LISTAHÁSKÓLI ÍSLANDS
Iceland Academy of the Arts

Department of Music

Musical Composition For Tactile Perception

MMus Thesis

Kurt Uenala

Spring 2018

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New Audiences and Innovative Practice

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Supervisor: Berglind Tomasdottir

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Abstract

The main reason why people play, compose and listen to music is its ability to induce emotions in themselves and others. But how does a deaf person experience music? Do they feel the same music-induced emotions that a hearing person feels? Does a minor chord that is generally labelled as "sad" feel the same to a non-hearing person?

This topic in music research refers to the idea that music expresses emotions that listeners actually feel. Although musical emotions felt by a deaf and a hearing person can be related to each other, they may be distinct and therefore reflecting different mechanisms.

This project aims to explore the emotional impact of music composed especially for the purpose of being **felt** through the skin and **not heard** through the air via the ears. To transmit the music, a prototype device called the "0dB chair" was constructed. The chair will transmit vibrations on 5 separate channels through numerous haptic transducers which are located on specific points on the body of the "listener". It features music commissioned from a selection of hearing and also deaf musicians.

New findings of linking touch with visual stimuli support the idea that music, delivered in vibrational and visual form, offers a complete and profound musical experience. For that reason, the 0dB chair also features a visual component generated by a laser system that will attempt to visualize the music and further enhance the experience.

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Acknowledgements

I would like to thank my supervisor, Berglind Tomasdottir, for her guidance through each stage of the process.

Also, I am forever indebted to the contributing composers Andre Ceres, Erol Unala, Stephan Stephenson and Peter Hayes for their beautiful creations.

Appreciation is due to Aki Asgeirsson and Hreinn Bernhardsson for assistance in the technical side of the project.

Inspiration

I had the pleasure of meeting a young man named Andre at a performance in the summer of 2018 at a festival in Zürich. He was staying very close to the subwoofers during the performance and I was worried he would harm himself in doing so. It turns out he was deaf from birth. He explained that he was "feeling" the music through his body rather than hearing it with his ears. We talked extensively and I got interested in his way of experiencing music. In our discussions, it became clear that sound really is just vibrations that does not necessarily need to go through the auditory system of the human hearing apparatus. Hearing, just like touch, requires sensitivity to the movement of molecules in the world outside our body. When experiencing music by hearing, we interpret impulses generated by the air hitting the eardrum. When experiencing touch, it's impulses from receptors in the skin.

Basic Concept

Start by placing your hand on an audio speaker when it's playing music. What you will find is that mainly the low frequency signals (bass and rhythm section) can be felt. For people who are deaf, this tactile feeling is the main method of experiencing musical information. But this method also only allows for a simplified representation of the music that was composed for the hearing population. Try placing your fingers on your throat when you sing, and feel the change that happens when you change the pitch of your voice; the rate of vibration rises with rising pitch. When you are at the highest voice register, the vibrations get weaker and weaker, until we can no longer feel anything in your fingertips.

Motivation

In December 2018 I went to Switzerland and did a test session with Andre whom I met in August. It turns out that he is also a deaf electronic musician. The preliminary experiment revealed that rhythmical information such as metrical strength and note lengths are highly correlated with emotional expression in this deaf person. Pitch, loudness and harmonic modes were in general less significant. However, minor and major chordal context and different diatonic modes revealed surprising similarities among emotional states of hearing versus deaf listeners. The preliminary test used a small dataset of musical stimuli through arpeggiated chords of varying musical characteristics and different tuning systems were explored (just intonation versus tempered “normal” tuning). The results are of significance but must be compared to a larger number of test subjects to gain an accurate analysis of how a deaf person feels and processes musical information into emotions. The findings would make it possible to create guidelines on how to compose music with the non-hearing community in mind and also help deaf composers create music.

Introduction

I had the immense pleasure to be introduced to Dr. Brian Gantwerker, a cranio-spinal specialist in Los Angeles. He is also interested in music and how it affects the brain which made him the perfect expert involved in this project.

