Sonification of Standstill Recordings

Exploring Human Micromotion through Sonification

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Abstract

The goal of this thesis was to develop and experiment with a set of sonification tools to explore participant data from standstill competitions. Using data from the 2012 Norwegian Championship of Standstill, three sonification models were developed using the *Max/MSP* programming environment. The first section of the thesis introduces sonification as a method for data exploration and discusses different sonification strategies. Momentary Displacement of the position was derived from the position data and parameter mapping methods were used to map the data features with sound parameters. The displacement of position in the XY plane or the position changes along the Z-Axis can be mapped either to white-noise or to a sine tone. The data variables control the amplitude and a filter cut-off frequency of the white noise or the amplitude and frequency of the sine tone. Moreover, using sound spatialization together with sonification was explored by mapping position coordinates to spatial parameters of a sine tone. A "falling" effect of the standing posture was identified through the sonification. Also audible were the participants' breathing patterns and postural adjustments. All in all, the implemented sonification methods can be effectively used to get an overview of the standstill dataset.

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Abbreviations

This section includes some of the abbreviations used in this thesis.

CSV Comma Separated Values

ECG Electrocardiogram

EDA Exploratory Data Analysis

EDM Electronic Dance Music

EEG Electroencephalogram

EMG Electromyographic

GUI Graphical user Interface

Max Max/MSP programming environment

MAA Minimum Audible Angle

MBS Model Based Sonification

MoCap Motion Capture recording system

QoM Quantity of Motion

Chapter 1

1 Introduction

As a drummer, I always feel strongly connected to the music with my motion in a performance and I am fascinated by how a genre or the type of music influences the body movements. During the studies in Music, Communication and Technology study program, I had the opportunity to actively participate in the Norwegian Championship for Standstill competition in 2019 and grasp the methods of the whole process starting from setting up the Motion Capture system to choosing the final winner of the competition. The MoCap system outputs a rich continuous data stream with a larger number of data points and my motivation behind the thesis was to combine this data stream with sound to hear the participants' movements. Moreover, this implementation can be used as an instrument for a "Standstill performance" and opens a new door for a sonic interaction space with human micromotion.

Music and body motion are strongly interconnected. where musicians produce sound via body motion and music produces body movement in listeners. The listeners tend to produce numerous types of movements to the presence of a clear pulse in music (Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2013). Also, the occurrence of head movements is an indication of listeners trying to follow the rhythmic features of the music. According to the study, low-frequency spectral flux and high-frequency spectral flux have a strong influence on the speed of head and hand movements. The study further suggests that the head movement is most noticeable due to its biological structure which is likely to move more according to the beat. The music produces positive emotions and 'groove' is defined as the characteristic that tempts to move the body (Janata, Tomic, & Haberman, 2012). Also, this depends on sensory and motor factors (Janata et al., 2012). Music with a strong groove character tends to produce a larger amount of movement in the body. The study by Burger et al. (2013) suggests that a strong beat or pulse has a larger impact on the movement of the torso and leg movements and implies that the listeners can easily be synchronized to a stronger pulse compared to a weak pulse.

The background of this thesis is based on the involutory movements that happen when people try to stand still while listening to music. A study was conducted by Ross, Warlaumont, Abney, Rigoli, and Balasubramaniam (2016) to research the postural sway that happens while listening to high-groove and low-groove music. Parameters such as sway variability, local entrainment, global entrainment have been studied. One important result of the study is that the lowest radial sway was noticed in the highest grooves and highest radial sway in silence. This implies that the level of a groove in the music has an impact on the balance control and variability of sway. The study suggests that the musical experience of the listener can influence the entrainment to music and musical experience decrease the sway variability. Also, the study suggests that the non- musicians are more likely to have changes in postural sway and entrainment to music.

1.1 Research Questions

The thesis is based on several research questions on applying sonification to explore the standstill data. The main research question broadly addresses on exploring the connection between the music and involuntary motions of the body.

- How can sonification be used as a method to explore music-related micro-motion?

During the Norwegian Championship of Standstill competition, the participants are in a forced condition to not move. And based on past studies, there is statistical evidence that music stimuli have an impact on standing still. Apart from using a visualization method to analyze the micromotion, sonification can be used to listen to the data and find out any audible patterns. The main objective of this question is to find out what kind of difference can be noticed in the motion during the music stimuli is played and whether the sonification can reveal any information that was not visible in statistical studies. In the thesis, I would like to address two other sub-questions that are related to the main question.

1. What kind of motion patterns are audible from the standstill competition data?

While the past statistical evidence confirms the influence of music for standing still, it will be interesting to investigate any synchronicity between the micromotion and music. Also, another interesting aspect would be to find out if sonification can reveal overall motion patterns such as breathing patterns, postural adjustments. And most importantly past studies suggest that a "sinking" in the posture can be noticed when standing still for long periods and it will be an interesting phenomenon to investigate if sonification can provide any evidence or insight on such an event. Also, it will be interesting to find out if keeping the knees locked or not, keeping the eyes open or not have an impact on the standstill motion.

2. How can spatial audio be used in the sonification of human standstill?

By introducing a spatial sound element to sonification, it will be possible to navigate through the motion patterns by listening to the ambisonic sound filed. Humans have a great capability of recognizing the directionality of a sound source and this provides the potential to track down the motion patterns happening in the three-dimensional field.

1.2 Limitations

In this thesis, the sonification modules are developed using the visual programming environment *Max/MSP*[1] and no other approaches have experimented with programming languages. Building a fully functional data filtering and sorting module with *Max/MSP* was not a reachable goal. Choosing the position data based on the demographic data variables was not fully explored in the sonification. For individual participant data sonification module, only

[1] https://cycling74.com/products/max/

three participants were chosen and listening to a larger number of participant's position data was not explored due to time constraints. Only the displacement of position and the Z-Axis values is chosen as the data inputs for the non-spatial sonification modules. The external Max/MSP module for spatializing the sound doesn't support binaural rendering for headphones and thus listening to the ambisonics audio had limitations. However, the IRCAM spat[2] module provides an advanced and sophisticated set of tools for sound spatialization, but it was not explored in this thesis since it requires an in-depth study on the tool. Implementing these sonification modules in a real-time standstill competition was planned with the 2020 standstill competition but due to the COVID-19 pandemic situation, the events had to be postponed. Also implementing a real-time sonification requires experimenting with Motion capture suit and this was not a possible goal due to the closing of university buildings and labs due to the situation.

1.3 Thesis Outline

This Thesis work was on developing three sonification models for exploring the standstill competition data. An overview of this sonification project including sound samples, video demonstrations of the Max patches is attached to the thesis (see Appendix for details) and are also available as a blog post.[3]

Chapter 2 – Background

The first section in this chapter consists of a review of standstill competition and its previous studies. Next, different sonification techniques, their potential applicability, and their requirements are discussed. Moreover, some of the previous projects on sonification are described, and looking into approaches of mapping strategies, sound parameter selection, and potential tools for sonification was essential in the process of designing the experiment and models.

Chapter 3 - Design and Methods

This chapter presents the designing process of the three sonification models and describes the data variables, development of *Max/MSP* patches, sound parameters, and mapping strategies. Finally, the results of the sonification are presented by discussing the sound samples from the sonification.

Chapter 4 – Conclusion

This chapter summarizes the thesis work and discusses the results and the research questions are addressed based on the findings and a discussion on the potential future work is included.

[2] https://forum.ircam.fr/projects/detail/spat/
[3] https://mct-master.github.io/masters/2020/05/13/Sonification-of-Standstill.html

Chapter 2

2 Background

The background for the thesis is based on the work which has been done with The Norwegian Championship of standstill experiments. The competitions are held annually (from 2012 to present) and multiple studies were done based on the gathered data. While standing still, micromotion tend to occur due to the breathing, pulse, and postural adjustments and these actions can be identified as unconscious and involuntary(Jensenius, 2017). The purpose of this series of experiments based on standstill, is to quantify the small movements happen during standing still and explore how music influences these micro-motions.

2.1 Norwegian Championship of Standstill 2012

Figure 2.1: A session from the Norwegian standstill competition. The Mocap system tracks down each marker placed on participants' heads and the real-time position values were recorded into a .csv file. (Jensenius, Zelechowska, & Gonzalez Sanchez, 2017)

Over 100 people have participated and the data of 91 participants were used in the study. The sessions were conducted in groups of 5-17 people. The duration of standing still was 6 minutes which consisted of 3 minutes of silence and 3 minutes of music. The music included 7 pieces of short musical passages. The sound samples were arranged to start with slow music and progressed towards highly rhythmic music. Each participant had a marker placed on their heads and a motion tracking system was used to track the markers at a speed of 100Hz. (Jensenius et al., 2017)

The position of a marker consists of three coordinate values x, y, and z. Three axes of the motion coordinate represent the following motions.

X-axis – sideways
Y-axis – front and back
Z-axis – Up and down

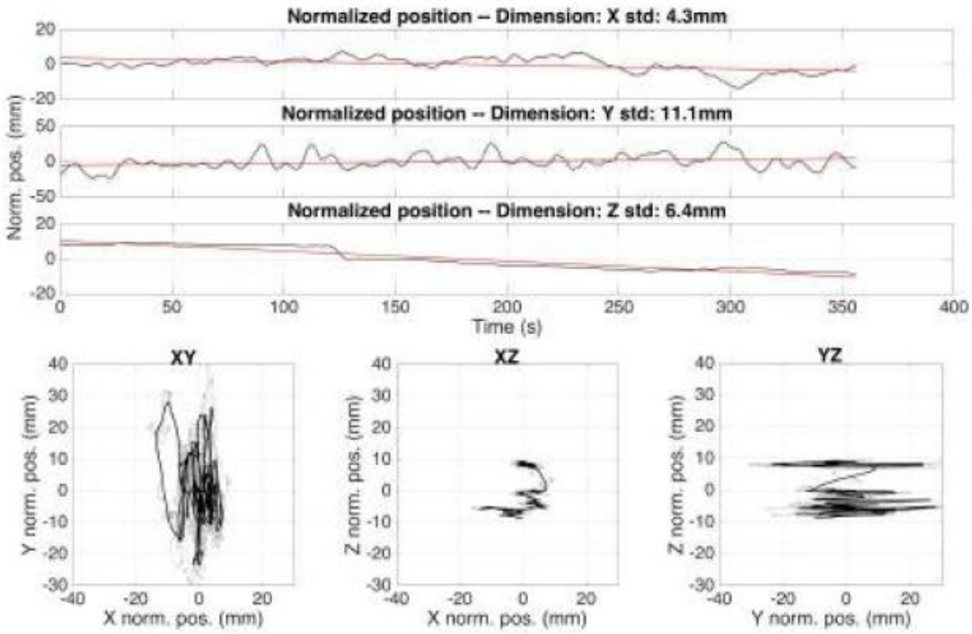

Figure 2.2: A participant's motion plots in XY, XZ and YZ planes for a normalized head marker position (Jensenius et al., 2017).

In standstill experiments, one of the key variables is the Quantity of Motion. QoM is a measurement that is used to quantify how much movement happened in participants during standing still. The Higher values of QoM means a higher level of motion. The QoM is calculated by summing up all the position differences of the consecutive samples to the marker.

