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A CONTINUED MUSICAL AND PERSONAL DIALOGUE WITH THE WAVES OF EPILEPSY.

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University of Plymouth

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University of Plymouth

**A CONTINUED MUSICAL AND PERSONAL DIALOGUE WITH THE WAVES
OF EPILEPSY**

by

ALAN D. MILES

**A thesis submitted to the University of Plymouth
in fulfilment for the degree of**

RESEARCH MASTERS

School of Humanities and Performing Arts

September 2017.

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- Professor Eduardo Miranda at the Interdisciplinary Centre for Computer Music at the University of Plymouth for his guidance.
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AUTHOR'S DECLARATION

At no time during the registration for the degree of Research Masters has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

Work submitted for this research degree at the University of Plymouth has not formed part of any other degree either at the University of Plymouth or at another establishment.

A programme of advanced study was undertaken, which included:

- Advanced Topics in Computer Music.
- Research Skills in the Arts & Humanities.

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Signed.....

Date.....

Abstract.

Alan D. Miles.

A Continued Musical and Personal Dialogue with the Waves of Epilepsy.

In the early hours of the morning several years ago I awoke with paramedics leaning over me. In a state of confusion, my first conscious decision was to enter my music production studio while they attempted to lead me to the ambulance. Music was important to me even in a disorientated post-ictal state (*an altered state of consciousness following a seizure*). Two weeks later I awoke with paramedics standing over me again. I had started to experience multiple seizures.

During the previous weeks, I also experienced numerous incidents of memory loss when delivering presentations at work, feelings of being returned to the room following an absence of consciousness and suffering from temporal disorientation. I also experienced multiple episodes of déjà vu, aromas that were difficult to identify, visual distortions and waves of euphoria like momentary intoxication of an unknown origin. These experiences began to increase in frequency until my first tonic-clonic seizure. Following medical tests, I was diagnosed with epilepsy. It was a confusing period with no history of epilepsy in my family and no physiological causes could be identified. I viewed epilepsy as an overwhelming authority, it takes control of your life and asserts its power upon you, forcibly changing your reality in an instant.

When I saw the EEG readouts from my tests I noticed how similar they were to sound waves (*figures 1 and 2*).

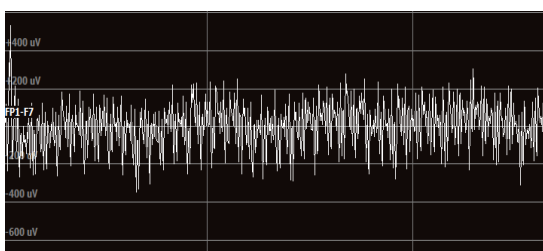


Figure 1: EEG waveform

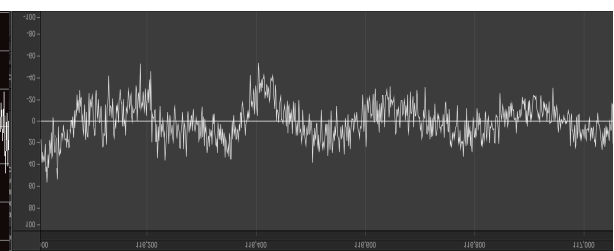


Figure 2: Audio waveform

As an electronic musician, this project is being used as an artistic and cathartic opportunity to creatively transform the power of epilepsy and reassert my personal identity upon it. Symbolically reclaiming personal control and creatively transforming the psychological perception of personal power that is lost through the experience of epilepsy. Transforming it from an internal destructive force into an external and creative activity in my life. Capturing the cultural and emotional experiences of epilepsy and transforming them into cinematic electronic soundscapes using research and musical experimentation with EEG epilepsy signals. It is an existential exploration, the results will be tangible, accessible and reasonable in the transformation of the EEG epilepsy recordings from the uncontrollable unconscious into the creative conscious. This project will apply transposition, mathematics, research and creative exploration to map epilepsy EEG events into computer synthesized soundscapes, transforming the passive nature of diagnoses and treatment into a proactive and creative process. This thesis shares an individual's research and experiences of epilepsy with a community that have an interest in transforming the passive sufferer into a creatively active and articulate patient.

Professor Dan Lloyd (*Thomas C. Brownell*) Professor of Philosophy at Trinity College states that:

“It is observed that fMRI (Brain) activity is more similar to music than it is to language...” Lloyd D. (2011).

If, as Lloyd suggests, brain activity is more like music than language then what might epilepsy be saying or possibly singing during these events? What are the audible timbres of these events?

Researchers such as Wu et al, Psyche et al, Chafe and Parvizi have previously interpreted EEG data of epilepsy EEG events to aid medical research, but it is not exploring the emotional timbre of epilepsy from a patient's perspective. The previous research derived musical notes from EEG signals to trigger MIDI instruments and modulate non-epilepsy

related audio sources for medical identification purposes. This project examines the possible timbres derived directly from the EEG data to explore and creatively describe the emotional and physical experience from a patient's perspective.

This thesis presents the personal experience of epilepsy, the development of electroencephalography (EEG), the sociocultural history of epilepsy. the sonification and musification of EEG data, plus the concepts involved in the design of timbre and sound effect. For this project, a bespoke granular synthesizer called '*The Oblique-Granizer*' (programmed with Cycling74's MAXMSP) has been constructed that employs EEG signals, converted to digital audio, to synthesize timbres that explore the description of human experience and emotions related to epilepsy. This thesis includes research that has been carried out into mathematical algorithms to generate musical notes and melodic information in electronic music compositions using EEG epilepsy seizure activity. The aim is to take back personal control by creatively transforming the EEG data and my psychological perception of epilepsy into electronic soundscapes and sonic textures through exploration of sonification and musification techniques.

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Audio Content.

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1. The Esoteric Voyage of Hans, Nikolai and Zedel (1924)
2. Dante and Virgil Descend Past the Minotaur.
3. Threat of Focal Onset.
4. Lost.
5. Out Beyond the Öpik–Oort Cloud.
6. Requiem for a Neuron.
7. Into the Absence.
8. Interpolate Between Safety and Seizure.
9. Cyclic Rhythmic Sampler Experiment.

Audio Examples Folder:

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2. Example 1b-chb01_03-FULL SEIZURE ALL ELECTRODES 256k SPEED.wav
3. Example 2-Mapped Notes - Wu examination-120bpm.wav
4. Example 3-Mapped Notes - My Method 1-120BPM.wav
5. Example 4-Mapped Notes - My Method 1-120BPM-(-2 octaves).wav
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8. Example 6b-Slowed-Timbre-examples_1-4_x_10.wav
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11. Example 8-Breaking the Threshold Improvisation 1.wav
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14. Example 11-Cyclic Rhythmic Sampler Experiment.wav *(also included as composition)*

MAX/MSP Synthesizer Folder:

The Oblique-Granizer' MAX/MSP Synthesizer Project.

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1. Epilepsy and EEG.

“Approximately 1% of the world’s population exhibits symptoms of epilepsy” (Shoeb 2004)

According to the United Nations (2017) the world’s population is over 7,000,000,000.

This means 70,000,000 (1-in-100) people may suffer epilepsy worldwide. After experiencing my first tonic-clonic seizure, an Accident and Emergency Department nurse stated that *“everyone is entitled to one fit in their lives, but if you have two you have epilepsy!”*

1.1 What are Epilepsy Seizures?

The brain functions using electrical activity to communicate from cell to cell. When there is a disruptive burst of electrical activity it can cause a seizure. There are different types of seizures and symptoms relative to the area of the brain affected by the electrical disruption, seizures can affect all or just parts of the brain. The seizures we often associate with epilepsy are called tonic-clonic seizures, this is where the sufferer loses consciousness and is not aware of their surroundings and have symptoms that include being very stiff (*tonic*) or convulsive shaking (*clonic*). Absence seizures where the sufferer appears awake and aware but is not, the sufferer may not remember any of the time during this type of seizure. Focal onset seizures where the sufferer is awake and aware but experiencing sensations such as unidentifiable smells, tastes, déjà vu, jamais vu and repetitive physical movements and calling out. There are also seizures that happen during sleep called nocturnal seizures. People with epilepsy can experience a range of seizure types, starting as one type then developing into another, or experience only one type such as nocturnal seizures. Seizures can start in one part of the brain whilst aware and then spread to other or all parts of the brain leading to unconscious and convulsive states.

In some cases, the cause of seizure is a result of physical injury, disease or genetic damage to the brain, but in other cases a person can suffer seizures without an identified cause.

1.2 Triggers.

There are numerous triggers for seizures, some sufferers can identify these and begin to avoid them. Photosensitive epilepsy is a common epilepsy trigger, television programs that include flash photography provide warnings of its inclusion and avoidance strategies can be employed. It is important to differentiate between the triggers and the underlying cause of epilepsy, tiredness, stress, alcohol and drugs can trigger seizures (Epilepsy Action 20114). Some people can experience seizures where the triggers are not identified. My experiences include a range of seizure types such as nocturnal, focal onset, tonic-clonic and absence seizures. I have been diagnosed as suffering from temporal lobe epilepsy, originating in the right temporal lobe of my brain. The seizures can be managed via medication but the triggers in my case have also not yet been identified. Earlier in this thesis, the term psychological perception was used when describing how I viewed epilepsy, the consideration of the psychological effects of epilepsy that a patient experiences are important. I began to lose trust in my own brain's processing of perceived reality following the experience of having seizures in public places, at work and at home, they eroded the trust I previously took for granted. This insecurity stopped me from leaving my house and stopped me from going to work. In a community-based survey of unemployment figures of people with epilepsy in the North East of England, it was identified that 46% of people with epilepsy were unemployed compared with 19% of the same age and gender control group without epilepsy. The unemployment figures could be related to individual sufferer's confidence and health. This could also be explained by an employer possibly preferring to hire someone without epilepsy when another applicant with epilepsy has the same skills for the job being applied for. (Elwes et al 1991).

My perception of epilepsy created new thought processes which began to take control, an example of this is the notion of personal safety and security. Activities and situations that were normally taken for granted as safe are now challenged: if I experienced a seizure now would I be safe? This transformation of thought processing became the norm in many of life's situations. Epilepsy began to foster insecurity and a lack of trust in my own perception of reality and personal safety, combined with the physiological symptoms, the psychological effect was the development of depression because of the perception of the condition. Epilepsy was now controlling my life; how could I reclaim some control? Having relied on music and creativity throughout my life, this EEG based music project could be a proactive and transformative activity to creatively reclaim some personal power from epilepsy.

1.3 What is an EEG?

Epilepsy brainwaves are recorded via electroencephalography (EEG). Figure 3 is the first published electroencephalogram of human brain activity by *Hans Berger 1924*.

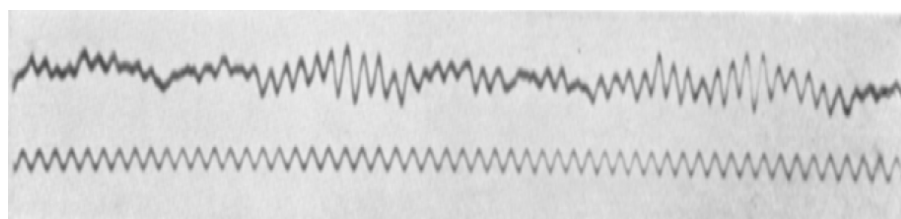
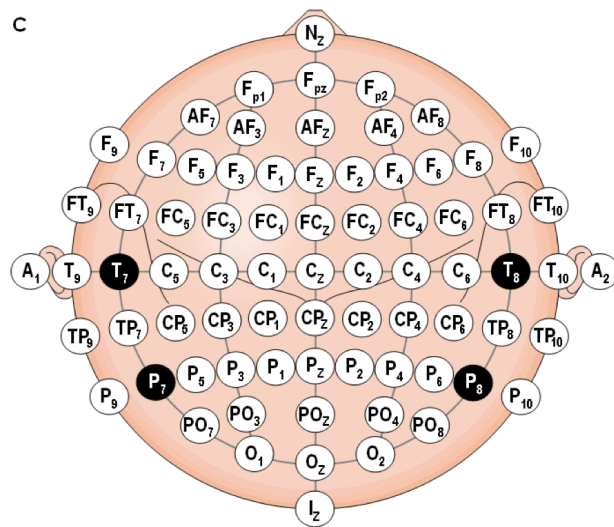


Figure 3: First published Electroencephalogram of a human by *Hans Berger 1924*.

The previous figure 3 is one of the first EEGs appearing in Berger's first report. The top trace is the EEG recorded from a young male patient, the bottom trace is a 10 Hertz (Hz) frequency reference. The first person to discover electrical activity in the brain was the British physician Richard Caton in 1875 whilst experimenting with the exposed brains of rabbits and monkeys. Nearly 50 years later in 1924 the German psychiatrist Hans Berger recorded an electrical signal from a human brain on a strip of paper without having to cut through the skull. (Teplan 2002). It was a neurological breakthrough that was called electroencephalography, the causes of seizures in patients with epilepsy could now begin to be studied, diagnosed and perhaps understood. (Haas, L. F. 2003).

Electrodes are used to capture the electrical brainwave activity. Figures 4 A, B & C illustrate the *'International 10-20 System'* that measures and records the tiny voltages



from the brain between sensors placed on percentage positions around the skull

"Spontaneous activity is measured on the scalp or on the brain. The amplitude of the EEG is about 100 μ V when measured on the scalp, and about 1-2 mV when measured on the surface of the brain. The bandwidth of this signal is from under 1 Hz to about 50 Hz". (Goldberger et al 2000).

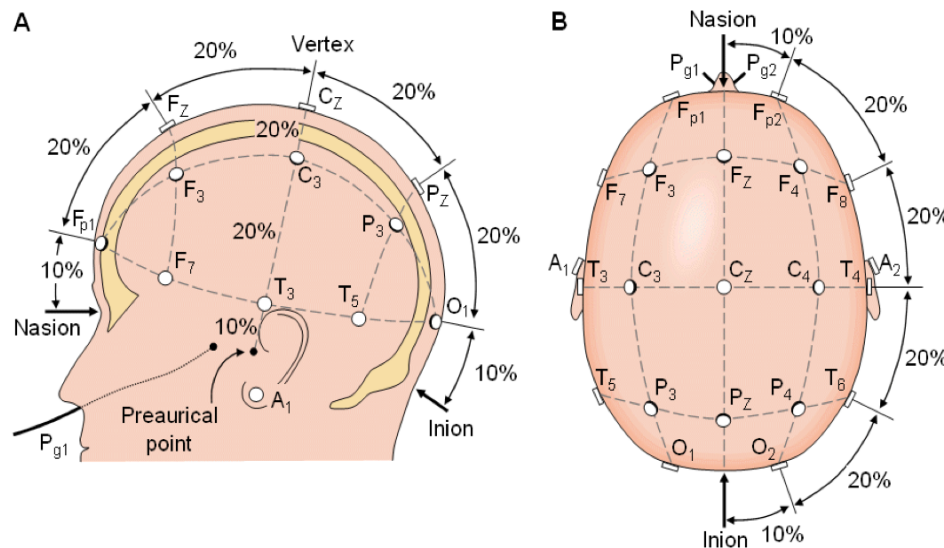


Figure 4: A, B and C - The International 10-20 System (Goldberger et al 2000).

The electrical activity captured and recorded via EEG electrodes is a low amplitude signal to capture, especially via electrodes placed on the scalp. Eye movements, blinking, muscle spasms and physical motion can all influence the minute electrical signals captured by EEG.

1.4 Volta and EEG Voltage Levels.

During my childhood, we used to play a game of dare where we would put our tongues on a battery shorting out the positive and negative elements to get a tiny shock, although it was more like an uncomfortable taste than an electric shock. This illustrates

the low level of the electrical activity captured by the electrodes on the scalp during an EEG recording. The 9-volt signal is 90,000 times stronger than the 100µV captured by EEG electrodes on a scalp.

A small 9-volt battery = 9,000,000 µV

An EEG signal = approx. 100 µV

$9,000,000 \text{ µV} / 100 \text{ µV} = 90,000$ times difference in signal strength.

$20 \log(9,000,000 / 100) = 99$ dBuV difference.

This taste experienced by shorting the contact points on the battery was originally identified by Alessandro Volta in his experiments with metals and the artificial generation of electricity. Volta researched the power of different metals in the derivation of electricity. He discovered the stimulation of the gustatory nerves associated with taste in his experiment by arcing bimetallic materials with his tongue and noting the acidic taste (Piccolino, M. 2006).

The work by Volta began the development for the invention of the battery in 1800. Volta extended the work of Luigi Galvani in the late 1700's who carried out the famous experiments with electricity causing the twitching of a dead frog's legs. Galvani used the electricity from a thunderstorm, connecting the frog's nerves with long wires pointing skyward which made the dead frog's legs twitch like they were alive. Some years later this discovery is said to have influenced art and literature giving Mary Shelley the inspiration to author Frankenstein. Galvani discovered that the frog's muscles and nerves responded to external electric impulse, but also had its own intrinsic electricity which he called '*animal electricity*' (Johnson, J. P 2001). This began the fundamental stages of development towards EEG technology and the understanding of electricity in human physiology. The resulting EEG signals are represented in EEG graphs, see figure 5 below, where each electrode signal can be examined visually. *Note:* The epilepsy EEG data sets employed for this project are from the public access CHB-MIT Scalp EEG database. The data sets were archived in the European data format (.edf) and have been converted to digital audio files for use in the musification and synthesis processes during this project.

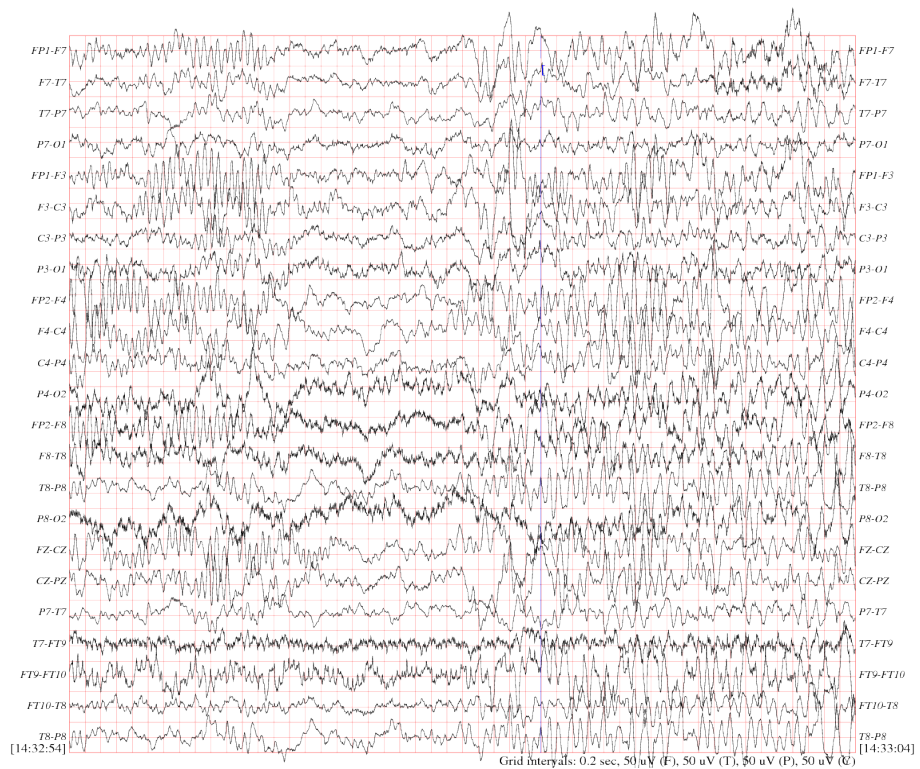



Figure 5: CHB-MIT Scalp EEG database – Goldberger et al 2000.

There is an opportunity to listen to the original epilepsy EEG data files converted to audio (*in the Audio Examples Folder*). They give an example of the source material used for the musification to develop timbres, soundscapes and melodic information to create cinematic sonic explorations of epilepsy events or experiences.

Note: The audio files below are shortened in time by a ratio of 172.265625 when compared to the actual length of the seizure experienced by the patient. This is a result of the conversion process from EEG to audio format which is explained in detail within *chapter 9. Mapping Experiment #3: Sampler Cyclic Edits* (page 56).

 Play *'Example 1a-chb01_03-Full EEG Recording.wav'*

Note: The file above is the full EEG recording. Seizure starts at 17.4 and is 0.23219 seconds long.

 Play *'Example 1b-chb01_03-FULL SEIZURE ALL ELECTRODES 256k SPEED.wav'*

Note: The file above is the seizure only edit. Seizure edit is 0.23219 seconds long.

2. Previous Research and Musical Experimentation with Epilepsy and EEG.

This project is interested in the processes that generate electronic timbre and pitch to explore and apply creative, transformative musical processes with EEG epilepsy data.

American composer and pioneer in the use of neurofeedback David Rosenboom.

suggests:

“Musical artists, along with many other groups, are interested in how music neuroscience can inform and inspire creative practices.” (Rosenboom. 2014).

This project work explores the creation of electronic soundscape productions and music compositions through the perspective of an epilepsy patient with transformative creative processes. What music and timbre can be found within the analysis of the EEG data in sonification or musification? Is there solely chaos and dissonance within epilepsy brainwaves? Or can harmony and order be found? Rhythmic events and sequences can also be observed in epilepsy EEG data. Can I transform an overwhelmingly authoritative medical condition into a positive creative process and reclaim some power from epilepsy?

Lloyd D. (2011) suggests ideas in the *'Mind as Music'* that the brain functions more like music than language. That said, we communicate things about the mind and brain in terms of language, but is it possible that it speaks to us in music? And if so, should we be learning to listen and understand the mind in terms of the music it might be making in waves recorded in the brain?

In *“The alternative to the Language of Thought is the Music of Thought, MOT rather than LOT.”* Lloyd noted that brain activity appeared more like the dynamics of music than that of language. (Lloyd, D. 2011). This reflects the idea that language is constructed with singular symbols and characters formed into discrete words, sentences and paragraphs, whereas the brain functions in electrical voltage waves analogous to that of music and sound.

Previous research that has been carried out with sonification of epilepsy EEG data for the medical field has been to '*rapidly learn identification of epileptic seizures from sonified EEG.*' The assertion is that by using an algorithm to sonify EEG recordings people will be able to identify normal brain activity and seizures by listening to the audible results alone (Psyche et al 2014).

Stanford Scientists Chris Chafe and Josef Parvizi transformed EEG recordings of epilepsy activity into music, they embarked upon this with artistic aspirations. They went on to develop the '*brain stethoscope*', a device that turns brain activity into sound using a patented sonification algorithm and FM Synthesis to modulate selected pre-recorded vocal samples. Chafe et al (2015) created the to listen to epilepsy and normal brain activity sonified in real-time.

"We've really just stuck our finger in there. We know that the music is fascinating and that we can hear important dynamics, but there are still wonderful revelations to be made." Chafe, C. (Carey, 2013).

Thomas Deuel developed a device they called the Encephalophon. "*A novel musical instrument and biofeedback device*" (Deuel et al 2017) that triggered or controlled a synthesizer piano. This was also first developed with an artistic intention but then developed further with medical therapeutic possibilities. Deuel started to think beyond music, how this may help patients with disabilities to train the mind in a therapeutic environment when interacting with brain computer interfaces. (Boyle, A 2016).

American composer David Rosenboom pioneered the use of neurofeedback experimentation with brainwave music in the late 1960's with '*Brainwave Noise Experimental*' (1968). In 1970 Rosenboom composed and performed a piece called '*Ecology of the Skin*' that employed the EEG signals from collaborators taking part, using individual electronic signal processing to generate visual and soundscape elements for the performance. (Rosenboom 1990).

On January 18th, 1971 Frank Bakerich and Robert T. Scully filed a patent application for the *'Electroencephalophone and Feedback System'* (approved August 21st, 1973) which provided a method to sonify EEG signals for: "*audio study and analysis of the type and character of brain waves being generated.*" The patent application describes how the *Electroencephalophone* functions. The EEG brainwave activity was recorded with electrodes secured on a scalp cap. An electronic transducer combined the resulting EEG frequency modulation and amplitude information into an audible oscillator which generated tones for sonic recognition of brainwave activity. In the late 1970's experimental musicians Pauline Oliveros and David Rosenboom used the electroencephalophone and EEG signals when composing works such as *'Brainwave Music'* and *'On Being Invisible'* (Psyche et al 2014).

Rosenboom's experimental music combines human performance, synthesized materials, dance and brainwave generated material. In his writing *'Extended Musical Interface with the Human Nervous System - Assessment and Prospectus'* he describes his work as exploring:

"... such art forms as music, visual art, kinetic art and dance [...] "cross-cultural collaborations, performance art, computer music systems, interactive multi-media, compositional algorithms, and extended musical interface with the human nervous system." (Rosenboom 1990).

Rosenboom's musical works retain and create an aesthetic that can be enjoyed beyond the confines of objective medical exploration and research. It is perhaps the nature of subjective human interaction with the brainwave recordings combined with objective algorithms that enable this musical aesthetic within his work. When listening to Rosenboom's works one can hear that it is not pure objective sonification of brainwave events. There are subjective artistic, and perhaps emotive, interactions within Rosenboom's work that create aesthetic musifications of brainwave activity beyond pure sonification and data interpretation for medical purposes.

Within Rosenboom's music there is a diversity of musical timbre, repetition, rhythm, harmony, tension, dissonance, drones, atmosphere and dynamic that work artistically beyond neurofeedback data analysis. This kind of artistic work with EEG epilepsy events is relevant to this project work. A listener of electronic and experimental music does not need to know what has generated the music for it to have an aesthetic affect that could be enjoyable, disturbing, challenging, provocative, hypnotic and transformative.

From a listener's perspective, the sonification processes could be considered secondary in a purely aesthetic sense. Scientifically the objective data processing can be purposeful, rewarding and interesting but can also be manipulated for subjective aesthetic value.

Rosenboom has experimented with harmonic resonances found within brainwave patterns to transform into musical elements, combining science and technology with a musical aesthetic for performance. He describes this work as "*inquiring the nature of human awareness and what we perceive as the self and the universe.*" (Rosenboom 2015).

When listening to '*Brainwave Music*' by Rosenboom (1975), in the composition called '*Portable Gold and Philosophers' Stones*' (*Music from Brains in Fours*), one can hear modulations moving through the harmonic series. If you have ever swung a '*whirly-tube*' around, faster and slower with varying forces, you will recognize the sound of the tube modulating through notes from the harmonic series. This is due to the waveforms resonating within the body of the tube being directly relative to the tube's length. As the force or velocity of the tube swinging is increased it activates resonances at higher frequencies. In an open-ended resonating tube, there are wavelengths that are:

F1: Twice the length of the tube (*the fundamental harmonic*) e.g. 440Hz.

F2: The same length as the tube (*the first overtone an octave higher than the fundamental*), e.g. 880Hz

F3: $2/3^{\text{rd}}$ the length (*the second overtone an octave and a perfect fifth higher than the fundamental*) e.g. 1320Hz.

F4: Four times the length of the e.g. 1760Hz tube... and so on up the harmonic series in multiples of the original fundamental frequency (F1).

This musical phenomenon can be heard in Rosenboom's *'Brainwave Music'* is a familiar sound, the mathematics make sense and our brain enjoys it instinctively and aesthetically. On reading Rosenboom's paper called *'On Being Invisible'* (1982) he opens by stating:

"Much music is conceived physically under the broader concept of resonance. This includes the conception of the physical materials of music as being embodied in the geometry of vibrations of air molecules in a bounded space, inside which the concept of the "outside" of this space is meaningless." (Rosenboom 1982).

These resonances of the harmonic series are created by manipulating the source material from brainwaves with artistic intent emphasizing the harmonic content with electronic synthesis, this begins an artistic and aesthetic dialogue with brainwaves.

It is important to state this research will not be experimenting with commercial EEG related devices, of which there are several, that can convert EEG signals to MIDI information. BCI (*Brain Computer Interface*). There are issues with what exactly these commercial devices are measuring or sensing with their EEG devices. Muscle movement, blinking eyelids, muscle movements and spasms all effect the signal being recorded masking the lower level brainwaves of interest. (Miranda et al 2003).

Others have concerns about commercial EEG headsets. In an online article by Loren Grush (2017) called *'Those 'mind-reading' EEG headsets definitely can't read your thoughts. What EEG can and can't do'* asserts that commercial EEG headsets pick up anything that generates an electrical voltage such as muscle movement, heartbeats, eye movement, blinking and possibly not brain activity at all.

It is not ethical, and could be dangerous, to experiment with live epilepsy patients or myself for this project. This project work does not intend to induce any seizures specifically for the music created during this project, for these reasons this project work does not employ commercial EEG equipment. The public domain CHB-MIT Scalp EEG database of EEG epilepsy events, recorded at the Children's Hospital Boston, provide authentic source materials which are converted to digital audio specifically for this

project. The sonification and musification experiments have been carried out with the EEG epilepsy recordings using *'The Oblique-Granizer'* Granular synthesizer created specifically for this project (programmed with MAX/MSP), plus the application of digital music production techniques with Logic X sequencing software.

Inducing seizures specifically for a creative project has been attempted previously by a dance artist for a public performance in 2008 at Bradford Playhouse. The performance piece was called *'Involuntary Dances'* and was funded by a £13,889 arts council grant. The choreographer and dancer Rita Marcalo asserted that she was performing it to the public to raise awareness and challenge the stigma of the epilepsy condition. Representatives from Epilepsy Action and the *National Society for Epilepsy* doubted that this would reduce the stigma and might make audiences uncomfortable (The Telegraph 2009). Marcalo stopped taking medication of her own free will and held the performance for 24 hours but failed to induce a seizure. (BBC News 2009). Twelve hours into the performance with no seizure being induced, Marcalo stated that she became angry at her epilepsy because it often took control of her life and this was one opportunity where she was attempting to take control of it. Epilepsy was being difficult to control on her terms. Marcalo reflected positively saying that the performance had generated public discussion about the condition. (National Society for Epilepsy 2009). Marcalo received national media coverage highlighting the epilepsy condition, arguably achieving her objective without inducing a seizure.

3. Objectivity and Subjectivity: *'WITH and ABOUT'* Methodology.

Commercial artists have previously composed songs about epilepsy. They are subjective artistic realizations and include lyrical narrative explorations about the condition.

Examples include:

a). *'She's Lost Control'* – Joy Division. Released: Aug 1980. This includes a narrative about a girl Curtis knew who later died as a result of an epilepsy seizure; Curtis also suffered from epilepsy.

*“But she expressed herself in many different ways,
Until she lost control again.
And walked upon the edge of no escape,
And laughed I've lost control.
She's lost control again.”*

Written by Bernard Sumner, Ian Kevin Curtis, Peter Hook, Stephen Paul David Morris • Copyright © Universal Music Publishing.

The previous excerpt from the lyrics resonated with me because a person with epilepsy might not be able to keep full control of it, with or without medication, sometimes there is no escape. However, it is not the whole person's identity but a small part of who they are, they can *'express themselves in many different ways'*. They are not *'epileptics'* they are people with epilepsy. It is important to one's identity to be more than a labelled condition, the first line in Curtis' song alludes to this.