1. Dr. Brian Gantwerker (Neurosurgeon) in discussion with the author, April 2020

What I learned from our conversations is that the brain remains flexible over the entire lifespan. [1] The ability of the central nervous system to adapt to changing requirements is also known as neural plasticity. Neural plasticity makes it possible for deaf or near deaf people to be able to process speech and also music. There is clear evidence that brain plasticity, especially the use of the auditory cortex for processing visual and tactile information, contributes significantly to this phenomena. [2]

It was found that when vibrations are sent to the palms and fingers, activation of the auditory cortex is greater and more pronounced in deaf participants than in hearing participants. [3]

Neurophysiological Considerations

There are two conventional ways of hearing for humans: air conduction and bone conduction.

- Air conduction is what most people are thinking of when they talk about hearing. The sound waves are passing through the air and cause the eardrum to vibrate. The eardrum then transfers the vibrations to the cochlea.
- Bone conduction is when vibrations are imparted to the bone structure of your body (mostly the jaw and the skull) and the vibrations are transmitted to the cochlea that way, bypassing the eardrum (bone conduction product). I have experimented with bone conduction headphones years ago but they only work if you have a healthy inner ear apparatus (cochlea).

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2. M. Alex Meredith, James Kryklywy, Amee J. McMillan, Shveta Malhotra, Ryan Lum-Tai and Stephen G. Lomber. *Crossmodal Reorganization in the Early Deaf Switches Sensory, but not Behavioral Roles of Auditory Cortex*. (Chicago: Proceedings of the National Academy of Sciences of the USA, 2011), 1.

3. Dean Shibata. *Differences in brain structure in deaf persons on MR imaging studied with voxel-based morphometr*y. (Washington: American Journal of Neuroradiology, 2007), 243.

So I resort to a third way, and that is to feel the sound pressure as vibrations through the somatosensory system, mainly through the skin covering our bodies, but also through the skeleton, also known as tactile perception. [4]

Overview Of Tactile Perception

The somatosensory system is our perception of changes at the surface and inside our body **without** utilizing our typical sensory organs (eyes, ears, nose, tongue). This neural system processes information from skin, joint and muscle receptors and therefore primarily serves to capture sensory qualities such as pressure, touch, pain and temperature. The integrity of this system is an essential factor for processing complex stimuli, such as the recognition of three-dimensional structures and objects. Furthermore, the somatosensory cortex plays a fundamental role in the collection of movement information and the perception of arm and hand position in the room. The somatosensory system therefore plays an important role in how deaf persons perceive the conditions and situations around them.

When young children discover the world, it is not enough for them to just watch and listen. They have to touch everything new in order to understand shape, texture and meaning. And even beyond the baby years, the sense of touch remains an important tool to learn new things.
But the sense of touch is only one but an essential part of the somatosensory system. In addition, it consists of at least three other senses: the temperature sense, the sense of pain and depth sensitivity or proprioception. While the latter serves the body's self-perception, i.e. provides information from the inside, the most important external location of the somatosensory system is by far our largest sense organ - the skin.

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4. Juan Huang, Darik Gamble, Kristine Sarnlertsophon, Xiaoqin Wang, Steven Hsiao. *Feeling Music: Integration of Auditory and Tactile Inputs in Musical Meter Perception*. (Baltimore: PLOS, 2012), 1.

From there, signals permanently enter the brain via the spinal cord. More specifically to the somatosensory cortex, which helps to convert the stimuli into perceptions. [5]
It is perceptions that not only provide essential information about the environment and our own body, but also enrich our quality and enjoyment of life. A walk on the beach would not be so special if we didn't feel the warm sun on our skin and the sand under our feet. And imagine tenderness and intimacy without the ability to feel a lover's touch.

The cells that capture vibrations in the skin are called mechanoreceptors [6]. We all often felt sound pressure through the body when experiencing very high sound pressure levels such as amplified concerts and in dance clubs or even in movie theaters. The feeling of your organs vibrating and the bass hitting your chest and abdomen has nothing to do with your eardrums, it's all coming from the somatosensory system - your body’s mechanoreceptors.
The main players in capturing stimuli from the 0dB Chair are the Meissner Mechanoreceptors which are highly sensitive and mostly present in the glabrous (smooth/hairless) skin (Fingertips, palms). They are located in the upper layers of the skin. The other important Mechanoreceptors are the Pacinian Corpuscles, which are deeper in the skin and are very present in the abdominal area where they mainly transfer information on vibrations from the skeleton (they can also be found in the legs of cranes to detect movement in the water). [7]

---

5. Anne J. Blood, Robert J. Zatorre, *Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion*. (Washington: Proceedings of the National Academy of Sciences, 2001) 1.