P is the two dimensional or the three-dimensional position vector of the marker. T is the total time of the recording. N is the total number of samples. It is possible to calculate the instantaneous QoM values and the average QoM values. Jensenius, Zelechowska, & Gonzalez Sanchez (2017) have defined the QoM as follows (p. 2).

$$\boldsymbol{QoM} = \frac{\mathbf{1}}{\boldsymbol{T}} \sum_{\boldsymbol{n}=2}^{\boldsymbol{N}} \| \; \boldsymbol{p}(\boldsymbol{n}) - \boldsymbol{p}(\boldsymbol{n}-\mathbf{1}) \; \|$$

Moreover, temporal levels are introduced to categorize the motion patterns of standing still data according to a time scale. The motion can be identified in three temporal levels which are micro, meso, and macro (Jensenius, 2017).

- **Micro**: The "Micro" is considered as the motions that happen in a scale of milliseconds.
- **Meso:** Periodic motion that happens in five-second intervals.
- **Macro**: motions that occur in longer periods in 2-3 minutes (Jensenius, 2017).

Particularly, the data from the "standstill" experiment held in 2012 was used to implementing methods for this thesis. The following section describes a series of experiments and results regarding standstill research.

2.1.1 Results of the 2012 Studies

In this section, I would like to mention some of the findings from the 2012 standstill competition data. The Quantity of motion was mostly consistent over the period for most participants (Jensenius et al., 2017). The Average QoM value of 6.4 mm/s for the XY plane is only slightly less than the average QoM value of the 3D plane (6.5 mm/s), and this indicates that the most of motion was happening in the horizontal plane. The vertical motion along the Z-axis reported slightly higher average QoM values during the music stimuli than the moments of silence.

Overall, the average QoM values were higher during music stimuli compared to the sections with silence, which indicated that even in a condition where the participants are forced to stand still, the music has an impact on the level of motion happening. And from further analyzing the demographic data, the study shows that younger people tend to move more, and participants who exercise regularly tend to move more. Also, the subjective experience reveals that the more tired the participants feel, the more they move during the music stimuli, compared to the silence sections.

2.1.2 Other Relevant Studies

Another significant study was conducted with relevance to the 2017 standstill competition. The primary aim of this study was to assess the level of micro-motions to different features of the music-stimuli (Gonzalez-Sanchez, Zelechowska, & Jensenius, 2018). To experiment with different musical features, three types of music samples, which are EDM (Electronic Dance music), Classical Indian music, and Norwegian folk music were used during the competition. According to the results, the taller participants tend to move more during the session. And keeping the knees unlocked tends to reduce the amount of motion. From the three types of Music samples, only EDM tends to impact the participants' QoM values more significantly and which corresponds to higher movement. (Increased the QoM value by 0.65mm/s). The finding from the experiment reveals that the musical features like the pulse clarity and higher tempo of EDM music seem to have a higher impact on the involuntary micro-motions during standing still. Also, the study suggests that the anticipatory vertical motions that are found for all three types of music stimuli are an outcome based on how participants trying to embody bright sounding instruments as vertical motions.

The result from another observational study shows that the standing still was mostly stable when eyes were open and standing still with locked knees (Jensenius, Bjerkestrand, & Johnson, 2014). As mentioned in the study, standing with open knees can be useful for exploring micromovements, and locking knees can also be explored in a performance aspect of standing still. However, applying different mental strategies does not seem to affect the level of standing still. Having a marker on the head provides noisier data compared to having a marker on the neck.

2.1.3 SVERM Project

A result of a pilot study that was based on analyzing micromovements shows the artistic possibilities of using micromotion in a performance context (Jensenius & Bjerkestrand, 2011). Some observational methods have been carried out to capture several recordings of standing still with different physical and mental strategies. The experiment also included testing room placements, visual strategies (eyes open, close), listening strategies (music, silence, active listening ,and passive listening)(Jensenius, 2015). The study reveals that there is continuous movement in the “micro” temporal level of motion. And in the “meso” level, the spikes that are prominent in every 5 second periods, can be aligned with the breathing patterns of the participants. The patterns were more specific to each participant (Jensenius, 2015). the statistical data reveals that an interesting pattern can be seen in the meso level when the participants raise or lower shoulders due to tension and/ fatigue. This is an interesting feature to experiment in a live performance. Also, at the macro level, there were noticeable spikes for every 2-3 minutes which are assumed to occur due to slight postural adjustments of participants due to standing for a longer period. This observational study in the “sverm” project lead to an understanding of controlling “voluntary” and “involuntary” motion which helped later in the performance sessions.

A follow-up study named *“Sverm2”* reveals that the experience of standing still is also can be affected by the participant’s location inside the room (Jensenius, 2017). Even when the eyes are closed, a significant difference in the experience was noticed due to the acoustic properties in the room. The observations suggest that some other physical strategies to gain more stability will be, placing the feet in shoulder width, facing forward, and letting the arms hang down straight during standing still.

2.2 Data Sonification

Sonification is a method of listening to data. As opposed to data visualization, in sonification data is converted into sound. When the data comes from scientific experimentation, the sonification is emphasizing "scientific sonification"(Kaper, Wiebel, & Tipei, 1999). In this section, I would like to mention some of the definitions for sonification to generalize an idea about what is sonification. Kramer et al. (2010) emphasize the point of specifically using non-speech audio with sonification.

"Sonification is defined as *the use of nonspeech audio to convey information. More specifically, sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation"* (Kramer et al., 2010, p. 4)

By taking away the restriction for speech and taking data and data relations separately, Worrall, Tan, and Vanderdonckt (2019) describes data sonification as,

> Data sonification is the acoustic representation of informational data for relational non-linguistic interpretation by listeners, in order that they might increase their knowledge of the source from which the data was acquired.(p. 25)

He further explains that the data sonification is not really about sonifying the data relations, but the data itself and data relations are different abstractions from the data. As Hermann (2008) describes, sonification includes a sonification algorithm that translates the data features into sound, and he employs a scientific approach for defining sonification.

> A technique that uses data as input and generates sound signals (eventually in response to optional additional excitation or triggering) may be called sonification, if and only if (C1) The sound reflects objective properties or relations in the input data. (C2) The transformation is systematic. This means that there is a precise definition provided of how the data (and optional interactions) cause the sound to change. (C3) The sonification is reproducible: given the same data and identical interactions (or triggers) the resulting sound has to be structurally identical. (C4) The system can intentionally be used with different data, and also be used in repetition with the same data.(Hermann, 2008, p. 2).

2.2.1 Why Sonification?

Visualization of data can be considered as the most common and widely used technique for data exploration. Using dimensionality reduction provides the ability to explore patterns in complex, high dimensional data structures. These data transformation techniques deliver the capability of detecting very subtle patterns through visual detection. Using the sound to explore data is less widely used in data mining may be due to the difficulties in communication about the sound than visual patterns (Hermann & Ritter, 1999). The Stethoscope is a great example of a tool that allows detecting subtle patterns in a sound through listening (Hermann & Ritter, 1999).

As Hermann and Ritter (1999) further suggest, sonification is a good method for rapid screening methods since an auditory stream can be understood with less effort and a higher capability can be achieved when combined with visualization techniques. Also, Herman admits the importance of using ear training in the field of sonification to enhance the analytical capabilities and interpretation of the data. However, sonification will not be suited for all kind of data exploration, but certain kinds of data will provide higher success compared to using other data exploration techniques.

In this research, data exploration is mainly focused through utilizing sonification methods by mapping data into sound parameters. Through sonification, it is possible to make judgments on a category of data, a relative size of a data value, or a specific value of the data, and these fall into nominal, quantitative or qualitative data representations (Nasir & Roberts, 2007).

2.2.2 Auditory Display

A good example of an auditory display would be the Electrocardiogram (ECG) machine which monitors the heart rate and produce the pulsing sound based on the heart rate. The electrodes attached to the body detects the electric activity produced by the heart muscles. The machine is producing a sound based on the increasing and decreasing levels of electricity and facilitates monitoring patient's heart rate. Any irregularity of the heart rate can be identified from the sound pattern. Another example would be the Geiger Counter that produces a clicking sound based on the amount of radiation emitting from an object. A Geiger counter can move around as a navigational auditory display (Brazil & Fernström, 2011b). Auditory displays are useful as an alternative support for visual monitoring (Kramer et al., 2010). Kramer (2010) further suggests that the auditory displays are useful as alarms when there are multiple visual attention has to be made in a situation.

According to the description from Walker and Nees (2011),

"Auditory display can be broadly defined as any display that uses sound to communicate information. Sonifications are a subtype of auditory displays that use nonspeech audio to represent information" (Walker & Nees, 2011, p. 1)

According to Walker and Nees (2011), Auditory displays can be mainly categorized into four types based on functionality. Which are,

- Alarms/alerts/warnings.
- Status, process, and monitoring messages.
- Data exploration.
- Art, entertainment, sports, and exercise applications.

Alerts and warnings indicate an event that happened and don't convey a lot of information about the event. Status and progress monitoring applications reveals more information based on the human's ability to identify small changes in the auditory event (Walker & Nees, 2011). On the other hand, data exploration is providing a much more general idea of the data rather than occurring events. As Walker and Nees (2011) points out about data exploration, "These are what is generally meant by the term "sonification" and are usually intended to encode and convey information about an entire data set or relevant aspects of the data set" (Walker & Nees, 2011, p. 5).

In Art and entertainment, sonification is used to express the data with a musical approach rather than trying to convey information like in the other three approaches. Auditory displays are further categorized based on their interactivity level with the user. Sonification approaches with non-interactivity with the display are in "concert mode" while the interactive displays are in "conversation mode" (Walker & Nees, 2011, p. 6).

Data exploration is one of the tasks that can involve either getting a general idea of the data or reaching for an analytical approach (Walker & Nees, 2011). Data exploration can be applied for many applications and one of them is point estimation and point comparison. This is a similar approach of point estimation using graphs but with sounds. The user listens to the sonification and then based on the pitch of the sound, the user determines the represented size, and compares it with a base value to finalize the estimated point(Walker & Nees, 2011). Another application is Trend identification. In this, the user is more considered in identifying overall patterns in the data set. And understanding data structures can be achieved with model-based sonification approaches. The data also can be explored without having prior questions to consider and sonification may reveal a pattern that is not visible through visualization methods(Walker & Nees, 2011).

2.3 Methods of Data Sonification

In this section, I will discuss some of the key concepts regarding data sonification, techniques, and approaches.

2.3.1 Audification

Audification is used to present a series of data points as an output of sound. Dombois and Eckel (2011) defines Audification as,

> Audification is a technique of making sense of data by interpreting any kind of one-dimensional signal (or of a two-dimensional signal-like data set) as amplitude over time and playing it back on a loudspeaker for the purpose of listening.(Hermann, Hunt, & Neuhoff, 2011, p. 301)

It is a method of directly translating data into sound. Data that has equally spaced metric in one dimension can be used for Audification and it is a useful tool with larger datasets where the dataset is arranged in a time series form (Worrall et al., 2019). When visually represented, data that appear as a waveform shape can be used for Audification. As an example, the signal values from an ECG data can be translated to amplitude values for a loudspeaker. By this transformation, certain patterns can be revealed which were not recognized before. In the audio playback, any number of audio processing techniques such as filtering, compression, pitch-shifting can be applied for improvements of the information extraction (Worrall et al., 2019). Another benefit of using audification is the ability to explore a larger quantity of data which is difficult to achieve with visualization techniques. Also, it provides the ability to analyze huge datasets spending less time (Worrall et al., 2019).

Dombois and Eckel (2011) describes four types of data that can be used in Audification: sound recording data, general acoustical data, Physical data, and Abstract data

- ***Sound Recording*** – sonifying signal data of a sound recording can reveal unnoticed aspects of the original sound. sound recordings that contain frequency content which is beyond the human listening range can transform into audible range using audification.

