
$low-beta\,(electrode\,1+2)$	$12-16$	140
$beta\,(electrode\,1+2)$	$16-20$	180

The modulation frequency is controlled by data streaming from the EEG recordings via Open Sound Control (OSC) through a python processing hub. The carrier frequency modulates according to the amplitude of the EEG signal. Furthermore, the user has the possibility to control the index of modulation, and the harmonicity ratio, which expands the sonic palette of each channel regardless of the chosen carrier and modulation frequencies.(Figure 1)

Two additional knobs per channel control the envelop decay and the rate, which adds a rhythmic dimension to the instrument. The position of each channel in the stereo image reflects the position of the electrodes during the measurement. Each EEG frequency band has a separate level slider, and a start checkbox, which allows performers to omit certain channels according to their intentions. A master channel introduces a basic reverb effect as well as control for the overall level (see Figure. 2). Thus, the performer has ample means to control the sound output, which facilitates explorations of different characteristics and relationships of the sound together with the available data, by means of interactive music making.

First tests with the BVI led to the conception of the Brainwave Etudes (BE). They are a series of musical compositions, based on the sonification of EEG data described above. Steering towards the musical realm, the BE present the sonification process as an aesthetic one, in which data of brainwaves is the raw material to develop pieces of music. Nevertheless, numerical relationships in the EEG dataset, and tasks performed by the subject during the recording, served as inspirational basis for the compositions.

4. THE BRAINWAVE ETUDES

The Brainwave Etudes are a series of small compositions that are created to exemplify some of the possibilities of brainwave sonification through the Brainwave Virtual Instrument. Seven etudes have been composed, reflecting seven tasks performed by the participant:

- Rest, eyes open
- Rest, eyes closed
- Mental calculation, eyes open
- Mental calculation, eyes closed
- Social creativity: Joint telling of a wild story, eyes open
- Individual creativity: Thinking up uncommon uses for a brick, eyes open
- Individual creativity: Thinking up uncommon uses for a paper clip, eyes closed

Each of these tasks can be expected to increase activation in one or more EEG frequency bands. For example, in rest situations, relaxation (EEG alpha) can be expected - and even more so when

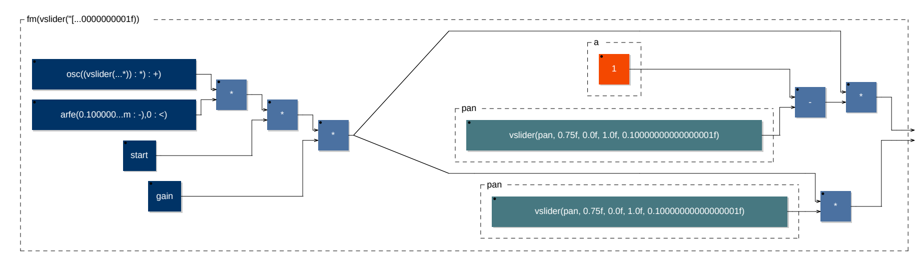

Figure 1: *FM unit.*

the eyes are closed. Mental math is expected to activate low beta and beta frequencies. When the task is easy for the participant, Low Beta dominates. When calculations become more difficult, higher beta frequencies can fuse in, reflecting intense concentration or even stress. Creative activities are expected to activate alpha frequencies. When tasks endure for longer times, and creative flow wanes, this can elicit stress (high beta), or the participant becomes drowsy and begins to idle (theta). The etudes aim to accentuate and reinforce the appearance of those frequencies in the piece, where relevant dynamics are expected during task performance.

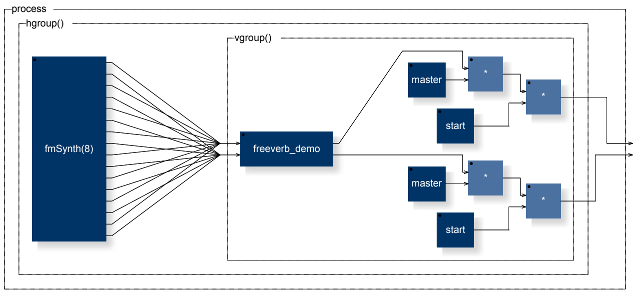

Figure 2: *Brainwave Virtual Instrument design.*

5. CONCLUSIONS

We have presented the Brainwave Virtual Instrument together with a series of sample compositions, to demonstrate artistic outcomes of neuroscientific measurements described above. We hope the approach helps to spark the curiosity of neuroscientists and interested listeners from various fields, as well as to spark the artist's interest in possibilities of transforming data into music or other forms of art.

The implementation of an instrument such as the BVI in Faust can help to bridge the knowledge of audio programming, data-intense research like neuroscience, and creativity research as conducted in design thinking, through the use of a common and rather accessible computer language.