6. V. Abraira, D. Ginty, *The Sensory Neurons of Touch*. (Washington: National Library Of Medicine, 2013), 2.

7. Purves D, Augustine GJ, Fitzpatrick D, *Mechanoreceptors Specialized.* (Sunderland: Neuroscience 2nd Edition, 2011), 2.

Anatomy of the Cutaneous Perception of Music

The tactile sensory system, which can also be called as cutaneous sense, provides stimulation through our skin.

The basic elements of tactile perception are pressure, touch, vibration, temperature and pain. The first three sensations, pressure, touch and vibration, are most important to convey musical information. These vibrational stimuli cause mechanical deformations of the skin and are registered by our mechanoreceptors which are located in various layers of the skin. Mechanoreceptors register stimuli due to temporary physical deformation of their plasma membranes. The feeling of pressure and vibrations are difficult to separate. From a sensory viewpoint, both sensations sometimes overlap, depending on the intensity level.

Pressure and vibratory stimulation are registered by four mechano-receptive neurons in the superficial skin and deeper tissue. The different types are categorized by their adapting speed and receptive field. The four major types of tactile mechanoreceptors are:

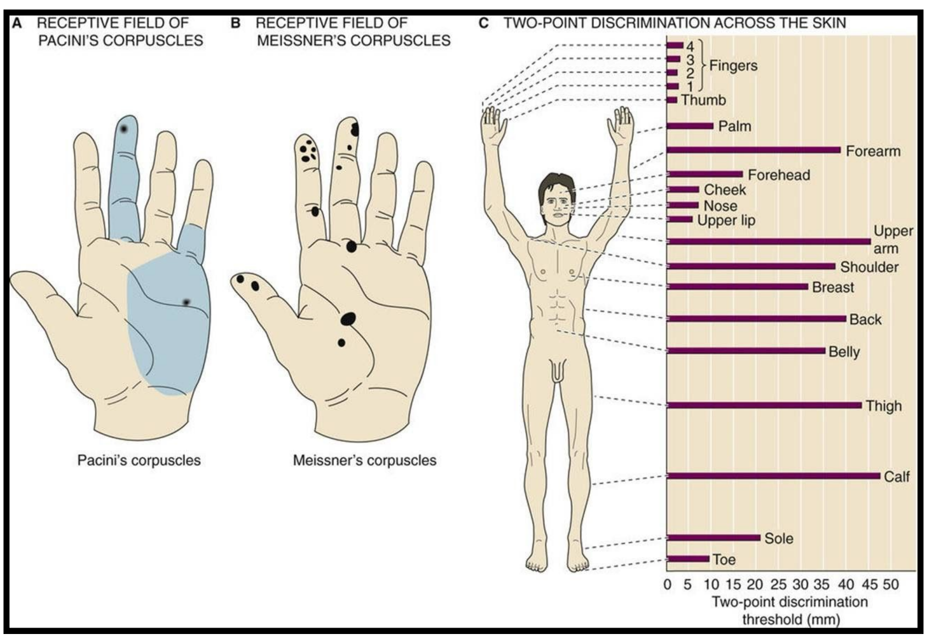
- Merkel's disks are slow-adapting and respond to light touch
- Ruffini endings are slow adapting and respond to skin stretch
- Pacinian corpuscles are rapidly-adapting, deep receptors that respond to deep pressure and high-frequency vibration. They capture vibrations form the skeleton, which is very important in this project
- The 4th and most important neuron for sensing vibrations of the transducers used in this project are the Meissner's corpuscles as they respond to fine touch and pressure, but they also respond to low-frequency vibrations. They are found primarily in the glabrous skin on the fingertips and eyelids.