- ***General Acoustic data*** – data that has the same characteristics of acoustical sound waves can be used. As an example, Stethoscope, use Mechanical waves of vibrations as direct audification.

- ***Physical data*** – data of physical processes that do not fall under the mechanical domain. As an example, using the audification of voltage fluctuation data in EEG introduce a different perspective of interpreting the data which not a familiar experience.

- ***Abstract data*** – Data that has a non-physical form such as stock market data or the sound of a fax machine. Abstract data may or may not satisfy the wave equation and interpretation can be difficult due to its unfamiliarity.

Moreover, as Dombois and Eckel (2011) describe, Audification process can be defined into three stages.

- ***Data Acquisition***

For the audification technique, the data set is required to have the potential to be transformed into a signal (Dombois & Eckel, 2011). Since all input and output are considered signals, there are important factors to consider in the sampling process of signals. When converting analog signals to a digital signal, the sampling rate should be greater than twice the bandwidth of the input signal to get rid of the "aliasing" artifact. Signal to noise ratio is another important factor that contributes to the headroom of the signal. If clipping occurs, there will be data in the digital signal which does not correspond to the analog signal. This can be eliminated by having a larger headroom for the signal.

- ***Signal Conditioning***

Dombois and Eckel (2011) describe several approaches to consider in signal conditioning.

- Using no conditioning – In a case where the audio sample rate is higher than the data rate, audification can be done without using any conditioning.
- Using re-sampling.
- Filtering the signal to eliminate unwanted signals and using bandpass filtering to reduce masking.
- Applying dynamic compression to minimize the difference between very loud and very soft signal levels.
- Using other special tools such as time-reversal techniques, gates, noise reduction tools, frequency shifters, and reverbs.

- Using advanced spectral tools such as phase vocoders for time stretching audio without pitch changes

- ***Sound Projection***

This stage involves mapping the above-mentioned signal to the spatial domain (Dombois & Eckel, 2011). When there are multiple signals, each signal can be mapped into separate speakers. Also, spatial audio rendering can be introduced to translate the sound into binaural streams and speaker systems.

As Dombois and Eckel (2011) further describe, The dataset should contain a large number of data points (minimum few thousands of samples should include) and should be represented as a time series. The audification can be more successful if the data is coming from a physical source and has a round shape – wave-shaped signals. Moreover, this is a useful approach to work with noisy data where slow changes in data characteristics can be much easily recognized. Audification is useful when working with multiple signals simultaneously and can reveal about the synchronicity of patterns in multiple signals. This is a useful technique for data screening which provides a quick overview of the characteristics of the data set.

2.3.2 Auditory Icons

Auditory icons are comparable to graphical icons and they are sounds that we find in our day to day life. But the meaning of the sound has to be learned as the sounds are metaphorically related to our everyday actions (Brazil & Fernström, 2011a). An example would be the "Sonic Finder" which came as an application of Apple's Macintosh computers. When the user is performing an event like emptying the trash folder, a sound would be generated similar to crunching a paper. Similarly, when certain items are copied to a folder, a varying pitched sound will indicate the amount that completed. Auditory icons can be categorized based on sounding objects as "fully formed objects" or "evolutionary objects" (Brazil & Fernström, 2011a). In fully formed objects the sound is played from start to end as the event occurs. As Brazil and Fernström (2011a) points out,

> The hitting action creates a sound, but you have no control of this sound after the hitting action whilst in the case of the filling action you can change the rate of pouring continuously. This separation can be in terms of a discrete sound versus a continuous sound.(Hermann et al., 2011, p. 332)

A challenge would be to use the proper sounds for the auditory icons since they need to be easily understood. Certain sound can be misleading and provide a different meaning to the event, As an example, the sound of frying can be misinterpreted as the sound of rain or vice versa(Brazil & Fernström, 2011a).

Mynatt (1994) describes several factors that affect the design and usability of Auditory Icons. These factors are based on how much the user can recognize the sound, How well the sound mapping is complementing the user interface of the auditory Icon, The physical parameters of the sound relates to the quality of sound and how the sound can make the user emotionally attach to the user interface (Mynatt, 1994). Moreover, a methodology has been proposed by Mynatt (1994) on the designing of auditory icons.

2.3.3 Earcons

Earcons are different from Auditory Icons because there are no meaningful relationships between the sounds and the signified meaning. Earcons can be categorized as four types which are one element Earcons, Compound Earcons, Transformational Earcons, Hierarchical Earcons. According to McGookin and Brewster (2011), One Element Earcons are used to represent information with a single parameter, similar to notification sounds in a mobile phone. Compound Earcons are a combination of multiple One Element Earcons that represent a message. Transformational Earcons are based on a set of rules on how elements can be mixed up to represent a certain message. An example would be representing information in Theme park rides combining the ride type, ride intensity, and ride cost (McGookin & Brewster, 2011). Hierarchical Earcons are similar to Transformational Earcons but are set up in a tree of nodes where each node inherits properties from the node above it (McGookin & Brewster, 2011).

2.3.4 Parameter Mapping Sonification

In parameter mapping sonification, the data information is mapped with sound parameters. This is achieved by mapping data features into physical sound parameters such as frequency, amplitude, psychophysical parameters like pitch, loudness, or parameters of perceptual coherence (timber, rhythm)(Worrall et al., 2019). The parameter mapping can afford to listen to multiple data categories at the same time and the mapping can be changed easily according to experimentation (Worrall et al., 2019). In Audification the data streams are directly mapped to the sound parameters while parameter mapping provides the flexibility to choose the potential data features as inputs for the mapping function. (Worrall et al., 2019).

The data can be categorized based on their features and can be divided as continuous or discrete data. A dense continuous data stream based on the time dimension can produce smooth sound streams since it has the characteristics of analog continuity (Grond & Berger, 2011). As Grond and Berger (2011) further describes, The designing of a parameter mapping sonification should involve careful interchange between data features and sound synthesis, which requires active thinking, tuning, and listening.

Grond and Berger (2011) point out that the data preparation level can include dimensionality reduction of the data set. This provides much efficiency for sound parameter mapping while reducing noise and distortion in data streams results in separating the information from the noise. As a result, the correlations between multiple data channels will be available more clearly for the sonification.

- **Calculating Derivatives**

In the preparation, data can be transformed into other types such as derivates. Derivatives can be express movements or posture changes in the data channels (Grond & Berger, 2011).

- **Extracting events**

Also, events such as maxima, tuning points, zero crossings, and intersections of data channels can be extracted for either continuous or discrete data (Grond & Berger, 2011).

- **Mapping data to Sound parameters**

The mapping function is the primary basis of the parameter mapping sonification which connects the data channels and the sound synthesis parameters to understand the structures of the data (Grond & Berger, 2011)Also in some cases, the mapping function can be linear, exponential, sigmoid or step functions (Grond & Berger, 2011).

Mapping can be identified as the process of connecting data elements to sound synthesis parameters. Four types of mapping are mentioned by Grond and Berger (2011).

- *One-to-one mapping*
  In one to one mapping, only one data feature is mapped with only one sound synthesis parameter. This mapping is only valid for the parameters in the signal domain (frequency, gain, time, etc.) and not for perceptual sound parameters (brightness, timbre, loudness, etc.) since perceptual is not an independent domain (Grond & Berger, 2011).

- *One-to-many mapping*
  In this, one data feature is mapped to many synthesis parameters. The combination of all the sound parameters can produce a differentiable sound stream although the range of each sound parameter can be kept small (Grond & Berger, 2011).

- *Many-to-one mapping*
  In many-to-one mapping, multiple data features are mapped to one sound parameter. This type of convergent mappings is used in gesture control music interfaces to improve the expressiveness of the instrument. The use of many-to-one mappings in sonification is less regarded since expressivity is mostly considered in performance while sonification is prioritized in finding the relationships in a data set (Grond & Berger, 2011).

- *Many-to-many mapping*
  It is a method of mapping multiple input data features to many sound parameters. This can be identified as a step further from the many-to-one mapping. This kind of mapping can is suitable for exploring expressivity.

The designing process of a parameter mapping sonification involves connecting the data features with sound synthesis. As further described by Grond and Berger (2011), sound synthesis can be divided into three main sections which are parameter domain, signal domain, and perceptual domain. The parameter domain focuses on the mapping topologies, the mapping functions (linear, exponential, etc.), and the signal domain consists of parameters such as frequency, gain, spectrum, time/duration, and envelope. The perceptual domain can be divided further into two categories as sound objects and auditory scenes. The sound object includes characteristics of the sounds as pitch, timbre, loudness, brightness, and roughness. The Auditory scene is considering the perceptual effects such as masking, segregation, fusion, localization. Parameter mapping sonification allows the designer to address challenges of

Masking, stream fusion, and segregation individually which is not a possibility in audification (Grond & Berger, 2011). Grond and Berger (2011) point out some of the key elements to be considered in parameter mapping sonification.

- *Polarity*
  Polarity describes the direction of the sound parameter to the direction of the data sequence movement. An increasing number pattern can be mapped into an increasing or decreasing sequence of the sound parameter values. This is largely depending on the problem and how inverted polarity can be suited to best describe the relationship of the data.

- *Scale*
  The range of the data values may be unsuitable to be mapped for frequencies and therefore, the data should be scaled appropriately to efficiently represent the data as sound.

- *Context*
  Providing an auditory reference point is important in parameter mapping sonification as it can be beneficial in adding information as instructions for the user.

One or more attributes in the signal domain have a contribution to the parameters of the perceptual domain. As an example, the perceived loudness is subjective from person to person and depends on the frequency content and the amplitude of a sound (Kaper et al., 1999). In a parameter sonification design, attention is required to eliminate or minimize the auditory masking which occurs due to the relativity between sound parameters (Grond & Berger, 2011). Another factor is the aesthetics of sound. According to a study on investigating how the naturalness of a sonic feedback affects the perceived usability and pleasantness of a human-computer interface, the subjects has indicated that the natural sounds are more pleasant and useful than non-natural sounds (Susini, Misdariis, Lemaitre, & Houix, 2012).In a study, Vickers and Hogg (2013) differentiate between musical and non-musical sonification. The study points out that the use of musical sounds tends to engage the listener more actively in listening and aesthetically pleasant sounds will reduce fatigue and annoyance (Vickers & Hogg, 2013).

Another approach of using sound for data exploration is by Model-Based Sonification.

2.3.5 Model Based Sonification

As Worrall (2011) points Out, "Model-based sonification allows one to create virtual data instruments, which can then be investigated to reveal information about the dataset by the nature of the sounds produced in response a user's interaction with the model" (p. 42).

The parameter mapping sonification is well suited for data with higher degrees of dimensions but still has some limitations (Hermann & Ritter, 1999). As Hermann and Ritter (1999) further describe, the model-based sonification can overcome the limitations such as lack of unique mapping, Limited dimensionality, Invariance to data, Some parameters are not independent. In model-based sonification, virtual objects are made based on the data and the users interact with these objects as interacting in real-world objects but inside a virtual environment. Similarly in real objects, these virtual data objects can be beaten, shaken, touched, or squeezed by the users (Hermann & Ritter, 1999). As Hermann et al. (2011) further describe, if the data is in a time series, the most suitable approach will be to use audification or parameter mapping sonification and Model-Based Sonification is very rarely used for time-indexed data. In parameter mapping sonification the interpretation of sound requires the knowledge of mapping while model-based sonification offers the capability of using everyday listening skills (Hermann et al., 2011). As Hermann and Ritter (2005)point out, the main difference between parameter mapping and Model-Based Sonification is that the MBS allows bypassing the complex mapping by a generic use of the data.