Being diagnosed with a medical condition introduces the mode of labelling. A person becomes a patient with a label, an objective that the diagnostic and curative processes must be applied to and carried out with. The result is a depersonalization and promotes a passivity to the mechanics of diagnoses and treatment. In the Wellcome Trust publication *'Where does it hurt?'* Batchelor and Cudd (2014) assert that this categorization affects self-confidence and independence. They identify a key aim in the self-care of vulnerable people is to *'promote the confidence of the patient and reduce stigma that is associated with a condition'*. This identity shift from person to patient is an

important psychological part of the individual being well. If I am now an epileptic what does that make me now? Has individuality been diminished by the condition? This psychological perception of who you are now (the labelled patient) is important. The labelling can be a negative transformation process. How can this transformation be positive, productive and independently creative? If the result of a diagnoses is recognized as causing depression, can this be avoided before the transformative thought processes related to the stigmas cause it?

Peter Hook (*Joy Division and New Order bass player*) writes that during the recording of 'Closer' Curtis went missing from the session and Hook eventually found him unconscious in the toilet after splitting his head open during an epileptic seizure, which he said happened often. After two unsuccessful attempts of suicide on the day before Joy Division's first American tour (18th May 1980) Ian Curtis took his own life at the age of 23. The medication Curtis was prescribed caused mood swings and he suffered from depression, having to cope with seizures during tours and recording sessions, culminating with the pressure of having to embark on an American tour. The stress, excitement, poor diet, lack of sleep and tiredness that life on the road in a band can cause, all of which can exacerbate the epilepsy condition. It is understandable to see how daunting this might have been for him. On viewing the film based on Curtis' life called 'Control' (2007), in which it details his medication prescription, I recognized one medication I had initially been prescribed called Carbamazepine (Tegratol). The medicine's information listed the side effects that included: headaches, dizziness, loss of coordination, problems with walking, nausea, vomiting, drowsiness, memory problems and dry mouth, plus thoughts of suicide in among 1-in-500 patients. I experienced strong side effects with this medication and eventually opted for the seizures rather than take the medication and continue with the side effects. Following diagnoses, one is also informed of SUDEP (Sudden Unexplained Death in Epilepsy) that patients with epilepsy

can experience, all can a negative psychological effect on a newly diagnosed sufferer of epilepsy.

In an interview with Q Magazine Joy Division's guitarist Bernard Sumner described how Curtis had met a girl with epilepsy at a rehabilitation centre where Curtis worked. She suddenly stopped coming in and he learned that she had passed away because of an epileptic seizure. Later Curtis started experiencing seizures himself whilst recording the Joy Division album *Unknown Pleasures*. Curtis' seizures got progressively worse until his suicide in 1980.

Another lyric important in the description of epilepsy is the following verse:

*“And she gave away the secrets of her past,
And said I've lost control again,
And a voice that told her when and where to act,
She said I've lost control again.”*

It is possible the previous lyric explores the inability to fully control yourself post-ictal (an altered state of consciousness following an epilepsy event). One might be completely absent from the reality of a situation even if one appears to be functioning or acting fully aware. The lyric from Joy Division's *'She's Lost Control'* describes this experience of appearing to function during an absence seizure; *“and a voice that told her when and where to act.”*

In a post-ictal state, one's inhibitions can also be reduced and one might say or do things out of character, or perhaps say something one would not usually express to another. The Joy Division lyric *“she gave away the secrets of her past, and said I've lost control again”* also illustrates this.

b). *'Epilepsy Is Dancing'* - Antony and the Johnsons. This is another narrative about a girl with epilepsy. In an interview with Martin Cranston for an online magazine called *'Fader'* in 2009, Antony Hegarty the singer of *'Antony and the Johnsons'* says:

“And she had this kind of wild experience where everything gets shiny and dancing - a vision almost -- and when she comes to, she’s frightened and has a sense of brokenness as well. The song is about how she was engulfed in chaos but then stepping back from it, she starts to see the pattern, starts to see the choreography of it, which is why I set the song to a waltz.” (Cranston, M. 2009).

The lyrics in Hegarty’s song describe the experience as “*dancing*” but I have not found this to be a suitable description. This analogy is often used but I do not consider it dancing, it is a daunting or sinister experience. In a paper called ‘*The Representation of Epilepsy in Popular Music*’ by Sallie Baxendale from the Institute of Neurology, University College London, she describes contemporary stereotypes of epilepsy in modern music lyrics as coming from a range of genres such as hip-hop and blues that include associations of epilepsy being of lunacy, madness and horror, but also associating it with euphoric dance and sexual ecstasy. (Baxendale 2008).

“*Dancing*” might not be considered a suitable analogy for epilepsy by sufferers of the condition. However, when Hegarty states “*she was engulfed in chaos but then stepping back from it, she starts to see the pattern, starts to see the choreography of it, which is why I set the song to a waltz.*” I can empathize with this distinction between “*dancing*” and the use of it as a metaphor for seeing the patterns and repetition that can be experienced during epilepsy events. When experiencing focal onset seizures (*also known as partial seizures which affect one part of the brain*) I can often feel it starting to happen before a full seizure occurs. A set of pre-determined steps, movements, experiences or feelings, that I have followed previously but cannot stop. I began to recognize the patterns having experienced multiple seizures. Hegarty also expresses a religious theme in the song ‘*Epilepsy is Dancing*’ which is often combined with epilepsy in historic narratives. In the first verse of the song he sings:

*“Epilepsy is dancing
She’s the Christ now departing
And I’m finding my rhythm
As I twist in the snow
Ooh now, it’s passing
Ooh now, I’m dancing”*

c). *'Epilepsy'* - by Aleksis Torri. A song not commercially released but made available in the public domain via YouTube. In Aleksis Torn's song about epilepsy he sings "*it's there creeping up on me*" which suggests something or someone with possibly evil or malevolent intentions. This was also my personal experience when developing epilepsy, I could feel it creeping up on me, other sufferers I have spoken with have also expressed that they can *'feel epilepsy coming closer'*. I am often reminded of Boris Karloff in the film *'Nosferatu'* (Figure 6). This became a visual image reference for epilepsy and my own descriptive perception, being effective beyond words.



Figure 6: Nosferatu (1922) Director: F.W. Murnau. Writers: Henrik Galeen. Bram Stoker (based on the novel: "Dracula"). Public domain.

The feeling that one experiences with focal onset seizures is initially one of euphoria but which quickly turns to fear once the feeling has been identified through multiple epilepsy experiences. A description recorded by an epilepsy nurse stated I had described it as a "*cosmic feeling*" on one occasion. It is easy to empathize why people without modern medical knowledge would develop other-worldly superstition and suspicion.

The specific lyrical descriptions of epilepsy might be useful and illuminating, as much as they might be inaccurate to some. The previous artists given as examples explore emotive subjective experiences to write lyrics and songs about epilepsy and not with the objective data. Whereas the medical algorithms and research that take purely objective data and create sonification and musification with this data that perhaps overlook any emotive and subjective experience. The aims of this project explore an artistic approach using the objective data and the subjective narratives. Incorporating exploration from

personal experience and cultural research alongside epilepsy data from EEG recordings, combining and transforming these elements in the creation of cinematic electronic music soundscapes to describe epilepsy events and experiences.

4. Ancient Medicine, Supernatural and Religious Themes.

Dancing has been historically linked to epilepsy for centuries, imagine being told that you must dance all day to cure your epilepsy and then becoming so exhausted that you died and went to hell immediately. In the medieval era dancing was considered a cure for epilepsy particularly in Brittany and Belgium. In the 15th century there was a traditional cure administered prior to St. Bartholomew's feast by a Franciscan inquisitor called Franciscus Florentinus who would make all the people who suffered from epilepsy dance at their local church all day, in the hope that they would be free from seizures for the rest of the year. Some sufferers died from exhaustion and were considered to have descended to hell immediately. (Murphy, E. 1959).

Temkin (1945) and Murphy (1959) also state that the protestant reformer Martin Luther (1483-1546) called epilepsy the *morbus demoniacus* (disease of demons or the devil).

Kanner (1930) stated that there were thirty-seven religious saints associated with epilepsy and convulsive illnesses. Saints were often invoked in superstitious cures.

In the early thirteenth century, there was a woman called '*Christina the Astonishing*' who was considered to have epilepsy and saintly credentials. She was also known as Christina Mirabilis, *Christina the Admirable*, *Saint Christina* and *Blessed Christin*, although she has not yet been formally *beatified* by a Pope (Catholic Saints.info 2008). Her life was documented by Cardinal Jacques de Vitny, who is said to have known her personally, and Thomas de Cantimpré professor of theology at Louvain whose account was recorded nearly a decade after her death by interviewing witnesses (Baxendale 2008). Christina's association with epilepsy begins with an incredible story of her being assumed to have died following a severe seizure, but leaping back to life from her open coffin during the

funeral service. It is reported that Christina levitated to the rafters of the church complaining that she could smell the stench of human sin. She was ordered down from the rafters by the priest to explain her behavior. Christina explained that she had been to hell, purgatory and heaven. She believed she had returned to earth to lead the recently died souls to purgatory, and those in purgatory she led to paradise in heaven. (Catholic Saints.info 2008 and Baxendale 2008). Christina experienced '*ecstasies*' (*physical senses being suspended*) and it was during these events that Christina stated that she was visiting purgatory saving souls. (Catholic Saints.info 2018). The instances of Christina's smelling the odours of sin could be explained by the odours or smells experienced by epilepsy sufferers in focal onset seizures. The '*ecstasies*' she experienced could be explained as tonic-clonic seizures.

Supernatural and religious themes appear throughout historic literature with regularity including many references to sufferers being possessed by demons or evil spirits, this was also recorded in Babylon several thousand years ago. Researchers at the Institute of Epileptology, King's College, London studied a Babylonian text, referred to as the epilepsy tablet from the era of the Babylonian king Adadapaliddina in the second century BC, which detailed neurological diseases with accurate descriptions of epilepsy seizures. The Babylonians did not know about the functions of the brain and considered epilepsy seizures to be supernatural possession of the patients by named demons associated with various seizure types. (Reynolds, E. et al 2008).

Over 3000 years ago in the ancient Indian medicine system called Ayurveda, epilepsy was described as Apasmara which means a loss of consciousness. (Pierce 2012).

Apasmara is also a mythological demon that the Hindu god Shiva dances upon within Hindu iconography that is associated with epilepsy. (Seshadri KG 2014).

Epilepsy also appears in the Bible where it is mentioned in three Gospels, an example being Jesus miraculously healing a child possessed by an unclean spirit with epilepsy in the Gospel of Luke, Chapter 9:

“38 And, behold, a man of the company cried out, saying, Master, I beseech thee, look upon my son: for he is mine only child.

39 And, lo, a spirit taketh him, and he suddenly crieth out; and it teareth him that he foameth again, and bruising him hardly departeth from him.

40 And I besought thy disciples to cast him out; and they could not.

41 And Jesus answering said, O faithless and perverse generation, how long shall I be with you, and suffer you? Bring thy son hither.

42 And as he was yet a coming, the devil threw him down, and tare him. And Jesus rebuked the unclean spirit, and healed the child, and delivered him again to his father.” Luke Chapter 9. King James Version.

Humans have been suffering and treating epilepsy for millennia. Treatments have ranged from casting out demons or evil spirits, numerous medications, operating on the sufferers and sterilization by the Nazis (1933). The Nazis introduced a law called *“The Law for the Prevention of Hereditarily Diseased Progeny”* (Gesetz zur Verhinderung erbkranken Nachwuchses) which legalized the sterilization of psychiatric patients and their families who suffered from illnesses such as epilepsy, schizophrenia, depression, physical deformities, alcoholism, congenital blindness and deafness. The law was based on an American eugenicist called Harry Hamilton Laughlin from the early 1940’s. (Noack et al. (2007). Hippocrates explored epilepsy in his **writing ‘On the Sacred Disease’** 400 B.C.E. He viewed people who considered epilepsy as a supernatural force, or having a sacred character, as charlatans and magicians hiding behind superstition. They had no idea of what caused the condition and created mythological or religious stories to hide their ignorance, devising superstitious remedies and treatments to maintain their position of power and knowledge (Jones, 1923). The research carried out for this thesis into the sociocultural themes related to epilepsy are of creative interest and inspiration, they form narratives within the musification of the EEG data. The sociocultural research will give the creative aesthetic direction and conceptual substance, just as cinema provides the story and music underpins its narratives. An example of this can be found in the musification soundscape entitled *‘Dante and Virgil Descend past the Minotaur’*.

4.1. 'Dante and Virgil Descend past the Minotaur'

This soundscape explores the religious themes presented by the historical perceptions of epilepsy and uses these as an aesthetic narrative for the creative musification of the epilepsy EEG data. In the first part of Alighieri's epic poem '*The Divine Comedy - the Inferno*,' it describes Virgil leading Dante in their descent to hell past the Minotaur in recognition of sin, then ascending through purgatory in the renunciation of sin.

(MacAllister, A, T. 2009). This narrative from the poem also evokes the story of Franciscus Florentinus' dancing cure for epilepsy, the participating sufferers were free from epilepsy for the year but if they failed they descended straight to hell.

These narratives were explored as psychological stimuli during the creation of the soundscape '*Dante & Virgil Descend Past the Minotaur*'. Sounds of descending and ascending pitch were designed that illustrate Dante and Virgil's descent into hell and their ascent through purgatory. This soundscape also employs a church styled organ instrument synthesized from the EEG data to subliminally suggest religious themes. The following quote is taken from '*Dante Alighieri - The Inferno*' (1317) translated by John Ciardi (1954).

"The Poets begin the descent of the fallen rock wall, having first to evade the MINOTAUR, who menaces them. Virgil tricks him and the Poets hurry by."

As a bull that breaks its chains just when the knife has struck its death-blow, cannot stand nor run but leaps from side to side with its last life

So danced the Minotaur, and my shrewd Guide cried out: "Run now! While he is blind with rage! Into the pass, quick, and get over the side!"

So we went down across the shale and slate of that ruined rock, which often slid and shifted under me at the touch of living weight.

I moved on, deep in thought; and my Guide to me: "You are wondering perhaps about this ruin which is guarded by that beast upon whose fury I played just now. I should tell you that when last I came this dark way to the depths of Hell, this rock had not yet felt the ruinous blast.

But certainly, if I am not mistaken, it was just before the coming of Him who took the souls from Limbo, that all Hell was shaken. (Ciardi 1954).



Play composition called '*Dante & Virgil Descend Past the Minotaur*'

The historical superstitions surrounding epilepsy are narratives used as creative inspiration for the cinematic soundscape, but do not support epilepsy as a religious punishment or affliction. However, the experiences of pre-seizure auras do have a euphoric feeling that, with some imagination, could be misunderstood as being associated with religion by a superstitious culture living in the medieval ages.

5. Sonification, Musification and Mapping.

Psyche et al (2014) state. *“Methods to sonify EEG data remain relatively unique as some have devised means but no method has shown an extreme utility compared to any other”*.

For this project to be successful it will need to map the EEG data in some form or another, this initiated the research for others who have researched this previously. Some have used electronic equipment such as EEG headsets for performance and composition. The first person to use an EEG headset as an electronic compositional tool was Alvin Lucier with *'Music for a Solo Performer'* 1965. This is an innovative, noisy and primitive exploration of EEG composition created over 50 years ago employing alpha brainwaves waves and rhythms. (Straebel, Thoben, 2014). Lucier's brainwaves were influenced by sounds from the audience, when he closed his eyes and concentrated on minimizing his brain activity or when engaged in mental exercise. Lucier used these changes in brainwave activity to consciously to influence the EEG signal by suddenly opening his eyes and changing his conscious thought patterns. This was the first time someone had a certain amount of control on an audio signal in a music performance, a groundbreaking experimental piece of EEG music performance.

“By letting go of control, Lucier passively inserted himself into the music circuit, contributing just as much to the music as the technological components within the system.” (Lutters, B., & Koehler, P. 2016).

In Lucier's piece, the brainwaves required the signal to be used as an agitator in combination with an additional element that resonated with its own inherent harmonics within the human hearing range, such as a cymbal. If the EEG frequencies are used

directly for sonification they require transposition, this is because brainwaves captured by EEG are low frequencies between 0.5 to 42 Hz which are below, and at the low end of the human hearing range. The human hearing range is approximately 20-20,000 Hz, with the high frequency range dropping dramatically as we get older. In audiometric tests, I am unable to hear frequencies above approximately 14kHz.

“Alpha activity is induced by closing the eyes and by relaxation, and abolished by eye opening or alerting by any mechanism (thinking, calculating). Most of the people are remarkably sensitive to the phenomenon of “eye closing”, i.e. when they close their eyes their wave pattern significantly changes from beta into alpha waves.” (Teplan 2002).

This is a self-directed creative project; commercial EEG equipment or pre-existing musification software have not been employed. They lie outside the remit of this creative project. As previously asserted it must be considered unethical to experiment with epilepsy sufferers in real-time for musification purposes. The public database of pre-recorded EEG data sets from epilepsy events provide an ethical approach for this creative project work. Questions asked at the beginning of this project included - will the sounds of epilepsy be created through pure subjectivity or use objective processes and algorithms? How will EEG epilepsy events be mapped to musical works? Purely subjective musification and/or objective sonification?

5.1 Mapping Experiment #1.

As an initial starting point, an experiment was carried out in the creation of a tribute musification to Hans Berger, Nilolai Guleke and Zedel with objective mapping to a musical stave. Hans Berger first recorded human EEG signals while a neurosurgeon called Nilolai Guleke operated on a seventeen-year-old male student called Zedel who had experienced two previous cranial operations for the removal of a brain tumor. This experiment employed a simple overlay method using the image of the first human EEG recording of brain activity (*Figure 7*). This was loaded it into an image editor, overlaid with a treble and bass clef and finally notating the peaks of the waveforms that

intersected the staff lines (Figure 8). A musical structure was maintained with correct number of note values per bar. The result of this experiment can be seen in Figure 9 and heard in ‘*The Esoteric Voyage of Hans, Nikolai & Zedel (1924) Audio Example*’. This is an extended composition that employs the resulting themes provided by four bars of EEG notation with additional subjective music production techniques.

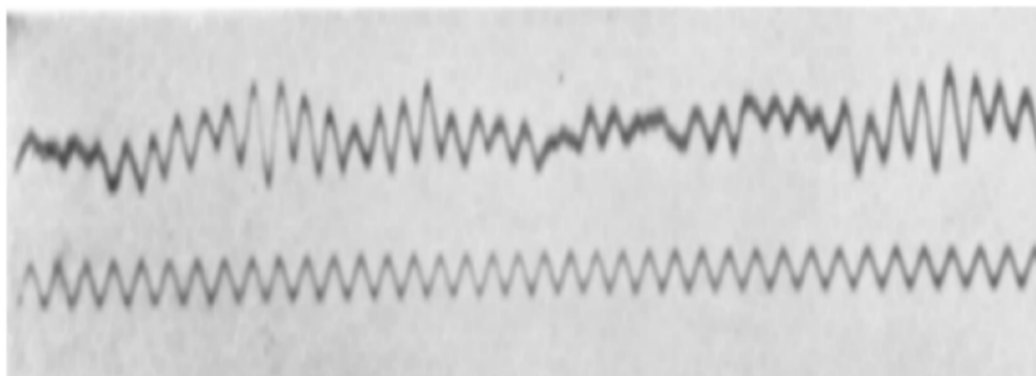


Figure 7: The original Hans Berger (1924) image above,

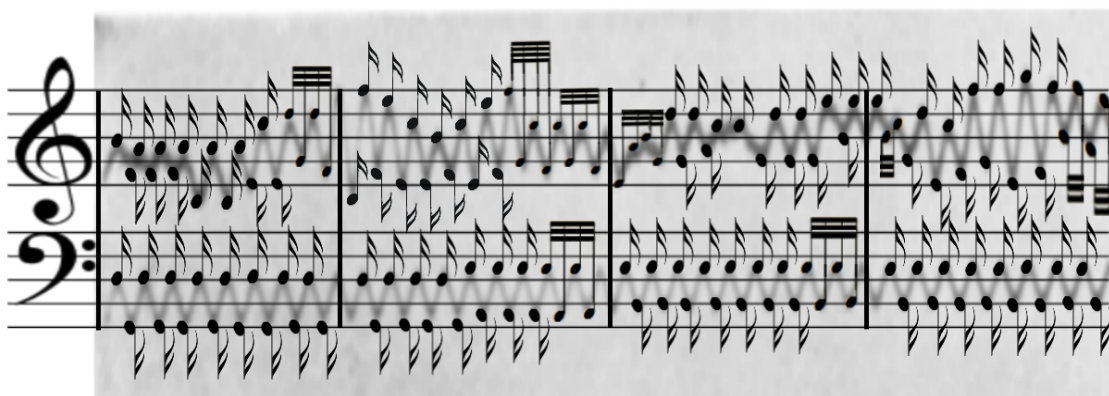


Figure 8: Overlaid the bass and treble stave and notes above.

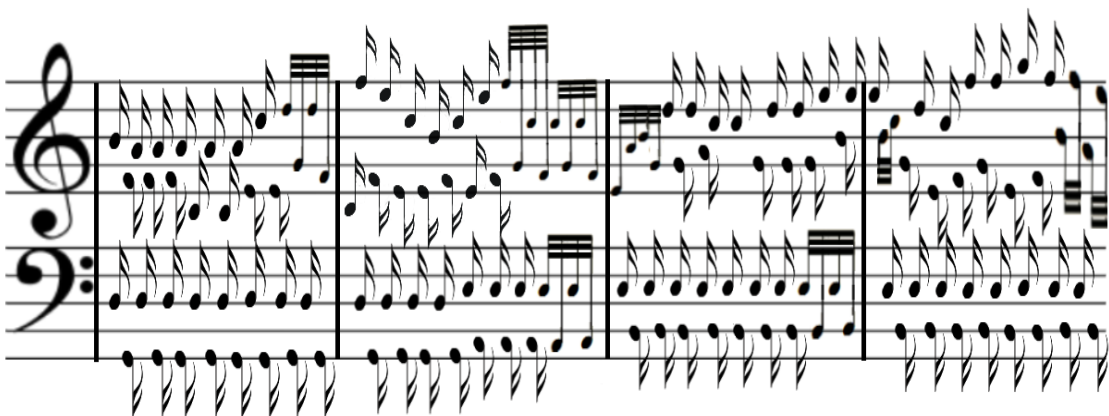



Figure 9: The resulting notation above with the Hans Berger (1924) image excluded.

The results were effective in relation to providing a rhythmic structure and melodic information. It was interesting to hear a musification of these pioneering EEG events 93 years after their capture. The 10 Hz guide signal in the lower part of the visual EEG recording provided a stable and repetitive structure for a bass pattern, with the complex nature of the waveform of Zedel's brain activity in the top section of the image provided the treble pattern and melodic activity. The musification process also included subjective arrangement techniques and the application of modern production values, incorporating audio effects and automation, to produce approximately three minutes of music with this musification experiment.

 **Play composition called *'The Esoteric Voyage of Hans, Nikolai & Zedel (1924)'***

6. Exploration and Examination of Musification and Mapping Technique #1 (Wu et al 2009).

Although medical research was not the original intention for this project work, it is interested in the methods previously used for medical sonification and musification of EEG data. The research paper called 'Scale-Free Music of the Brain' by Dan Wu¹, Chao-Yi Li^{1,2}, De-Zhong Yao¹ (2009) was examined during the research process of this thesis. The paper states:

"... Sonification rules may identify the mental states of the brain, which provide a real-time strategy for monitoring brain activities potentially useful to neurofeedback therapy?" Wu, D. et al (2009).

It is crucial to this project work that the EEG epilepsy data can be mapped to music and sound. Analysing the methods Wu et al (2009) employed to map EEG data for 'Scale Free Music of the Brain' provided an opportunity to assess and apply techniques developed in this area of research. Wu et al (2009) employed mathematical algorithms in the musification process. Reverse engineering the methods they employed provided an insight into this discipline. Wu et al (2009) first "established a sonification rule between the amplitude of an EEG waveform and the pitch of a musical note." Understanding the Wu et al model was important in gaining a detailed awareness of the musification of EEG data.

Wu et al: "Mapping the change of EEG power energy to notes volume according to the Fechner's law, and the period of EEG to the notes duration. [...] According to Fechner's law, the relationship between music pitch and the frequency (fM) of an instrument is..." (Wu et al, 2009).

$$\text{Pitch} = c \log_{10} fM + d$$

"... where $c = 40$ and $d = -36.6$ In the MIDI standard, there are 128 pitch steps with semitone intervals among them. In this work, we choose the usual pitch range [24 108] with the frequency fM in the range [33 4186] Hz. [...] We usually take the maximal value of amplitude $Amp = 200$ mV, and the x values of EEG range from 0.5 to 1.5. In this work, unit mV was took directly, because the only difference for different unit is the constant n . If we choose $x=1.10$ and with $c=40$, we have $R=84$; thus, the pitch may vary from 24 to 108 in the range of the 128 pitch steps in MIDI." (Wu et al, 2009).

If the range of an instrument is between 33Hz and 4186Hz the previous equation defines a Hz frequency range between 33Hz and 4186Hz mapped to a musical range between 24 and 108 MIDI note numbers.

$$33\text{Hz} \rightarrow 33 \log_{10} x 40 - 36.6 = \text{MIDI note } 24$$

$$4186\text{Hz} \rightarrow 4186 \log_{10} x 40 - 36.6 = \text{MIDI note } 108$$

* Note: In the Wu et al document states "... where $c = 40$ and $d = -36.6$ In the MIDI standard" but in calculation of the equation $-40 / 1.1 = -36.363636363636$, and/or, the relationship between 440 and 12 notes = $440 / 12 = 36.6666$ possibly a typo or rounding? Although this possible rounding or typo results in little difference to the outcome of an integer MIDI note number.

R = Range of MIDI notes:

where $c = 40$

where $x = 1.1$

where Max Amp = 200uV

$$R = c / x \log_{10} \text{Amp}$$

$$40 / 1.1 x (200 \log_{10}) = 83.6738 \text{ (84)}$$

Taking a range of 84 notes between MIDI notes 24 and 108 (Wu et al, 2009).

Wu et al then used the following algorithm to calculate note pitches from the amplitude of segmented windows within an EEG waveform:

$$\text{Pitch} = m \log_{10} \text{Amp} + n$$

where $c = 40$

where $m = -c / x = m = -36.3636364$

where $x = 1.1$

where $n = \text{MIDI note } 108 = C8$

(Wu et al, 2009).

Wu et al gave an example of EEG generated notation derived from an EEG Graph (*figures 10 & 11*) via the previous equation. The EEG amplitude levels were mapped to derive the note pitch and the segmented wavelength cycles were used to obtain note duration.



Figure 10: Wu et al's 'Scale Free' EEG notation.

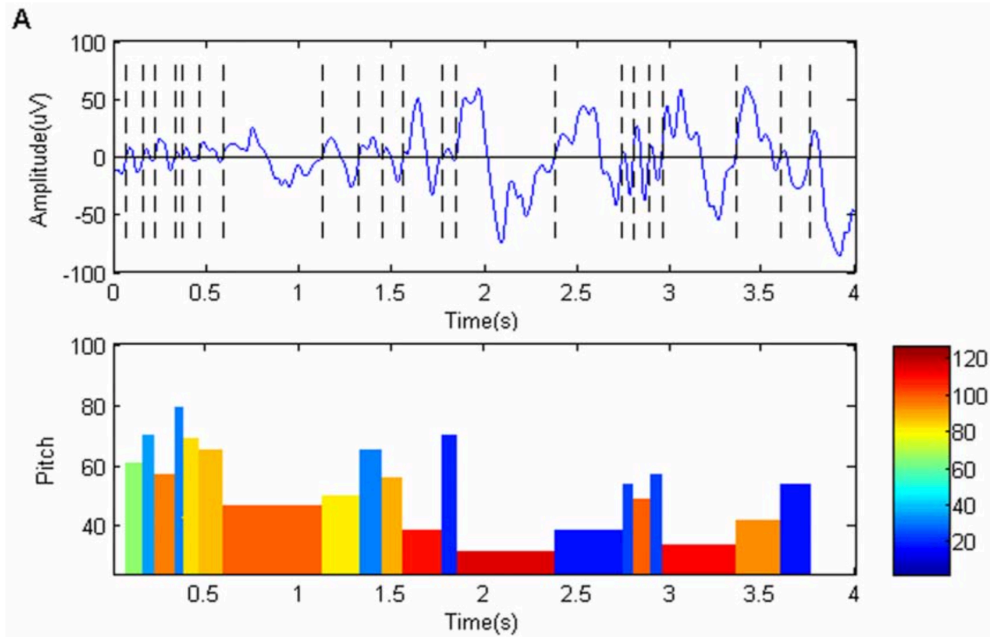


Figure 11: Wu et al's 'Scale Free' EEG segmentation and amplitude graph.

Wu et al's formula had the result of assigning lower amplitudes measured to higher pitch/notes.

6. 1 Testing Wu et al Musification Formula and Mapping.

Experimenting with the formula and the notation provided by Wu et al created an opportunity for comparison with the final data they produced. Nobel Prize winner Sir Paul Nurse stated on the BBC documentary 'Science Under Attack' when viewing the archives of the Royal Society:

"350 years of an endeavor which is built on respect for observation, respect for data, respect for experiment. Trust no-one. Trust only what the experiments and the data tell you." (Nurse, P. 2011)

Working through the formula and resulting notation provided by Wu et al enabled an understanding of the equation they employed. The same MIDI note and amplitude results were derived when experimenting with their equation. A final checking process

was carried out by mapping the derived notes to a MIDI piano in Logic X sequencer and viewing the notation which also confirmed the same results. The final notation of these results sounded like a random set of notes, hence Wu et al calling it 'Scale Free Music of the Brain.' The resulting notation may not relate to cultural acceptance of note structuring through traditionally recognized musical scales, or perhaps what is considered as popular music.

 **Play – 'Example 2-Mapped Notes - Wu examination-120bpm'**

Note 1: is C₄ on the bass clef from the Wu et al notation (*figure 10 page 40*) using 1.1uV as the reference.

$$\text{Pitch} = m \log_{10} \text{Amp} + n$$

$$(m) = -40/1.1 = -36.36363636 \times (\log_{10} \text{Amp} = 21 \log_{10}) = -48.0807016 (-48)$$

$$-48 + (n) = 108 = \text{MIDI note } 60$$

$$\text{e.g. } 261.63\text{Hz} \rightarrow 261.63 \log_{10} \times 40 - 36.6 = 60.1075016 = \text{MIDI note } 60 = \text{C}_4$$

Note 2: is A₄ on the bass clef:

$$-40/1.1 = -36.36363636 \times (11.8 \log_{10}) = -38.9775275 (-39)$$

$$-39 + 108 = \text{MIDI note } 69$$

$$\text{e.g. } 440\text{Hz} \rightarrow 440 \log_{10} \times 40 - 36.6 = 69.138107 = \text{MIDI note } 69 = \text{A}_4$$

Note: The full calculations and resulting notes from testing the Wu et al formula is included in: Appendix B: Table 1 *Testing Wu et al formula Results* (page 105).