The Physical/Musical Part of the 0dB Chair

Considerations in System Design

It was found that the sensitivity of tactile perception on our body differs depending on the location. A team of researchers around Dr. Rowe in Australia investigated the threshold of tactile perception and measured the pressure discrimination threshold on the whole body. They examined the sensitivity of vibrotactile perception using 200 Hz vibrotactile stimuli and found that hands and soles of the feet are the most sensitive, followed by the head, the larynx region and abdomen.[8]

Fig 1 Location and sensitivity of the Meissner's mechanoreceptor neurons

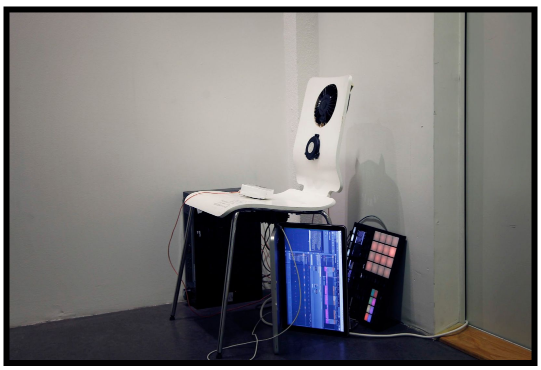


8. Mahns, Perkins, Robinson, Sahai, Rowe, *Vibrotactile Frequency Discrimination in Human Hairy Skin*. (Pittsburgh: Journal Of Neurophysiology, 2006), 1442.

As you can see from the image above, the lower the bar, the more sensitive to tactile stimulation is the area. The fingertips are the most sensitive. [9]

Also, the abdomen is more sensitive than the back, which is why the chair's design has been altered from the initial prototype.

Fig 2, Initial prototype of the 0dB Chair at the Iceland University of the Arts, Reykjavik 2018



Compositional Language for the Sense of Touch

Sounds can be easily converted into physical sensations, which can be turned into tactile energy.

I have experimented with varying frequency, intensity, duration, waveform or spectral content and also space (the location of the placement of the vibrational transducers on body) and found that all content should take place below 500Hz and that note length and tempo are a big factor in the emotional perception of the composition (see the “motivation” section above”).

But unlike feeling the voice when we sing, music that is made up of many instruments and multiple voices is very hard to decode and represent as tactile sensations with one device. In a conventional modern pop song recording, the audio material originating from voices, drums, bass, guitars, pianos and strings are combined into a very complex waveform. It was composed to be perceived through functioning hearing organs.

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9. Yann Roudaut, Aurelie Lonigor, *Touch Sense*. (Austin: Channels, National Center For Biotechnology, 2012), 234.

If we use a normal stereo system and try to feel the sounds with our hands, we can only feel vibrations resulting from the lower frequency signals. They also mask the quieter, less intense, higher tones. So I need to make sure we have a multi channel tactile playback system where the higher and lower frequencies are represented by separate “speakers”, or tactile transducers. They have to be separate sensations.

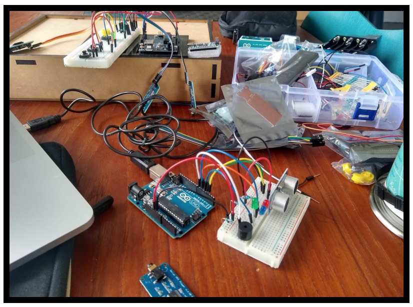
The ear uses countless sensors to capture the spectrum of sound but our skin cannot naturally access the complex signals that comprise conventional music.
So, to effectively use the skin's ability to “hear", we must spatialise the frequencies or sound sources and try to approximate a representation of the sounds recorded.

Technical Specifications and Construction

I created the chair to contain 6 vibrational transducers for 5 separate channels of haptic energy. They are powered by an amplifier that can accommodate numerous 4 ohm transducers (in place of traditional speakers) and carry enough wattage to produce sufficient haptic energy to create a cutaneous sensation and therefore be felt by the human skin.
Additionally, the 0dbChair has a 3 dimensional Laser visualisation component to complement the musical experience (see next chapters).