Among other upcoming projects, we aim to create sound installations and multichannel audio performances that will add a parameter to sonification that is not so frequently explored: spatial audio. In the sonification of brain data, this spatial positioning seems intuitive, as brain activity itself is distributed spatially across the head.

Further iterations of the BVI can include implementations in the Bela platform, coupled with accessible EEG recording devices such as OpenBCI, Muse2 or BITalino. This would be an approach to amend the instrument itself, adding possibilities of additional channels and inputs. Further developments can be directed at a redesign of the user interface, e.g. in JUCE. Moreover, we want to encourage and include open source contributions from scientists, audio programmers and musicians alike.

The Brainwave Virtual Instrument can be found at `https://github.com/nicodaleman/brainwave_virtual_instrument`, including both FAUST and Python code. Musical examples and the Brainwave Etudes are available at `www.soundcloud.com/nicodaleman`.

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7. REFERENCES

[1] Gregory Kramer, Bruce Walker, Terry Bonebright, Perry Cook, John Flowers, Nadine Miner, and John Neuhoff, "Sonification report: Status of the field and research agenda," International Community for Auditory Display, 1997.

[2] Karin Bijsterveld, *Sonic Skills Listening for Knowledge in Science, Medicine and Engineering (1920s–Present)*, Palgrave Macmillan, London, 2019.

[3] Gregory Kramer, Ed., *Auditory Display: Sonification, audification, and Auditory Interfaces*, Reading, Mass., 1994.

[4] Bruce N Walker and Michael A Nees, "Theory of sonification," in *The Sonification Handbook*, T. Hermann, A. Hunt, and J. G. Neuhoff, Eds., chapter 2, pp. 9–39. Logos Publishing House, 2011.

[5] Josef Parvizi, Kapil Gururangan, Babak Razavi, and Chris Chafe, "Detecting silent seizures by their sound," *Epilepsia*, vol. 59, no. 4, pp. 877–884, 2018.

[6] Alberto de Campo, Robert Hoeldrich, Gerhard Eckel, and Annette Wallisch, "New sonification tools for EEG, data screening and monitoring," in *Proceedings of the 13th International Conference on Auditory Display*, Montréal, Canada, June 2007.

[7] Thomas A. Deuel, Juan Pampin, Jacob Sundstrom, and Felix Darvas, "The encephalophone: A novel musical biofeedback device using conscious control of electroencephalogram (EEG)," *Frontiers in Human Neuroscience*, vol. 11, pp. 213, 2017.

[8] "SINES: An LSD brainwave and soundart hackaton," `https://axnscollective.bandcamp.com/releases`.

[9] Gerold Baier, Thomas Hermann, and Ulrich Stephan, "Multichannel sonification of human EEG," in *Proceedings of the 13th International Conference on Auditory Display*, Montréal, Canada, June 2007.

[10] Leon Papke, Carla Terboven, Philipp Trenz, and Simon Witzke, "Brainwave sonification toolbox," 2020, Presentation in the neurodesign lecture, HPI, Potsdam, Germany. Accessible at: `https://www.tele-task.de/lecture/video/7999/#t=0`.

[11] Noel Danz, "Real-time EEG sonification with the BITalino platform," Presentation at the MIC conference 2020: Nurturing Creative Potential.

[12] Tim Strauch, Lukas Hartmann, Luca Hilbrich, Philipp Steigerwald, Chris Chafe, and Julia von Thienen, "Audible spatialization of EEG data in the context of creativity studies," Bologna, Italy, 2020-09-16, Presentation at the MIC conference 2020: Nurturing Creative Potential.

[13] Nicolas D'Aleman, Chris Chafe, and Julia von Thienen, "Brainwave etudes: Composition and improvisation with brain data," Bologna, Italy, 2020-09-16, Presentation at the MIC conference 2020: Nurturing Creative Potential.

[14] "Neurodesign," www.hpi.de/neurodesign.

[15] Julia von Thienen, Caroline Szymanski, Joaquin Santuber, Irene Sophia Plank, Shama Rahman, Theresa Weinstein, Babajide Owoyele, Matthias Bauer, and Christoph Meinel, "Neurodesign live," in *Design Thinking Research*, C. Meinel H. Plattner and L. Leifer, Eds. Springer, 2020.

[16] Priyanka A Abhang, Bharti W Gawali, and Suresh C Mehrotra, *Introduction to EEG-and speech-based emotion recognition*, Academic Press, 2016.

[17] Andreas Fink and Mathias Benedek, "EEG alpha power and creative ideation," *Neuroscience & Biobehavioral Reviews*, vol. 44, pp. 111–123, 2014.