The examination of Wu et al's methodology provided a valuable opportunity to explore the mathematics used for the musification of epilepsy data in a previous study. However, as Miranda et al (2003) who carried out research called 'On Harnessing the Electroencephalogram for the Musical Braincap' states:

"The problem is that the raw EEG data is a stream of unsystematic, random-like numbers of little musical interest. Sophisticated analysis tools are needed to decipher the complexity of the EEG before any attempt is made to associate it with musical parameters, and this is a very difficult problem." Miranda et al (2003).

7. Exploration of Musification and Mapping Technique #2 (Kiong et al 2014).

“According to Fechner’s law, the pitch and its corresponding frequency follow the exponential relationship, which is shown: $f = \text{base} \times 2^{(P - P_{\text{base}} / 12)}$.” (Kiong et al 2014).

Researchers Chu Kiong Loo et al (2014) used a musification formula incorporating ‘Fechner’s law’ for creating frequency ranges and MIDI pitch notes. They incorporated this in the examination of EEG for musical results for their research paper ‘*Signification for EEG Frequency Spectrum and EEG-Based Emotion Features*’. In this second examination of an EEG musification method there is another reference to the application of the Fechner’s Law in an EEG musification process, but what is its relationship within Kiong et al’s EEG equation?

7.1 Weber-Fechner Law.

This law describes the subjective perception of an objective stimulus. It is not perfect but adequately describes people's responses or perceptions of fluctuation in stimulus. The stimulus might be any measurable objective, weight is an example. If a weight is held by a person and the load is increased, there is a point where the weight increase is just noticeable. If 1kg was being held and a gram were added then this might not be noticeable, if this is further increased enough that the person holding the 1kg weight notices the additional weight, then the ‘*just noticeable difference*’ (JND) ratio can be calculated. This might be 5 grams as an example, the JND ratio will be the just noticeable weight increase divided by the initial weight: $JND \text{ Ratio} = 5 / 1000 = 0.005$

This means that if that person was given a 3kg weight, the JND ratio could be applied to derive the noticeable difference by multiplying the new weight by the JND ratio. The JND threshold could be approximated and added: $3000 * 0.005 = 15 \text{ grams}$

As a basis for measuring subjective perception this JND ratio becomes the value by which any weight can be multiplied to obtain the JND. Although not perfect, because

perception is subjective to individuals, it does offer some calculable common ground for measuring or mapping possible outcomes. This can also be seen with measurements such a Sound Pressure Level (SPL). The smallest sound a human can hear is said to be 0.00002 Pascals (Pa). One decibel fluctuation in sound pressure level (dB SPL) is the unit that is considered a just noticeable difference.

This is a ratio of: $10^{(1/20)} = 1.122018454301963$

Any multiplication of a measured SPL by this ratio results in an addition of 1 dB SPL. For example, the JND beyond the reference level for Pa is:

$$0.00002 \text{ Pa} \times 1.122018454301963 = 0.000022440369086 \text{ Pa}$$

$$20\log(0.000022440369086 / 0.00002) = 0.9999999999848 = 1 \text{ dB SPL}$$

Choose any Pa level and multiply it by the JND ratio will result in an addition of 1 dB SPL

$$14 \text{ Pa} \times 1.122018454301963 = 15.70825836022749 \text{ Pa}$$

$$20\log(15.70825836022749 / 14) = 1 \text{ dB SPL}$$

Multiply any Pa level by the JND ratio numerous times, for example by the power of 3:

$$14 \text{ Pa} \times 1.122018454301963 \times 1.122018454301963 \times 1.122018454301963 =$$

$$19.77552562471854 \text{ Pa}$$

$$20\log(19.77552562471854 / 14) = 3 \text{ dB SPL}$$

As the stimulus is multiplied by the JND ratio there is an addition of perceived sensation.

This has been applied in Wu et al and Kiong et al's musification mapping methods.

Using the JND with the MIDI note standard of one semitone, the relationship for any noticeable difference in this standard will be:

$$2^{(1/12)} = 1.059463094359295 = \text{ratio of 1 semitone}$$

Any frequency multiplied by this ratio will be an addition of 1 semitone:

$$440\text{Hz (A}_4) \times 1.059463094359295 = 466.1637615180898\text{Hz (A}\#_4)$$

$$130.81\text{Hz (C}_3) \times 1.059463094359295 = 138.5883673731394\text{Hz (C}\#_3)$$

Again, if Hz is multiplied by this JND ratio multiple times (*exponentially*) it will result in an addition of semitones relative to the power of multiplication e.g. 3 semitones:

$$440\text{Hz} * 1.059463094359295 * 1.059463094359295 * 1.059463094359295 = 523.2511306011969\text{Hz}$$

$$\log_2(523.2511306011969 / 440) * 12 = 3 \text{ semitones} + 69 = \text{MIDI note } 72$$

However, on further reading and examination what is also true about this law is that there is a deeper logarithmic relationship between the JND and the JND ratio.

The *log of the stimulus* plus the *log of the JND ratio* provides the log of the next stimulus.

$$10^{(\log SI + \log JND \text{ Ratio})} = \text{next stimulus value.}$$

$$466.1637615 \text{ Hz} / 440 \text{ Hz} = 1.05946309431818 \text{ (JND ratio)}$$

$$\log 1.05946309431818 = 0.025085832955145 \text{ (log of JND ratio)}$$

$$\log 466.1637615 = 2.668538509441333 \text{ (log of stimulus)}$$

$$2.668538509441333 + 0.025085832955145 = 2.69362434239633$$

$$10^{2.69362434239648} = 493.8833012177951 \text{ Hz} = \text{next stimulus value.}$$

It is also true that $10^{(\log JND + \log JND \text{ ratio})}$ provides the value is added to the current stimulus for the next stimulus intensity (SI).

$$10^{(\log JND + \log JND \text{ ratio})} + \text{current stimulus} = \text{next stimulus value.}$$

For example:

$$10^{(1.41770018159636 + 0.025085832955)} = 27.71953971778277 + 466.1637615 \text{ Hz} = 493.88330121778277 \text{ Hz}$$

Note: Included in Appendix A (page 104) of this document is a table with the implementation of the Weber-Fechner law in a musical context.

* Weber-Fechner Law reading sources: (Nutting, P. G. 2017. Woodruff, B. 2002).

7.2 Application of Weber-Fechner Law Within Kiong et al MIDI Note Hz Mapping

Method. The Kiong et al formula is as follows:

$$F = fbase \times 2^{(p-pbase) / 12}$$

Where:

$$fbase = 440 \text{ Hz}$$

$$pbase = \text{MIDI note base relating to } 440 \text{ Hz}$$

$$p = (k \times f \text{ origin} + b)$$

Where:

$$k = P \text{ high} - P \text{ low} / 50\text{Hz}$$

$$f \text{ origin} = \text{low or high Hz range}$$

$$b = P \text{ low MIDI note}$$

Chu Kiong et al mapping frequency formula:

$$f_{target} = fbase \times 2^{((k \times f \text{ origin} + b) - pbase) / 12}$$

With an EEG frequency range of 0.1 to 40Hz:

$$k = P \text{ high} - P \text{ low} / 50\text{Hz} = 108 - 24 / 50 = 1.68$$

$$f \text{ base} = 440 \text{ Hz}$$

$$f \text{ origin} = \text{between } 0.1\text{Hz or } 50\text{Hz (EEG Filtered frequency range)}$$

$$b = P \text{ low} = 24 \text{ (MIDI note)}.$$

Low range Hz:

$$440 \times 2^{(((1.68 \times 0.1) + 24) - 69) / 12} = 33\text{Hz}$$

$$1.68 \times 0.1 + 24 - 69 / 12 = -3.736$$

$$2^{-3.736} = 0.075050214217826 \times 440 = 33.02209425584324 \text{ (33Hz)}.$$

High range Hz:

$$440 \times 2^{(((1.68 \times 50) + 24) - 69) / 12} = 4186\text{Hz}$$

$$1.68 \times 50 + 24 - 69 / 12 = 3.25$$

$$2^{3.25} = 9.513656920021768 \times 440 = 4186.00904480957792 \text{ (4186Hz)}$$

Conversion of Hz range to MIDI notes:

$$\text{MIDI note} = \log_2 (\text{Hz} / 440) \times 12 + 69$$

Low range MIDI note:

$$\log_2(33 / 440) \times 12 + 69 = 24 = \text{MIDI note } 24.$$

High range MIDI note:

$$\log_2(4186 / 440) \times 12 + 69 = 108 = \text{MIDI note 108.}$$

Note: If the calculator does not have access to a log₂ button, the above is carried out as follows:

$$\log(33 / 4400 / \log(2) \times 12 + 69 = 24 = \text{MIDI note 24.}$$

$$\log(4186 / 440) / \log(2) \times 12 + 69 = 108 = \text{MIDI note 108}$$

When analyzing Kiong et al's equation they have used the 0.1-50 Hz range from the EEG data and they have calculated high and low note pitch range, but what is the relationship in the increase of EEG Hz within the equation per semitone? This is highlighted this in red:

$$F = f_{base} \times 2^{(((k \times f_{origin} + b) - p_{base}) / 12)}$$

Low Range Hz:

$$440 \times 2^{(((1.68 \times 0.1) + 24) - 69) / 12} = 33\text{Hz}$$

$$1.68 \times 0.1 + 24 - 69 / 12 = -3.736$$

$$2^{-3.736} = 0.075050214217826 \times 440 = 33.02209425584324 (33\text{Hz}).$$

High Range Hz:

$$440 \times 2^{(((1.68 \times 50) + 24) - 69) / 12} = 4186\text{Hz}$$

$$1.68 \times 50 + 24 - 69 / 12 = 3.25$$

$$2^{3.25} = 9.513656920021768 \times 440 = 4186.00904480957792 (4186\text{Hz}).$$

MIDI note 24 to 25

- Checking against semitone ratio formula: $\text{Hz} \times 2^{(1 / 12)} = 1.0594630943593 \times 32.70319566 \text{ Hz} = 34.64782887 \text{ Hz}$
- Formula for Hz to MIDI note: $\log_2(\text{Hz} / 440) \times 12 + 69 = \text{MIDI note number}$
 $\log_2(34.64782887 / 440) \times 12 + 69 = 25 = \text{MIDI note number 25.}$
An alternative is: $n = 69 + 12 \times \log(\text{freq}/440) / \log(2) = \text{MIDI note number 25}$
- Finding the **X** Hz of the first increase by working backwards from the Hz:
 $34.64782887 \text{ Hz} / 440 = 0.07874506561364 \rightarrow \log_2 = -3.666666666754417 \times 12 = -44.000000001053 + 69 = 25 - 24 = 1 \quad 1 / 1.68 = 0.5952380952381$
 $440 \times 2^{(((1.68 \times 0.5952380952381) + 24) - 69) / 12} = 34.64782887 \text{ Hz}$
- Finally, **X** fluctuation in Hz per semitone within the equation = $0.59523809524601 - 0.00000000000793 = 0.59523809523808 \text{ Hz (approx. 0.6 Hz).}$

MIDI note 25 to 26

- Checking against semitone ratio formula: $\text{Hz} \times 2^{(1/12)} = 1.059463094359293 \times 34.64782887 = 36.70809598744145 \text{ Hz}$
- Finding the next **X** Hz:
 $36.70809598744145 / 440 = 0.08342749088055 \rightarrow \log_2 = -3.583333333421132 \times 12 = -43.00000000105358 + 69 = 25.99999999894642 - 24 = 1.99999999894642 / 1.68 = 1.19047618984906$
 $440 \times 2^{(((1.68 \times 1.19047618984906) + 24) - 69) / 12} = 36.70809598744205 \text{ Hz}$
- Finally, **X** fluctuation in Hz per semitone within the equation = $1.19047618984906 - 0.5952380952381 = 0.59523809461096 \text{ Hz}$ (approx. 0.6 Hz).

MIDI note 107:

$$440 \times 2^{(((1.68 \times 49.40476190476990) + 24) - 69) / 12} = 3951.06641005206944 \text{ Hz}$$
$$2^{(((1.68 \times 49.40476190476990) + 24) - 69) / 12} = 8.979696386481976$$

MIDI note 108:

$$440 \times 2^{(((1.68 \times 50) + 24) - 69) / 12} = 4186.0090448 \text{ Hz}$$
$$2^{(((1.68 \times 50) + 24) - 69) / 12} = 9.51365692$$
$$9.51365692 / 8.979696386481976 = 1.059463094 \text{ (the ratio between semitones).}$$

In Kiong et al's formula when the EEG Hz increases or decreases by 0.6 Hz there is an exponential increase by 1.05946309435929. The note pitch increases or decreases by 1 semitone.

Knowing the base EEG Hz ranges for note pitch would allow for programming of modal interpretation of EEG data, one could exclude or ignore the Hz ranges that do not adhere to a chosen modal scale. This would allow for breaks in note triggering as well as promote diverse note duration, or the space in-between triggered notes. This would create opportunities for creative movement towards musification than pure sonification. For example, we could choose the Aeolian Mode in C (C, D, Eb, F, G, Ab, Bb), calculate the EEG Hz values within the formula and reject any falling outside of this range as follows: $440 \times 2^{(((1.68 \times x) + 24) - 69) / 12}$.

Table 10: The value of 'x' in Kiong et al's formula for the Aeolian Mode.

C1	D1	Eb1	F1
0.000000000000793	1.19047619048413	1.78571428572222	2.97619047619841
G1	Ab1	Bb1	C2
4.16666666667461	4.76190476191270	5.95238095238890	7.14285714286509

These previous musification equations also specify a base and a range for high and low frequencies.

440Hz = MIDI note 69 (base)

High note 108

Low note 24

Therefore, any noticeable difference can be calculated incorporating the base and the range confines, whilst still adhering to the JND. This relates it to the changes in either EEG Hz or voltage amplitudes, whichever is chosen as the stimulus i.e. any fluctuations between these factors (Hz or uV) can be mapped and quantized to the MIDI note standard. This is at the centre of what researchers Wu et al and Chu Kiong et al are doing when mapping the amplitude of EEG voltages and cyclic Hz fluctuations to pitch for musification purposes. They are effective, functional ideas and processes that yield results. The brainwave Hz is mainly below human hearing range and does not produce wide enough fluctuation ranges for linear mapping to musical note Hz fluctuations. The formula applied in the work of Wu et al where the stimulus is the amplitude of voltage mapped to MIDI note pitch standards, and the work of Chu Kiong et al where linear fluctuations in EEG brainwaves is mapped to exponential fluctuations in musical pitch Hz are therefore effective mapping techniques in a musification process.

8. Mapping Experiment #2:

Experiment with Wu et al EEG Graph Data.

This is an experiment with the visual EEG graph data provided by Wu et al. It was carried out by calculating a ratio between the full window of time and the cyclic length of the segmented waveforms, then mapping them to frequency Hz. The calculations were carried out by visually measuring the data provided in the Wu et al waveform graph (figure 11, page 40) to calculate ratios combined with chosen EEG Hz sample rates.

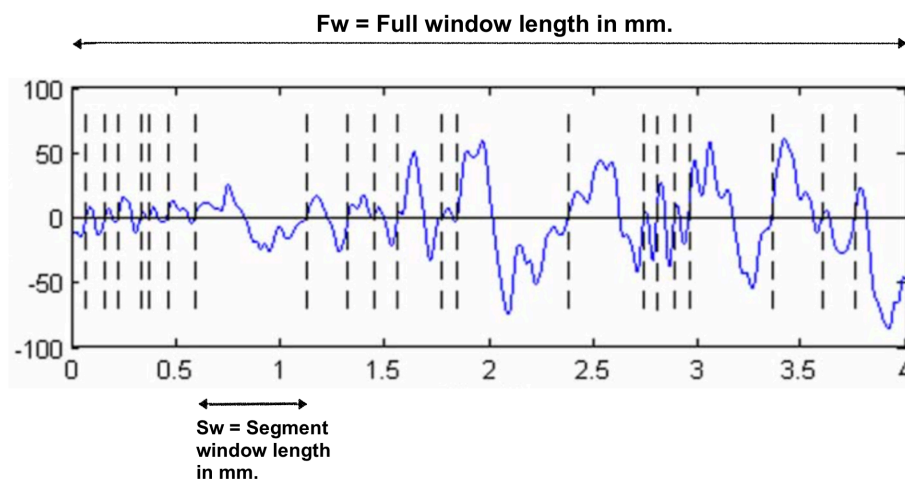


Figure 12: Experiment with Wu et al Graph Data.

Method: Devising a formula for deriving the Hz for each segmented window in the Wu et al EEG graph data using conversion from visual measurements in mm to Hz.

$$\text{Cycle Hz} = B / S$$

$$S = ((F_s / (F_w / S_w)))$$

$$R = F_w / S_w$$

$$S = F_s / R$$

Where:

S = samples in the segment.

B = bandwidth sampler rate of EEG in Hz.

F_s = full segment window length in no. of samples.

F_w = full window length in mm.

S_w = segment window chosen in mm.

R = ratio between full window and segment.

The ratio of each zero-crossing segmented waveform in the graphical representation of EEG activity can be calculated by using the full window length divided by the segment chosen to arrive at a ratio. If the full window length is known in seconds, the ratios between full window length and segments can be used to calculate the frequency in Hz of each cyclic waveform from the resulting number of samples within the full window provided.

The chosen sample rate will determine how many samples are in the full window length, and how many samples are in each segment. The pitch (frequency Hz) can be calculated using the following formula: $\text{Hz} = \text{Fw} * (\text{B} / \text{R})$

Where:

* **Fw** = length of full EEG window chosen e.g. 4 seconds.

* **B** = sample rate chosen e.g. 44,100 per second.

* **R** = ratio of zero-crossing segments e.g. 1/16th of full window length.

Measure the length of full window e.g. 40cm (400mm)

Measure the chosen segment e.g. 2.5cm (25mm)

Divide full window length by segment length to derive ratio, $40\text{cm} / 2.5\text{cm} = 1/16\text{th}$ ratio.

If the full window is 4 seconds at 44,100 samples per second ($4 * 44,100 = 176,400$), divide this by 16 to arrive at how many samples the segment will be.

$$176,400 / 16 = 11,025 \text{ samples in the segment.}$$

Then apply the following formula to derive the frequency (Hz):

1). How many samples in a given frequency (Hz)?

Sample rate / frequency (Hz) = samples

441Hz at a sample rate of 44100 = $44100 / 441 = 100$ samples.

2). What is the frequency Hz in a given number of samples?

Sample rate / no. of samples = frequency (Hz)

441Hz at a sample rate of 44100 = $44100\text{Hz} / 100 \text{ samples} = 441 \text{ Hz.}$

Confirmed by examining this in a digital wave editor with a signal generator set to 441Hz and counting the number of resulting samples (see following Figure 13).



Figure 13a: 100 samples = 441 Hz confirmation via signal generator and bounced into wave editor.

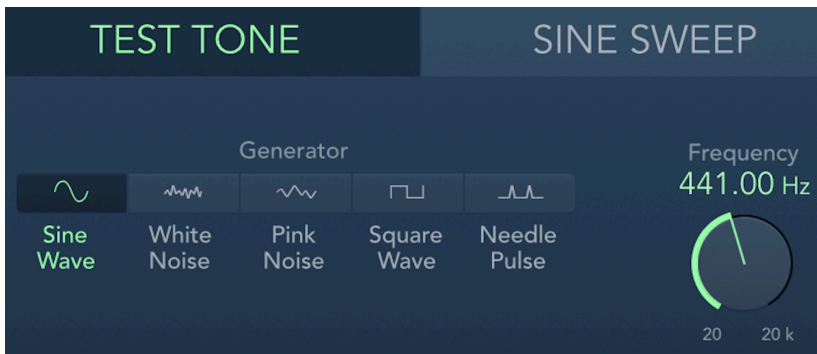


Figure 13b: detail from signal generator 441 Hz.



Figure 13c: detail from 441 Hz Sine wave bounced then confirmed as 100 samples in wave editor.

2): How many samples in a given frequency (Hz)?

Sample rate / frequency (Hz) = samples

441Hz at a sample rate of 44100 = 44100 / 110 = 401 samples.

What is the frequency Hz of a singular wave cycle (*compression & rarefaction*) in a given number of samples? $Sample\ rate / no.\ of\ samples = frequency\ (Hz)$

441Hz at a sample rate of 44100 = 44100Hz / 401 samples = 110 Hz.

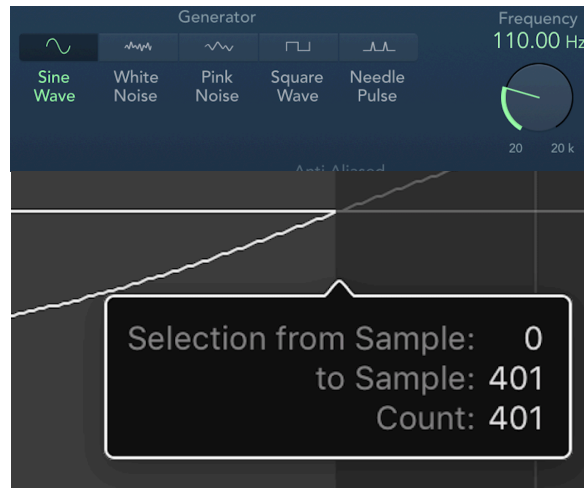


Figure 14: 401 samples = 110 Hz confirmation in wave editor.

Again, confirmed by examining this in a digital wave editor with a signal generator set to 441Hz and counting the number of resulting samples (figure 14).

'Scale Free Music of the Brain' paper by Wu et al (2009) "The signals were recorded by a 32 channel NeuroScan system with a sampling rate of 250 Hz and were band-pass filtered from 0.5 Hz to 40 Hz."

Checked against Wu et al's 'NeuroScan' 250Hz rate below, a full window of chosen EEG of 4 seconds with a sample rate of 250 Hz will give the following range of samples per segment window:

$$250 \text{ Hz} * 4 \text{ seconds} = 1000 \text{ samples.}$$

Example below from Wu et al's graph example 1:

Note: Wu et al have used 'tied' notes.

Wu et al's segment windows are 20 in all (figure 11, page 40)

Segment 7 (tied notes 7-8);

Segment 13 (tied notes 14-15-16);

Segment 14 (tied notes 17-18);

Segment 18 (tied notes 22-23);

Full window: 21.6cm (216mm) - there are two unused segments; 1 (3mm) at the beginning & 1 (13mm) end of the full window.

Note: Full table of results from this experiment in Appendix C: Table 11: page 111).

8.1. Reflection on Previous Experiments.

What can be heard in these initial visual mapping experiments with Wu et al's equation and the provided EEG graph and notation, is that although the resulting notes from each method may be different, the rhythmic structural nature of the results make each piece sound similar. Although the 'Scale Free' nature of the notes are different. They appear as unrelated notes in succession with no emotional connection between them. Playing the notes on a pure instrument like a MIDI piano at a mid-range pulse also does not appear to aid the musical flow or provide an emotive musicscape.

Experimenting within Logic X Sequencing program by slowing the pulse down to 10 BPM (*Beats Per Minute*), then assigning an ethereal sounding synthesizer sound appeared to create a musical emotion within the set of EEG generated notes. Assigning more complex timbre and adjusting pulse made a self-perceived emotive difference to both the Wu et al generated notes and the experiments carried out with the visual data here. The following audio is a of the previous audio examples 1 - 4 with slowed pulse and change in instrument and timbre.

 Play - 'Example 6-Slowed-Timbre-examples_1-4'

Taking this idea further with the above example time-stretched 10 times longer using the *Polyphonic* time-stretch algorithm below:

 Play - 'Example 6b-Slowed-Timbre-examples_1-4_x_10'

The example below is time-stretched 10 times longer using the *Tempophone* time-stretch algorithm below:

 Play - 'Example 6c-Slowed-Timbre-examples_1-4_x_10'

The slowing-down of the transposed EEG had a musicality that enabled space for phrases to develop in my perception of the stream of notes generated by the EEG musification process. Decreasing the pulse and assigning sounds that had longer sustain duration also

has the effect of lengthening the notes dramatically. This began to create a musical emotive platform for the notes to sustain and help the listening imagination search for possible meaning. Using the time-stretch algorithm that lengthened the audio another ten times in length also created additional timbre and sonic character.

This experiment with slowing the tempo or pulse has been used previously by the minimalist artist La Monte Young in the early 1960's. In *'Trio for strings 1958'* composed by La Monte Young. This is an hour long 12-tone chamber piece based upon Schoenberg's Serialism concept, the first sound is for four and a half minutes. In *'Composition 1960 #7'* La Monte Young's score instructs the player that the notes are "to be played for a long time." There are just two notes B and F# being played concurrently creating harmonic tones and pulses over a long period of time. La Monte Young slowed down and lengthened the timeframe of the music into long tones, creating space for resonance, sustain and reflection. Slowing down the notes and applying a different timbre or instrument may work aesthetically for one listener but does the same apply for another person with a differing aesthetic opinion and musical taste? It does prompt the consideration of whose aesthetic? Whose timbre? Professor Denis Smalley, a composer specializing in electroacoustic music also considers this question in an article called *'Defining timbre - Refining timbre'* where he questions the meaning of timbre:

"What is timbre? When is it meaningful to use the term? How useful is a concept of timbre in the context of electroacoustic music? Defining timbre is a hazardous operation. "Talking about timbre," says Philippe Manoury "is as delicate as talking about taste" (1991) ". (Smalley 1994).

In an interview by Martin Gayle for the Guardian from an edited extract of *'A History of Pictures: From the Cave to the Computer Screen'* (Hockney & Gayford 2016), David Hockney discusses what turns a picture into a masterpiece'. He states:

"The Chinese say you need three things for paintings: the hand, the eye and the heart. I think that remark is very, very good. Two won't do. A good eye and heart is not enough, neither is a good hand and eye".

Hockney's quote about the Chinese perspective on painting is a similar concept to the

'three pillars of flamenco' discussed by flamenco dancer Eva Yerbabuena. When identifying song, guitar and dance as the three pillars of flamenco, says, "*If one of those fail it can become dangerous*". Yerbabuena is suggesting that if any of those three are missing (or fail to convey the passion in some way) then the flamenco is weakened by its absence. Both the Hockney and Yerbabuena quotes could perhaps be applied to music and substituted with the terms *'melody, timbre and pulse'*, although the addition of *'harmony, dynamic and rhythm'* could also be considered. The attention to pulse influencing the results of the EEG musification was as important as the notes themselves.

This subjective musical editing and the imposition of creative decisions upon the data is important for the sonification results to develop a musical aesthetic. This could be considered as putting the heart and soul into a piece, to develop the sonification beyond being solely the indicator of events, and move aesthetically into the musification of data. If musification of data is the aim, the results need to create emotive or aesthetic musical experiences when listening to it. Miranda et al (2016) explored the importance of musical aesthetic in the sonification of *'Sea temperature and salinity data is used to create a musification of climate change phenomena'*; Miranda asserts that there may be enthusiasm and interest surrounding the initial concept for the sonification of scientific data, but the consideration of the musical aesthetic is important for the results to be successful. This is because the music derived from the sonification can be disappointing for audiences if not aesthetically pleasing or rewarding in a musical context. (Miranda et al 2016).

9. Mapping Experiment #3: Sampler Cyclic Edits.

This experiment involved using EEG data files from a public database of EEG epilepsy recordings. The EEG seizure files used for this project were accessed at a public database for research purposes: The CHB-MIT scalp EEG database. The International 10-20 system of EEG electrode positions was used for these recordings. The files were recorded and digitized at a sample rate of 256Hz with 16-bit resolution and compiled and stored in the European Data file format (.edf). This file format was created by medical engineers in the late 1980's and published in 1992 for a range of digitized polygraphic recordings for use in multicenter research projects and commercial EEG equipment. (Braintronics B.V. 2017).

The EEG files were recorded at 256Hz but the conversion to digital audio format alters the sample rate and has direct implications on the timeframe and pitch of the waveforms. Conversion from 256Hz to 44100Hz .wav shortens the timeframe, therefore the Hz frequency and increase in the resulting pitch of the audio. This brings the low frequency EEG into the human hearing range, but by how much exactly in relation to frequency and pitch? How many semitones and cents? By how many Hz? This can be calculated in cents, Hz, seconds and samples precisely using mathematical formulae and double checked practically using a digital wave editor. Calculating and considering the transposition of time and pitch in the file conversion process was important to fully understand the files, timeframes and frequency ranges during recording, storage and conversion for musical production purposes. The following sub chapter gives an of the EEG file conversion process.

9.1. The EEG .edf File Conversion for Music Production Purposes

File sample rate:

The EEG data Files were recorded at 256Hz per second sample rate.

Sample rate conversion ratio:

The conversion from .edf file to .wav (from 256Hz to 44100Hz) for musical production purposes.

Conversion ratio:

$44100\text{Hz} / 256\text{Hz} = 172.265625$ (Ratio i.e. 44100 sample rate includes 172.265625 times more samples per second).

Sample rate conversion percentages:

$$44100 / 256 = 172.265625 \times 100 = 17226.5625\%$$

$$256 / 100 = 2.56 \times 17226.5625\% = 44100$$

and the inverse...

$$256 / 44100 = 0.00580498866213 \times 100 = 0.580498866213\%$$

Original length of EEG recording = 1 hour = 60mins x 60 seconds = 3600 seconds

At 256Hz it shortens the timeframe when importing to 44,100 Hz .wav file:

$$3600 \text{ seconds} / \text{sample rate conversion ratio } 172.265625 = 20.89795918367347$$

seconds at 44.1kHz sample rate (confirmed in SMPTE code below in Figure 15).

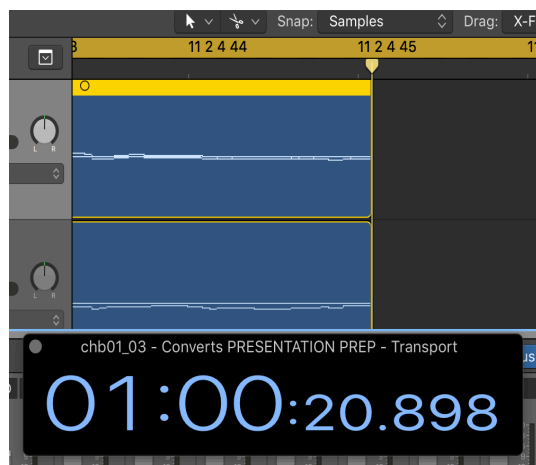


Figure 15: Conversion Image 1: practical confirmation of length in seconds from real-time to 256Hz conversion

Length in samples from 256Hz to 44.1kHz conversion:

Length in samples = file length / length of 1 sample at 44,100Hz

20.89795918367347 seconds / 0.00002267573696 seconds = 921600.000058982427

samples in length after conversion from 265Hz to 44,100Hz (*calculations checked against sample length of whole recording within a digital wave editor confirms 921600 samples in length, see following Figure 16*).