There are 4 major components that make up the 0dB Chair:

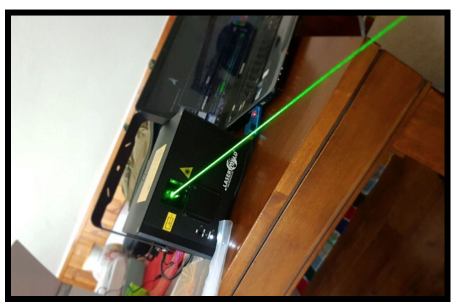
Arduino 5.1 Wav Player



Surround Sound Amplifier

Vibrational Transducers

Laser image projector

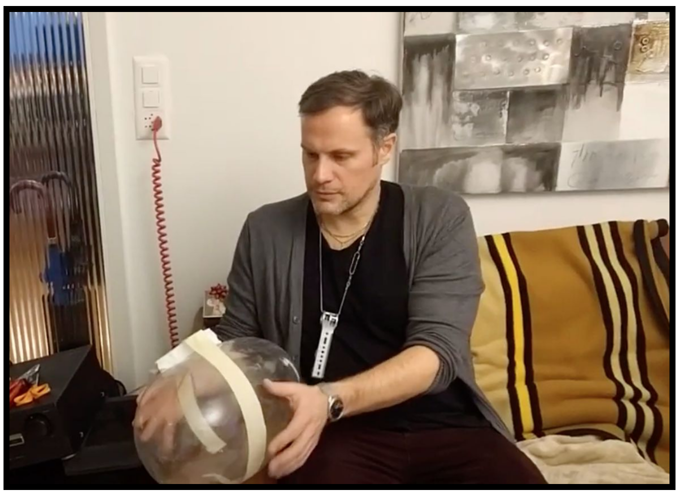


The chair was constructed with the generous help of Hreinn Bernharðsson of the Design Workshop at the Iceland University of the Arts in Reykjavik.

The programming of the Arduino component has been done by Aki Asgeirsson at the Iceland University of the Arts in Reykjavik.

The Composers

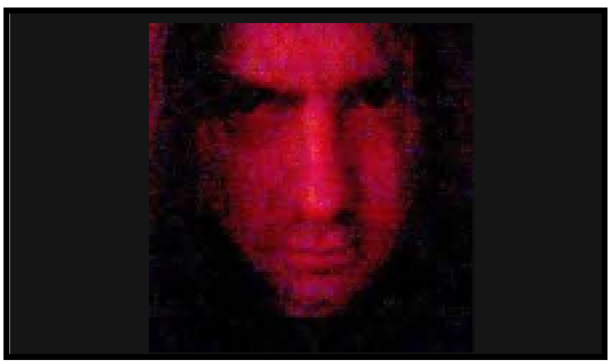
Andre Ceres - Deaf from Birth - Electronic Musician - Self



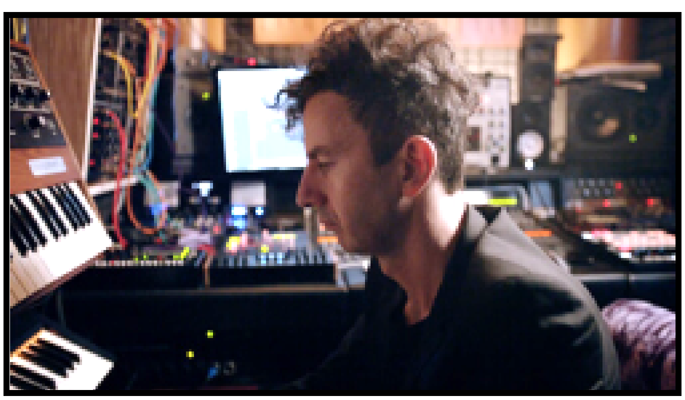
Peter Hayes - Hearing - Producer/Guitar player - Black Rebel Motorcycle Club

Stephan Stephensen - Hearing - Electronic Musician - President Bongo, Gusgus

Erol Unala - Hearing - Rock Musician/Guitar player - Celtic Frost



Kurt Uenala (Author of this paper) - Hearing - Electronic Musician - Null & Void



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The Visual Component

Background

Although the perception of music/sound (auditory) and visual (ocular) stimuli is fundamentally different, they do have a common Intersection. The temporal structure, the rhythm is similarly received both visually and audibly. They are both time based mediums. When the two worlds are synchronized, a profound experience for both the hearing and deaf "listener" can be created.

As the historical record shows, attempting to "decode" and visualize the emotional information inside music has not been proven effective. Rather, it was about finding a tool or trying to create an infrastructure that allows to synthesize images derived from, or at least related to the music. It all started from color systems to audio oriented video synthesis to video art and finally to current computer generated visuals that I am currently experimenting with.