According to Hermann et al. (2011), there are several differences between parameter mapping and Model-based sonification. Model-based sonification can produce a sound that has far more complexity and richness compared to the sounds produced from the parameter mapping methods. Also, model-based sonification can be unitized with fewer parameters while parameter mapping methods require complex mapping conditions.

2.3.6 Sonification Methods Used in “Sverm”

“Sverm3” was the final part of the initial “sverm” project, which was an experiment on using micromotion to produce sound, and to initiate a dance/music performance (Jensenius, 2017). The sonification process of “sverm” performance had mainly two concepts. The first method knows as “waving sines” is done by mapping a sine tone to the vertical position of the participant. The QoM was mapped inversely where the amplitude of the sound gets higher when the participant reaches stillness. The result created interesting beating patterns based on the micromotions(Jensenius, 2015). In a pilot study, a similar mapping was used with noise. And this has created an interesting feature of tension as the performer approached stillness (Jensenius & Bjerkestrand, 2011). Also, this pilot study reveals that mapping of sine tone with vertical movement produced the breathing and heartbeat patterns that could recognize easily.

The second method was called “granulated violin”, which was controlling parameters of a granulator by the position of the performer. The initial idea was to play the sound of a violin from movements. The vertical position of the performer controlled the playback position of the violin sample, while the position in the horizontal plane was controlling the grain size and the distance of the granular effect. This approach allowed the performer to directly control the sound in subtle ways with micromovements (Jensenius & Bjerkestrand, 2011).

2.4 Using Spatial Audio

Spatial exploration can be utilized with parameter mapping sonification techniques. It can be used in the data exploration of spatial domains because of the human capability of identifying a sound source and its location based on the temporal, spectral and amplitude indications (Grond & Berger, 2011). In a study conducted by Zhao, Plaisant, Shneiderman, and Duraiswami (2004) suggest four principles that can be useful in parameter mapping sonification for spatial exploration. The study was based on a sonification method for identifying geographical data distribution patterns and it suggests the Auditory Information Seeking Principle (AISP) as follows:

- *Gist*: Gist is a short sound that represents the overall trends or patterns in the data set.

- *Navigate*: In navigation, the user goes through the data set quickly and be able to listen to selected sections of the data.

- *Filter*: Filtering out unwanted data will reduce the size of the large data sets and will provide the user to quickly navigate in interesting portions of the data.

- *Details on demand*: The user can select groups or items of data and get details.

The spatial information consists of positional information in three-dimensional space. The position can be a location in the physical world or a location in a virtual space and the sound also contains spatial elements where a location of a sound source can be identified with the human capabilities (Nasir & Roberts, 2007).

"There is obviously a synergy between spatial data and sonification." (Nasir & Roberts, 2007, p. 1).

As Nasir and Roberts (2007) suggest, it is a difficult task to map spatial data into sound because of several reasons. The visualization of the spatial data seems to more accurate than with sonification.

> Spatial data is positioned on an x,y grid and may be accurately located and hence comprehended. While in sonification, although sound may be spatial, it is not inherent how to map the information, and the perception of the information is less precise. For instance, although sound may be mapped to a position in the azimuth plane, users are unable to accurately locate the position of the sound source as accurately as they could locate the information in an equivalent graphical visualization. (Nasir & Roberts, 2007, p. 1)

The localization can be used as an enhancement of the sonification or as a way of representing quantitative data. Nasir and Roberts (2007) describe several methods of using localization of the sound. I will like to discuss the methods briefly.

- ***Interaural Time Difference (ITD)***
  Interaural Time Difference is based on the difference in time of arrival of sound between the two ears. This provides the information on the directionality of a sound source based on the angle. There are applications of using ITD as stereo effects where the user was enabled in identifying groupings of data based on the location of the sounds.

- ***Interaural Intensity Difference (IID)***
  This describes the level or loudness of the sound can be higher in one ear than the other because of a person's head works as an obstacle for the sound. Nasir and Roberts (2007)points out that no evidence of work that has only used IID for mappings.

- ***Combination of Interaural Time Difference (ITD) and Interaural Intensity Difference (IID)***
  A combination of ITD and IID can be used to introduce sounds with elevation in the azimuth plane

- ***Doppler effect***
  Using the doppler effect can be utilized to introduce the perception of any source is moving closer or moving away from the observer.

2.5 Applications of Sonification

One of the projects on using spatial sound in sonification was done by Polli (2004), for sonifying a storm condition in which the data was created by a sophisticated and accurate model of a weather system (Polli, 2004). As Polli (2004) suggests, the purpose of sonification was to reveal aspects of the data that are not described by visual representation (Such as atmospheric pressure and temperature information). The complete model included storm activity in 5 elevated positions and data of 10 km area. Six out of nine variables were used in the sonification which is atmospheric pressure, water vapor, relative humidity, dew point, temperature, and total wind speed. Some interesting mapping strategies have experimented with the sonification. First, each variable was directly mapped to the pitch of different timbres of sound based on the type of the variable. Variables related to temperature and pressure were mapped with long tones while water-related variables were mapped with short percussive sounds. Then the wind speed was directly mapped with the amplitude of the sound which generated a strong spatialization effect. As Polli (2004) points out, by mapping the atmospheric pressure data with a low-frequency sound, the listeners experienced a direct sense of the storm. Another prominent approach was using filtering for the sound samples that are mapped with variables. A band-pass filter was mapped to dew point values which controlled the sound that represents the temperature. And similarly, water vapor values were filtered by the humidity variable. Polli (2004) points out an interesting decision about using noises for filtering:

> We found at this point that we needed to choose sounds with a wide spectrum in order to hear the filtering most effectively. White noise has the widest spectrum and selecting 'noisy' sound samples proved the most effective in communicating the data and also was the most effective aesthetically due to the variation in the resulting sounds (Polli, 2004, p. 4).

Polli (2004) points out that using a global scaling for certain parameters were creating a less effect since the storm data consists of multiple levels and the variables had large differences in values between each level of elevation of the storm.

Moreover, sonification is widely used in data mining and to navigate through data. Data mining methods involve extracting useful information from large datasets. As Brazil and Fernström (2011b) points out, data mining has two phases: Exploratory data analysis and Confirmatory data analysis. The purpose of the exploratory data analysis is to detect patterns of the data and auditory displays can be used as an alternative approach for visual analysis.

> Using an auditory display is one suitable method for data mining EDA as it allows listeners to interpret sonifications or audifications to improve their understanding of a data space as well as for pattern detection (Hermann et al., 2011, p. 515)

Sonification was widely used for studying stock market data in the past years and experimentations were done to test interesting mapping strategies. Kramer (1991) applied audification for the weekly closing price of a commodity futures index, a government T-bond index, the US federal funds interest rates, and the value of the US dollar. The data features are mapped to pitch, amplitude and frequency modulation, filtering (brightness) and envelop control (attack time). Brewster and Murray (2000) developed a method of listening to share prices. The price data values were mapped with the pitch using midi note numbers and the participants were monitored while they do trades by using graphical graphs and with sound graphs. The results indicate that there was no difference between the two approaches and participants have mentioned a reduction in the workload (Brewster & Murray, 2000). Janata and Childs (2004) introduced another method of applying sonification to real-time financial data. Through sonification, price movements of the market have been studied and compared between visualization and sonification. Two types of experiments were conducted and Janata and Childs (2004) indicate a great accuracy was obtained by using the auditory display.

Moreover, Worrall et al. (2019) describes another sonification experiment on studying the perceptual flow of trades in a day. The data consisted of time-sequenced trading data of a mid-sized market. As Worrall et al. (2019)point out, lower-valued trades occur more frequently than the higher value trades at a given moment. This finding led to using an inverse relationship between the frequency of the sound and the value of the total trading in a moment. Also, to gain the perceptual balance, the duration of the sound and frequency was inversely mapped.

> Similarly, there appears to be an inverse relationship between the duration of an event type and it's approximate frequency (of occurrence). When compared to smaller events, larger events in the same domain occur less often and last for a longer period of time than smaller ones: the snap of a twig is more frequent and shorter than the crash of a tree, the scurry of mice more frequent than a stampede of elephants etc. So, when sonifying larger $valued trades at lower frequencies, it is necessary to increase their relative duration, comparatively, in order to provide perceptual balance(Worrall et al., 2019, p. 240)

Apart from Financial Analysis, Sonification has been used as a method of navigating through medical data. In one of the studies, Electromyographic (EMG) data were studied by using sonification, where 6 EMG sensors were mapped to the amplitude of individual sine oscillators (Hunt & Pauletto, 2006). The sounds that produced are complex but easily understandable compared to visually monitoring the EMG data.

Moreover, Electroencephalogram (EEG) data contains complex temporal and rhythmic patterns of data which indicated the brain activity (Brazil & Fernström, 2011b). By using sonification, it is possible to identify epileptic seizure conditions where these spatiotemporal brain activities start to show an ordered rhythmic pattern. In this scenario, the sonification can be used for the onset detection of these rhythmic patterns, identifying outliers and pitched patterns of the data(Brazil & Fernström, 2011b).

Barrett (2016) experimented on the possibilities of using spatial audio with sonification for multi-dimensional data exploration, and introduced an application called “Cheddar”. Cheddar was implemented using *Max/MSP* and possible to apply sonification for six variables at one time. With Cheddar, the users can define a mapping for the sonification of three spatial variables, two user-defined variables with any type, and one time-stamped variable that is in any data range. The data can be input from a data file or a data stream of an external data source. This includes filtering data based on high, low or bandpass values of data and automatically identifying data ranges and updating. In the sound section in Cheddar, the user can choose pre-sampled sounds or to use their sounds. Additionally, the sound section consists of test signals including sine wave, saw-tooth wave, and noise. And also a granular approach was implemented where a data point can be used to trigger a section of sound, and Cheddar has a grain transformation section that can control grain parameters: Attack and decay amplitude envelope, Duration, Pitch transposition, Volume, Band-pass filter center frequency (for noise inputs), Attack enhancement Equal-loudness compensation. In the mapping, any of the data variable can be mapped to pitch transposition, signal frequency or band filtering, volume, sound grain duration, attack and release duration. The functioning of pitch transposition in Cheddar is implemented with changing the playback speed of a sound. One-to-one mappings and one-to-many mapping were used in Cheddar. Barrett (2016) describes that using one-to-one mapping affect the perceptual characteristics of the sound since perceptual parameters are interrelated and using one-to-many mapping is a better approach. Cheddar also uses one-to-many mapping. “The reason here is to avoid the possibility that users may mistakenly map data to transformations that conflict perceptually”(Barrett, 2016, p. 63).

Higher-order Ambisonics is used for the spatialization in Cheddar, which was implemented using the spat objects from the IRCAM spat library (Barrett, 2016). Barrett (2016) further points out that mapping velocity or acceleration to pitch and amplitude is a better method for sonifying the change of speed rather than using a doppler effect. One-to-many mapping is used in the spatial mapping in Cheddar. Barrett (2016) emphasizes that it is an integral part of Cheddar.

> One data parameter controls spatial location, whereas distance-relative amplitude attenuation, the ratio between direct and reverberant signal, and air absorption (which has been reintroduced in the latest version) are automatically calculated with respect to the distance of the point from the listening location (Barrett, 2016, p. 63).