Figure 16: Conversion Image 2: Practical confirmation of length in samples from 256Hz to 44.1kHz conversion

Start, end and length of EEG epilepsy event in time (seconds):

EEG file information:

File name: chbo1_o3.edf

File start time: 13:43:04

File end time: 14:43:04

Number of seizures in file: 1

Seizure start time: 2996 seconds

Seizure end time: 3036 seconds

Start time conversion: In the originally provided .edf data file the seizure starts at 2996 seconds in the details relating to the original .edf file. Conversion from 256Hz to 44100Hz .wav changes the timeframe:

2996 seconds / 172.265625 (ratio) = 17.39174603174603 seconds

Seizure starts at 17.39174603174603 seconds in the converted .wav file.

End time conversion: In the originally provided .edf data file the seizure ends at 3036 seconds. The conversion from 256Hz to 44100Hz changes this timeframe:

$$3036 \text{ seconds} / 172.265625 \text{ (ratio)} = 17.62394557823129 \text{ seconds.}$$

Seizure ends at 17.62394557823129 seconds in the converted .wav file.

File length conversion: Length of EEG epilepsy episode in seconds = 17.62394557823129 - 17.39174603174603 = 0.23219954648526 seconds (pre-sample rate conversion - originally 40 seconds long).

Start, end and length of EEG epilepsy episode in samples:

Start-point conversion = epilepsy event start point in seconds / length of one sample in seconds.

$$\text{Length of one sample at } 44,100 \text{ Hz} = 1 \text{ second} / 44100 = 0.00002267573696 \text{ seconds}$$

$$17.39174603174603 \text{ seconds} / 0.00002267573696 \text{ seconds} = 766976.000049086387 \text{ epilepsy event samples start point (confirmed in Figure 17 below).}$$



Figure 17: Conversion Image 3: Epilepsy event start point in samples from 256Hz to 44.1kHz conversion.

End-point conversion = epilepsy event samples start point - epilepsy event samples end-point

$$17.62394557823129 - 17.39174603174603 = 0.23219954648526 \text{ seconds (with .wav sample rate conversion - originally 40 seconds long).}$$

Length of EEG epilepsy episode at 44100Hz sample rate:

= 0.23219954648526 seconds / length of a sample at 44,100 = 0.00002267573696
seconds = 10240.000000655326 samples in length = **10240 samples in length**
(confirmed Figure 18 below).

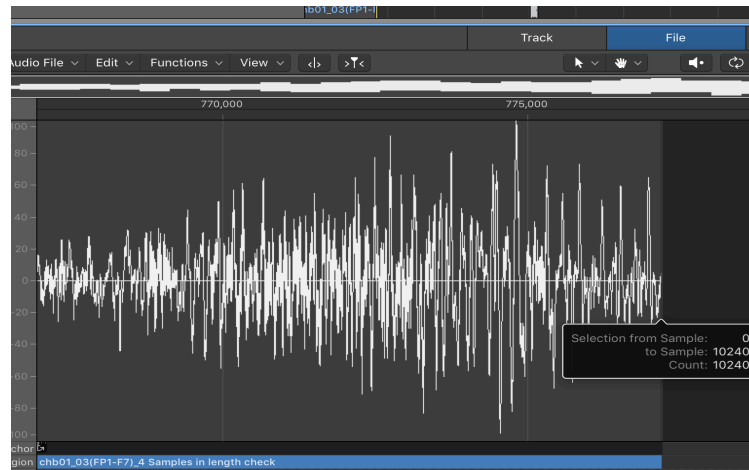


Figure 18: Conversion Image 4: Epilepsy event length in samples from 256Hz to 44.1kHz conversion.

9.2 Pitch and time-stretching .edf File conversion calculations.

The sample rate conversion affects pitch as well as time, there is an increase in frequency and therefore pitch during this conversion between sample rates. This increase can be identified. After extracting the seizure time stated in seizure records the region came to 10240 samples in length as follows:

$40 \text{ seconds} / 172.265625 = 0.23219954648526 \text{ second seizure length after conversion.}$

$0.23219954648526 \text{ seconds} / \text{sample length (1 second} / 44,100 \text{ sample rate)} = 10240.000000655326 \text{ samples in length...}$

Difference between two frequencies. Hz sample rates: ratio & cents formula:

Example: 44.1kHz vs. 48kHz:

$\text{Log}(44100 / 48000) \times 3986.313714 = -146.7 \text{ Cents}$

$2^{(147 / 1200)} = 1.08861966312463$

Ratio between sample rates 44,100 Hz and 48,000 Hz = 1.08861966312463

Note: The 'constant' figure (3986.3137138648374) in the previous formula is derived from the logarithmic relationship between 12 note divisions in an octave as follows:

For semitones:

$$\log(F_1/F_2) \times (12/\log(2))$$

$$\log(2) = 0.301029995663981$$

$$12 / 0.301029995663981 = 39.86313713864837$$

$$\log(F_1/F_2) \times 39.86313713864837 = \text{semitone difference between two frequencies.}$$

For cents:

$$\log(F_1/F_2) \times (1200/\log(2))$$

$$\log(2) = 0.301029995663981$$

$$1200 / 0.301029995663981 = 3986.3137138648374$$

$$\log(F_1/F_2) \times 3986.3137138648374 = \text{cents difference between two frequencies.}$$

Applying the above to calculate the cents difference between the .edf EEG file conversion from 256Hz to 44.1kHz is:

$$\log(256 / 41000) \times 3986.313714 = -8914.18924270140507 \text{ Cents}$$

$$2^{(8914.18924270140507 / 1200)} = 0.00580498866111$$

Ratio between sample rates 256 Hz and 44,100 Hz = 0.00580498866111

Cents difference between sample rates 256 Hz and 44,100 Hz =

8914.18924270140507 cents

This is also confirmed in the sample lengths:

10240 samples x 172.265625 ratio = 1764000 samples for converting back to real-time epilepsy event:

$$\log(10240 \text{ samples} / 1764000 \text{ samples}) \times 3986.313714 = -8914.18924270140507 \text{ cents.}$$

Note: Logic X audio sequencer was used to carry out this task, but Logic X cannot time-stretch as much as -8914.18924270140507 cents in one process breaking it down to -2229 cents x 4 was closest to actual difference.

Region 10240 samples time stretched in *Time & Pitch Machine* in Logic by -2229 cents x 4 = -8916 cents resulted in 1765965 samples length in Logic.

Calculating the difference in cents following rounding up = with destination set to 0.1113% (after stretching -2229 cents x 4) resulted in sample length of 1764001 samples

Checking practical wave editor processes above against mathematics:

Difference in cents between two sample lengths = $\log(S_1/S_2) \times 3986.313714 =$
 $1765965 / 1764000 = 1.00111394557823 \rightarrow \log = 0.00048351165174 \times 3986.313714 =$
1.92742718860504 cents.

2 Cent variation: 1765965 samples / 1764000 samples = 1.00111394557823 x 100 = 100.111394557823... and 0.1113% is what *Time & Pitch Machine* displayed for destination % for +2 cents = 100% of original length plus 0.1113% for +2 Cents.

9.3. Reflection on EEG .edf File Conversion.

The previous calculations provide a detailed account of the time and pitch differences between the original recorded sample rates and the conversion to audio data. This is provided here as analytical data to understand the files, their timings and pitches in preparation for musification experiments. Having a detailed understanding of this data provides the opportunity to make decisions that relate to how close to stay to original pitch-and-time data during the musification production processes.

The process for mapping experiment #3 involved importing the EEG audio files (converted to 44.1kHz therefore decreasing timeframe and increasing pitch by ratios of 172.265625) into a sequencer (*Logic X*) and editing cyclic segments from the audio data, taking each cycle at zero-crossing points including one compression and rarefaction, importing each cycle segment created into a sampler instrument (*Logic X EXS24*) and calculating the pitch (*frequency and note pitch*) via the mathematical following formulae.

Samples to Hz formula: *What is the frequency (Hz) of a given number of samples? For example, 21 samples?*

$$44100 / 21 = 2100 \text{ Hz}$$

Finding the corresponding MIDI note number from Hz frequency means applying (see below): Using 440Hz A4 MIDI note 69 as the referenced note:

$$n = 69 + 12 * \log(\text{freq}/440) / \log(2), \text{ where } n \text{ is the MIDI note number.}$$

$$69 + 12 * \log(2100/440) / \log(2) = \text{MIDI note } 96$$

Previous formula also possible as following:

$$(\text{Hz} / 440) \rightarrow \text{press } \log_2 \text{ button } \times 12 + 69$$

$$\log_2(2100/440) \times 12 + 69 = 96.0577667883459 = \text{MIDI Note } 96$$

Note: the full list of resulting notes generated by this cyclic segmentation of EEG experiment can be found in Appendix E of this document (page 124).

Table 15: Repetition of notes within cyclic segmentation experiment #3:

C	C#	D	D#	E	F	F#	G	G#	A	A#	B
19	15	11	6	5	5	8	5	10	8	7	6
/	/	/	/	/	/	/	/	G#3=1	/	/	/
C4=1	C#4=1	/	/	E4=1	/	/	/	G#4=4	A4=3	A#4=2	/
C5=2	C#5=4	D5=2	D#5=2	E5=2	/	F#5=3	G5=3	G#5=3	A5=4	A#5=2	B5=4
C6=13	C#6=5	D6=9	D#6=3	E6=2	F6=3	F#6=4	G6=2	G#6=2	A6=1	A#6=3	B6=2
C7=3	C#7=5	/	D#7=1	/	F7=2	/	/	/	/	/	/

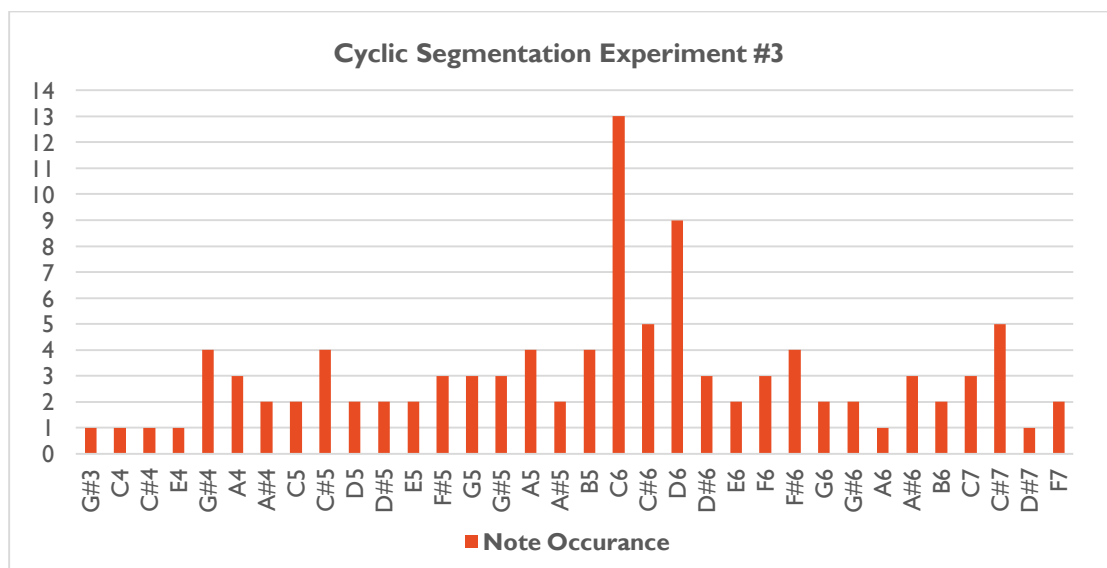


Figure 19: Repetition of notes within cyclic segmentation experiment #3:

This experiment, exploring the segmentation of individual cyclic waveforms, proved to be an interesting one in the sense that it provided a wide range of notes across the chromatic scale, albeit across several octaves all 12 tones are present. In Dan Lloyd's writing relating to *'Mind as Music'* (2001) he discusses the *'sparsity'* of words within language. He describes that some words are used with high repetition and others with less regularity, asserting that sparse languages are easier to learn but require expression and ambiguity. Whereas a language that is dense with individual words used only once is more difficult to learn and is *'dense'*. The chromatic music scale could be considered a sparse language which requires and relies on the diverse expression of this sparsity and therefore can create ambiguity. With the previous note table, the construction of threshold rules for musification could be considered. This could include making the most frequently repeated note the root note of a scale or melody. In the case of the previous table it is evident that the note C appears with the highest regularity and could therefore be the root note of any musification with the notes generated with cyclic segmentation. The regularity and sparsity with an applied threshold could provide a scale or mode. For example, construct a scale or melody from notes repeated on and above a 2-digit repetition threshold and in order of repetition, and most frequently repeated descending choice of each note (*and rotate octave value if sparse*):

C6=13 - C#7=5 - D6=9 - G#4=4 - C7=3 - C#6=5 - D5=2 - G#5=3 - C5=2 - C#5=4 - D6=9 - G#6=2 - C4=1 - C#4=1 - D5=2 - G#3=1

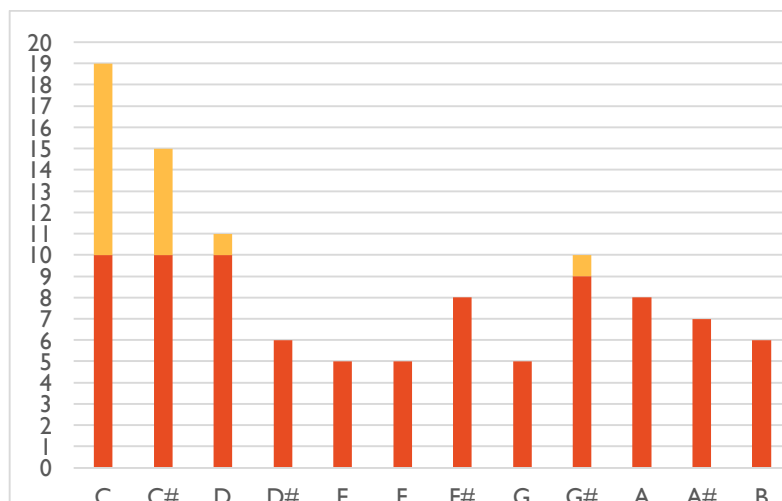


Figure 20: 2-digit repetition threshold graph.

Improvisational experiments followed using variations of C C# D G# from above graph that break through the set threshold using solely the EEG epilepsy audio data loaded into 'The Oblique-Granizer' MAX/MSP synthesizer. During synthesis of these improvisations the emotions and experiences of epilepsy seizure were contemplated, such as waves of altered levels of consciousness during focal onset. Please listen:



Play – 'Example 8-Breaking the Threshold Improvisation 1'

Play – 'Example 9-Breaking the Threshold Improvisation 2'

Play – 'Example 10-Breaking the Threshold Improvisation 3'

A rhythmic and melodic experiment was carried out with this first 29 notes of the EEG cyclic segmentation in *Appendix E* (page 124) which can be heard in the following audio example below. The extracted EEG wave-cycles were quantized to the nearest 64th of a bar for rhythmic material and selected notes in succession for melodic phrases. The dissection of the EEG cycles into rhythmic patterns does not express the wave-like nature of experiencing epilepsy, the feelings I have experienced in epilepsy events come in waves and do not feel like discrete rhythmic patterns.



Play – 'Example 11-Cyclic Rhythmic Sampler Experiment'

10. Mathematics is Fundamental to Music but...

Melody, harmony, tuning and rhythm can all be analyzed and constructed using mathematical formulae. Pythagoras recognized the harmonic nature of tones when hearing the Blacksmith's Hammer striking lengths of iron of different lengths. Music relies on the brain quickly and subconsciously carrying out the mathematics. The perception of an increase or decrease by an octave as a similar note, higher or lower, is purely because the frequency (Hz) is double or half the referenced note.

The organization into melodic forms, harmonic relationships and rhythmic sequences also relies on instinctive mathematics. In what is recognized as harmony there are often satisfying mathematical relationships between the notes played concurrently, for example the harmonic series. The same is true for consecutive notes with melody and rhythm. Dissonance can also be satisfying with non-integer relationships between notes, although constant dissonance can require resolution with mathematical harmony, or the human mind begins to search for this, unless constant dissonance is the objective.

The work previously researched in the subject of epilepsy EEG sonification and musification has been carried out with a proactive intention towards creating and developing a positive medical tool for early onset identification and warning of seizure events. On listening to Wu et al's *'Scale Free Music of the Brain'* or the EEG modulated audio with Chafe and Parvisi's *'Stethoscope of the Brain'* it is possible that carers or sufferers of epilepsy might not want to listen to with continuity or with regularity. When multitasking in a medical identification scenario the audible modality would provide an opportunity to work on other tasks whilst listening to EEG musification.

In a musically aesthetic context, considering the mathematical harmony that can be found in music, the sonification of EEG data with mathematic algorithms alone lack the expression and spectrum of human experience and emotion. The resulting music Wu et al created with their formula, and the experiment carried out here with cyclic waveform Hz

derivatives alone, did not provide aesthetic musical satisfaction because of this exclusion of modality, repetition, subjective expression, the human emotion and narrative we often require within music. The resulting melodically unorganized notes might also suggest abnormality in a wider public consumption of this music, the identity stereotypes and stigmas associated with epilepsy might be reinforced by this. The melodic results of Wu et al's '*Scale Free Music of the Brain*' algorithm, and especially the modulated music of Chafe et al with the use of vocal samples that repeat vowels in an almost comical tone, sound as if the music has an identity issue because it does not conform to traditional modality or form that we identify as music. This might strengthen stereotypes among non-epilepsy listeners. In a paper called '*Epilepsy myths: Alive and foaming in the 21st century. Epilepsy and Behavior*' by Baxendale, & O'Toole. (2007) they state:

"Movie characters with epilepsy are frequently mad, bad, or dangerous, with demonic possession, lunacy, idiocy, and divine revelation as regular features." [...]
"... the belief that people with epilepsy have more personality problems than others." (Baxendale, O'Toole. 2007)

Repeated motifs, developing melody, mathematical organization of notes and relative rhythms that form conventional definitions of music, are not naturally provided by epilepsy EEG recordings unless algorithms can be developed to interpret them, quantize and organize them, into modal and rhythmic sense for listener.

Is musification any more effective than sonification for identifying seizure activity? If music is to be used to provide early onset warning of epilepsy events in a domestic scenario, it is imaginable that Chafe and Parvisi's '*Stethoscope of the Brain*' frequency modulation of audio samples could be implemented to modulate or interrupt audio signals when listening to normal household radio, television or personal sound systems when using audible modality to warn of epilepsy events in a patient or individual. Otherwise a simple sonified alarm like a *Geiger Counter* could also provide a satisfactory audio warning of epilepsy. Human beings find sudden modulation of pitch, the stereo field and visual stimuli difficult to ignore so this might be a useful implementation of

modulated audio in epilepsy warnings. This is possibly due to the primal nature of survival that alerts our senses when our environment changes suddenly. If any of our senses identify a modulating source we begin to track it instinctively, visually, aurally and impulsively checking for possible threat.

11. Timbre is Difficult to Put into Words.

In *'Mind as Music'* Lloyd discusses the sparsity and density of the coding of language within the human brain and relates this to music. People have experimented with sonification, and more specifically musification, of EEG signals recorded from within the human brain and have developed sparse musical coding in the shape of musical notes on a staff. This is a simplistic approach and when compared to the depth of language used within verbal communication it might not be dense or detailed enough coding to express all the meaning and detail, especially as we mainly communicate with verbal semantics than musical semantics.

The notes on a staff could be considered the letters from an alphabet, and melody considered words constructed from it. But human communication, with the use of the alphabet as a code and verbal semantics, perhaps operates much more densely with subtle and detailed depth. In everyday verbal communication, it is important to consider the timbre or expressive nature of conversation as well as the meaning of the words and language. In the musification of EEG, a sparse code can be used to generate sets of discrete musical notes but what might it sound like beyond the simple mapping of pitch? What are the possible timbres?

The transcribing of EEG data to simple notes, melody and harmony on a staff might not be detailed enough to communicate the experiences of an epilepsy event. Consider the music listened to in post modernistic culture, it could be suggested, with new experimental and developing electronic music genres, that timbre is as important than the mapping of notes to a staff. Arvo Pärt touches upon this when discussing tone when he states:

"I have discovered that it is enough when a single note is beautifully played. This one note, or a silent beat, or a moment of silence, comforts me. I work with very few elements – with one voice, with two voices. I build with the most primitive materials – with the triad, with one specific tonality." Pärt, A. (accessed online March 5th, 2017)

Timbre has developed beyond a set of notes played on a range of acoustic instruments, in modern electronic music genres notes are often limited but timbre rich, detailed and exciting because of electronic oscillators, synthesis types such as granular synthesis and numerous techniques using digital manipulation of audio. This project is also exploring what the timbre of these EEG waveforms might be beyond their pitch or note on a staff. If analogies can be drawn with language, the notes alone are too simplistic, timbre is communicating and exploring diverse and nuanced meaning. We could ask just how far melody alone can take us into the understanding and nuances of language, communication and thought? Timbre should also be considered important in this process. The simple alphabet is needed to shape language as are musical notes in music, but without the nuance of timbre it does not have sonic depth and diversity, the language of music becomes limited to something like a basic MIDI file. Solely mapping EEG data to musical notes on a staff may not be enough to understand the nuances embedded within the epilepsy and EEG brain-waveforms. One single note could express many different things with the manipulation and expression of timbre

The previous medically based musification research methods do not appear to say anything about the human spectrum of experience or emotions, *'the timbre of events'*, they sound random and unemotional pieces of music, beyond the initial novelty the dialogue or emotive narrative fades quickly. Creation of algorithms that provide emotionally connective music might provide value in this area of research, the results may provide a narrative that explores understanding beyond words. Music is considered to express the human condition beyond verbal description. In a paper entitled *'Entangling the Medical Humanities'* the authors Brian Hurwitz and Paul Dakin assert that science alone is not enough to understand health, illness and disease. There is a need to consider ethics and social science for a holistic understanding. (Richards et al 2006). This should also include the narratives and experiences of the sufferers themselves.

Epilepsy sufferers also find the emotions, physical and mental experiences difficult to put into words, especially where consciousness is combined with the epilepsy experience of 'auras' or focal onset seizures, with 'Déjà vu' or 'Jamais Vu' being a common description. Epilepsy disruption in the temporal lobes can affect emotions and behaviour. People who experience temporal lobe epilepsy (TLE) describe it as feeling like a dream, but find the sensations difficult to describe. This can include expressing fear, intellectual fascination, anxiety, memories, music, smells, tastes and even joy can be used to describe the sensations experienced by TLE sufferers. Panayiotopoulos (2005) includes a description by a patient who experienced auditory temporal lobe seizures who stated:

"It is a strange 'difficult-to-describe' sensation" [...] "Here it is again. That buzzing in both ears. It is just buzz. I cannot describe it..." (Panayiotopoulos CP. 2005).

There are also nomenclature issues related to individual patient's descriptions of TLE experiences:

"Dreamy states', 'psychic or mental symptoms', 'intellectual aura' and 'experiential phenomena' are the terms most widely used to denote symptoms of temporal lobe seizures that uniquely relate to the patient's personality regarding identity, experience, emotion, thought and memory." (Panayiotopoulos CP. 2005).

Music experimentation could illuminate this further, as a sufferer and musician I want to express it beyond words using music and timbre. This project has researched methods to make music with EEG epilepsy data to capture its native form, but also entering into a musical dialogue that describes epilepsy events and the human experience through musification of the EEG data. The perception of Epilepsy has been explored and illustrated in art, television and cinema but the study of it within music has been rare. (Baxendale 2008).

As American composer and pioneer in the use of neurofeedback David Rosenboom asserts, there are unexplored aspects of the brain and music's relationship with it. That neuroscience could benefit from viewing the brain with musical principles which might provide further insights into its activity. (Rosenboom 2014).

12. The Timbre of Events and the Cinematique.

This project work integrates and develops multiple musical mapping methods, mathematics and synthesis techniques to serve as tools for musification and sonification of EEG epilepsy data and exploration of the emotional human experience of epilepsy. This could be called the '*the timbre of events*'. One might have individual ideas on what the timbre of epilepsy events may be, but will it mean the same to another? This prompts the exploration of the meaning of '*timbre*' which also has nomenclature issues related to individual descriptions of sound. As an electronic musician, this means the harmonic content of sound, the entry, exit, duration, modulation, sustain qualities and characteristics. For others, this might mean subjective language, perception and understanding of sound for example, bright, dull, dark and aggressive. Researchers have carried out work in this area that included descriptive words such as:

“Synthetic; cold; high; gritty; airy; big; harsh; open; crunchy; thin; clean; dull; nasal; hard; sharp; gentle; solid; thick; muffled; close; wooden; ringing; clamorous; distant; dry; rough; metallic; short.” (Sarkar et al 2009).

The survey identified descriptive terms that were agreed upon when tested which were *bright, resonant, full, clean, dense, percussive, harsh, airy, shrill, acoustic pure* and *close*. However, there was more agreement in the exclusion of descriptive words such as *open, hard, thin, light and heavy*. (Sarkar et al 2009). This surveying of descriptive terms might also be made more complex with modern electronic music where cultural meanings of words can be ambiguous, words like *hard, rough, gnarly, deep, dark and heavy* could imply positive exclamations of music and descriptions of timbre in various cultural groups.

This discussion on the description and characterization of sound and timbre has become complex since the development of electronic sampling and synthesis where many new sounds can be manipulated beyond original context and created from non-acoustic sources. The 20th Century brought a new and diverse palette of sonic possibilities with

electronic oscillators, complex modulation functionality, the recording of sounds to be manipulated beyond recognition with magnetic tape, and later with digital samplers and software. New synthesis types, technology and pioneers working within this field created new timbres not previously experienced in music composition. The music created by musicians using these new electronic instruments is often called '*electroacoustic music*'. Professor Denis Smalley describes this genre as including sounds that are real and surreal, with the listener being unable to link them to physical sounds or instruments they are familiar with.

"Gone are the familiar articulations of instruments and vocal utterance; gone is the stability of note and interval; gone too is the reference of beat and metre." (Smalley, D. 1997).

An interesting example on the discussion on timbre and sound in Electroacoustic music beyond the Classical Western tradition is the following by Pierre Henry (*a pioneer of 'Musique Concrete'*). Henry discusses a classification beyond notes in the following text (*translated, originally in French*) from '*Journal de mes sons*' (Journal of My Sounds. 1982).

"In other studios, the classification of sounds is based on scientific data. In my case, there are no normalized sounds, etalons, but entities which in themselves are microscores. Composers work with sounds to do everything. The equivalent of musical notes. I have no notes, I never liked the notes. I need qualities, relationships, forms, actions, Characters, materials, units, movements. And all that, these are my notes to me. For example, there are sounds that I call oval. They exist as very typical beings, evoking war, or the storm, or the cosmos. They were made from a finger scraping on a pick-up needle, Very amplified and role in a room of natural echo. My oval sounds are big sounds. Not big notes, that's insufficient, notes. It's nothing. It gets lost It's stupid. We cannot work with the notes. The notes are good for composers." (Henry, P. 1982).

In the quote above we can see Pierre Henry describing the processes of his sound creation beyond traditional notions of notes. He is illustrating what he wants them to evoke via descriptive terms of their possible timbre, for example '*oval*' and '*big sounds*.' The descriptions in Henry's quote suggests a need for consideration of new musical terms, categories and classification of timbre in the electroacoustic age.

The computer and music software have broadened the possibilities of timbre. Sound generation, synthesis and sonic transformation capability have become accessible to a wide range of music consumers and creators due to the proliferation of digital music software, music recording and manipulation no longer requires expensive equipment, specialized engineers and studio space. It is also possible to consider the computer and electronic music as folk music, where it is accessible and available to all whether musically trained or not. Dennis Smalley makes a comparison of electroacoustic music as an oral activity against the heritage of transcribed western art music. Smalley suggests that electroacoustic music is not as easy to transcribe to notation as western classical music is. (Smalley 1997). The separation of performing music and writing music is not practiced as extensively in an electroacoustic setting, therefore being similar to the oral tradition of folk music. The internet hosts a vast resource of people sharing electronic music ideas and tutorials, tips for achieving specific sounds, genres and synthesis techniques. This could be described as an oral tradition like the transmission of folk music was prior to the digital internet era.

The music industry has complained about reduction in revenue since the computer download era. The accessibility of computer music software enables increasing numbers of people to make music, upload theirs and others for free to *Soundcloud*, *Bandcamp*, *Youtube*, personal websites and peer-to-peer platforms. A vast amount of music is freely available for the listening public to consume without purchasing it. Consider the analogy that historically it was only an educated few who were literate, but as the population became educated they might also have been concerned about how they might continue to make a living if many more of the population could now read and write. Perhaps music making in the computer age is similar? Music might now be a language that does not require a professionally trained scribe. The population further also develops an intrinsic understanding of diverse genres and cinematic style music through multimedia consumption of cinema, television, the internet and gaming soundtracks.

This may be an interesting analogy but we do continue to appreciate specialist authors, scriptwriters and journalists where writing is a specialized profession worthy of revenue for their skills. It is reasonable to suggest that specialized music creators deserve this and it is reflected with the continued success of live performance despite free download issues. There is no substitute to seeing a favorite music artist perform, enabling the continuation of a professional musician.

Regarding the discussion on exploration and identification of timbre, it is reasonable to suggest that the non-electroacoustic musician has a sophisticated internal dialogue and understanding of diverse timbre from cinematic soundscape. Consider the atmospheric soundscape of film and television, examples include the electroacoustic sound design for the famous 'Dr. Who's 'Tardis' sound effect designed by Brian Hodgson. This has permeated and diversified our listening palettes beyond the singular activity of '*listening to music*'. Hodgson first constructed a verbal description of what the sound should sound like, describing the sonic qualities and then began designing it. The use of language and vocabulary being important to the creative sound design process and the eventual timbre of the desired sound. In an interview for BBC News by Paul Hayes and Martin Barber called '*Doctor Who: How Norfolk man created Dalek and Tardis sounds*' Hodgson states:

"I don't know who thought of it, but we came up with the 'rending of the fabric of time and space'." (Hodgson, B. 2013).

'*The Tardis*' would need to achieve the timbre of a 1960's Police Box hurtling through '*the fabric of time and space*.' The realization of this sound design relied on the timbre of imagination and not the timbre of actual events. Viewers and sound designers were unlikely to have a realistic perception of this so an internal cinematic imaginary dialogue is employed. The '*Tardis*' was created by recording the scraping a key along the bass strings on a piano, layered with other recordings of the same action, speeding and

slowing them down, and adding a rising note combined with feedback and “*The Tardis was born*” (Barber, M. Hayes, P. 2013).

The cinematic soundscape can be apparent and conscious but can also be subliminal in its inhabitation of a large percentage of our television and film experience. The home cinema is ubiquitous in many homes and the accompanying soundscapes and background music move beyond popular music genre. However, although the listener or viewer might have an instinctive internal dialogue with cinematic soundscape, their ability to describe the timbres verbally might have vast differences between each listener.