History

Already Pythagoras dealt with the relationship between the audible and visual. His number-based science system was the basis for understanding the connection between numbers and musical harmonies. He employed himself with spheric music, which consisted of purely mathematical sounds. These sounds had a visible equivalent on a scale of his valid color spectrum. [10]

Later, Aristotle ordered the seven notes of an octave to the colors white, yellow, red, purple, green, blue and Black. This colortone theory retained its validity until the beginning of the 18th century when in 1704, Newton proved in the publication Opticks, that the composition of white light is that of seven spectral colors and the mathematical correspondence with the seven intervals of the scale.

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10. Dominique Proust, *The Harmony of the Spheres from Pythagoras to Voyager*. (New York: Proceedings of the International Astronomical Union, 2011), 2.

In 1725, Louis Bertrand Castel, a french jesuit priest, developed one of the first concepts for a color keyboard instrument. With each key press, in parallel to the sound of the harpsichord, a small shaft to opened, allowing light to shine through a piece of stained glass. Even the renowned baroque composer Georg Telemann travelled to France to see this innovation and ended up composing several pieces for the instrument. It included a keyboard with five octaves. The first octave was associated with pure color shades. The higher octaves represent the same hues but their brightness was stronger. Louis Bertrand Castel was convinced that his concept was a new Art form, a music of colors. [11]

Fig. 3: color harpsichord

Another interesting attempt was the pyrophone, introduced in 1893 by Frederick Kastner. It was based on the hissing sound and the light of gas lamps as this was before the discovery of electricity in interior lighting. Glass pipes of varying length and width were filled with burning gas and sounds similar to the human voice and also strings were possible. Simultaneously, the instrument also produced lighting effects.

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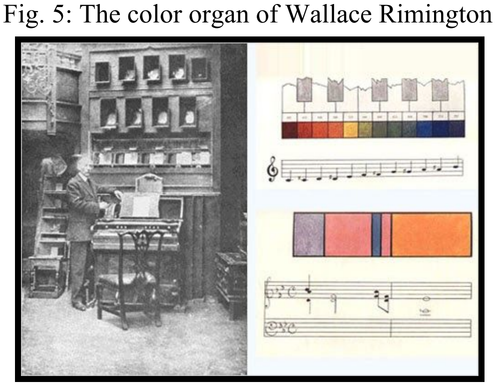
11. Marteen Franssen, *The Ocular Harpsichord*. (Amsterdam: Department Of Philosophy Essay, 1991), 1.

The luminous gas was ignited and regulated by pressing a key on the keyboard. Compared to the previous inventions mentioned above, the Pyrophone or Flammenorgel, could artificially create tones and light at the same time.

Fig. 4: Pyrophone

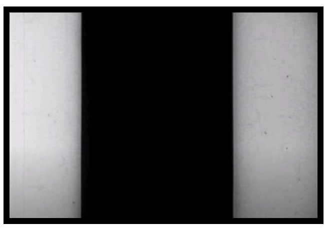
The most famous musical color instrument of the 19th century was patented in 1893 by Alexander Wallace Rimington. He was a professor of art at Queen's College in London named his device a "color organ". This becomes a generic term for apparatuses of this kind. Two years later, the first demonstration of "color music" on the color organ takes place. The overture to the opera Rienzi by Wagner is accompanied by the color organ. This visual performance consists of pulsating informal color sequences. For each played note, a color hue is projected. With the tempo of the piece increasing, the color changes became so fast that they could no longer be perceived by the eye. Rimington realized too late that form is an indispensable factor in the visual art of his time and consequently the performance was ripped apart by the reviewers.

Fig. 5: The color organ of Wallace Rimington



By the early twenties, the interest shifted to an art form independent of sound. Light manipulation and the relatively young medium film/moving pictures were becoming more popular with creators and audiences.

Fig. 6: Hans Richter - Rhythmus 21, 1921



The discovery of the electron and the cathode ray tube (both 1897) form the basis for electronic creation and also transmission of images. The recording of the Image signals (instead of audio only as it was before) by a magnetic tape recorder (1951) can be viewed as a fusion of film (as storage medium) and television. The result was the new medium of video.

The colored projections and displays of the color organs around the turn of the century were replaced by the video. The discussion around the relationship between sound and image is now reignited and is made possible by technical links between the two mediums. But the interest in the synaesthetic relationship between audio and vision moves into the background.