Also mapping non-temporal data into non-spatial sound is possible in Cheddar and incorporates one-to-many mapping where one data parameter can control the grain duration, scan point, attack duration, attack enhancement, and relative volume. Cheddar is powerfully utilizing the higher order ambisonics, which provides the capability of using the application as a scientific tool for exploration or on the other hand, as an approach for artistically expressing the data.

“Users’ goals and their personal choices, rather than necessarily the sonification approach, liberates the output to wander back and forth between scientific and artistic domains” (Barrett, 2016, p. 67).

Using spatial audio for representing quantitative, qualitative and categorical data through an audible pie chart was experimented by Franklin and Roberts (2003). They introduced five design aspects for a pie chart representation using sonification. Using the positioning of a sound source can be useful in presenting navigational information. However, it has the limitation of determining the position accurately because of the Minimum Audible Angle (MAA)(Franklin & Roberts, 2003). MAA is the smallest angle between sound sources where the listener can notice the direction. Four of the design patterns consider the MAA and sound spatialization where the fifth design was inspired by the Morse Code. And they used short and long beeps to represent percentage values of each part of a pie chart.(Franklin & Roberts, 2003).

2.6 Tools for Sonification

In this section, I would like to briefly discuss some of the available tools for sonification. Walker and Cothran (2003) introduced the *"sonification sandbox"* which is an application that can be used to map multiple data parameters with sound, using a graphical interface. The data can be imported as a CSV file and the individual data sets can be mapped to pitch, timbre, volume, and pan parameters. Some tools have been made to cater for specific tasks such as exploring scientific data. *"xSonify"* is such an application that can apply sonification for space physics data (Candey, Schertenleib, & Diaz Merced, 2006). It is capable of sonifying one-dimensional data with three modes (pitch, loudness, and rhythm) and several control options: play, stop, loop, speed change, time points.

On the other hand, certain data exploration tasks require the applications to specifically address the requirements of the sonification and using pre-built applications might not provide enough dynamic control over the design (Worrall, 2011). *Supercollider*[4] and *Csound*[5] are some of the widely used programming languages which are used for building sonification applications. Vowel based synthesis modules for sonification were built by Grond, Bovermann, and Hermann (2011) from using the *Supercollider,* where it provided the required flexibility in sound design.

> In order to fully explore the sound design flexibility we chose to implement it in SC, because many of the requirements mentioned above can only be met if the sound synthesis can be flexibly scripted through a text based programming language (Grond et al., 2011, p. 2)

"SonEnvir" is another sonification environment where the prototype was built using *Supercollider* and *PureData* (de Campo, Frauenberger, & Höldrich, 2004). As de Campo et al. (2004) points out, *Supercollider* and *PureData*[6] provide a rich audio synthesis and processing libraries and pre-built objects that can be used. Moreover, Worrall et al. (2019) describe a sonification framework which is built upon *Python*[7] programming language where

[4] https://supercollider.github.io/
[5] https://csound.com/
[6] https://puredata.info/
[7] https://www.python.org/

its features that allow for a comprehensive sonification design. And *SoniPy*[8] is a set of Python-based modules that are specifically built for data sonification. As Worrall, Bylstra, Barrass, and Dean (2007) empasize,

> Instead of sonification researchers trying to make a decision about which particular piece of software to use for an experiment, based hopefully on a best-fit evaluation of existing software capabilities, SoniPy can afford a continuity a framework of both existing and developing of tools not currently available(Worrall et al., 2007, p. 7)

However, As emphasized by Grond et al. (2011), working with programming languages has a steeper learning curve but can fulfill the typical needs in a sound design task. On the other hand, *PureData* and *Max/MSP* provides an environment to experiment with different methods through a graphical user interface.These platforms provide a gentle learning curve for a researcher who is in the early stages of experimenting sonification. As Worrall et al. (2019) points out,

> Whilst the scripting-versus-GUI debate is still active, it is clear from the large user-base and active development of new Patch objects for these platforms that the GUI approach is appealing to some users, and perhaps offers a gentler initial learning curve for exploratory sonification researchers who are visually inclined (Worrall et al., 2019, p. 152)

2.7 Discussion

In this chapter, I have discussed the different sonification techniques that can be utilized for the sonification of standstill data. The data from the standstill competition is a continuous data stream that represents positional information of three-dimensional space. Most of the micro-motion of standing still occurs in the XY plane. Quantity of Motion is a key variable defined from the positional data which is a measurement of the level of motion. There is statistical evidence from the past studies that the music influences the level of motion during standing still.

One approach of Sonification is to use sound for exploring data sets and the skill of listening plays an important role in extracting meaningful information from data. Audification is suitable for time series data that represents a physical source and a useful technique to provide a quick overview of the data. Auditory Icons and Earcons can be identified as ways of notifying events based on the data input. These are more suitable for Alerts, status notifications, warnings, etc. However, the most common approach is parameter mapping sonification which provides a wide range of applicability for data exploration and analysis. Among several mapping strategies to map data features with sound parameters, One-to-one mapping and One-to-many mapping strategies are well suited for parameter mapping sonification in a data exploration context. However, it is important to consider the factors that contribute to the perceptual

[8] https://www.sonification.com.au/sonipy/index.html

domain of a sound. As an example, frequency and amplitude affect the subjective experience of the perceived loudness or brightness of a sound. The x, y, z Axes coordinates of a position can be used to introduce spatialization to sonification by mapping the position values to spatial attributes of a sound. On the other hand, Model -Based Sonification is mostly applicable for data that is not in a time series. MBS model utilizes the everyday listening skills where parameter mapping sonification requires to have a trained ear, and a clear understanding of the mapping. In parameter mapping sonification, having a trained ear and understanding of the mapping is essential to extract information from the "sonified" data. Examples of data sonification can be found in many research areas including financial markets and medical research. One of the successful sonification applications is "Cheddar" which utilizes both spatial and non-spatial data with effective mapping strategies. Applications for sonification can be built by using visual programming environments code-based programming languages. These approaches have their advantages and disadvantages based on the learning curve, data handling options, and customization.

Chapter 3

3 Design and Methods

This chapter presents a description of the sonification process that I applied for standstill competition data. I will present the data selection methods, the sonification strategy, and finally the results. As already discussed in the background section in Chapter 2, the sonification is applied for data from the 2012 standstill competition data. Initial idea was to build a prototype using the 2012 standstill data and use it for the exploring rest of the database including yearly data for the competition. According to Jensenius et al. (2017), around 100 participants were joined the study, and the final data set consists of 91 participants. The sessions were held in groups for about 5-17 participants at a time.

For making the sonification, I decided to use *the Max/MSP* environment. Due to the steeper learning curve, lack of coding experience, and limited time frame, using a programming language such as *"supercollider"* or *"Python"* felt like an unrealistic goal for this thesis. *Max/MSP* provides a great GUI based programming environment that has a much faster learning curve and also a large community of users which is helpful. Applications such as "Cheddar" prove that it is possible to design and implement a data sonification from a large number of data points using *Max/MSP* (Barrett, 2016). A list of video demonstrations for each implemented sonification model is available in Appendix A.

3.1 Data Set.

From the recorded data, two data sets were available to use for the sonification. The first data set consists of all the x, y, z position data for each participant, which is 273 columns and 35601 rows of data.

A	B	C	D	E	F
159.6	1845.6	1732.2	927.26	1928.8	1696.3
159.58	1845.5	1732.1	927.27	1928.8	1696.4
159.58	1845.3	1732.1	927.28	1928.8	1696.4
159.59	1845.2	1732.1	927.26	1928.7	1696.4
159.6	1845.1	1732.1	927.28	1928.7	1696.4
159.62	1845	1732.1	927.27	1928.7	1696.4
159.64	1844.8	1732.1	927.26	1928.7	1696.4
159.66	1844.8	1732.1	927.24	1928.7	1696.4
159.68	1844.7	1732.1	927.23	1928.8	1696.3
159.7	1844.6	1732.1	927.22	1928.8	1696.3
159.71	1844.6	1732.1	927.22	1928.8	1696.3
159.72	1844.5	1732.1	927.22	1928.8	1696.3

Figure 3.1: first 6 columns of the data set including the position data of first two participants.

The second data set is based on the demographic data of each participant and consists of quantitative and qualitative data. I like to mention the data variables that consist of the participant demographic data set. Which are the group each participant belongs(A, B, C, D, E, F, G, H, P), Participant number, Age, Sex, Height, Music listening hours per week, Music performing/production hours per week, Dance hours per week, Exercise hours per week. And some measurements were based on a Likert-Scale: Tiresome experience of the session (1 to 5), Experienced any motion (1 to 5), Experienced any motion during the music segment (1 to 5). Two other variables indicate if the participant had their eyes open/close or had locked knees/or not during the experiment.

3.2 Sonification Strategies

Considering all the available variables, there are several ways of categorizing the position data for exploration. To experiment on the main research question and sub-questions, the sonification is divided into three main sections. Which are,

1. Sonification of individual participant data.
2. Sonification of group average position data.
3. Using spatial sound with individual position data.

In each option, the first half of the data (3 min) represents the participants standing with silence and the second half (3 min) with the music stimuli. In that way, one of the aims was to experiment if the sonification can reveal information on how the music stimuli affect the motion during standing still. Another aspect was to explore how keeping the eyes open/closed or having locked knees can affect the motion. According to Jensenius et al. (2017), there was no statistical evidence that these factors affected the micro-motions. Minimum and maximum position values of each Axis x, y, z was calculated for each participant in *Excel* and these values were used for scaling the parameter values during the mapping process.

In the standstill experiment, data were recorded at a rate of 100hz and each session lasts for 6 minutes. Listening to the sonification faster than real-time can provide better insights on the patterns that occur in the data set and the first step was to implement a strategy to read the data from the CSV file and have the option to change the data reading speed.

To gain the maximum flexibility in the experimentation of the research questions, it was one of the main requirements to implement a flexible method to filer and sort data based on user preference. As an example, to select a group and get the average position data, to filter out the participants who kept their eyes open, etc. After experimenting with many methods, I decided to use *MUBU*[9] which is a toolbox that can use in *Max/MSP* for Advanced data processing and audio analysis. However, Unfortunately, due to the time constraints implementing a fully functional data structure is kept for future explorations. Figure 3.2 shows a snippet from the max patch which is used to read data from the CSV file. The *mubu.play* object outputs the data values as rows in the given sample rate. The *zl* object process list data and the *zl.nth* object is used to output data values for selected columns.