The relationship, and perhaps internal dialogue, with cinematic electronic music and sound began in the early 1950’s. An early example was the eerie sound of the electronic Theremin in ‘*The Day the Earth Stood Still*’ score by Bernard Herrman with the Theremin played by Samuel Hoffman Paul Shure in 1951. The first fully electronic movie soundtrack is considered to be ‘*Return of The Monster from The Id*’ in 1956, with the score and sound design by Louis and Bebe Barron 1956. Bebe Barron says:

“That to me is a perfect example of our work, I mean we were out to make the loveable monster”. (Barron 1956).

Louis Barron says that the equipment circuits used were not instruments but performers. Barron was also a competent and confident electronics engineer who built and created all his own electronic equipment giving him the opportunity to experiment and innovate without the reliance on anyone else. They were both members of the New York Avant-garde teaming up with artists and composers such as John Cage, experimenting with tape splicing, looping and “*monkeying around*” (Louis Bebe) with different circuits to see what it would produce sonically. Cage’s “*Williams Mix*’ was created as a collaboration between by cutting and splicing tiny slithers of tape and putting them back together with chance-operation. Louis Bebe wanted to experiment with “*plugging things in wrong*” to see what would happen. Randomization and happenstance were encouraged with the

circuitry, Louis called them *'behavioral circuits.'* They were being organic, doing what they wanted to do. Louis and Bebe Barron avoided stabilizing their equipment so it would not sound the same every time they were played, providing opportunities for equipment to change each time it was used. Instability became a creative form within the circuitry and their creative processes. (Hollings, K. Burman, M. (2013).

It could be argued that this process of respecting the instability of early electronic circuitry was listening to what the circuitry was communicating sonically before imposing constraints through the search for stability. Developing a real dialogue between equipment and electroacoustic artist was a positive creative environment at the beginning of the cinematic electronic soundscape.

The film director Alfred Hitchcock knew the importance of Sound to design the atmosphere within his films, describing the emotional experience. Who can forget the infamous stabbing sound in the shower scene in Hitchcock's *'Psycho'* punctuated by the sound design, slashing through our modernist domesticity, puncturing the safety of our shower-time for ever after witnessing that scene and that sound. The ability to create atmospheres with sound beyond a simple definition of *'music'* has been extremely important in cinema. The 1963 Hitchcock film *'The Birds'* used an electronic synthesizer called *'The Trautonium'* - none of the bird sounds were natural. Hitchcock wanted a new dimension of terror. Scored by Bernard Hermann.

"When you put music to a film, it's just another sound really." Alfred Hitchcock. (Wadsworth, C. 2016).

This is the reason the term *'cinematique'* was previously used within this document as a categorization in the creation of electronic soundscape. Music consumption has been influenced by the internal dialogue and listening modes we have developed through cinematic soundscape. As cinema and television provide the images for sound designers this project hopes to provide the sound design for the listener to create their own internal cinema for epilepsy. In the musifications developed for this project this idea has

been applied, in the composition and sound design, to attempt to recreate the timbre of events, emotions and experiences of epilepsy events. As with the film *'The Birds'*, where there were no *'musical instruments'*, the electronic sounds have created the timbre of the physical and psychological objectives. An example of this within the soundscapes produced for this project is the Minotaur sound design in *'Dante and Virgil Descend Past the Minotaur.'* The Minotaur devouring human flesh and the footsteps that can be heard are electronic realizations of the physical and psychosocial objectives.

In the composition *'Lost,'* produced as part of this project, there is an attempt to recreate the feeling of being lost following a personal experience of an absence seizure on an evening bus. On returning to consciousness I found myself walking in a part of the city at night I was not familiar with. This experience created confusion and the fear of being lost. The soundscape has attempted to recreate the cinematique of the event. Musical form appears absent, all is lost, musical-like sounds pierce the scene as the return to consciousness takes place. As Walter Murch, famous for film sound design such as *'Apocalypse Now'* suggested in a television documentary about the Sound of Cinema (Burman et al 2013):

"When you put meaning into the sound effects... as a listener you can pull meaning from it." (Murch, W. 2013).

Being especially important to this project work is that the sound design uses the authentic epilepsy EEG data directly to recreate the psychological timbre of real epilepsy events.



Listen to composition called - *'Lost'*

13. Recapitulation.

Looking for music within EEG epilepsy brain waves does not simply produce wonderfully formed music as we might know it. Expecting to find melody, harmony and rhythm that might be considered popular forms or realizations of music is possibly unrealistic. It could be likened to a malfunctioning CD Player or Record Deck to play broken compact discs or damaged records and expecting the results be popular or easy-listening music. Although new music genres do use the sound of malfunction as sonic texture and aesthetic possibility, exemplified by genres such as 'Glitch' or the repetitive looping of small fragments of sound in a digital sampler. The brain is malfunctioning during epilepsy seizures and the music made from the EEG recordings must reflect this, listening to the original epilepsy EEG data confirms the noise and chaos present in EEG and the brain during a seizure. Noise has been previously defined as music in artistic movements. The Futurists were fascinated with the noise of the twentieth century, the new noise of machinery and war. In *'The Art of Noise'* (The Futurist Manifesto, 1913) Luigi Russolo stated that they were bored with the "soft and limpid purity of sound and the caressing of the ear by suave harmonies." They asked provocatively, "is there anything more ridiculous in the world than twenty men slaving to increase the plaintive meowing of violins?" The Futurists considered the new mechanical noise of the modern age as possible music, rhythms and exciting timbre. Encouraging musicians to rid themselves of traditional notions of music, melody and rhythm creating new sonic developments for the composition palette. If the Futurists had the opportunity to transform and listen to the EEG noise of a brain during epilepsy they may well have been excited by this noise and redefined it as music too.

The objective analysis of pure sonification data may well be useful to scientifically understand the brain waves during these epilepsy events, but musification for aesthetic listening may not? As an electronic musician, the creative subjectivity becomes a

motivating factor and influences the musical results which possibly '*corrupts*' objectivity relating to data analysis. Objective sonification is part of the process employed during a project like this via algorithms employed, but there becomes a point, or fulcrum, where musicians enter an aesthetic musification process which begins to alter and influence the data subjectively.

Is there a place for subjective musical interpretations of epilepsy EEG data in science?

Connecting academic disciplines might be important, as Physicist David Bohm discusses in '*Wholeness and the Implicate Order*' specifically the chapter '*Fragmentation and wholeness*' where Bohm asserts that humanity has continued to divide itself into racial groups, separate nations, different religions, opposing politics and beyond. Dissatisfied with these categories, people have further split into various '*specialties*' within interdisciplinary subjects such as art, science, technology, medicine, politics and religion causing to divide humanity into fragments that can promote conflict, opposing opinions and separated definitions. Whereas Bohm promotes a '*wholeness*' ideal in a global community where '*human work*' no longer fragments, which he argues is the cause conflict and confusion. (Bohm, D. 2002). When we look at the world we see radical separatism in many human activities, political and ideals. The reconnection of fragmented ideas within a distinct discipline is important, but also relevant to different disciplines such as art and science, as well as the relationship between medical practitioner and patient.

Musicians are directly influenced by varying aesthetic values and ideals, just like the results of sonification and musification of the EEG data are influenced directly by the algorithms used. The recorded EEG brain waves function below human hearing and require transformation or transposition into audible ranges, the methods of organization of the EEG data into audible musical form influences and alters the results. Therefore, once the data has been collected and the musification process begins, the objective data results become aesthetic musification, but that does not mean it cannot inform or

contribute to science. Scientific algorithm sonification processes can also result in moving away from the original musically relative data. If the data is to be interpreted scientifically it does not necessarily need to relate musically to the original brain waves as far as frequency and timbre is concerned. This is evident in algorithms such as Wu et al and others, the resulting pitch of sonified notes are not musically related to the original wavelengths' pitch, and therefore might be considered as not musically related. Although this aesthetic musical relativity might not be important to scientific interpretation of data it might be closer to the truth if considered important, the aesthetic could inform the scientific in an objective sonification scenario.

In the musification of this data, a selective process is required in the movement towards the artistic aesthetic, the collection and analysis of data with mathematical algorithms can throw up large amounts of data to sift through. If the aim is for scientific purposes objective analysis of the data sets are important to avoid subjective '*corruption*' of the sonification, but a selection process is vital for artistic or aesthetic musification processes. The methods undertaken during this project, in the derivation of notes and frequency ranges before musification, do create objective results that could be analyzed further if this project were aimed at the scientific sonification for EEG epilepsy analysis in a neurological framework. There may well be relationships between frequency ranges and cyclic repetition that could be analyzed objectively, within an auditory framework, in any future neurological development of this project.

The '*Scale-Free*' algorithms also throw up large amounts of real-time data sonification, but the processing of the data is free from the aesthetic if operating within a scientific framework. When using the data for musification the aesthetic goal reduces the freedom to use large amounts, or long streams of the data because of the recognized aesthetic musical structures we have constructed as musical beings can be narrow. In the western tradition, we employ twelve notes with fewer notes within recognized scales and keys.

When compared against large amounts of harvested data, the mapping to aesthetic models are reduced to simple data sets that can be suitable for musical mapping. (Furlong: Miranda et al 2016).

The philosophic ideas behind the initial project idea included the consideration of metaphors, symbolism, ideology, exploring interconnections, engaging with ideas within music, epilepsy (*history and culture*) and incorporate these within this project. When one analyzes the MAXMSP 'Oblique-Granizer' synthesizer created for this project it could act as a simplistic metaphor for the mind, with its interconnections, complex routings, mathematical calculations and numerous triggers whilst processing the EEG brainwaves. As it grows and develops, imperfections and faults creep in, there are compromises in design and functionality, sometimes it glitches and crashes like the brain might during seizure. It would be grandiose to suggest it is a mind, but as a metaphoric concept it serves to be '*like the mind*', with ideas and thoughts that can be loaded into it like sound-samples, morphed into sonic material via the exploration of personal emotions and metaphors. Different parts of the brain, lobes, could be likened to the individual granular generators, the matrix generating musical notes pulsing like the heart to create a final sonic realization of this idea.

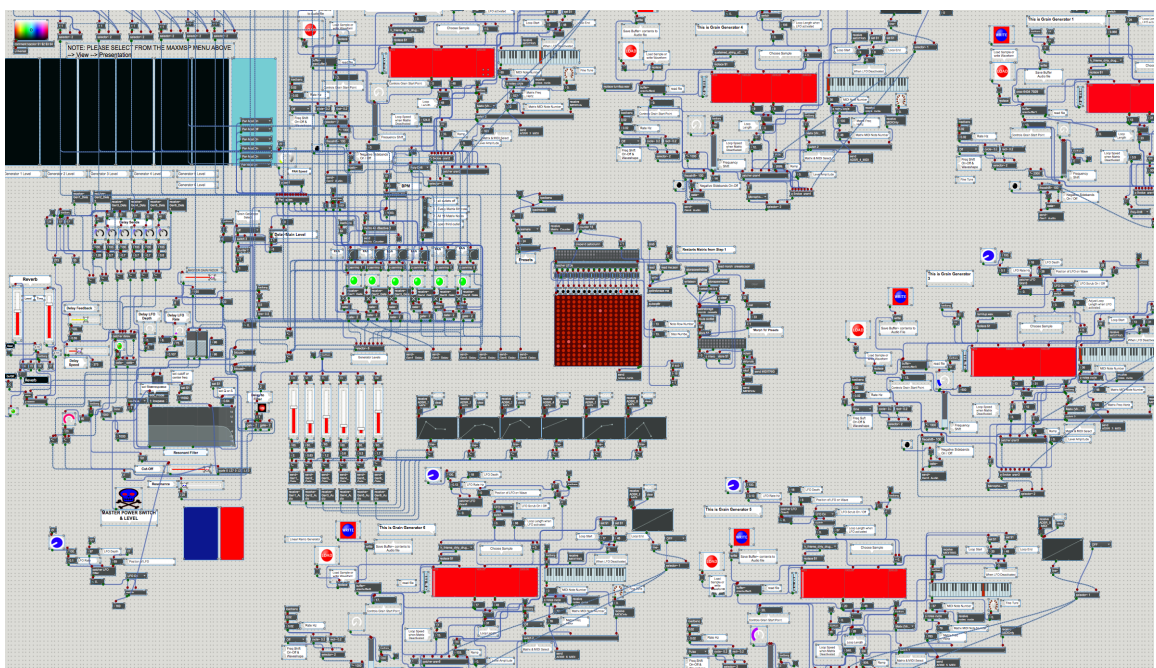


Figure 21: The 'Oblique-Granizer' synthesizer' internal functional connections.

The research into cultural and historic perceptions of epilepsy directly influenced the aesthetic of the musical outcomes. Religious themes, a sense of perceived loss of independence when first developing epilepsy, confusion, danger, fear and loneliness all influenced the musifications subjectively, but with one objective rule; to use the EEG epilepsy data as the source sonification to remain sincere to the project intentions. Objectively restricting the source sonification material to using the recordings of real EEG epilepsy events, but then to employ subjective musification to attempt to capture and explore the emotional and cultural experiences of epilepsy. Sonification has been the primary process but the aesthetic musification has also been pivotal. This created a fulcrum between sonification and musification that produced a balancing process between the two throughout the project. Restricting the process to pure sonification with the original EEG data produced aesthetically uninteresting noise, but moving too far towards the musical aesthetic risked merely making music about epilepsy.

In the research paper *'Sound, Listening and Place: The aesthetic dilemma'* the electroacoustic composer Barry Truax also identifies something similar to a fulcrum between the aesthetic and the message the electroacoustic artist is attempting to communicate when he states:

"The composer and sound artist become caught in the dilemma of either aestheticising the sounds of the environment, for instance, or else subordinating artistic values in order to convey a social message?" (Truax, B. 2012).

Truax asserts there is a potentially wide audience that is prepared to listen to electroacoustic soundscapes, outside of commercial music, if the artist has something meaningful and real to communicate. Truax believes sound-based art is about communication. He expresses the importance of exploring sociocultural and environmental issues creatively, combined with careful consideration for how it is being communicated within the soundscape environment. The sound designer and *'acoustic ecologist'* identified as pivotal to this creative extension in the art of composition.

13.1. The Success in Capturing Emotional Timbres Involved with Epilepsy?

When Hodgson designed the Tardis sound effect for the BBC television drama *'Doctor Who'* he described it verbally as *"ripping the fabric of time and space."* What descriptive terms might be used to describe the experiences and emotions of epilepsy? Desolate, isolating, creeping, dark, ominous, psychologically inter-dimensional, cosmic, waves of fear and confusion. Other epilepsy patients have similar and varying terms:

"it was as if time and space had stood still." (Epilepsy Society, Personal Stories, Jane Manwaring 2018).

"I thought I was going crazy." (Epilepsy Society, Personal Stories, Laura Grainger 2018).

"I felt I was floating out of my body. The instances were quite euphoric." (Epilepsy Research UK, Real stories, Nelle Fagan 2018).

"A sudden feeling of panic" (Epilepsy Research UK, Real stories, Dave Hellings 2018).

"One of my patients described it as oceanic." (Dr. Alasdair Coles 2013).

"You suddenly feel the presence of eternal harmony in all its fullness. It is nothing earthly." (Dostoevsky, *The Devils* 1871–1872 - Seneviratne, U. 2010).

There are numerous forms of epilepsy resulting in differing verbal descriptions of the epilepsy experience between sufferers. If placed within the possible context of a soundscape aesthetic this will add another variant relating to sonic semantics. This will be a result of the individual semantic interpretations of the experience and source-bondings they may have with sound. The success of the soundscapes will be subjective. However, the soundscapes created during this project will serve as one authentic artistic example created from EEG epilepsy events through personal experiences of epilepsy.

In the production called *'Requiem for a Neuron'* there is a tearing sound moving across the stereo field. When monitoring on headphones this has the psychoacoustic effect of moving through the brain. It represents the post-ictal phase of epilepsy when the brain is exhausted from the seizure experience, pain is spread across the brain and feels torn in the epicenter of the seizure where it transmitted through the brain. Following a seizure

event there can be a feeling of loneliness because of the solitary and clinical nature of the experience. The loss of control and the inability to hold onto conscious reality is mourned, a complex form of relief and depression sets in after the post-ictal phase when order begins to return. These themes have been intentionally and creatively communicated in this soundscape.

It is debated if neurons in the brain die during seizures. It is an interesting subject area to explore within the soundscape and certainly something the sound design process considered in relation to the feeling of loss in a post-ictal state. Where might the feeling of loss come from? The sufferer may have experienced a loss of consciousness, but does the brain consciously recognize neuron loss? When researching this area, it became personalized because of the personal experiences of temporal lobe epilepsy that have progressed to convulsive seizures. These seizure types are considered more likely to cause neuronal loss. Clinical research considers repetitive and prolonged temporal lobe seizures that develop into tonic-clonic convulsive seizures could cause neuronal loss especially in adults. (Dingledine et al 2014). The listener can decide if it has achieved the capture of emotional timbres such as these. The sonic metaphors created and present in this production are interesting and valid in the personal communication of these epilepsy experiences, emotions and concepts.

The source material (EEG audio) and Synthesis tools also have a direct effect on the timbre of the final sonic textures and compositions. Synthesis methods have sonic character that influence the results, as does the Oblique-Granizer MAX/MSP synthesizer created for this project and how it implements sample-based Granular Synthesis with the EEG material. The experience of manipulating the EEG recordings *'live'* via the synthesizer is perhaps more rewarding, the printing to *'fixed media'* soundscapes had the aesthetic effect of closing the dialogue with the EEG and finalizing the creativity. The experience of playing the EEG *'live'* and continuing the development of dialogue was found to be more rewarding from a personal artistic point of view.

The synthesis tools, source material and subjective narrative all combine and contribute to the final sonic results. The sound design process followed the methodology of *'with and about'* epilepsy by producing the music and sonic textures using the objective EEG material. The expression of the subjective aesthetic about the epilepsy condition from personal experience provided an opportunity for the soundscapes and sonic textures to communicate an authentic and meaningful message. Thus, relating it to the aim of being a proactive and creative transformation of the negative epilepsy experience and diagnoses.

The soundscapes and sonic textures within the *Oblique-Granizer* synthesizer created for this project can be experienced by an audience without the contextual information relating to the use of epilepsy. It could be contextualized completely differently by the remote listener (*the term 'remote' to refer to a listener who does not access any composition detail, context and the mechanics of production*). As Denis Smalley discusses, it may not be relevant to the listener and the listening experience to know exactly how and why the composer created the music. What the composer set out to portray to the listener, the processes and techniques employed, can be aided or hindered by program notes because it is not always relevant. Smalley has identified that the listener has various *'source bondings'* with sound, timbre and context these may be similarly shared amongst a listening audience but the sound and timbre *'bondings'* may also be completely different. Smalley defines the term *'source-bonding'* as resulting from wider cultural associations as well as from smaller community group experiences. They can also be imagined by individuals or learned through experience. Listeners can hear the same sound or music and it mean something completely different to them as a result of their personalized bonding with sound through culture, experience and social grouping. (Smalley 1997).

When contemplating a common bonding or *"common aesthetic framework"* we may all share (Miranda et al 2016), it is possibly due that easy access to ever-widening modern

electronic music genres via the internet, and multimedia experiences such as computer-gaming. A continuously developing cinematic musical language amongst global audiences through television and film also widen the sonic palette audience experiences (*and is prepared to experience*) as music. ‘Source-bonding’ continues to be defined and developed within these multimedia experiences across a modern consumerist common-aesthetic-framework. It is possible the ability for audiences to comprehend similarly detailed meanings expressed by the composer, within their compositions, becomes a common language we might understand beyond linguistic origin. As mentioned earlier in this document, film sound designer and editor Walter Murch stated (Burman et al 2013):

“When you put meaning into the sound effects... as a listener you can pull meaning from it.” (Murch, W. 2013)

13.2. Who might find this thesis, the soundscapes and synthesizer created for this project interesting and useful?

Patients, carers and medical practitioners interested in examples of how someone can interact creatively and cathartically with epilepsy could find this work engaging and useful. In the *‘Medical Journal of Australia’* in an article called *‘Medical Humanities: To Cure Sometimes, to Relieve Often, to Comfort Always’* (2005) Jill Gordon asserted that there is a growing public interest in artworks created by patients of psychiatric conditions, citing examples such as *‘The Art of Schizophrenia’* by Bryan Charney who suffered from the condition for his adult life until his premature death at 42 years of age (1949-1991). In the decade prior to his suicide Charney explored his experiences of schizophrenia and created a series of paintings exploring the suffering of mental illness, and finally producing a set of seventeen self-portraits whilst experimenting with various doses of the heavy medication he was prescribed. Artworks created by people living with illness can transform perspectives, challenge prejudice and stereotypes by providing personal insights into their lives and conditions for the wider public. This change in

perspective may also be true for medical professionals involved in the care and treatment of these patients, creativity could be promoted to augment the treatment and management of the condition.

Medical practitioners, carers and nursing staff could access this work as a creative and cathartic activity example with patients who can also access it independently. EEG recordings could be provided to patients on request to engage in creative and cathartic sonification and musification activities with their own EEG brainwaves. This could form part of therapeutic recovery in the form of transformative workshops changing a diagnosis into a creative activity. When informing an epilepsy nurse of this project she stated that some patients use painting to express their feelings, but she had not heard of patients making music from epilepsy EEG recordings. This activity could contribute to a portfolio of creative and cathartic transformative activity as part of a wider portfolio with a range possible activities for interacting with their conditional creatively.

There is an opportunity to further develop a portfolio of artistic and creative activities that do not solely involve professional 'medical treatment' in the care of patient's well-being, with this being provided by artists as well as therapists. This is demonstrated in schemes like the *'Arts on Prescription'* practice where it is considered that effects of the arts and creative activities offer a range of benefits for patients with psychological problems and social isolation. This suggests that the prescription of creative activities might be a therapeutic alternative for some people, as anti-depressants could be for others. The arts in health care has been considered a *'legitimate intervention'* since the 1970's with official recognition of the social value of the arts the World Health Organization, the Royal College of Psychiatrists and British Medical Association. It has been asserted in research that participation in therapeutic prescribed creative art groups promoted confidence in participants, inspiring some to pursue further education and employment, gaining new skills and promoting a positive outlook on life. (Stickley, Hui.

2012). Matt Peacock from *'Streetwise Opera'* who works with homelessness questioned that self-esteem was ranked lower than physiological needs in Maslow's hierarchy of needs. Peacock asserts that the arts give people dignity, improves their self-esteem and makes people realize they are more than the sum of their problems and that they can have a positive purpose in life. (Holden et al 2014).

This Research Masters study, using creative research to transform the EEG epilepsy brainwaves into soundscape, has enabled the personal transformation of the power that epilepsy asserts on an individual into a proactive and creative production process. During this project, the transformation process has proactively facilitated the creation of a bespoke granular synthesizer, a suite of soundscapes, a research thesis and a collaborative contemporary music concert involving musicians who do not have the epilepsy condition but have also been making music with it. The collaborators for the concert have expressed excitement and enjoyment of the work they have produced, while unintentionally learning more about the epilepsy condition. In line with Smalley's suggestion of the importance of the soundscape artist communicating sociocultural themes, this project could communicate a meaningful message through soundscape and sociocultural research. The chief executive of Epilepsy Action Phillip Lee stated that this project work is a good way to raise awareness of the misunderstood epilepsy condition by creating a shared experience. Epilepsy has a rich history of human experience, medicine, technology, mythology, superstition, religion, literature, art and music, when one acquires this condition one can become an active part of this history with creative proactivity and not passivity. This project work has been productive, creative and positively transformative for myself. The work produced could augment a portfolio of creative social well-being opportunities a patient or practitioner could access in post-diagnoses therapeutic and collaborative care. Other sufferers of the condition may contribute authentic aesthetic interpretations to the soundscape of epilepsy in the future. This may also serve as an auditory portfolio as exemplars created by patients.

This thesis offers soundscape examples and contributes methods of musification and sonification to enter a musical dialogue with the waves of epilepsy. This work could be provided to patients with interests in the arts to proactively reclaim positive creative control from epilepsy.

Medical practitioners involved in the treatment and care of epilepsy patients may consider the patient experience in different perspectives, an individualized focus on treatment and care with the subject considered as well as the objective. Practical and creative activities could empower patients towards positive self-motivated perspectives beyond diagnoses and medication. In my case I wanted to enter deeper discussion about epilepsy beyond the tests that confirmed the condition and the instructive prescription of medication. The psychological affect could be discussed in detail and related to creative processing towards coping with the condition. Patients can be articulate and want to explore the finite detail of diagnoses. Enter a two-way dialogue with medical practitioners, explore the condition in new creative, transformative and personalized ways. Roy Porter identifies the '*articulate sufferer*' in '*The Patient's View: Doing Medical History from below*' (1985). He asserts that initiatives and innovations have come from patients as well as medical practitioners, that medical history should encompass the range of patient's experience with focus on care as well as cure. Porter also asserts that there are 'admirable' histories of epilepsy but none from the sufferers themselves. In a review of Porter's work thirty years later it is still asserted that the patient's view remains underdeveloped (Bacopoulos-Viau, A. Fauvel, A. 2016).

The electroencephalographer in my case was not able to discuss and articulate the details of EEG diagnoses despite my expressing an interest in the waveforms. I could openly discuss Hz ranges and waveform types, but when I enquired about the waveforms that he had identified as proof of epilepsy in my EEG results he asserted that '*they were just present throughout the EEG.*' Did the electroencephalographer believe I was not articulate enough to understand? Or was there no time to discuss it with a patient? The

enthusiasm I have for waveforms as an electronic musician is transferable, or can be transformed to that of electrical EEG waveforms if given an interdisciplinary opportunity to further develop this enthusiasm and knowledge. An electronic musician with epilepsy like myself could contribute to developments in the management of psychological well-being with my own epilepsy and perhaps others through creative means. As Porter asserts, patients may have something to contribute to knowledge and innovation in science and medicine. I had a desire to interact with my diagnoses in a detailed, articulate and creative manner to "*overcome the separation of clinical and humanistic inquiry*" (Gordon, J. 2005). This project work is an inquiry, a continued dialogue with the waves of epilepsy, independently transforming the passive patient into a creatively active one through inquisitive and transformative creative processes.



13.2. Final Compositions Summary Narrative Detail.

- *The Esoteric Voyage of Hans, Nikolai and Zedel (1924)* - I experimented with overlaying an EEG Graph onto a musical stave as a tribute musification to Hans Berger, Nilolai Guleke and Zedel - "*The first patient involved with this study was a 17-year-old college student by the name of Zedel who had undergone two craniostomies for the removal of a brain tumor, leaving him with a large cranial defect over the central sulcus and its adjacent motor and sensory gyri.*")
- *Dante and Virgil Descend Past the Minotaur* - to continue their journey through the inferno Dante and Virgil must trick their way past the Minotaur, that acts as a metaphor for navigating epilepsy to continue one's everyday life. It is also influenced by the story that epilepsy sufferers were made to dance for 24 hours at the St. Bartholomew dance with some dying from exhaustion and descending straight to hell.

- ***Threat of Focal Onset*** - exploring the ominous feeling that a seizure could happen at any time.
- ***Lost*** - is an exploration of returning from an absence seizure in an unknown physical location.
- ***Out Beyond the Öpik-Oort Cloud*** - a theoretical cloud surrounding the sun in interstellar space. I was looking for metaphorical subjects at the edges of our solar system to contribute to the cosmic feelings of focal onset seizures prior to full seizure. The Öpik-Oort Cloud is said to be influenced by the gravitational pull of passing stars and our own Milky Way, the gravity of epilepsy and consciousness both pulling my life in different directions or consciousness.
- ***Requiem for a Neuron*** - there is a tearing sound moving across the stereo field, when monitoring on headphones this has the psychoacoustic effect of moving through the brain. This represents the post-ictal phase of epilepsy, the brain is exhausted from the seizure experience, pain is spread across the brain and feels torn in the epicenter of the seizure and where it transmitted through the brain.
- ***Into the Absence*** - it is an unsettling experience drifting into a seizure through focal onset, but still functioning as far as observers are concerned. People who are present when experiencing an epilepsy absence seizure often discuss your behavior or actions when you were absent, but you have been beyond the observable.
- ***Interpolate Between Safety and Seizure*** – exploring the idea of the movement between consciousness and unconsciousness.
- ***Cyclic Rhythmic Sampler Experiment*** – experiment with segmentation of epilepsy EEG data for rhythmic and melodic phrasing.

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Appendix A: Weber-Fechner law in musical context.

Sensation Level Semitone	Stimulus Intensity Hz SI	JND Ratio	JND Hz	Log SI	Log JND	Log JND Ratio	$10^{(\log JND + \log JND \text{ Ratio})}$ is added to Stimulus for next stimulus value	$SI + 10^{(\log JND + \log JND \text{ Ratio})}$ = next stimulus value
0	440			2.64345267648619				
1	466.1637615	1.05946309431818	26.1637615	2.66853850944133	1.41770018159636	0.025085832955	27.7195397177920	493.883301217791
2	493.8833012178	1.05946309431818	27.7195397	2.69362434239648	1.44278601455151	0.025085832955	29.3678293224876	523.251130540279
3	523.2511305403	1.05946309431818	29.3678293	2.71871017535162	1.46787184750665	0.025085832955	31.1141313274109	554.365261867690
4	554.3652618677	1.05946309431818	31.1141313	2.74379600830677	1.49295768046179	0.025085832955	32.9642738531609	587.329535720851
5	587.3295357209	1.05946309431818	32.9642739	2.76888184126191	1.51804351341694	0.025085832955	34.9244315784218	622.253967299273
6	622.2539672993	1.05946309431818	34.9244316	2.79396767421705	1.54312934637208	0.025085832955	37.0011463473784	659.255113646651
7	659.2551136467	1.05946309431818	37.0011463	2.81905350717220	1.56821517932723	0.025085832955	39.2013490025132	698.456462649164
8	698.4564626492	1.05946309431818	39.2013490	2.84413934012734	1.59330101228237	0.025085832955	41.5323825156495	739.988845164813
9	739.9888451648	1.05946309431818	41.5323825	2.86922517308249	1.61838684523752	0.025085832955	44.0020264944364	783.990871659250
10	783.9908716593	1.05946309431818	44.0020265	2.89431100603763	1.64347267819266	0.025085832955	46.6185231460661	830.609394805316
11	830.6093948053	1.05946309431818	46.6185231	2.91939683899278	1.66855851114780	0.025085832955	49.3906047848749	879.999999590191
12	879.9999995902	1.05946309431818	49.3906048	2.94448267194792	1.69364434410295	0.025085832955	52.3275229756299	932.327522565821

Table 3: Testing application of Weber-Fechner formula in musical context.

Appendix B: Testing Wu et al Formula Results.

Table 1: Testing Wu et al formula against notation provided.