Nam June Paik, together with Steina and Woody Vasulka become the central figures of the early video synthesizer development.

Woody Vasulka says: “The invention and use of the audio oscillator became the natural link. As in our case, many of our colleagues and friends used oscillators of audio synthesizers to generate their first video images. The first video instruments were inspired by the architecture of audio instruments, and the first organization of images was created in a similar way“.[12]

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12. Woody Vasulka, *Eigenwelt der Apparatewelt - Curatorial Statement*. (Santa Fe: Vasulka dot org, 1992), 12.

In 1963, Nam June Paik presented a modified television set, which distorted the picture received from a TV station.

In 1969, he and the TV technician Shuya Abe created the Paik/Abe synthesizer which is considered one of the first devices to abandon video and instead generate/synthesize original visual content. In 1970, the video synthesizer was used to capture the pictures of the television program "Video Commune - The Beatles from Beginning to end ". In a 4 hour performance, Paik created a wild colored image whirlwind to the soundtrack of the Beatles. Japanese TV recordings without subtitles were intercut. [13]

Steina, a native Icelander and Woody Vasulka moved to New York in 1965 and began working with the medium video. In 1971, they founded "The Kitchen", an initial small theater intended for electronic media which is still active today.

In 1970, the Vasulkas demonstrated the possibility of an instant electronic interaction between picture and sound by means of a live video and audio feedback system which they called a video ballet. A human performer, a TV system and a Moog audio synthesizer all interacted. The television picture and the performer that was abstracted and deformed through video feedback circuits which were controlled and by voltage changes coming from the electronic Musical instrument, the Moog synthesizer. The musical instrument modulated the video playback system so that the electronic sound and the abstraction on the TV screen corresponded to the movement of the dancer (performing live, on stage).

In 1976 Atari released the first music visualizers for home use, the Atari Video Music system (also known as the migraine machine for it's intense colors and shapes). The built in shapes were reacting to the amplitude and frequency spectrum of the audio signal and played on a TV set.

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13. Shuya Abe, Nam June Paik, *Eigenwelt - Explanation*. (New York: Vasulka dot org, 1992), 129.

Fig. 7: Atari Video Music System

One of the first artists to use personal computers to digitally create images was John Whitney, an american animation filmmaker. In the course of his artist-in-residence program at IBM, he gained access to one of the first powerful personal computers. He created moving images reacting to musical pieces. The results were ornamental patterns.

Fig. 8: John Whitney IBM Visuals

With the arrival of more powerful computer systems and the fast technological progress it is now possible to generate moving pictures entirely digitally. While audio synthesizers are still widely used as hardware devices today, the production and performance of synthetic moving images happens almost entirely in a software environment.

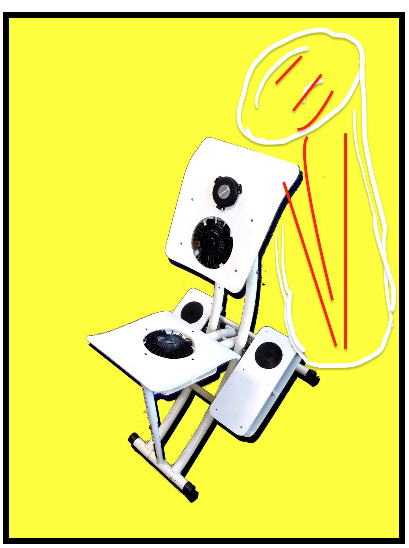
Visual System Design

Audio and music consist of overlays of vibrations of varied sound pressure and frequency. The resulting signal is converted from the analog transmission into an electrical vibration (electronic sound generation systems and software can, of course, generate this signal directly). In the converted signal (analog to digital or voltage data) the size of the voltage corresponds to the sound pressure or amplitude of the analog signal and the frequency of this voltage represents the pitch. While the audio signal contains a lot of the information to be used to create visual content.

Although the perception of music and sound is fundamentally different, they do have a common Intersection. The temporal structure, the rhythm is similarly received both visually and audibly. They are both time based mediums. When the two worlds are synchronized, an profound experience can be created.

As the 0dB chair has the "listener" sit facing forward and looking down, I felt that it was ideal to have a 3 dimensional visual component created via a laser system.