[9] https://forum.ircam.fr/projects/detail/mubu/

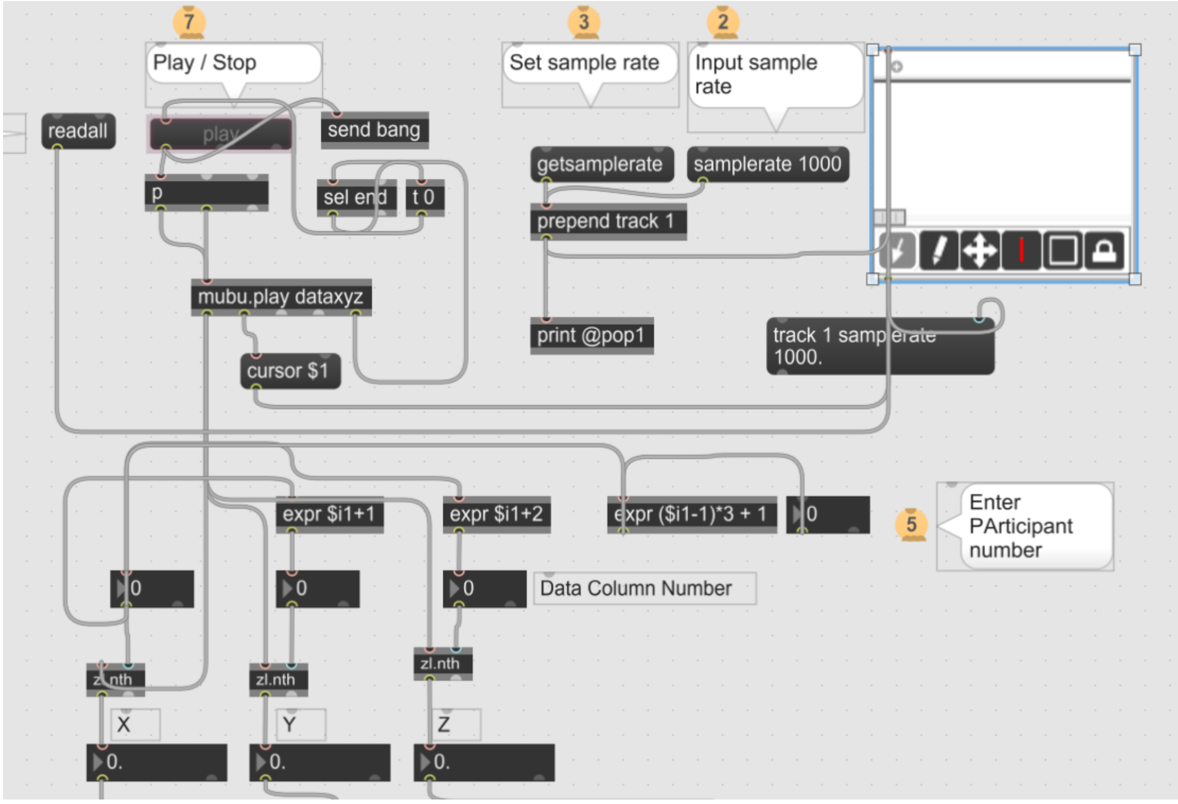

Figure 3.2: This section of the patch allows to read data from a .txt file and output x, y, z position values for a chosen participant

3.2.1 Displacement of Position

As described in Chapter 2, the QoM is a measurement of the sum of displacements from one point to the other. Instead of directly mapping the x, y, position data, a new variable is defined which is the displacement of the position. However, I'm not dividing the displacement of the position by the time factor to calculate the rate of change of the QoM since the rate of the displacement also depends on the chosen *sample rate* in the patch.
Figure 3.3 shows a part of the patch which calculates the change of the position (displacement). First, the displacement of position is calculated for each axis of data. In each moment, the previous position value is subtracted from the current position value and the absolute value is calculated. By using this value, the displacement can be derived for each plane (XY, YZ, XZ) by pairing the sums of individual position displacements for each x, y and z Axes. According to the results of the study by Jensenius et al. (2017), most motion is happening in the XY plane, and in the sonification, primarily the displacement of the XY plane is considered.

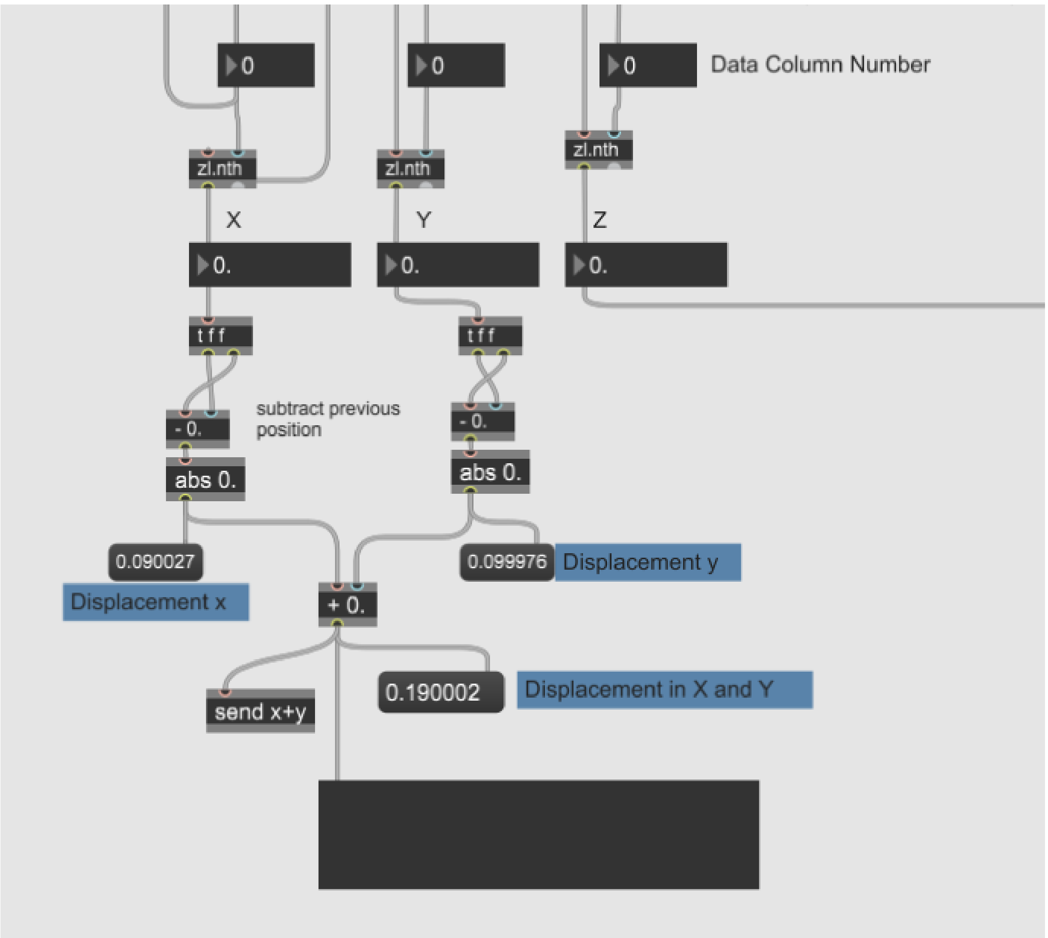

Figure 3.3: This section of the patch calculates the displacment of the position values for x, y axis sperately and then added together to calculate the total dispalcement in the xy plane.

3.2.2 Mapping

The data output can be considered as a continuous data stream and the parameter mapping sonification method is chosen for the sonification. For mapping, one-to-one mapping and one-to-many mapping methods were used. Many-to-one mapping or Many-to-many mapping is mostly suitable for enhancement of expressivity in instrument building and performance context (Hermann et al., 2011).

Simply a white-noise and sine tone was chosen for sound generation. As shown in figure 3, the user can select between the noise and the sine tone. White noise consists of the total frequency spectrum and suits for applying a filter control. Polli (2004) has used a similar approach in a previous study of a weather model sonification.

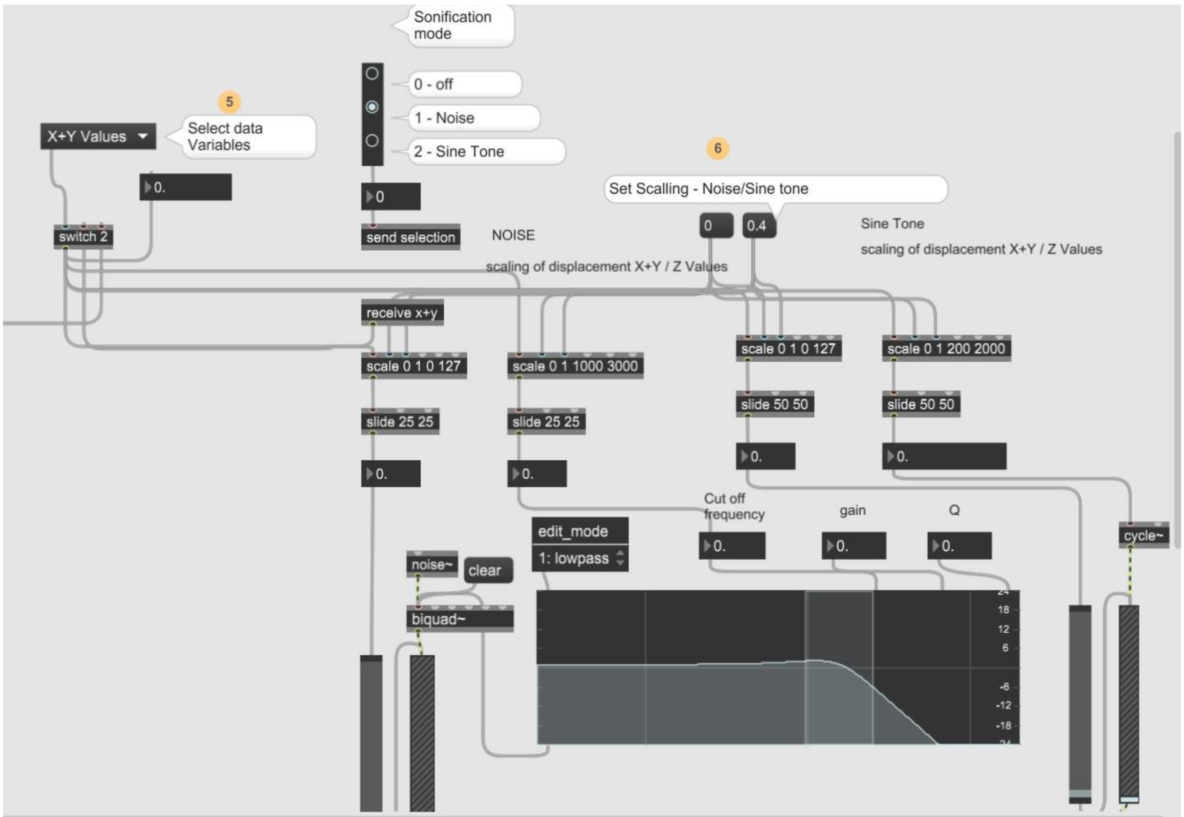

Figure 3.4: The user can choose between the data variables by selecting the z-axis or x+y values and can be mapped to a parameters of white noise or a sine tone.

3.2.3 Sonification of Individual Participant Data

As presented in Figure 3.4, displacement position values in the XY plane or position values of the Z-Axis can be selected for the sonification. For mapping in the noise section, the total displacement of position in the XY plane or the position values from the Z-Axis can be mapped to the amplitude of the noise and to the cut-off frequency. In this one-to-many mapping method, scaling plays an important aspect in the range of sound parameter control. The option to have automatic data range detection from the input data is not available as a feature. The range of the displacement values can be determined by the *multislider* object as shown in figure 3.3. For the mapping of the amplitude, the input range on displacement values is converted into a range from 0 to 127 of a logarithmic scale. However, mapping the converted values of the continuous data stream directly to the amplitude control seems to produce drastic sudden fluctuations of a sound and therefore, some data averaging was needed between data points. The *slide* object is used to smooth the data logarithmically and slide up and slide down values can be manually controlled.The displacement of position in the XY plane is also mapped to the cut-off frequency of the filter.The lower and upper limits of the cut-off filter can be defined in the scaling. Additionally, the filter mode, the gain, Q-value of the filter can be adjusted in the *filtergraph* as shown in figure 3.4.

Similar to the noise mapping, the amplitude and frequency of the sine tone can be controlled by the displacement position values of the XY plane or the Z-axis position data.