<p>Note 1: is C4 on the bass clef from the Wu et al notation (<i>figure 10 page 40</i>) using 1.1uV as the reference.</p> <p>Pitch = m log₁₀Amp + n</p> <p>(m) = -40/1.1 = -36.36363636 x ($\log_{10} Amp = 21 \log_{10}$) = -48.0807016</p> <p>-48 + (n) = 108 = MIDI note 60</p> <p>e.g. 261.63Hz-> $261.63 \log_{10} \times 40 - 36.6 = 60.1075016 = \mathbf{MIDI\ note\ 60 = C4}$</p>
<p>Note 2: is A4 on the bass clef:</p> <p>-40/1.1 = -36.36363636 x ($11.8 \log_{10}$) = -38.9775275 (= -39)</p> <p>-39 + 108 = MIDI note 69</p> <p>A4 = 440Hz = MIDI note 69</p> <p>e.g. 440Hz --> $440 \log_{10} \times 40 - 36.6 = 69.138107 = \mathbf{MIDI\ note\ 69 = A4}$</p>
<p>Note 3: is G#3 on the bass clef:</p> <p>-40/1.1 = -36.36363636 x ($27 \log_{10}$) = -52.0495914</p> <p>-52 + 108 = MIDI note 56</p> <p>G#3 = 207.65Hz = MIDI note 56</p> <p>e.g. $207.65 \log_{10} \times 40 - 36.6 = 56.09327741 = \mathbf{MIDI\ note\ 56 = G\#3}$</p>
<p>Note 4: is F#5 on the bass clef:</p> <p>-40/1.1 = 36.36363636 x ($6.6 \log_{10}$) = -29.8015976 (= -30)</p> <p>-30 + 108 = MIDI note 78</p> <p>F#5 = 739.99Hz = MIDI note 78</p> <p>e.g. $739.99 \log_{10} \times 40 - 36.6 = 78.169034 = \mathbf{MIDI\ note\ 78 = F\#5}$</p>
<p>Note 5: is G#4 on the bass clef:</p> <p>-40/1.1 = 36.36363636 x ($12.6 \log_{10}$) = -40.013474 (= -40)</p> <p>-40 + 108 = MIDI note 68</p> <p>G#4 = 415.30Hz = MIDI note 68</p> <p>e.g. $415.30 \log_{10} \times 40 - 36.6 = 68.13447724439513 = \mathbf{MIDI\ note\ 68 = G\#4}$</p>
<p>Note 6: is E4 on the bass clef:</p> <p>40/1.1 = 36.36363636 x ($16.3 \log_{10}$) = -44.079549 (= -44)</p> <p>-44 + 108 = MIDI note 64</p> <p>E4 = 329.63Hz = MIDI note 64</p> <p>e.g. $329.63 \log_{10} \times 40 - 36.6 = 64.1210692182 = \mathbf{MIDI\ note\ 64 = E4}$</p>

Note 7: Bb2 = MIDI note 46

$$-40/1.1 = 36.36363636 \times (51 \log_{10}) = -62.0934609 (= -62)$$

$$-62 + 108 = \text{MIDI note 46}$$

$$\text{Bb2} = 116.54\text{Hz} = \text{MIDI note 46}$$

$$\text{e.g. } 116.54 \log_{10} \times 40 - 36.6 = \text{MIDI note 46} = \text{Bb2}$$

Note 8: Is also (tied note) --> Bb2 = MIDI note 46

$$-40/1.1 = 36.36363636 \times (51 \log_{10}) = -62.0934609 (= -62)$$

$$-62 + 108 = \text{MIDI note 46}$$

$$\text{Bb2} = 116.54\text{Hz} = \text{MIDI note 46}$$

$$\text{e.g. } 116.54 \log_{10} \times 40 - 36.6 = \text{MIDI note 46} = \text{Bb2}$$

Note 9: C#3 on the bass clef:

$$-40/1.1 = 36.36363636 \times (42 \log_{10}) = -59.02724692356002 (= -59)$$

$$-59 + 108 = \text{MIDI note 49}$$

$$\text{C\#3} = 138.59\text{Hz} = \text{MIDI note 49}$$

$$\text{e.g. } 138.59 \log_{10} \times 40 - 36.6 = \text{MIDI note 49} = \text{C\#3}$$

Note 10: E4 = MIDI note 64 (*the same as note 6*).

$$-40/1.1 = 36.36363636 \times (16.3 \log_{10}) = -44.079549 (= -44)$$

$$-44 + 108 = \text{MIDI note 64}$$

$$\text{E4} = 329.63\text{Hz} = \text{MIDI note 64}$$

$$\text{e.g. } 329.63 \log_{10} \times 40 - 36.6 = 64.1210692182 = \text{MIDI note 64} = \text{E4}$$

Note 11: Gb3 = MIDI note 54

$$-40/1.1 = 36.36363636 \times (30.5 \log_{10}) = -53.9745396 (= -54)$$

$$-54 + 108 = \text{MIDI note 54}$$

$$\text{Gb3} = 185\text{Hz} = \text{MIDI note 54}$$

$$\text{e.g. } 185 \log_{10} \times 40 - 36.6 = 54.086869 = \text{MIDI note 54} = \text{Gb3}$$

Note 12: D2 = MIDI Note 38

$$-40/1.1 = 36.36363636 \times (84 \log_{10}) = -69.973792 (= -70)$$

$$-70 + 108 = \text{MIDI note 38}$$

$$\text{D2} = 73.416\text{Hz} = \text{MIDI note 38}$$

$$\text{e.g. } 73.416 \log_{10} \times 40 - 36.6 = 38.0316287 = \text{MIDI note 38} = \text{D2}$$

Note 13: (is the same as note 2) A = MIDI note 69

$$-40/1.1 = -36.36363636 \times (11.8 \log_{10}) = -38.9775275 (= -39)$$

$$-39 + 108 = \text{MIDI note 69}$$

$$A4 = 440\text{Hz} = \text{MIDI note 69}$$

$$\text{e.g. } 440\text{Hz} \rightarrow 440 \log_{10} \times 40 - 36.6 = 69.138107 = \text{MIDI note 69} = \mathbf{A4}$$

Note 14: G1 = MIDI note 31

$$-40/1.1 = 36.36363636 \times (131 \log_{10}) = -76.991683 (= -77)$$

$$-77 + 108 = \text{MIDI note 31}$$

$$G1 = 48.999\text{Hz} = \text{MIDI note 31}$$

$$\text{e.g. } 48.999 \log_{10} \times 40 - 36.6 = 31.0075 = \text{MIDI note 31} = \mathbf{G1}$$

Note 15: (is the same as note 14, tied note) G1 = MIDI note 31

$$-40/1.1 = 36.36363636 \times (131 \log_{10}) = -76.991683 (= -77)$$

$$-77 + 108 = \text{MIDI note 31}$$

$$G1 = 48.999\text{Hz} = \text{MIDI note 31}$$

$$\text{e.g. } 48.999 \log_{10} \times 40 - 36.6 = 31.0075 = \text{MIDI note 31} = \mathbf{G1}$$

Note 16: (is the same as note 15, tied note) G1 = MIDI note 31

$$-40/1.1 = 36.36363636 \times (131 \log_{10}) = -76.991683 (= -77)$$

$$-77 + 108 = \text{MIDI note 31}$$

$$G1 = 48.999\text{Hz} = \text{MIDI note 31}$$

$$\text{e.g. } 48.999 \log_{10} \times 40 - 36.6 = 31.0075 = \text{MIDI note 31} = \mathbf{G1}$$

Note 17: (is the same as note 12) D2 = MIDI note 38

$$-40/1.1 = 36.36363636 \times (84 \log_{10}) = -69.973792 (= -70)$$

$$-70 + 108 = \text{MIDI note 38}$$

$$D2 = 73.416\text{Hz} = \text{MIDI note 38}$$

$$\text{e.g. } 73.416 \log_{10} \times 40 - 36.6 = 38.0316287 = \text{MIDI note 38} = \mathbf{D2}$$

Note 18: (is the same as note 17, tied note) D2 = MIDI note 38

$$-40/1.1 = 36.36363636 \times (84 \log_{10}) = -69.973792 (= -70)$$

$$-70 + 108 = \text{MIDI note 38}$$

$$D2 = 73.416\text{Hz} = \text{MIDI note 38}$$

$$\text{e.g. } 73.416 \log_{10} \times 40 - 36.6 = 38.0316287 = \text{MIDI note 38} = \mathbf{D2}$$

Note 19: F3 = MIDI note 53

$$-40/1.1 = 36.36363636 \times (32.4 \log_{10}) = -54.92891 (= -55)$$

$$-55 + 108 = \text{MIDI note 53}$$

$$F3 = 174.61\text{Hz} = \text{MIDI note 53}$$

$$\text{e.g. } 174.61 \log_{10} \times 40 - 36.6 = 53.08276 = \text{MIDI note 53} = \mathbf{F3}$$

Note 20: C3 = MIDI note 48

$$-40/1.1 = 36.36363636 \times (44.6 \log_{10}) = -59.975813 (= -60)$$

$$-60 + 108 = \text{MIDI note 48 on the bass clef:}$$

$$C3 = 130.81\text{Hz} = \text{MIDI note 48}$$

$$\text{e.g. } 130.81 \log_{10} \times 40 - 36.6 = 48.065638 = \text{MIDI note 48} = \mathbf{C3}$$

Note 21: (*is the same as note 3*) = G#3 on the bass clef:

$$-40/1.1 = -36.36363636 \times (27 \log_{10}) = -52.0495914$$

$$-52 + 108 = \text{MIDI note 56}$$

$$G\#3 = 207.65\text{Hz} = \text{MIDI note 56}$$

$$\text{e.g. } 207.65 \log_{10} \times 40 - 36.6 = 56.09327741 = \text{MIDI note 56} = \mathbf{G\#3}$$

Note 22: A2 = MIDI note 33

$$-40/1.1 = 36.36363636 \times (115.4 \log_{10}) = -74.9893 (= -74)$$

$$-75 + 108 = \text{MIDI note 33}$$

$$A2 = 55\text{Hz} = \text{MIDI note 33}$$

$$\text{e.g. } 55 \log_{10} \times 40 - 36.6 = 33.01451 = \text{MIDI note 33} = \mathbf{A1}$$

Note 23: A2 (*is the same as note 22, tied note*) = MIDI note 33

$$-40/1.1 = 36.36363636 \times (115.4 \log_{10}) = -74.9893 (= -74)$$

$$-75 + 108 = \text{MIDI note 33}$$

$$A2 = 55\text{Hz} = \text{MIDI note 33}$$

$$\text{e.g. } 55 \log_{10} \times 40 - 36.6 = 33.01451 = \text{MIDI note 33} = \mathbf{A1}$$

Note 24: F2 = MIDI note 41

$$-40/1.1 = 36.36363636 \times (69.6 \log_{10}) = -67.003972 (= -67)$$

$$-67 + 108 = \text{MIDI note 41 on the bass clef}$$

$$F2 = 87.307\text{Hz} = \text{MIDI note 41}$$

$$\text{e.g. } 87.307 \log_{10} \times 40 - 36.6 = 41.0419626 = \text{MIDI note 41} = \mathbf{F2}$$

Note 25: (is the same as note 19) F3 = MIDI note 53

$$-40/1.1 = 36.36363636 \times (32.4 \log_{10}) = -54.92891 (= -55)$$

$$-55 + 108 = \text{MIDI note 53}$$

$$F3 = 174.61\text{Hz} = \text{MIDI note 53}$$

$$\text{e.g. } 174.61 \log_{10} \times 40 - 36.6 = 53.08276 = \text{MIDI note 53} = F3$$

Note: MIDI to Hz can also be double checked using the following: each note's frequency is $2^{(1/12)}$ times the frequency of the previous note, $440 * 2^{(2/12)} = 493.8833012561241$ Hz. If MIDI note 69 (440Hz) is used as a reference the HZ can be calculated using the following formula:

$$\text{Frequency Hz} = 440 * 2^{((n-69)/12)} \text{ where 'n' is the MIDI note number.}$$

Note 25: F3 = MIDI note 53

$$\text{Hz} = 440 * 2^{((53-69)/12)} = 174.61411571650231 = 174.61\text{Hz}$$

Calculating the MIDI note numbers from frequency can also be treble checked via the formula:

$$n = 69 + 12 * \log(F/440) / \log(2)$$

Where n = MIDI note; F=Hz

$$n = 69 + 12 * \log(174.61411571650231/440) / \log(2) = \text{MIDI note 53}$$

Above also possible like this:

$$n = \log_2(F/440) \times 12 + 69$$

Where n = MIDI note; F=Hz

$$n = \log_2(174.61411571650231/440) \times 12 + 69 = \text{MIDI note 53}$$

Following the calculation of the voltage from the Wu et al notes, this is an experiment exploring the mapping of dB amplitude values (*in Table 2 below*) with the Wu et al graph (figure 11: page 40):

$$\text{Amplitude: dB} = 20\log_{10}(v/\text{ref})$$

Where v = voltage peaks measured via EEG

ref =reference voltage uV used to derive dB values.

Table 2: Amplitude exploration with Wu et al amplitude graph provided.

Note 1: $20\log_{10} x (21\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 25.6 \text{ dB}$	Note 14: $20\log_{10} x (131\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 41.52\text{dB}$
Note 2: $20\log_{10} x (11.8\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 20.6 \text{ dB}$	Note 15: $20\log_{10} x (131\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 41.52\text{dB}$
Note 3: $20\log_{10} x (27\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 27.8\text{dB}$	Note 16: $20\log_{10} x (131\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 41.52\text{dB}$
Note 4: $20\log_{10} x (6.6\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 15.56 \text{ dB}$	Note 17: $20\log_{10} x (84\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 37.66\text{dB}$
Note 5: $20\log_{10} x (12.6\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 21.18 \text{ dB}$	Note 18: $20\log_{10} x (84\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 37.66\text{dB}$
Note 6: $20\log_{10} x (16.3\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 23.42 \text{ dB}$	Note 19: $20\log_{10} x (32.4\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 29.38\text{dB}$
Note 7: $20\log_{10} x (51\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 33.32 \text{ dB}$	Note 20: $20\log_{10} x (44.6\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 32.16\text{dB}$
Note 8: $20\log_{10} x (42\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 31.64\text{dB}$	Note 21: $20\log_{10} x (27\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 27.8\text{dB}$
Note 9: $20\log_{10} x (16.3\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 23.42\text{dB}$	Note 22: $20\log_{10} x (115.4\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 40.42\text{dB}$
Note 10: $20\log_{10} x (30.5\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 28.86\text{dB}$	Note 23: $20\log_{10} x (115.4\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 40.42\text{dB}$
Note 11: $20\log_{10} x (84\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 37.66\text{dB}$	Note 24: $20\log_{10} x (69.6\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 36.02\text{dB}$
Note 12: $20\log_{10} x (11.8\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 20.61\text{dB}$	Note 25: $20\log_{10} x (32.4\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 29.38\text{dB}$
Note 13: $20\log_{10} x (131\mu\text{V} / 1.1 \text{ ref } \mu\text{V}) = 41.52\text{dB}$	

Appendix C: Experiment #2 with Wu et al Data (page 49).

Table 11: formula experiment with segmentation of EEG waveform provided by Wu et al.

<p>Segment window 1:</p> <p>$Fw / Sw = 216 / 5 = 43.2 =$ ratio between full window and segment window</p> <p>$Fs / R = 1000 / 43.2 = 23.14814814814815 =$ samples in the segment.</p> <p>$B / S = 250 / 23.14814814814815 =$ 10.8 Hz</p>
<p>Segment window 2:</p> <p>$Fw / Sw = 216 / 3.5 = 61.71428571428571$</p> <p>$Fs / R = 1000 / 61.71428571428571 = 16.2037037037037$</p> <p>$B / S = 250 / 16.2037037037037 = 15.42857142857143 =$ 15.43 Hz</p>
<p>Segment window 3:</p> <p>$Fw / Sw = 216 / 6 = 36$</p> <p>$Fs / R = 1000 / 36 = 27.77777777777778$</p> <p>$B / S = 250 / 27.77777777777778 =$ 9 Hz</p>
<p>Segment window 4:</p> <p>$Fw / Sw = 216 / 2 = 108$</p> <p>$Fs / R = 1000 / 108 = 9.25925925925926$</p> <p>$B / S = 250 / 9.25925925925926 =$ 27 Hz</p>
<p>Segment window 5:</p> <p>$Fw / Sw = 216 / 5 = 43.2$</p> <p>$Fs / R = 1000 / 43.2 = 23.14814814814815$</p> <p>$B / S = 250 / 23.14814814814815 =$ 10.8 Hz</p>
<p>Segment window 6:</p> <p>$Fw / Sw = 216 / 7 = 30.85714285714286$</p> <p>$Fs / R = 1000 / 30.85714285714286 = 32.4074074074074$</p> <p>$B / S = 250 / 32.4074074074074 = 7.71428571428572 =$ 7.71 Hz</p>
<p>Segment window 7:</p> <p>$Fw / Sw = 216 / 29 = 7.44827586206897$</p> <p>$Fs / R = 1000 / 7.44827586206897 = 134.25925925925918$</p> <p>$B / S = 250 / 134.25925925925918 = 1.86206896551724 =$ 1.86 Hz</p>
<p>Segment window 8:</p> <p>$Fw / Sw = 216 / 10.5 = 20.57142857142857$</p> <p>$Fs / R = 1000 / 20.57142857142857 = 48.61111111111111$</p> <p>$B / S = 250 / 48.61111111111111 = 5.14285714285714 =$ 5.14 Hz</p>
<p>Segment window 9:</p> <p>$Fw / Sw = 216 / 7 = 30.85714285714286$</p> <p>$Fs / R = 1000 / 30.85714285714286 = 32.4074074074074$</p> <p>$B / S = 250 / 32.4074074074074 = 7.71428571428571 =$ 7.71 Hz</p>

<p>Segment window 10:</p> <p>$Fw / Sw = 216 / 6 = 36$</p> <p>$Fs / R = 1000 / 36 = 27.77777777777778$</p> <p>$B / S = 250 / 27.77777777777778 = \mathbf{9\ Hz}$</p>
<p>Segment window 11:</p> <p>$Fw / Sw = 216 / 11.5 = 18.78260869565217$</p> <p>$Fs / R = 1000 / 18.78260869565217 = 53.24074074074075$</p> <p>$B / S = 250 / 53.24074074074075 = 4.69565217391304 = \mathbf{4.7\ Hz}$</p>
<p>Segment window 12:</p> <p>$Fw / Sw = 216 / 4 = 54$</p> <p>$Fs / R = 1000 / 54 = 18.51851851851852$</p> <p>$B / S = 250 / 18.51851851851852 = \mathbf{13.5\ Hz}$</p>
<p>Segment window 13:</p> <p>$Fw / Sw = 216 / 29 = 7.44827586206897$</p> <p>$Fs / R = 1000 / 7.44827586206897 = 134.25925925925918$</p> <p>$B / S = 250 / 134.25925925925918 = 1.86206896551724 = \mathbf{1.86\ Hz}$</p>
<p>Segment window 14:</p> <p>$Fw / Sw = 216 / 19.5 = 11.07692307692308$</p> <p>$Fs / R = 1000 / 11.07692307692308 = 90.27777777777775$</p> <p>$B / S = 250 / 90.27777777777775 = 2.76923076923077 = \mathbf{2.77\ Hz}$</p>
<p>Segment window 15:</p> <p>$Fw / Sw = 216 / 3.5 = 61.71428571428571$</p> <p>$Fs / R = 1000 / 61.71428571428571 = 16.2037037037037$</p> <p>$B / S = 250 / 16.2037037037037 = 15.42857142857143 = \mathbf{15.43\ Hz}$</p>
<p>Segment window 16:</p> <p>$Fw / Sw = 216 / 4.5 = 48$</p> <p>$Fs / R = 1000 / 48 = 20.83333333333333$</p> <p>$B / S = 250 / 20.83333333333333 = \mathbf{12\ Hz}$</p>
<p>Segment window 17:</p> <p>$Fw / Sw = 216 / 4 = 54$</p> <p>$Fs / R = 1000 / 54 = 18.51851851851852$</p> <p>$B / S = 250 / 18.51851851851852 = \mathbf{13.5\ Hz}$</p>
<p>Segment window 17:</p> <p>$Fw / Sw = 216 / 4 = 54$</p> <p>$Fs / R = 1000 / 54 = 18.51851851851852$</p> <p>$B / S = 250 / 18.51851851851852 = \mathbf{13.5\ Hz}$</p>

Segment window 18:

$$Fw / Sw = 216 / 21.5 = 10.04651162790698$$

$$Fs / R = 1000 / 10.04651162790698 = 99.537037037037$$

$$B / S = 250 / 99.537037037037 = 2.51162790697675 = \mathbf{2.51 \text{ Hz}}$$

Segment window 19:

$$Fw / Sw = 216 / 13 = 16.61538461538462$$

$$Fs / R = 1000 / 16.61538461538462 = 60.18518518518517$$

$$B / S = 250 / 60.18518518518517 = 4.15384615384615 = \mathbf{4.15 \text{ Hz}}$$

Segment window 20:

$$Fw / Sw = 216 / 8.5 = 25.41176470588235$$

$$Fs / R = 1000 / 25.41176470588235 = 39.35185185185186$$

$$B / S = 250 / 39.35185185185186 = 6.35294117647059 = \mathbf{6.35 \text{ Hz}}$$

Analysis of Mapping Experiment #2:

This musification of EEG data highlights the issue that EEG brainwaves are below the human hearing range, transposition is required to bring it into the aural and musical domain. Only one of the notes (*Segment Window 4 = Ao*) is just within the human hearing range in the first mapping. From the results table the lowest frequency is 1.86Hz and the highest 27Hz (*Segment Window 4 = Ao*). A transposition process was required to map the previous Hz frequencies within the human hearing range and assign to MIDI note numbers using the following formula. I simply multiplied the Hz ranges by 10^2 and then mapped to MIDI note pitches.

Finding corresponding MIDI note number from Hz: (*where n is the MIDI note number*).

$$n = 69 + 12 * \log_{10}(\text{freq}/440) / \log_{10}(2) * 10^2$$

Above also possible like this:

$$(\text{Hz} / 440) \rightarrow \text{press log2 button} \times 12 + 69 * 10^2$$

Table 12: formula development with added 10^2 for Hz segmentation of EEG data provided by Wu et al.

<p>Segment window 1: = 10.8 Hz *10² = 1080 Hz $\log_2(1080 / 440) * 12 + 69 = 84.54547060231403 = 85 = \text{C\#6}$</p>
<p>Segment window 2: = 15.43 Hz *10² = 1543 Hz $\log_2(1543 / 440) * 12 + 69 = 90.72195159655289 = 91 = \text{G6}$</p>
<p>Segment window 3: = 9 Hz *10² = 900 Hz $\log_2(900 / 440) * 12 + 69 = 81.38905773230857 = 81 = \text{A5}$</p>
<p>Segment window 4: = 27 Hz *10² = 2700 Hz $\log_2(2700 / 440) * 12 + 69 = 100.40860774096241 = 100 = \text{E7}$</p>
<p>Segment window 5: = 10.8 Hz *10² = 1080 Hz $\log_2(1080 / 440) * 12 + 69 = 84.54547060231403 = 85 = \text{C\#6}$</p>
<p>Segment window 6: = 7.71 Hz *10² = 771 Hz $\log_2(771 / 440) * 12 + 69 = 78.71072803668452 = 79 = \text{G5}$</p>
<p>Segment window 7: = 1.86 Hz *10² = 186 Hz $\log_2(186 / 440) * 12 + 69 = 54.09358917100036 = 54 = \text{F\#3}$</p>
<p>Segment window 8: = 5.14 Hz *10² = 514 Hz $\log_2(514 / 440) * 12 + 69 = 71.69117802803064 = 72 = \text{C5}$</p>
<p>Segment window 9: = 7.71 Hz *10² = 771 Hz $\log_2(771 / 440) * 12 + 69 = 78.71072803668452 = 79 = \text{G5}$</p>
<p>Segment window 10: = 9 Hz *10² = 900 Hz $\log_2(900 / 440) * 12 + 69 = 81.38905773230857 = 81 = \text{A5}$</p>
<p>Segment window 11: = 4.7 Hz *10² = 470 Hz $\log_2(470 / 440) * 12 + 69 = 70.14188679648411 = 70 = \text{A\#4}$</p>
<p>Segment window 12: = 13.5 Hz *10² = 1350 Hz $\log_2(1350 / 440) * 12 + 69 = 88.40860774096241 = 88 = \text{E6}$</p>
<p>Segment window 13: = 1.86 Hz *10² = 186 Hz $\log_2(186 / 440) * 12 + 69 = 54.09358917100036 = 54 = \text{F\#3}$</p>
<p>Segment window 14: = 2.77 Hz *10² = 277 Hz $\log_2(277 / 440) * 12 + 69 = 60.98858943029422 = 61 = \text{C\#4}$</p>
<p>Segment window 15: = 15.43 *10² = 1543 Hz $\log_2(1543 / 440) * 12 + 69 = 90.72195159655289 = 91 = \text{G6}$</p>
<p>Segment window 16: = 12 Hz *10² = 1200 Hz $\log_2(1200 / 440) * 12 + 69 = 86.36950772365468 = 86 = \text{D6}$</p>
<p>Segment window 17: = 13.5 Hz *10² = 1350 Hz $\log_2(1350 / 440) * 12 + 69 = 88.40860774096241 = 88 = \text{E6}$</p>
<p>Segment window 18: = 2.51 Hz *10² = 251 Hz $\log_2(251 / 440) * 12 + 69 = 59.28220608511349 = 59 = \text{B3}$</p>

Segment window 19: = 4.15 Hz *10² = 415 Hz

$\log_2(415 / 440) * 12 + 69 = 67.98729375251556 = 68 = \mathbf{G\#4}$

Segment window 20: = 6.35 Hz *10² = 635 Hz

$\log_2(635 / 440) * 12 + 69 = 75.35103681761844 = 75 = \mathbf{D\#5}$



Play – ‘Example 3-Mapped Notes - My Method 1-120BPM’

Play – ‘Example 4-Mapped Notes - My Method 1-120BPM-(-2 octaves)’

The concern I have with the first mapping in Table 12 (page 114) is that the MIDI note pitches are high, I experimented with them by transposing down by 2 octaves. But not only this, the arbitrary nature of multiplying the original Hz ranges by 10² does not make the audible notes ‘pitch relative’ to the original Hz of the EEG data. I wanted the transposition to be pitch relative to the original EEG Hz findings.

Another method employed to retain the relative pitches was to transpose the original EEG Hz findings up by several octaves, therefore retaining relative pitch to original findings. Again, the conversion of Hz to musical pitch which can be carried out via the following formula:

Following Table 13 includes Hz results with transposition increase by 4 octaves

(Pitch relative to original EEG Hz):

$$n = \log_2(1.86\text{Hz}/440) \times 12 + 69 + 48 \text{ (4 octaves)} = \text{MIDI note 22} = \mathbf{Bb}$$

$$\text{MIDI note 22} = \text{Hz} = 440 * 2^{((22-69)/12)} = 29.13523509488055 = 29.14\text{Hz}$$

Table 13: formula development returning Hz to relative Hz & pitch of EEG data provided by Wu et al.

Segment window 1: 10.8 Hz

$\log_2(10.8\text{Hz}/440) \times 12 + 69 + 48 \text{ (4 octaves)} = 52.81919632501415 = \mathbf{MIDI note 53} = \mathbf{F3}$

$\text{MIDI note 53} = 440 * 2^{((53-69)/12)} = 174.61411571650231 = 174.61 \text{ Hz}$


Segment window 2: 15.43 Hz

$\log_2(15.43\text{Hz}/440) \times 12 + 69 + 48 \text{ (4 octaves)} = 58.99567731925531 = \mathbf{MIDI note 59} = \mathbf{B3}$

$\text{MIDI note 59} = 440 * 2^{((59-69)/12)} = 246.94165062806259 = 246.94 \text{ Hz}$

<p>Segment window 3: 9 Hz</p> <p>$\log_2(9\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 49.66278345501569 = MIDI note 50 = D3</p> <p>MIDI note 50 = $440 * 2^{((50-69)/12)}$ = 146.83238395870409 = 146.83 Hz</p>
<p>Segment window 4: 27 Hz (A0)</p> <p>$\log_2(27\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 68.68233346366673 = MIDI note 69 = A4</p> <p>MIDI note 69 = $440 * 2^{((69-69)/12)}$ = 440 Hz</p>
<p>Segment window 5: 10.8 Hz</p> <p>$\log_2(10.8\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 52.81919632501415 = MIDI note 53 = F3</p> <p>MIDI note 53 = $440 * 2^{((53-69)/12)}$ = 174.61411571650231 = 174.61Hz</p>
<p>Segment window 6: 7.71 Hz</p> <p>$\log_2(7.71\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 46.98445375939049 = MIDI note 47 = B2</p> <p>MIDI note 47 = $440 * 2^{((47-69)/12)}$ = 123.47082531403127 = 123.47 Hz</p>
<p>Segment window 7: 1.86 Hz</p> <p>$\log_2(1.86\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 22.3673148936926 = MIDI note 22 = Bb0</p> <p>MIDI note 22 = $440 * 2^{((22-69)/12)}$ = 29.13523509488055 = 29.14Hz</p>
<p>Segment window 8: 5.14 Hz</p> <p>$\log_2(5.14\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 39.96490375073662 = MIDI note 40 = E2</p> <p>MIDI note 40 = $440 * 2^{((40-69)/12)}$ = 82.40688922821731 = 82.41 Hz</p>
<p>Segment window 9: 7.71 Hz</p> <p>$\log_2(7.71\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 46.98445375939049 = MIDI note 47 = B2</p> <p>MIDI note 47 = $440 * 2^{((47-69)/12)}$ = 123.47082531403127 = 123.47 Hz</p>
<p>Segment window 10: 9 Hz</p> <p>$\log_2(9\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 49.66278345501569 = MIDI note 50 = D3</p> <p>MIDI Note 50 = $440 * 2^{((50-69)/12)}$ = 146.83238395870409 = 146.83 Hz</p>
<p>Segment window 11: 4.7 Hz</p> <p>$\log_2(4.7\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 38.41561251919033 = MIDI note 38 = D2</p> <p>MIDI note 38 = $440 * 2^{((38-69)/12)}$ = 73.41619197935202 = 73.42 Hz</p>
<p>Segment window 12: 13.5 Hz</p> <p>$\log_2(13.5\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 56.68233346366673 = MIDI note 57 = A3</p> <p>MIDI note 57 = $440 * 2^{((57-69)/12)}$ = 220 Hz</p>
<p>Segment window 13: 1.86 Hz</p> <p>$\log_2(1.86\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 22.3673148936926 = MIDI note 22 = Bb0</p> <p>MIDI note 22 = $440 * 2^{((22-69)/12)}$ = 29.13523509488055 = 29.14Hz</p>
<p>Segment window 14: 2.77 Hz</p> <p>$\log_2(2.77\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 29.26231515298514 = MIDI note 29 = F1</p> <p>MIDI note 29 = $440 * 2^{((29-69)/12)}$ = 43.65352892912559 = 43.65 Hz</p>

<p>Segment window 15: 15.43 Hz</p> <p>$\log_2(15.43\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 58.99567731925531 = MIDI note 59 = B3</p> <p>MIDI note 59 = $440 * 2^{((59-69)/12)}$ = 246.94165062806259 = 246.94 Hz</p>
<p>Segment window 16: 12 Hz</p> <p>$\log_2(12\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 54.64323344635969 = MIDI note 55 = G3</p> <p>MIDI note 55 = $440 * 2^{((55-69)/12)}$ = 195.99771799087423 = 196 Hz</p>
<p>Segment window 17: 13.5 Hz</p> <p>$\log_2(13.5\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 56.68233346366673 = MIDI note 57 = A3</p> <p>MIDI note 57 = $440 * 2^{((57-69)/12)}$ = 220 Hz</p>
<p>Segment window 18: 2.51 Hz</p> <p>$\log_2(2.51\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) = 27.55593180783044 = MIDI note 28 = E1</p> <p>MIDI note 28 = $440 * 2^{((28-69)/12)}$ = 41.20344461410864 = 41.20 Hz</p>
<p>Segment window 19: 4.15 Hz</p> <p>$\log_2(4.15\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) 36.26101947522217 = MIDI note 36 = C2</p> <p>MIDI note 36 = $440 * 2^{((36-69)/12)}$ = 65.40639132514964 = 65.41 Hz</p>
<p>Segment window 20: 6.35 Hz</p> <p>$\log_2(6.35\text{Hz}/440) \times 12 + 69 + 48$ (4 octaves) 43.62476254032391 = MIDI note 44 = Ab2</p> <p>MIDI note 44 = $440 * 2^{((44-69)/12)}$ = 103.82617439498652 = 103.83 Hz</p>

 Play - 'Example 5-Mapped Notes - My Method 1-120BPM-(+4 octaves pitch relative)'

Appendix D: Analysing Kiong et al formula and results.