Fig. 9: Laser Viewer Mockup on the 0dB Chair



In my core practice as an electronic composer/performer, I have used Laser projectors before. I created very simple graphical shapes in a lighting software that was able to output images to the laser projector's flash storage. Having static images that I was able to transform was functional but ultimately very limiting. In order to create custom dynamic imagery that can react to music I have to create my own software tools.

With my extensive background knowledge in modular synthesis, the ideal choice for my purpose is visual programming or "graphical dataflow programming" language. [14]

The applications MAX/MSP or Pure Data are very similar in their use of cables, although in a simulated "virtual" form. I decided on a similar software but more geared towards visuals. It is called "Touch Designer".

Programming with Touch Designer is a unique interaction that is much closer to the experience of manipulating things in the physical world. The most basic unit of functionality is a box, and the program is formed by connecting these boxes together into diagrams that both represent the flow of data while actually performing the operations mapped out in the diagram.

Throughout the last decades, programmers worked with text-based programming languages. They wrote so-called "code", then initiated the processing inside the computer and got a result. Touch Designer works in "real time". This means that it doesn't function like the traditional programming scheme mentioned above, but that changes can be initiated during processing. As with a traditional musical instrument, the musician instantly hears the resulting changes and can react accordingly. This makes this program ideal for artists performing live.

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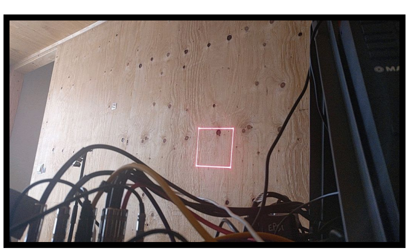
14. Greg Hermanovic, *Overview Touchdesigner*. (Toronto: Touchdesigner dor com, 2017) 1.

Touch Designer provides visual objects for its functions that the user can place, arrange and manipulate on the screen. These visual representations, small rectangles that are linked together by virtual cables, are inspired by working with analog studios in which electronic music was created before the computer age. Various synthesizer modules, now symbolized by rectangles, are connected by lines that symbolize connections between the boxes.

Due to these types of connections, Touch Designer is called a data stream-oriented programming language and is ideal for creating geometric forms that best visualize the musical stimuli of the 0dB chair.

Fig. 10: Testing laser visualisations for the 0dB Chair displayed in a 180 degree viewer

Fig. 11: Laser Pattern Test



Previous Work and Related Projects

Both hearing and touch are types of mechanosensations and in this project I will attempt to compose music for creating emotional impact for tactile enjoyment exclusively. I have used tactile transducers before when living in a small NYC apartment and having to resort to working on music with headphones. I attached a vibrating bass transducer (think of it of a speaker without the cone, just a moving coil) to my working desk and could feel frequencies below 80Hz through the table which gave the illusion of actual sound pressure.

One of my favorite audiovisual pieces is Reflektor Distortion [15] by Carsten Nicolai. The union of the vibrational aspects of sound and visualisation through a simple, naturally occurring phenomenon.
A sonic and also vibrational piece that is most important is the Sonic Bed [16] by Kaffe Matthews. It uses conventional speakers that are mounted on wood so therefore they do create vibrations but also auditory signals.

The idea of feeling music through vibrations is not groundbreaking but is a growing niche in computer game hardware that hopes to boost the gaming experience. The emotional effect of those vibrations on people does suggest that there is something deeper and more meaningful than just cheap thrills.

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15. Carsten Nicolai, *Reflektor Distortion*. (Berlin: Carstennicolai dot info, 2016) 1.

16. Kaffe Matthews, *Sonic Bed.* (Marfa: kaffematthews dot net, 2009), 1.

Fig. 10: Common devices containing haptic feedback

There are some products that allow you to “feel” music on the market or in development:

V.E.S.T.

Subpac

Soundshirt

I feel that the most interesting aspect of the project is that the performed music was composed for an audience that is deaf and broadcast through a multichannel medium that enables the user to differentiate the various parts of the musical piece.

Future Directions

5 channel sound reproduction is limited to compose for when using tactile transducers. I might create a 7.1 or 9.1 system to work on more complex pieces in the future. Another modification will also be a more advanced visualisation system and the ability to take a live input feed from musicians.

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