The total displacement is mapped to a larger frequency range to receive a maximum change of frequency for a smaller change in the position displacement. A similar approach has been followed in the sverm project: “The aim was to see if we could “hear” the micromovements hap-pening when standing still. For that reason we created a mapping from a small region (5 cm) to a large frequency range (200-5000 Hz)”(Jensenius & Bjerkestrand, 2011, p. 7).

3.2.4 Sonification of Group Average Position Data

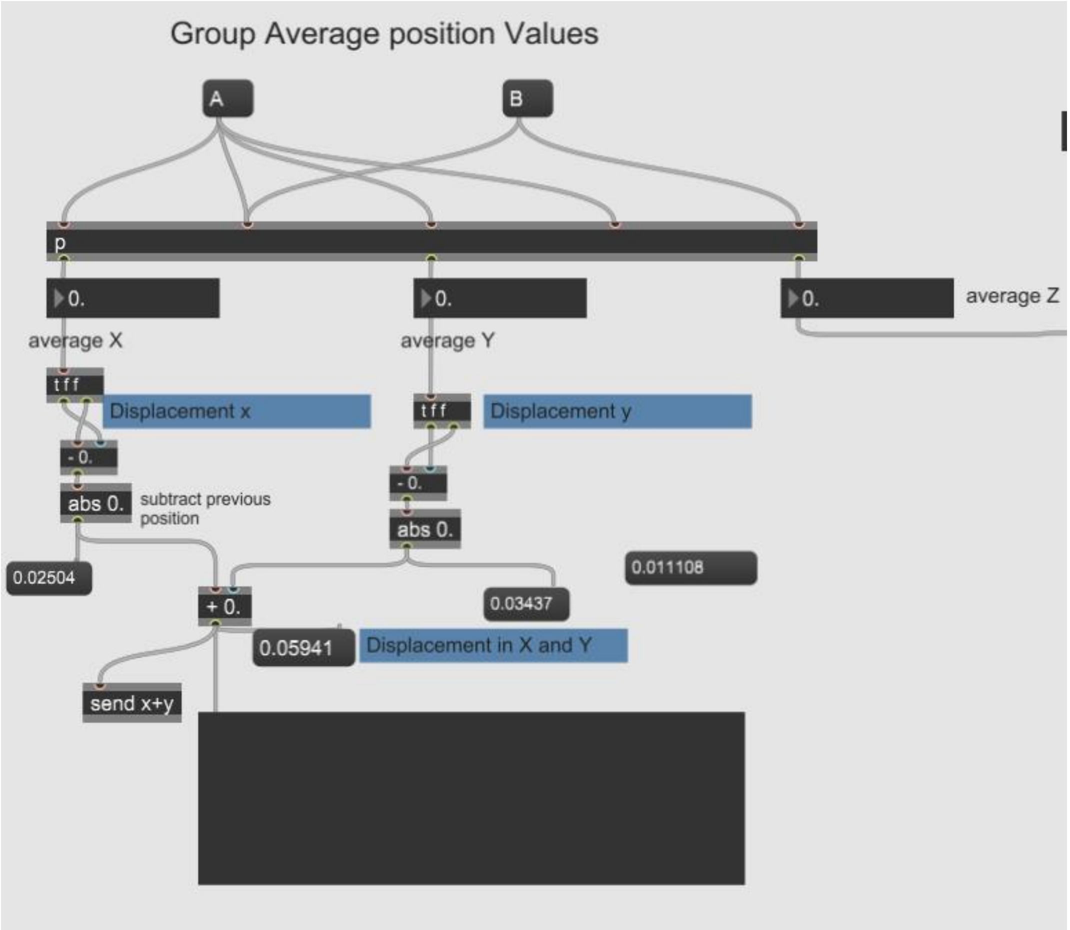

Figure 3.4: The group average position values are calcuted for each x,y and z axes and displacement of position variable is derived.

Figure 3.4 is an extract from the max patch that calculates average displacement values for each x, y, z Axes for two participant groups. However, this patch is only compatible with the 2012 standstill data and since the average values depend on the number of participants in the group, further customizations are necessary to use it with other standstill competition data sets. In the mapping, a similar approach to the individual participant mapping has being followed. The average position values are used to calculate the average displacement position values in the XY plane and mapped to control the noise amplitude and cut-off frequency or the Sine tone frequency and amplitude. Also, the average Z-axis values can be used to control the parameters of the noise section or the sine tone.

3.2.5 Using Spatial Sound with Individual Position Data

The third approach of the sonification is to apply spatialization for the position data. The position values of x, y, z Axes represent a location in the three-dimensional space and these values are used to “sonify” the motion using spatial attributes of a sound. The spatialization approach is developed by using the ICTS[10] ambisonics module for Max/MSP. It allows to simply input cartesian coordinates (X, Y, Z) or spherical coordinates (Azimuth, Elevation, and Distance) and render the sound output for a speaker system or headphones. In this patch, the position data is only controlling spatial parameters of a sine tone.

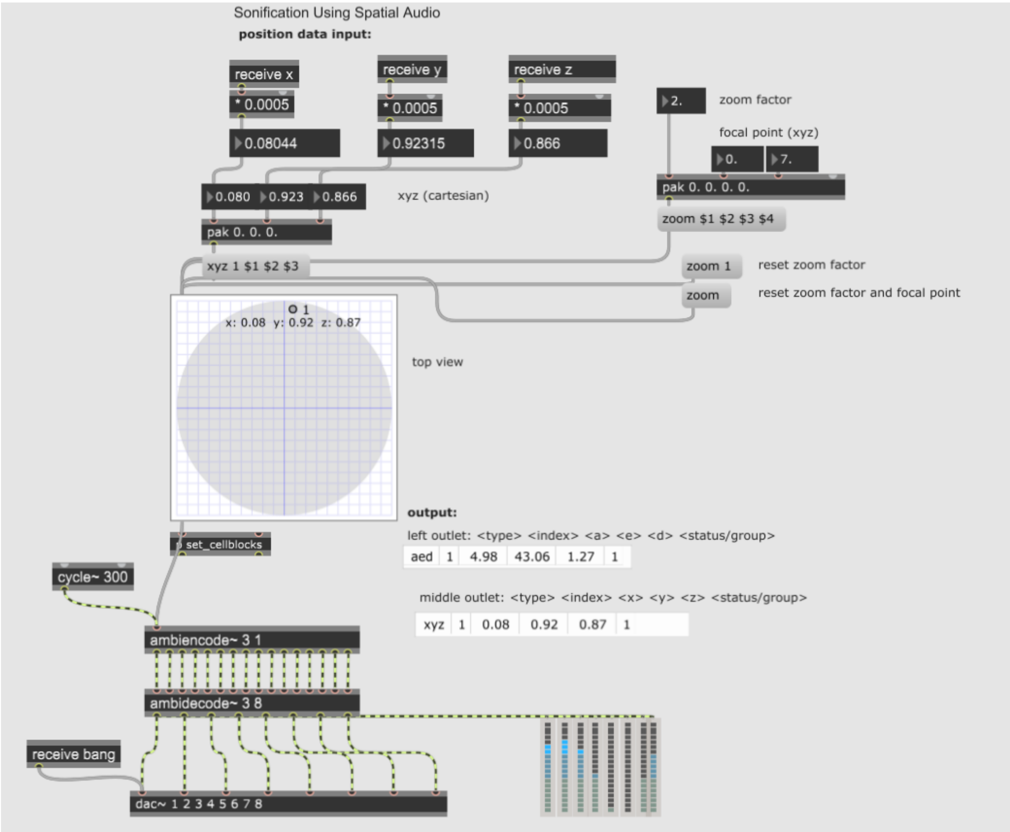

Figure 3.5: The position values in x, y, z are multiplied by the same value to fit into the cartesian scale between -1 to +1 and mapped to the ambimonitor Max/MSP object.

In this sonification approach, one-to-one mapping was used to map the direct x, y, z position values of the participants into the cartesian coordinate system. A simple sine tone was used for the sound and the aim of the direct mapping was to see if it is possible to identify any motion patterns by listening to the ambisonics audio output. However, the cartesian coordinate system in the ICTS ambisonics module accepts values from -1 to +1 therefore, scaling was necessary to have the position visually available in the *ambimonitor* object. Multiplying each position

[10] https://www.zhdk.ch/forschung/icst/software-downloads-5379/downloads-ambisonics-externals-for-maxmsp-5381

variables by the same factor (0.0005) represents proportionally correct values for the motion happening in each axis. The *ambiencode~* object encodes a given number of audio inputs into the ambisonics B-format and the *ambidecode~* object decodes the ambisonics B-format into a given number of audio output channels. In the module, I'm using 3rd order ambisonics encoding and decoding for 8 speaker output. However, an object for binaural decoding is not available in the ICTS module. After scaling the positions to fit the ICTS module's cartesian coordinate system, the motion patterns were not clearly recognizable and therefore, zooming option was added which can be used to zoom into an exact position.

As shown in Figure 3.6, another approach was experimented by scaling each position variable to fit in a range of 0 to 1 Cartesian range. The changes in the position of a participant were much clearly noticeable from the sound. but however, the relative correct proportionality between the x, y, z values are not maintained.

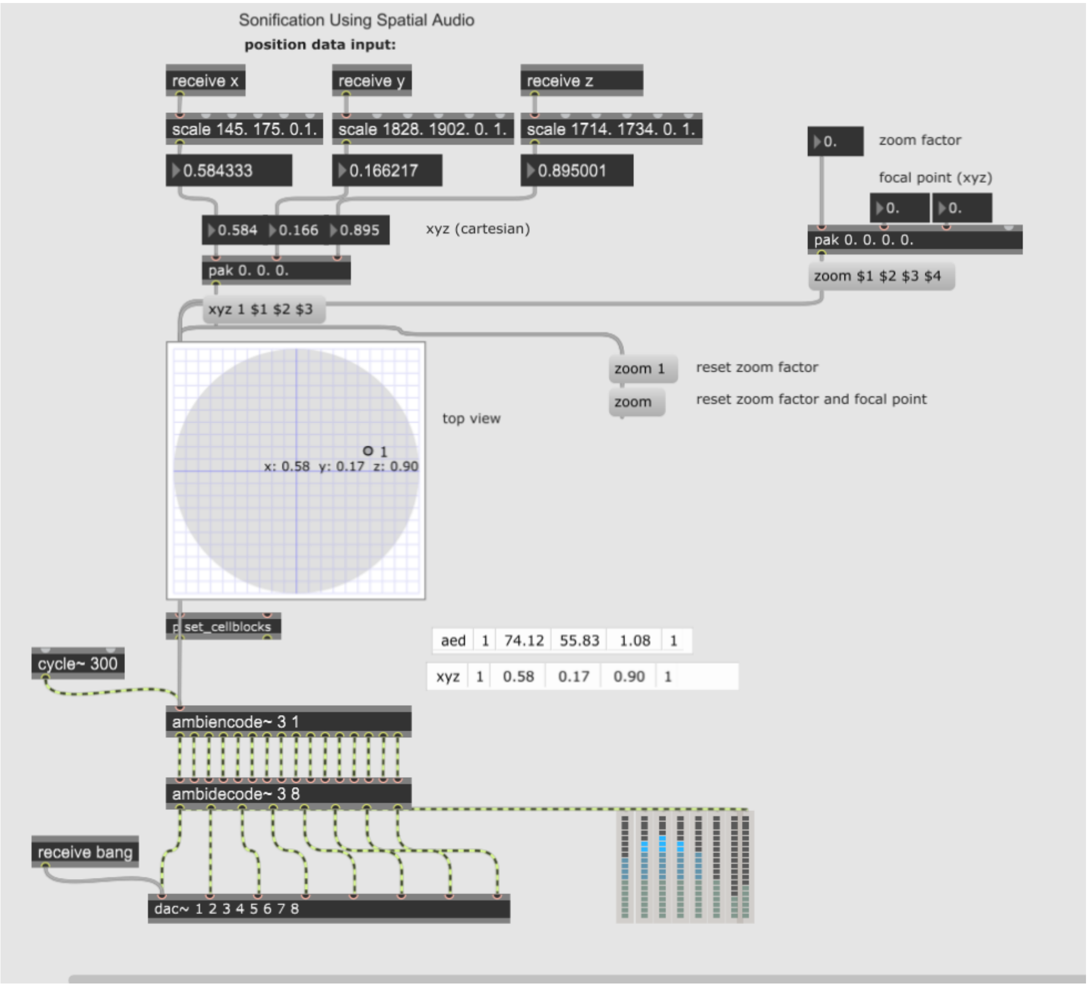

Figure 3.6: Each position values in x, y, z are scaled seperately to fit into the cartesian scale between -1to +1 and mapped to the ambimonitor Max/MSP object.