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	log2 of SI/440 alternative to above = LOG10(a) / LOG(2)	log2 of SI/440 * 12	log2 of SI/440 * 12 + 69	log2 of SI / 440 * 12 + 69 - 24	X = log2 of SI/440 * 12 + 69 - 24 / 1.68	Hz difference in X per semitone	Hz result from formula: $440 * 2^{(((1.68 * X) + 24) - 69) / 12)}$	Note Pitch
24	32.70319566	1.0594630943593	0.0743225445	-3.75	-44.999999999867	24	0	0.0000000000793		32.7031957	C1
25	34.64782887	1.0594630943593	0.07874506561849	-3.66666666666556	-43.999999999867	25	1	0.59523809524603	0.595238	34.6478289	C#1/Db1
26	36.70809599	1.0594630943593	0.08342749088569	-3.58333333333222	-42.999999999867	26	2	1.19047619048413	0.595238	36.7080960	D1
27	38.89087297	1.0594630943593	0.08838834764839	-3.4999999999889	-41.999999999867	27	3	1.78571428572222	0.595238	38.8908730	D#1/Eb1
28	41.20344461	1.0594630943593	0.09364419230486	-3.41666666666556	-40.999999999867	28	4	2.38095238096031	0.595238	41.2034446	E1
29	43.65352893	1.0594630943593	0.09921256574809	-3.33333333333222	-39.999999999867	29	5	2.97619047619841	0.595238	43.6535289	F1
30	46.24930284	1.0594630943593	0.10511205190680	-3.2499999999889	-38.999999999867	30	6	3.57142857143651	0.595238	46.2493028	F#1/Gb1
31	48.9994295	1.0594630943593	0.11136233976763	-3.16666666666556	-37.999999999867	31	7	4.16666666667461	0.595238	48.9994295	G1
32	51.9130872	1.0594630943593	0.11798428908530	-3.08333333333222	-36.999999999867	32	8	4.76190476191270	0.595238	51.9130872	G#1/Ab1
33	55	1.0594630943593	0.12500000000010	-2.9999999999889	-35.999999999867	33	9	5.35714285715080	0.595238	55.0000000	A1
34	58.27047019	1.0594630943593	0.13243288679501	-2.91666666666555	-34.999999999867	34	10	5.95238095238890	0.595238	58.2704702	A#1/Bb1
35	61.73541266	1.0594630943593	0.14030775603878	-2.83333333333222	-33.999999999867	35	11	6.54761904762699	0.595238	61.7354127	B1
36	65.40639133	1.0594630943593	0.14865088937546	-2.7499999999889	-32.999999999867	36	12	7.14285714286509	0.595238	65.4063913	C2
37	69.29565774	1.0594630943593	0.15749013123698	-2.66666666666555	-31.999999999867	37	13	7.73809523810318	0.595238	69.2956577	C#2/Db2
38	73.41619198	1.0594630943593	0.16685498177138	-2.58333333333222	-30.999999999867	38	14	8.33333333334128	0.595238	73.4161920	D2

Table 4: Testing Kiong et al's application of Weber-Fechner formula.

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	log2 0f Si/440 alternative to above = LOG10(a) / LOG(2)	log2 0f Si/440 * 12	log2 0f Si/440 * 12 + 69	log2 of Si / 440 * 12 + 69 - 24	X = log2 0f Si/440 * 12 + 69 - 24 / 1.68	Hz difference in X per semitone	Hz result from formula: $440 * 2^{(((1.68 * X) + 24) - 69) / 12)}$	Note Pitch
39	77.78174593	1.0594630943593	0.17677669529677	-2.4999999999889	-29.999999999867	39	15	8.92857142857937	0.595238	77.7817459	D#2/Eb2
40	82.40688923	1.0594630943593	0.18728838460973	-2.41666666666555	-28.999999999867	40	16	9.52380952381747	0.595238	82.4068892	E2
41	87.30705786	1.0594630943593	0.19842513149618	-2.33333333333222	-27.999999999867	41	17	10.11904761905560	0.595238	87.3070579	F2
42	92.49860568	1.0594630943593	0.21022410381359	-2.2499999999889	-26.999999999867	42	18	10.71428571429370	0.595238	92.4986057	F#2/Gb2
43	97.998859	1.0594630943593	0.22272467953526	-2.16666666666555	-25.999999999867	43	19	11.30952380953180	0.595238	97.9988590	G2
44	103.8261744	1.0594630943593	0.23596857817061	-2.08333333333222	-24.999999999867	44	20	11.90476190476980	0.595238	103.8261744	G#2/Ab2
45	110	1.0594630943593	0.25000000000019	-1.9999999999889	-23.999999999867	45	21	12.50000000000790	0.595238	110.0000000	A2
46	116.5409404	1.0594630943593	0.26486577359003	-1.91666666666555	-22.999999999867	46	22	13.09523809524600	0.595238	116.5409404	A#2/Bb2
47	123.4708253	1.0594630943593	0.28061551207756	-1.83333333333222	-21.999999999867	47	23	13.69047619048410	0.595238	123.4708253	B2
48	130.8127827	1.0594630943593	0.29730177875091	-1.7499999999889	-20.999999999866	48	24	14.28571428572220	0.595238	130.8127827	C3
49	138.5913155	1.0594630943593	0.31498026247396	-1.66666666666555	-19.999999999867	49	25	14.88095238096030	0.595238	138.5913155	C#3/Db3
50	146.832384	1.0594630943593	0.33370996354277	-1.58333333333222	-18.999999999867	50	26	15.47619047619840	0.595238	146.8323840	D3
51	155.5634919	1.0594630943593	0.35355339059355	-1.4999999999889	-17.999999999867	51	27	16.07142857143650	0.595238	155.5634919	D#3/Eb3
52	164.8137785	1.0594630943593	0.37457676921946	-1.41666666666555	-16.999999999866	52	28	16.66666666667460	0.595238	164.8137785	E3
53	174.6141157	1.0594630943593	0.39685026299236	-1.33333333333222	-15.999999999866	53	29	17.26190476191270	0.595238	174.6141157	F3

Table 5: Testing Kiong et al's application of Weber-Fechner formula (continued).

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	log2 of Si/440 alternative to above = LOG10(a) / LOG(2)	log2 of Si/440 * 12	log2 of Si/440 * 12 + 69	log2 of Si / 440 * 12 + 69 - 24	X = log2 of Si/440 * 12 + 69 - 24 / 1.68	Hz difference in X per semitone	Hz result from formula: $440 * 2^{(((1.68 * X) + 24) - 69) / 12)}$	Note Pitch
54	184.9972114	1.0594630943593	0.42044820762718	-1.2499999999889	-14.999999999866	54	30	17.85714285715080	0.595238	184.9972114	F#3/Gb3
55	195.997718	1.0594630943593	0.44544935907051	-1.16666666666555	-13.999999999866	55	31	18.45238095238890	0.595238	195.9977180	G3
56	207.6523488	1.0594630943593	0.47193715634121	-1.08333333333222	-12.999999999866	56	32	19.04761904762700	0.595238	207.6523488	G#3/Ab3
57	220	1.0594630943593	0.50000000000039	-0.9999999999889	-11.999999999866	57	33	19.64285714286510	0.595238	220.0000000	A3
58	233.0818808	1.0594630943593	0.52973154718006	-0.91666666666555	-10.999999999866	58	34	20.23809523810320	0.595238	233.0818808	A#3/Bb3
59	246.9416506	1.0594630943593	0.56123102415512	-0.83333333333222	-9.999999999867	59	35	20.83333333334130	0.595238	246.9416506	B3
60	261.6255653	1.0594630943593	0.59460355750182	-0.7499999999889	-8.999999999867	60	36	21.42857142857940	0.595238	261.6255653	C4
61	277.182631	1.0594630943593	0.62996052494792	-0.66666666666555	-7.999999999867	61	37	22.02380952381750	0.595238	277.1826310	C#4/Db4
62	293.6647679	1.0594630943593	0.66741992708553	-0.58333333333222	-6.999999999867	62	38	22.61904761905560	0.595238	293.6647679	D4
63	311.1269837	1.0594630943593	0.70710678118709	-0.4999999999889	-5.999999999867	63	39	23.21428571429370	0.595238	311.1269837	D#4/Eb4
64	329.6275569	1.0594630943593	0.74915353843892	-0.41666666666555	-4.999999999867	64	40	23.80952380953180	0.595238	329.6275569	E4
65	349.2282314	1.0594630943593	0.79370052598471	-0.33333333333222	-3.999999999867	65	41	24.40476190476990	0.595238	349.2282314	F4
66	369.9944227	1.0594630943593	0.84089641525436	-0.2499999999889	-2.999999999867	66	42	25.00000000000800	0.595238	369.9944227	F#4/Gb4
67	391.995436	1.0594630943593	0.89089871814103	-0.16666666666555	-1.999999999867	67	43	25.59523809524600	0.595238	391.9954360	G4
68	415.3046976	1.0594630943593	0.94387431268242	-0.08333333333222	-0.999999999866	68	44	26.19047619048410	0.595238	415.3046976	G#4/Ab4

Table 6: Testing Kiong et al's application of Weber-Fechner formula (continued).

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	log2 of Si/440 alternative to above = LOG10(a) / LOG(2)	log2 of Si/440 * 12	log2 of Si/440 * 12 + 69	log2 of Si / 440 * 12 + 69 - 24	X = log2 of Si/440 * 12 + 69 - 24 / 1.68	Hz difference in X per semitone	Hz result from formula: $440 * 2^{\frac{((1.68 * X) + 24) - 69}{12}}$	Note Pitch
69	440	1.0594630943593	1.000000000000077	0.00000000000111	0.00000000000134	69	45	26.78571428572220	0.595238	440.0000000	A4
70	466.1637615	1.0594630943593	1.05946309436011	0.083333333333445	1.00000000000134	70	46	27.38095238096030	0.595238	466.1637615	A#4/Bb4
71	493.8833013	1.0594630943593	1.12246204831024	0.166666666666778	2.00000000000134	71	47	27.97619047619840	0.595238	493.8833013	B4
72	523.2511306	1.0594630943593	1.18920711500364	0.250000000000111	3.00000000000134	72	48	28.57142857143650	0.595238	523.2511306	C5
73	554.365262	1.0594630943593	1.25992104989585	0.333333333333445	4.00000000000134	73	49	29.16666666667460	0.595238	554.3652620	C#5/Db5
74	587.329538	1.0594630943593	1.33483985417106	0.416666666666778	5.00000000000134	74	50	29.76190476191270	0.595238	587.3295358	D5
75	622.2539674	1.0594630943593	1.41421356237419	0.500000000000111	6.00000000000134	75	51	30.35714285715080	0.595238	622.2539674	D#5/Eb5
76	659.2551138	1.0594630943593	1.49830707687784	0.583333333333445	7.00000000000134	76	52	30.95238095238890	0.595238	659.2551138	E5
77	698.4564629	1.0594630943593	1.58740105196942	0.666666666666778	8.00000000000134	77	53	31.54761904762700	0.595238	698.4564629	F5
78	739.9888454	1.0594630943593	1.68179283050873	0.750000000000111	9.00000000000134	78	54	32.14285714286510	0.595238	739.9888454	F#5/Gb5
79	783.990872	1.0594630943593	1.78179743628205	0.833333333333445	10.00000000000134	79	55	32.73809523810320	0.595238	783.9908720	G5
80	830.6093952	1.0594630943593	1.88774862536484	0.916666666666778	11.00000000000134	80	56	33.33333333334130	0.595238	830.6093952	G#5/Ab5
81	880	1.0594630943593	2.000000000000154	1.000000000000111	12.00000000000134	81	57	33.92857142857940	0.595238	880.0000000	A5
82	932.327523	1.0594630943593	2.11892618872023	1.083333333333445	13.00000000000134	82	58	34.52380952381750	0.595238	932.3275230	A#5/Bb5
83	987.7666025	1.0594630943593	2.24492409662048	1.166666666666778	14.00000000000134	83	59	35.11904761905560	0.595238	987.7666025	B5

Table 7: Testing Kiong et al's application of Weber-Fechner formula (continued).

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	\log_2 of SI/440 alternative to above = $\text{LOG}_{10}(a) / \text{LOG}(2)$	\log_2 of SI/440 *12+69	\log_2 of SI / 440 *12 +69 -24	$X = \log_2 \text{ of SI}/440 *12+69-24/1.68$	Hz difference in X per semitone	Hz result from formula: $440 * 2^{(((1.68 * X) + 24) - 69) / 12)}$	Note Pitch
84	1046.502261	1.0594630943593	2.37841423000728	1.250000000000111	84	60	35.71428571429370	0.595238	1046.5022612	C6
85	1108.730524	1.0594630943593	2.51984209979169	1.333333333333445	85	61	36.30952380953180	0.595238	1108.7305239	C#6/Db6
86	1174.659072	1.0594630943593	2.66967970834213	1.416666666666778	86	62	36.90476190476990	0.595238	1174.6590717	D6
87	1244.507935	1.0594630943593	2.82842712474837	1.500000000000111	87	63	37.500000000000800	0.595238	1244.5079349	D#6/Eb6
88	1318.510228	1.0594630943593	2.99661415375568	1.583333333333445	88	64	38.09523809524600	0.595238	1318.5102277	E6
89	1396.912926	1.0594630943593	3.17480210393885	1.666666666666778	89	65	38.69047619048410	0.595238	1396.9129257	F6
90	1479.977691	1.0594630943593	3.36358566101745	1.750000000000111	90	66	39.28571428572220	0.595238	1479.9776908	F#6/Gb6
91	1567.981744	1.0594630943593	3.56359487256411	1.833333333333445	91	67	39.88095238096030	0.595238	1567.9817439	G6
92	1661.21879	1.0594630943593	3.77549725072969	1.916666666666778	92	68	40.47619047619840	0.595238	1661.2187903	G#6/Ab6
93	1760	1.0594630943593	4.000000000000309	2.000000000000111	93	69	41.07142857143650	0.595238	1760.0000000	A6
94	1864.655046	1.0594630943593	4.23785237744045	2.083333333333445	94	70	41.66666666667460	0.595238	1864.6550461	A#6/Bb6
95	1975.533205	1.0594630943593	4.48984819324096	2.166666666666778	95	71	42.26190476191270	0.595238	1975.5332050	B6
96	2093.004522	1.0594630943593	4.75682846001456	2.250000000000111	96	72	42.85714285715080	0.595238	2093.0045224	C7
97	2217.461048	1.0594630943593	5.03968419958339	2.333333333333445	97	73	43.45238095238890	0.595238	2217.4610478	C#7/Db7
98	2349.318143	1.0594630943593	5.33935941668426	2.416666666666778	98	74	44.04761904762700	0.595238	2349.3181433	D7

Table 8: Testing Kiong et al.'s application of Weber-Fechner formula (continued).

MIDI Note No.	Stimulus Intensity Hz (SI)	JND Ratio	SI / 440	log2 of Si/440 alternative to above = LOG10(a) / LOG(2)	log2 of Si/440 *12+69	log2 of Si/440 *12 +69 -24	X = log2 of Si/440 *12+69-24/1.68	Hz difference in X per semitone	Hz result from formula: $440 * 2^{((1.68 * X) + 24) / 12}$	Note Pitch
99	2489.01587	1.0594630943593	5.65685424949675	2.500000000000111	99	75	44.64285714286510	0.595238	2489.0158698	D#7/Eb7
100	2637.020455	1.0594630943593	5.99322830751136	2.583333333333445	100	76	45.23809523810320	0.595238	2637.0204553	E7
101	2793.825851	1.0594630943593	6.34960420787770	2.666666666666778	101	77	45.83333333334130	0.595238	2793.8258515	F7
102	2959.955382	1.0594630943593	6.72717132203492	2.750000000000112	102	78	46.42857142857940	0.595238	2959.9553817	F#7/Gb7
103	3135.963488	1.0594630943593	7.12718974512822	2.833333333333445	103	79	47.02380952381750	0.595238	3135.9634879	G7
104	3322.437581	1.0594630943593	7.55099450145939	2.916666666666778	104	80	47.61904761905560	0.595238	3322.4375806	G#7/Ab7
105	3520	1.0594630943593	8.000000000000619	3.000000000000112	105	81	48.21428571429370	0.595238	3520.0000000	A7
106	3729.310092	1.0594630943593	8.47570475488092	3.083333333333445	106	82	48.80952380953180	0.595238	3729.3100921	A#7/Bb7
107	3951.06641	1.0594630943593	8.97969638648193	3.166666666666778	107	83	49.40476190476990	0.595238	3951.0664101	B7
108	4186.009045	1.0594630943593	9.51365692002912	3.250000000000112	108	84	50.00000000000800	0.595238	4186.0090448	C8
	Ratio difference between these values is 1.0594631062	Note: 10 [^] of the log of the JND Ratio + the log of the SI is next SI Hz	Note: 10 [^] of The log of the difference between each of the increases here (JND) is added to the log of the JND Ratio gives you the next value in this column		MIDI note numbers			Note: The increase per semitone of X - approx. 0.6 Hz	Applying Fechner Law within Kiong et al's equation corresponds with traditional formula in column B	

Table 9: Testing Kiong et al's application of Weber-Fechner formula (continued).


Appendix E: Cyclic Segmentation of EEG Experiment.

(Note: shaded notes used as 4 chords in latter half of 'Requiem for a Neuron'):

Table 14: formula experiment with cyclic segmentation of EEG seizure data.

NOTE 1: 21 samples in length	$44100 / 21 = 2100 \text{ Hz} = \text{MIDI note } 96 = \text{C}7.$ (chord #1)
NOTE 2: 28 samples in length	$44100 / 28 = 1575 \text{ Hz} = \text{MIDI note } 91 = \text{G}6.$ (chord #1)
NOTE 3: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6.$ (chord #1)
NOTE 4: 29 samples in length	$44100 / 29 = 1520.69 \text{ Hz} = \text{MIDI note } 90 = \text{F}\#6.$ (chord #1)
NOTE 5: 35 samples in length	$44100 / 35 = 1260 \text{ Hz} = \text{MIDI note } 87 = \text{D}\#6.$ (chord #1)
NOTE 6: 21 samples in length	$44100 / 21 = 2100 \text{ Hz} = \text{MIDI note } 96 = \text{C}7.$ (chord #2)
NOTE 7: 16 samples in length	$44100 / 16 = 2756.25 \text{ Hz} = \text{MIDI note } 101 = \text{F}7.$ (chord #2)
NOTE 8: 33 samples in length	$44100 / 33 = 1336.36 \text{ Hz} = \text{MIDI note } 88 = \text{E}6.$ (chord #2)
NOTE 9: 22 samples in length	$44100 / 22 = 2004.55 \text{ Hz} = \text{MIDI note } 95 = \text{B}6.$ (chord #2)
NOTE 10: 27 samples in length	$44100 / 27 = 1633.33 \text{ Hz} = \text{MIDI note } 92 = \text{G}\#6.$ (chord #2)
NOTE 11: 23 samples in length	$44100 / 23 = 1917.39 \text{ Hz} = \text{MIDI note } = 94 = \text{A}\#6.$ (chord #2)
NOTE 12: 31 samples in length	$44100 / 31 = 1422.58 \text{ Hz} = \text{MIDI note } 89 = \text{F}6$
NOTE 13: 25 samples in length	$44100 / 25 = 1764 \text{ Hz} = \text{MIDI note } 93 = \text{A}6$
NOTE 14: 28 samples in length	$44100 / 28 = 1575 \text{ Hz} = \text{MIDI note } 91 = \text{G}6$
NOTE 15: 24 samples in length	$44100 / 24 = 1837.5 \text{ Hz} = \text{MIDI note } 94 = \text{A}\#6$
NOTE 16: 32 samples in length	$44100 / 32 = 1378.125 \text{ Hz} = \text{MIDI note } 89 = \text{F}6$
NOTE 17: 20 samples in length	$44100 / 20 = 2205 \text{ Hz} = \text{MIDI note } 97 = \text{C}\#7$
NOTE 18: 20 samples in length	$44100 / 20 = 2205 \text{ Hz} = \text{MIDI note } 97 = \text{C}\#7$
NOTE 19: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 20: 24 samples in length	$44100 / 24 = 1837.5 \text{ Hz} = \text{MIDI note } 94 = \text{A}\#6$
NOTE 21: 29 samples in length	$44100 / 29 = 1520.69 \text{ Hz} = \text{MIDI note } = 90 = \text{F}\#6$
NOTE 22: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6.$ (chord #3)
NOTE 23: 20 samples in length	$44100 / 20 = 2205 \text{ Hz} = \text{MIDI note } 97 = \text{C}\#7.$ (chord #3)
NOTE 24: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6.$ (chord #3)
NOTE 25: 36 samples in length	$44100 / 36 = 1225 \text{ Hz} = \text{MIDI note } 87 = \text{D}\#6.$ (chord #3)
NOTE 26: 43 samples in length	$44100 / 43 = 1025.58 \text{ Hz} = \text{MIDI note } = 84 = \text{C}6.$ (chord #3)
NOTE 27: 40 samples in length	$44100 / 40 = 1102.5 \text{ Hz} = \text{MIDI note } 85 = \text{C}\#6.$ (chord #4)
NOTE 28: 59 samples in length	$44100 / 59 = 747.46 \text{ Hz} = \text{MIDI note } 78 = \text{F}\#5.$ (chord #4)
NOTE 29: 54 samples in length	$44100 / 54 = 816.67 \text{ Hz} = \text{MIDI note } 80 = \text{G}\#5.$ (chord #4)
NOTE 30: 51 samples in length	$44100 / 51 = 864.71 \text{ Hz} = \text{MIDI note } 81 = \text{A}5.$ (chord #4)
NOTE 31: 54 samples in length	$44100 / 54 = 816.67 \text{ Hz} = \text{MIDI note } 80 = \text{G}\#5.$ (chord #4)
NOTE 32: 83 samples in length	$44100 / 83 = 531.33 \text{ Hz} = \text{MIDI note } 72 = \text{C}5$
NOTE 33: 107 samples in length	$44100 / 107 = 412.15 \text{ Hz} = \text{MIDI note } 68 = \text{G}\#4$
NOTE 34: 70 samples in length	$44100 / 70 = 630 \text{ Hz} = \text{MIDI note } 75 = \text{D}\#5$
NOTE 35: 95 samples in length	$44100 / 95 = 464.21 \text{ Hz} = \text{MIDI note } 70 = \text{A}\#4$
NOTE 36: 106 samples in length	$44100 / 106 = 416.04 \text{ Hz} = \text{MIDI note } 68 = \text{G}\#4$
NOTE 37: 55 samples in length	$44100 / 55 = 801.82 \text{ Hz} = \text{MIDI note } 79 = \text{G}5$
NOTE 38: 80 samples in length	$44100 / 80 = 551.25 \text{ Hz} = \text{MIDI note } 73 = \text{C}\#5$

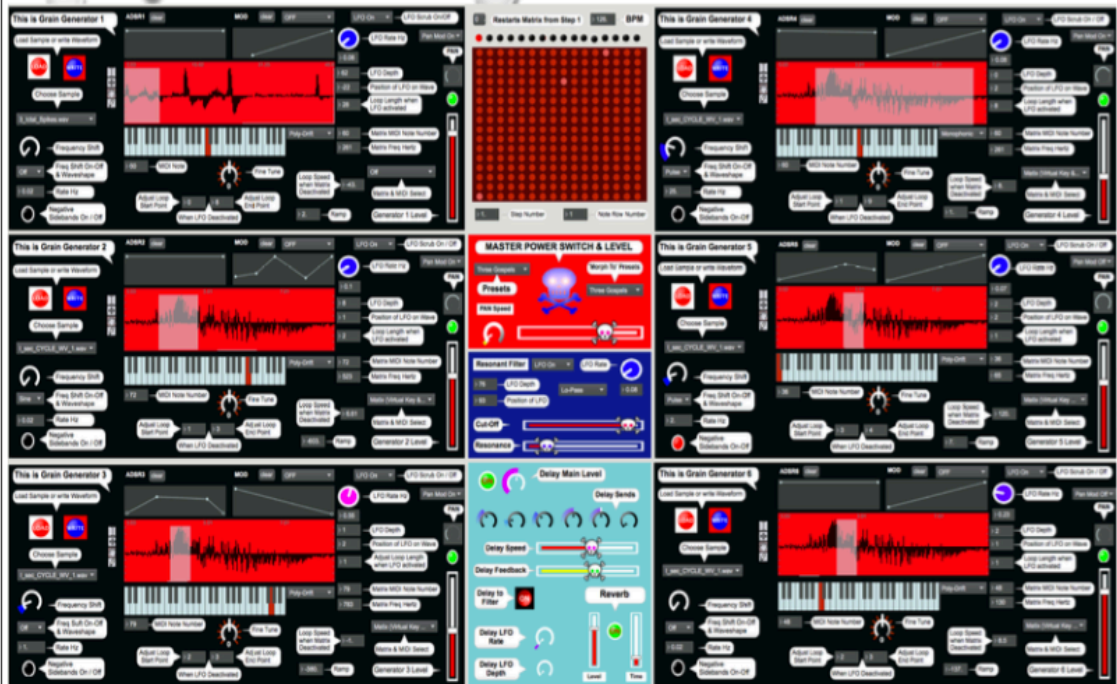
NOTE 39: 93 samples in length	$44100 / 93 = 474.2 \text{ Hz} = \text{MIDI note } 70 = \text{A}\#4$
NOTE 40: 106 samples in length	$44100 / 106 = 416.1 \text{ Hz} = \text{MIDI note } 68 = \text{G}\#4$
NOTE 41: 99 samples in length	$44100 / 99 = 445.45 \text{ Hz} = \text{MIDI note } 69 = \text{A}4$
NOTE 42: 103 samples in length	$44100 / 103 = 428.2 \text{ Hz} = \text{MIDI note } 69 = \text{A}4$
NOTE 43: 161 samples in length	$44100 / 161 = 273.91 \text{ Hz} = \text{MIDI note } 61 = \text{C}\#4$
NOTE 44: 134 samples in length	$44100 / 134 = 329.1 \text{ Hz} = \text{MIDI note } 64 = \text{E}4$
NOTE 45: 168 samples in length	$44100 / 168 = 262.5 \text{ Hz} = \text{MIDI note } 60 = \text{C}4$
NOTE 46: 215 samples in length	$44100 / 215 = 205.12 \text{ Hz} = \text{MIDI note } 56 = \text{G}\#3$
NOTE 47: 109 samples in length	$44100 / 109 = 404.59 \text{ Hz} = \text{MIDI note } 68 = \text{G}\#4$
NOTE 48: 79 samples in length	$44100 / 79 = 558.23 \text{ Hz} = \text{MIDI note } 73 = \text{C}\#5$
NOTE 49: 100 samples in length	$44100 / 100 = 441 \text{ Hz} = \text{MIDI note } 69 = \text{A}4$
NOTE 50: 56 samples in length	$44100 / 56 = 787.5 \text{ Hz} = \text{MIDI note } 79 = \text{G}5$
NOTE 51: 58 samples in length	$44100 / 58 = 760.35 \text{ Hz} = \text{MIDI note } 78 = \text{F}\#5$
NOTE 52: 48 samples in length	$44100 / 48 = 918.75 \text{ Hz} = \text{MIDI note } 82 = \text{A}\#5$
NOTE 53: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 54: 30 samples in length	$44100 / 30 = 1470 \text{ Hz} = \text{MIDI note } 90 = \text{F}\#6$
NOTE 55: 43 samples in length	$44100 / 43 = 1025.58 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 56: 35 samples in length	$44100 / 35 = 1260 \text{ Hz} = \text{MIDI note } 87 = \text{D}\#6$
NOTE 57: 43 samples in length	$44100 / 43 = 1025.58 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 58: 73 samples in length	$44100 / 73 = 604.11 \text{ Hz} = \text{MIDI note } 74 = \text{D}5$
NOTE 59: 66 samples in length	$44100 / 66 = 668.18 \text{ Hz} = \text{MIDI note } 76 = \text{E}5$
NOTE 60: 72 samples in length	$44100 / 72 = 612.5 \text{ Hz} = \text{MIDI note } 75 = \text{D}\#5$
NOTE 61: 51 samples in length	$44100 / 51 = 864.71 \text{ Hz} = \text{MIDI note } 81 = \text{A}5$
NOTE 62: 39 samples in length	$44100 / 39 = 1130.77 \text{ Hz} = \text{MIDI note } 85 = \text{C}\#6$
NOTE 63: 20 samples in length	$44100 / 20 = 2205 \text{ Hz} = \text{MIDI note } 97 = \text{C}\#7$
NOTE 64: 21 samples in length	$44100 / 21 = 2100 \text{ Hz} = \text{MIDI note } 96 = \text{C}7$
NOTE 65: 18 samples in length	$44100 / 18 = 2450 \text{ Hz} = \text{MIDI note } 99 = \text{D}\#7$
NOTE 66: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 67: 39 samples in length	$44100 / 39 = 1130.77 \text{ Hz} = \text{MIDI note } 85 = \text{C}\#6$
NOTE 68: 80 samples in length	$44100 / 80 = 551.25 \text{ Hz} = \text{MIDI note } 73 = \text{C}\#5$
NOTE 69: 44 samples in length	$44100 / 44 = 1002.27 \text{ Hz} = \text{MIDI note } 83 = \text{B}5$
NOTE 70: 76 samples in length	$44100 / 76 = 580.26 \text{ Hz} = \text{MIDI note } 74 = \text{D}5$
NOTE 71: 46 samples in length	$44100 / 46 = 958.7 \text{ Hz} = \text{MIDI note } 82 = \text{B}5$
NOTE 72: 79 samples in length	$44100 / 79 = 558.23 \text{ Hz} = \text{MIDI note } 73 = \text{C}\#5$
NOTE 73: 34 samples in length	$44100 / 34 = 1297.1 \text{ Hz} = \text{MIDI note } 88 = \text{E}6$
NOTE 74: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 75: 41 samples in length	$44100 / 41 = 1075.61 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 76: 45 samples in length	$44100 / 45 = 980 \text{ Hz} = \text{MIDI note } 83 = \text{B}5$
NOTE 77: 22 samples in length	$44100 / 22 = 2004.55 \text{ Hz} = \text{MIDI note } 95 = \text{B}6$
NOTE 78: 20 samples in length	$44100 / 20 = 2205 \text{ Hz} = \text{MIDI note } 97 = \text{C}\#7$
NOTE 79: 53 samples in length	$44100 / 53 = 832.1 \text{ Hz} = \text{MIDI note } 80 = \text{G}\#5$
NOTE 80: 32 samples in length	$44100 / 32 = 1378.13 \text{ Hz} = \text{MIDI note } 89 = \text{F}6$
NOTE 81: 42 samples in length	$44100 / 42 = 1050 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$

NOTE 82: 50 samples in length	$44100 / 50 = 882 \text{ Hz} = \text{MIDI note } 81 = \text{A}5$
NOTE 83: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 84: 41 samples in length	$44100 / 41 = 1075.61 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 85: 41 samples in length	$44100 / 41 = 1075.61 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 86: 85 samples in length	$44100 / 85 = 518.82 \text{ Hz} = \text{MIDI note } 72 = \text{C}5$
NOTE 87: 16 samples in length	$44100 / 16 = 2756.25 \text{ Hz} = \text{MIDI note } 101 = \text{F}7$
NOTE 88: 65 samples in length	$44100 / 65 = 678.46 \text{ Hz} = \text{MIDI note } 76 = \text{E}5$
NOTE 89: 39 samples in length	$44100 / 39 = 1130.77 \text{ Hz} = \text{MIDI note } 85 = \text{C}\#6$
NOTE 90: 40 samples in length	$44100 / 40 = 1102.5 \text{ Hz} = \text{MIDI note } 85 = \text{C}\#6$
NOTE 91: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 92: 52 samples in length	$44100 / 52 = 848.1 \text{ Hz} = \text{MIDI note } 80 = \text{G}\#5$
NOTE 93: 59 samples in length	$44100 / 59 = 747.46 \text{ Hz} = \text{MIDI note } 78 = \text{F}\#5$
NOTE 94: 45 samples in length	$44100 / 45 = 980 \text{ Hz} = \text{MIDI note } 83 = \text{B}5$
NOTE 95: 37 samples in length	$44100 / 37 = 1191.9 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 96: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 97: 56 samples in length	$44100 / 56 = 787.5 \text{ Hz} = \text{MIDI note } 79 = \text{G}5$
NOTE 98: 50 samples in length	$44100 / 50 = 882 \text{ Hz} = \text{MIDI note } 81 = \text{A}5$
NOTE 99: 43 samples in length	$44100 / 43 = 1025.58 \text{ Hz} = \text{MIDI note } 84 = \text{C}6$
NOTE 100: 37 samples in length	$44100 / 37 = 1191.89 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 101: 46 samples in length	$44100 / 46 = 958.7 \text{ Hz} = \text{MIDI note } 82 = \text{A}\#5$
NOTE 102: 29 samples in length	$44100 / 29 = 1520.69 \text{ Hz} = \text{MIDI note } 90 = \text{F}\#6$
NOTE 103: 38 samples in length	$44100 / 38 = 1160.53 \text{ Hz} = \text{MIDI note } 86 = \text{D}6$
NOTE 104: 27 samples in length	$44100 / 27 = 1633.33 \text{ Hz} = \text{MIDI note } 92 = \text{G}\#6$
<p>All calculated notes in this table were corroborated by the Tuner (<i>within a tolerance of +/-50 Cents</i>). All note sin the audio example are the actual EEG audio converted wave cycles.</p> <p> Play – ‘Example 7-chb01_03_SAMPLER_CYCLIC_EDITS_NO_FX’</p>	

Appendix F: 'The Oblique-Granizer' MAX/MSP Synthesizer.

THE OBLIQUE-GRANIZER MAXMSP SYNTHESIZER USER MANUAL.

THE OBLIQUE-GRANIZER is a 6 Generator Sample-Based Granular Synthesizer created with MAXMSP. Consider it a Sextet Ensemble of Sample-based Granular instruments.



The Oblique-Granizer Ensemble also includes a 16-Step Matrix for creating and triggering note sequences. The Matrix allows you to set a musical sequence up and then let it run whilst you synthesize sounds with the 6 Generators and various Editing and Modulation parameters that include:

- **LFO based scrubbing across the waveforms loaded into the Granular Generators.**
- **Virtual Keyboard & External MIDI triggering of the root notes of the Matrix Sequence.**
- **Reverb Unit.**
- **Delay functions with individual send levels for each Granular Generator.**
- **A Low-Pass Filter assigned to the signals from each of the 6 Generators.**
- **Frequency Shifter with an assignable LFO for sweeping through frequency bands.**
- **Separate Level and ON-OFF Switches for each Granular Generator.**
- **Loading of audio wavs into each of the Granular Generators.**
- **Writing of own waveforms within the Waveform Display Object screen.**
- **Monophonic and Polyphonic (Drift) parameters selectable for each Granular Generator.**
- **BPM Control.**
- **A range of example Presets and Morphing between presets to create 420 Sonic Textures.**
- **Note: The optimum view size in MAXMSP using a small Laptop is 50% (cmd – twice).**

ON (below)

OFF (below)

This is the **Oblique-Granizer's Main Power (On-Off) Switch; Preset Select and Main Level Control** (Left image - It is currently in the ON Mode).

Click on the Blue Skull to turn it on.

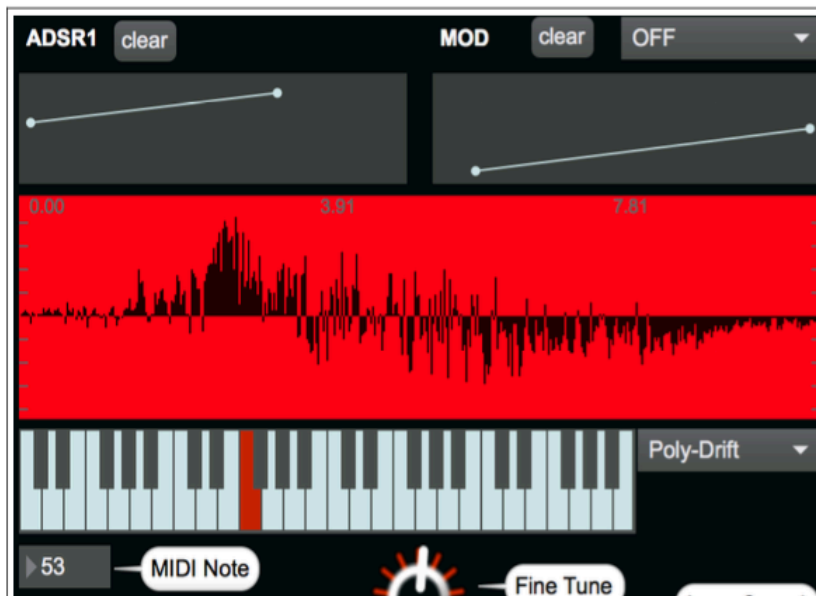
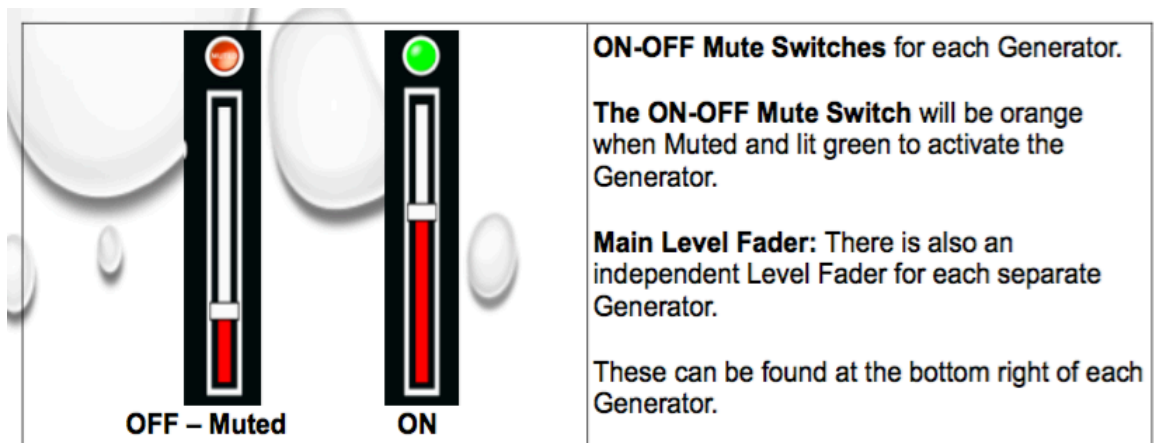
Select a Preset from the Drop-down Menu to the left. The **'Morph To'** Preset menu allows you to interpolate towards another preset providing numerous additional randomized sonic textures.

Move the white skull slider right for higher levels and left for lower levels.

The Oblique-Granizer's Main Power (On-Off) Switch (Left image - It is currently in the OFF Mode – the Skull's eyes will be bright).

The Oblique-Granizer Sample-Based Granular Generator 1

Note: When you have explored and learned the functionality of one Generator each of the others has the same functionality, but, you can have numerous settings of each completely separate and different samples loaded into each to create a sextet ensemble of generators whilst the Matrix triggers a sequence of notes leaving you the freedom to synthesize and experiment with sonic textures.



Waveform Control: In the centre of each Generator there is a waveform control with tools that enable you to:

Select Portions of the Sample to Loop (*The tool at the top of the Toolbox to the left of the waveform display*).

Edit the length of a selected Loop portion.

Zoom in and out of the waveform with the Hand Tool.

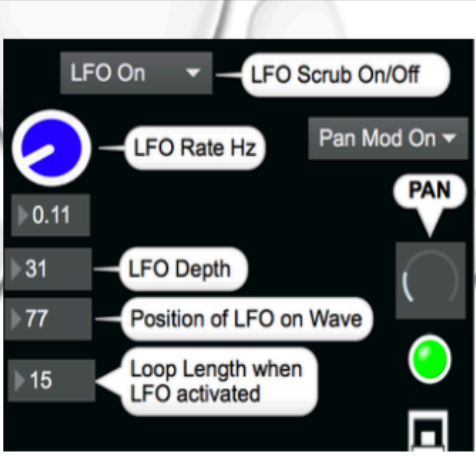
Draw your own waveforms with the Pencil Tool.

The **Keyboard** allows you to set the root note of the sequence triggered in the Matrix Sequencer. The **'MIDI Note Number'** number box displays the last selected MIDI Note but also allows you to enter the desired note by selecting the number box and entering in the MIDI Note Number desired.

The **'Poly-Drift'** drop down menu allows you to choose a 5-Voice Polyphonic or Monophonic mode. In **'Poly-Drift'** mode the Generator will play 5 Voices which will refresh (*steal older notes*) as the Matrix triggers new notes in the 16-Step Sequence.

ADSR1 is a multi-point Amplitude Envelope. This also has a **'CLEAR'** function for quick resetting of the parameters.

MOD is a multi-point Modulation Envelope assigned to Pitch. This also has a **'CLEAR'** function for quick resetting of the parameters and an ON/OFF switch.

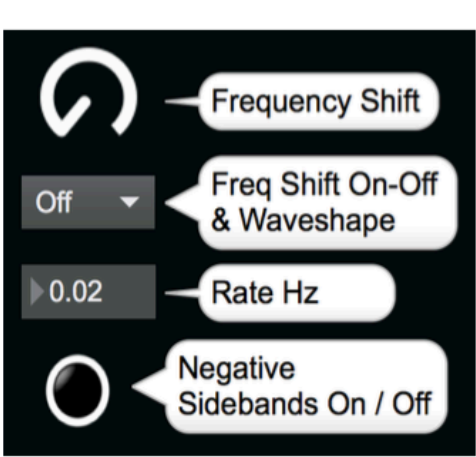


The LFO Scrub Section (to the top right of each Generator): This allows you to set continuous Modulated movement of a selected loop portion across the Sample.

- * **The LFO** can be switched On and Off with the drop-down menu.
- * **The Rate of the LFO** can be set with the knob or by entering in digits within the number box.
- * **The Depth** of the LFO can be set.
- * **The Loop Length** can be set.
- * **The Position** of the selected loop can be set.
- * **The Loop Length** (when LFO is activated) can be set.

Note: Number Boxes - You can click and drag up or down, or by entering in digits in the number box.

* **Pan Modulation** can be switched ON/OFF and its Rate is linked to the LFO.

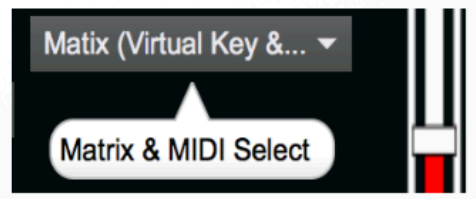


The Frequency Shifter (to the bottom left of each Generator): "A time domain frequency shifter, known as a single side-band Ring Modulator". This allows you to set a boosted frequency. The centre Frequency can be selected via the 'Frequency Shift' knob.

The Frequency Shift incorporates an LFO can be used to modulate around the centre frequency with a Sine or Pulse Waveform via the drop-down menu.

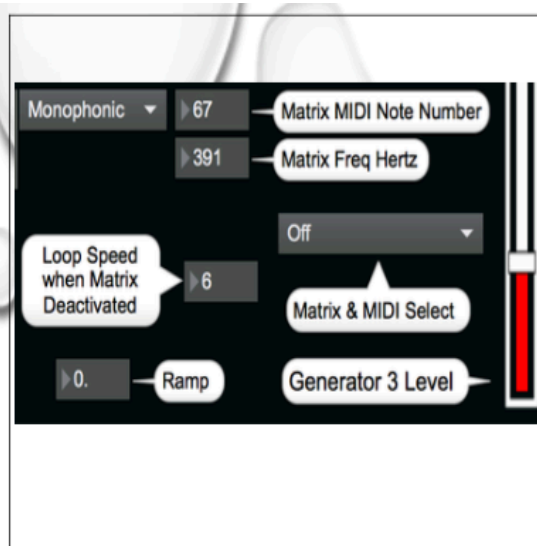
The Rate of the LFO can be set by entering in digits or clicking and dragging up or down in the number box (**Note:** The integer or decimals numbers can be edited depending on which of these you click and drag upon).

Negative Sidebands can be turned on and off for harmonic (OFF Mode) and inharmonic (ON Mode) frequency shifting.



Matrix, Virtual Keyboard & External MIDI Trigger Modes:

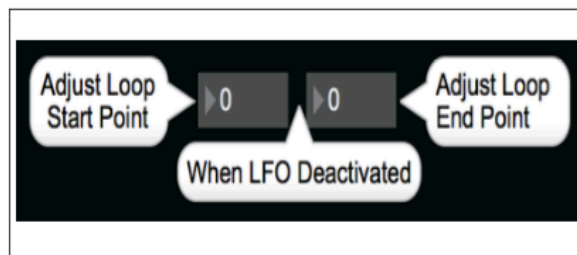
This drop-down menu allows you to select whether the current Generator will be triggered by the 16-Step **Matrix Sequencer, Virtual keyboard & External MIDI** or '**External MIDI Only**' .



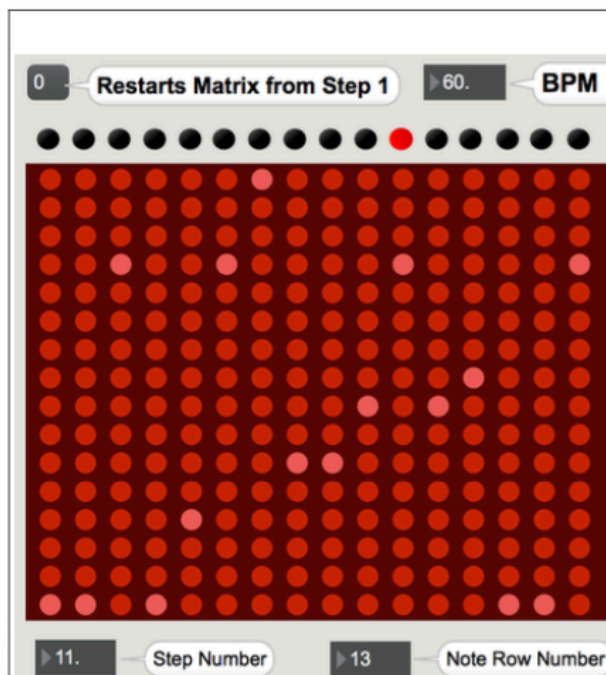
The **'Loop Speed when Matrix Deactivated'** number box allows you to set the speed of the selected loop portion, it will control pitch of the selected portion when the **Matrix, Virtual Keyboard & External MIDI Trigger Modes** are deactivated via the drop-down menu (Off Mode).

The **'Ramp'** number box allows you to set the Ramp of the grains being played, higher values can create smoother grains being played back.

The **'Matrix MIDI Number'** and **'Matrix Freq Hertz'** boxes are read-only and show what MIDI Note and Frequency being triggered by the 16-Step Matrix Sequencer in real time.



The **'Loop Length when LFO deactivated'** number boxes (situated below the keyboard) allow you to control the length of a selected loop portion. This can be used when the LFO has been deactivated, and, instead of using the 'Loop Select' tool in the tool-box menu.



The **'16-Step Matrix Sequencer'**: This triggers a 16 note sequence that can be assigned in each Generator.

The notes are entered by clicking on and off in the Matrix. The scale is chromatic (from bottom to top) and are triggered via the root key selected in each of the individual Generators for a wide range of melodic and harmonic timbres and sequences.

There is a BPM number box where the BPM can be entered via punching the desired number in the box or by selecting the number box and dragging up or down,

There is a button that allows you to restart the Matrix sequence from step 1.

There is also a row of LED's at the top of the 16-Step Matrix that give a real-time update of which step is currently being triggered.

The two number boxes at the bottom of the 16-Step Matrix are read-only boxes to inform you of the current step and row number in real-time.

The Delay and Reverb Unit Controls:
Each Generator has a separate Delay Send knob for individual control of Delay Send Amount.

The Delay has an ON-OFF and Main Level Controls (*Top left*).

Delay Speed Fader: This sets the overall speed of the Delay Repeats.

Delay Feedback Fader: This sets the overall Feedback of the Delay repeats.

Delay LFO Rate: This sets the Rate of the LFO assigned to Pitch Modulation of the Delay Repeats.

Delay LFO Depth: This sets the amount of Pitch Modulation assigned to the Delay repeats.

The Delay also has a '**Delay to Filter**' Switch that allows you to route the Delay Signal through the Low-Pass Filter, or, route the Delay signal to bypass the Filter. In the '**OFF**' mode the Delay signal routes straight to output.

The Reverb Unit: This has an ON-OFF Button plus Level and Time faders.

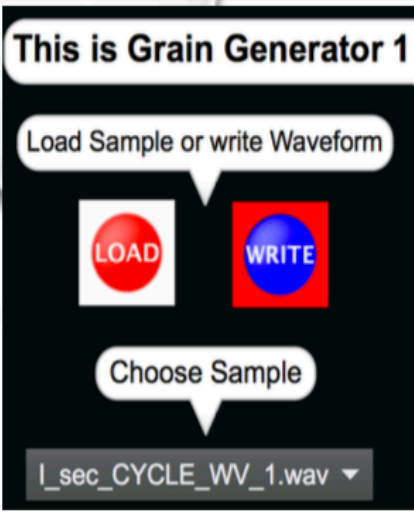
'Low-Pass Filter': There is a Low-Pass Filter that is assigned to the signals from all 6 Generators.

The 'Cut-Off' fader allows you to cut low frequencies.

The 'Resonance' fader enables you to boost the frequency at the Cut-Off point.

The LFO has a dedicated LFO for Cut-Off Modulation:

- * LFO ON/OFF Switch;
- * LFO Depth; Rate;
- * Position of LFO in Freq Range (*Centre frequency for Modulation*);

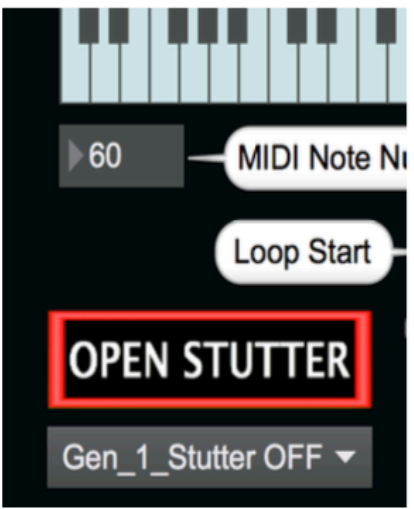


'Load Sample or write Waveform' Audio File Buffer:

'LOAD' will allow you to load a sample of your choosing into the waveform buffer.

'WRITE' will allow you to save a waveform you have created, or edited, with the pencil tool.

'Choose Sample' will allow you to choose/change a sample provided with default settings.



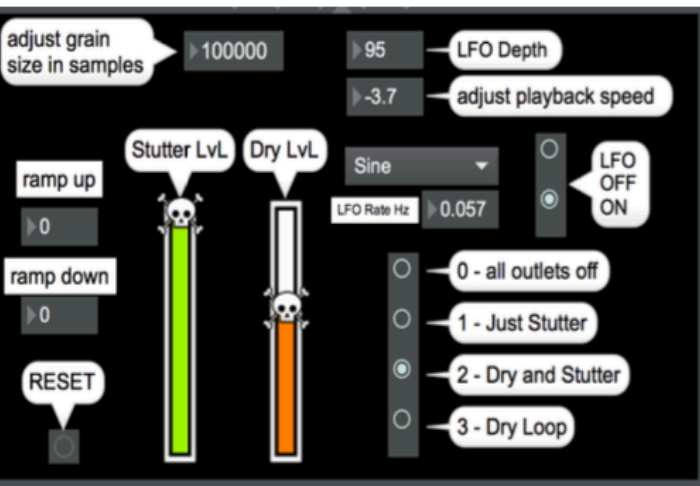
The 'Stutter' Function
 – On each Generator there is an additional editing features for Stuttering audio. This 'grabs' set numbers of samples and repeats them at set speeds, and with LFO Pitch functions. This allows for additional 'Glitchy' effects.

The '**OPEN STUTTER**' button will allow you to load the discrete Stutter editing window.

Below the Open Stutter button there is a **Stutter ON/OFF** drop- down menu.

'adjust grain size in samples' function allows you to select the number of samples to be grabbed for Stuttering.

'ramp-up/down' functions allow you to smoothen the introduction and exit of Stuttered samples.



The 'LFO' functions allow you to modulate the pitch of Stuttered samples via different modulation waveforms (*Rectangle; Sine; Sawtooth*).

'adjust playback speed' function allows you to edit the playback speed of Stuttered audio.

Additional functions include Adjusting Wet & Dry Levels between Stuttered audio and normal Generator playback.

'The Oblique-Granizer' EEG Timbres.

Note: The image below highlights the *Oblique-Granizer* synthesizer pre-set timbres & sonic textures created for compositions using pure EEG epilepsy data only

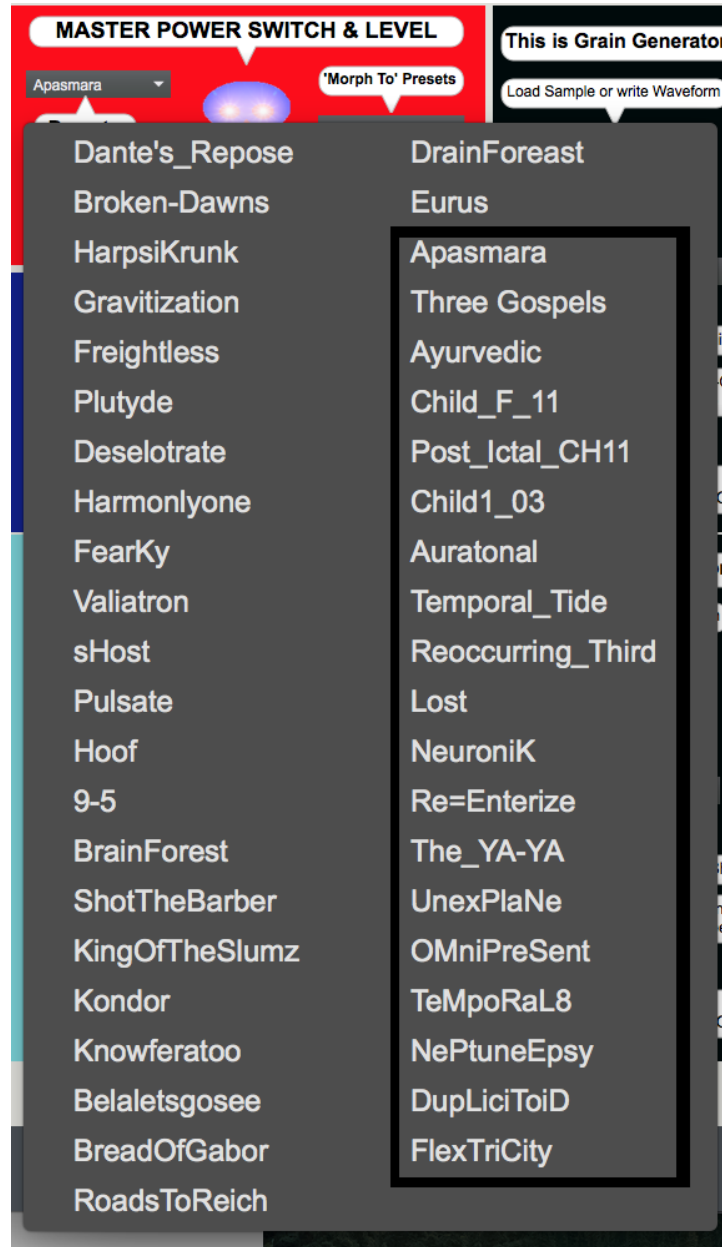


Figure 22: Pre-set timbres and sonic textures highlighted with pure EEG epilepsy data.

The other pre-set sounds detailed (*to the left* in Figure 22) are timbres and sonic textures created and designed whilst developing the MAX/MSP synthesizer for this project, using a drum loop, vocal and string sample (*any audio sample can be loaded into the Granular Generators*) in the creative model that can be seen in the creative flow chart on the following page.

Creative Flow Chart for Sound Design.

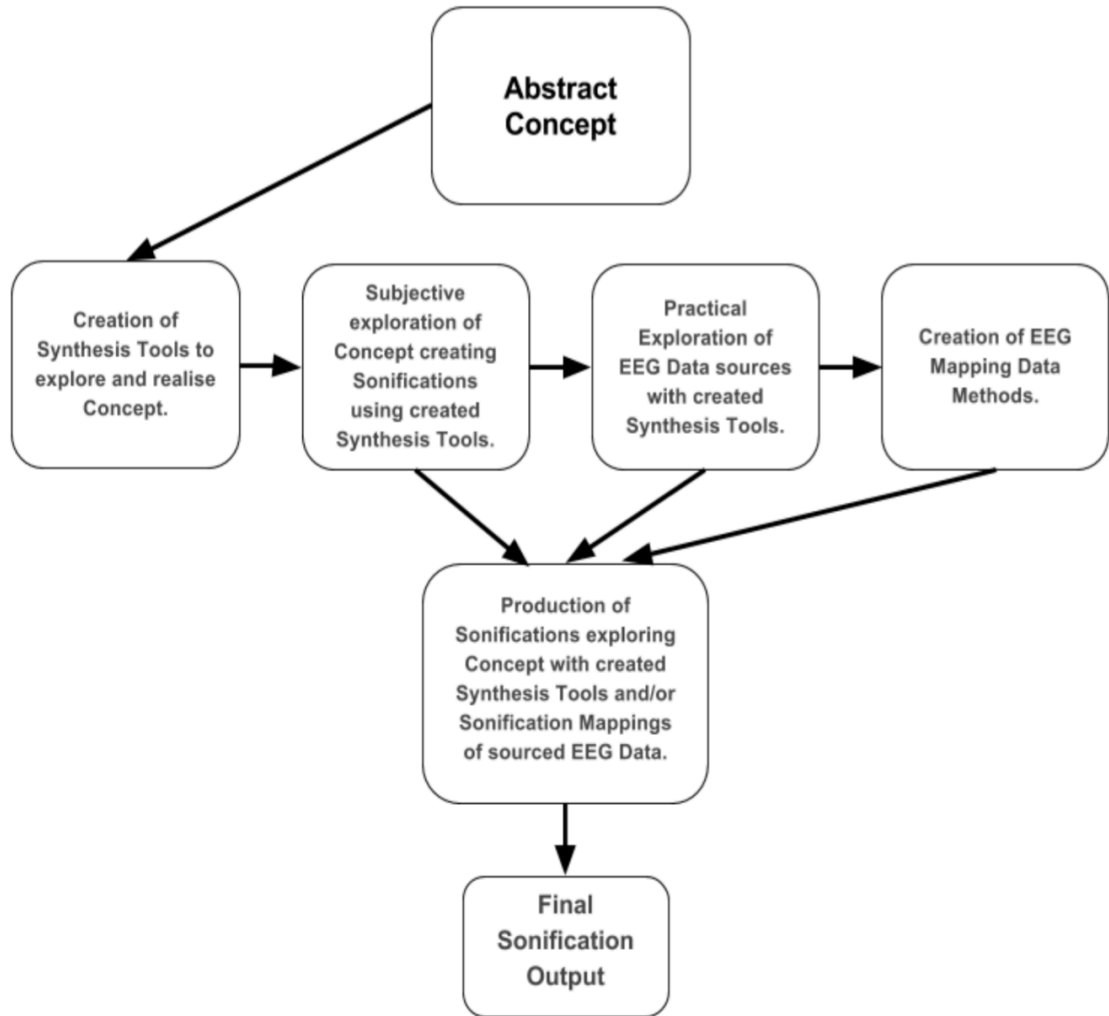


Figure 23: Creative Flow Chart for Sound Design.

From the diagram above we can see that it is possible to move from the subjective exploration of concept to the production of sonification with the created synthesis tools, bypassing EEG data sources to create an artistic and subjective realisation of the concept with any audio source. And/or onto the practical exploration of pure EEG data mappings, providing both subjective and objective sonification possibilities.