3.3 Results and Discussion

Audio samples were recorded for all three sonification models. For the sonification of individual participants, three participants were chosen from three groups: Participant number 1 – Group A, Participant number 10 – Group B, Participant number 20 – Group C. The sonification was done by either mapping the Z-axis positions or the displacement values with the noise or the sine tone, and tested with several levels of playback speeds, concerning different scaling and smoothing of the data. Additionally, audio samples were recorded in selected data playback speeds. A list of the recorded audio samples is available in Appendix A. After experimenting with two different mappings with the white noise and sine tone, the sine tone seems to produce a clear informative sound in higher data playback rates than the white noise. This can be due to the sine tone is producing a focused frequency of sound at a time, but the white noise is clustered with a frequency range.

First, I would mention the results for the mapping of white noise with data variables. The mapping of white noise to displacement position variable with a 100 Hz sample rate of data playback, produced a sound of rising and falling of the frequency filtering and the amplitude. These fluctuations were present for all three participants. These up and down movements of the sound can be distinguishable in three levels. First, a darker sound can be noticed with less volume which stays much stable with fewer fluctuations. These low fluctuations of the noise can probably explain by the stability of the standing still. Secondly, a much sharper rising and falling of the noise is noticeable for 5-15 seconds periods of time. The periodicity of these sounds is not sharply consistent. These sounds are shorter rises that last for about 2 seconds but clearly stands out from the much stable darker noise. These rising and falling of the noise can be related to the breathing patterns of the participants. Statistical evidence was found in previous standstill studies regarding similar periodic movements (Jensenius & Bjerkestrand, 2011). Thirdly, sudden quick bursts of the noise can be noticed, and they occur less frequently and not in any noticeable cycle. This type of sound may be occurring due to postural adjustments of the participants. As described in a study by Jensenius and Bjerkestrand (2011), some “spikes” that appear every 2-3 minutes were noticed in the analysis and these were assumed as postural re-adjustments. These sudden rises are clearly audible as very short bursts when playing with higher playback rates of 400 Hz or 800 Hz. Similar three levels of the white noise were audible in the sonification of average participant data of group A and B. But the fluctuations were audible as much more rapid changes in the sound. This might be due to the unique breathing patterns and postural adjustments of each participant, but some synchronicity of these patters can be explained by the rise and fall of the noise sounds happens with higher amplitudes compared to the sonification of individual participant data.

Moreover, an interesting phenomenon was noticed in the mapping of Z-Axis values. By listening to the mapping of Z-axis values with the sine tone, a gradual dropping of the sine tone frequency was noticed for all three participants. It can be noticed that the sudden fluctuations of the sound are very low compared to the fluctuations noticed in the mapping of displacement position values. Which could potentially result because of the less up and down movements of the head when standing still (Jensenius, 2017). The gradual drop of the sine frequency may probably be indicating a gradual fall of the position for standing over a longer period. As mentioned in a previous study of a standstill experiment, “This could be an indication that we ‘sink’ a little when standing still over time, but the numbers are too small to point to a strong conclusion” (Jensenius et al., 2014). And a sudden rise of the frequency can be noticed after certain frequency drops. This can be possibly due to the reason of participants re-adjust their postures by trying to straighten their back (Jensenius, 2017). Also, this falling of the sine frequency is strongly noticeable towards the very end of the session, and this might be indicating a falling of the posture due to fatigue for standing for a longer period. Moreover, two of the three participants (participant 1 and participant 10) indicate a dropping in the frequency of the sine tone after halfway through the session and keep a lower frequency until the end of the session. This might be indicating that the participants tried to relax the body to maintain the stillness when the music starts and resulted in a sudden falling of the height. However, this must be tested with a larger number of participants before having a strong confirmation.

Finally, mapping the position values for spatialization produced an interesting moving pattern in the ambisonic sound field. But any regularity or periodicity of the patterns was not noticed. However, details on the elevation of the sound are not accurately perceived from the headphones due to the lack of a binaural rendering option in the ICTS module.

Chapter 4

4 Conclusion

4.1 Summary

In this thesis, I have implemented a sonification design for exploring data from the 2012 edition of the Norwegian Championship of Standstill. My approach consisted of building three applications that approach the data set in different ways, and later the results are evaluated by listening to the produced audio samples. In Chapter 1, I presented my motivation behind the topic, introduced the main research question, and two other sub-questions of interest regarding the topic.

In Chapter 2, I established a theoretical background by presenting the results of previous standstill competition studies. A discussion on different sonification techniques and their applications was necessary for adapting a method to implement the sonification modules. Furthermore, different mapping strategies and sonification designing approaches were discussed by looking into several existing applications. This background study provided the basis for the design choices made during the development of the sonification models.

In Chapter 3, I am presenting my process of developing the sonification models. The mapping strategies, data selection methods, sound parameter selections for each of the three models are discussed. The implemented sonification strategies are evaluated and results are justified by listening to the sound samples produced by the models, and by comparing them with the results of previous studies on standstill.

4.2 Reflections

Now I would like to address my main research question and the sub-questions, based on the development and the results of the sonification process. First, I would like to consider the two sub-questions.

1. What kind of motion patterns are audible in standstill competition data?

By considering the results of the individual participant data sonification, the most noticeable finding is to be able to listen to the falling and re-adjustments of the posture of participants. As a previous study of standstill mentions, more strong evidence was needed to conclude the downward movement in the Z-Axis data (Jensenius et al., 2014). However, by listening to the sonification, this effect of falling of the posture is clearly audible and provides strong evidence that there is a noticeable gradual downward movement and sudden rises of the position marker along the Z-axis. Furthermore, the mapping of the noise with the position displacement variable provides supportive evidence that the breathing patterns and postural adjustments are audible from the sonification. However, a stronger investigation is needed to confirm the periodicity of such events at *"Meso"* and *"Macro"* temporal levels. But the sonification indicates that the micro-motions are in a reasonably stable state and have consistent motion.
However, by listening to the sonification for the sections with music and without music, it is difficult to notice any comparable differences between the movement patterns. By listening to

the sonification, it is difficult to notice if the participants' motion shows any synchronization to the music stimuli or not. But it was possible to notice a falling of the height (falling of the posture) when the music stimuli start, and towards the very end of the session. Moreover, by listening to the sonification, any recognizable effects on the micro-motion according to different postural choices such as keeping eyes open/close or keeping the knees locked/not locked was not noticeable.

2. How can spatial audio be used in sonification of standstill?

The possibilities of using spatial audio with the sonification of standstill are not fully examined in this thesis. By maintaining proportionality between the x, y, z position values in the spatial mapping, tends to produce a less noticed spatial movement of the sound due to the very small range of motion (micro-motion). However, another approach would be to expand the micro-motion by mapping the range of each x, y, z axes values into a larger range. But the patterns that audible in the ambisonics sound stream are not explainable with strong evidence and doesn't explain how these motions of the sound can be related to the micro-motion. Further, the development of the model is necessary to effectively draw any strong conclusions of the spatialization of the sonification.

Finally, I would like to reflect upon the main question of the thesis:

- How can sonification be used as a method to explore music-related micro-motion?

According to the results of the analysis of sound samples, a conclusion can be made that through sonification it is possible to identify patterns and events to a certain extent, which were not clearly visible in the visualizations of the standstill data. The introduced sonification modules, however, provides less opportunity to actively compare between sections. As an example, comparing a data section with music stimuli and without music stimuli was a difficult task since due to the high irregularity of the sound patterns. This kind of audio comparison demands a high skill of actively memorizing and comparing a certain characteristic of the patterns. One way to avoid this kind of complexity is to play different data streams simultaneously with each stream assigned with a unique distinguishable sound. As an example, mapping the position data of two participants into two frequency ranges of a sine tone and listening to both audio streams simultaneously. However, when developing such a sonification model, the psychoacoustic phenomena of *"masking"* should be potentially considered. The mapping of the position displacement values with the noise seems to produce a more effective and pleasing sound compared to the sine tone. A fluctuation of the filtered noise was mostly sounding closely related to the sound of breathing and felt more natural. And the sine tone seems to be an appropriate mapping for the values of the Z-axis since the gradual dropping of the frequency was more appealing to represent a downward movement of the position. The use of white noise seems to be aesthetically appealing. Using pleasant and natural sounds tend to improve the efficiency of a sonification model(Susini et al., 2012) However, these aesthetically pleasant sounds can also have the potential of distracting the listener and hide the important information from the sonification (Vickers & Hogg, 2013). Having a perfect balance between these factors is a challenge when designing a parameter mapping sonification for data exploration. Another aspect to consider in the mapping is the perceptual correlation between sound parameters. As an example, frequency and gain both contribute to the loudness parameter where higher frequencies tend to be perceived as loud or bright. As Grond and Berger (2011) point out, an efficient mapping for loudness can be achieved by applying a proper frequency- dependent amplitude compensation technique .

As final thoughts, the sonification models developed in the thesis are mostly appropriate for navigating through the standstill data set and gain a quick overview of the data patterns. To gain the full potential of the data features, more options should be developed for data management. These sonification methods can be utilized as guides along with the visualization techniques to explore the Standstill competition data. Even though the sonification can convey useful information from the data features, a successful evaluation of the sonification process heavily depends on the skill of listening. It is necessary to develop a “skill” to actively listen to the data set and identify potential information. As Hermann and Ritter (1999) emphasize, training is necessary to interpret the sonification correctly, and thus after a longer period of training it is possible to develop expertise on identifying subtle changes and patterns.

4.3 Future work

When re-thinking about the limitations faced during the thesis work, it will be necessary to develop functionality to fully explore the demographic details of participants. This provides the ability to use sonification for further investigation on how the variables such as music production hours, height, music listening hours, exercising hours affects the micro-motion. This might be able to achieve by experimenting with the data matrix methods available in the *MUBU* library or using *jit.matrix* object. On the other hand, It will be interesting to experiment on building sonification models by using a text-based programming language. like a combination of *Supercollider* and *Python,* which would provide the availability of more advanced data processing features. Larger data sets could then be handled in more efficient ways and would provide the potential to apply sonification for all the available standstill data from 2012 and onwards.

Another step in the future development of sonification strategies could be that of using more advanced spatialization models. Such as, *Spat* for *Max/MSP*. By looking at the work done by Barrett (2016), the *spat* library provides the capability to control nuances of higher-order ambisonics audio. Taking a step further, a real-time sonification model can be developed for the standstill competition data. The position data can be sent as Open Sound Control (OSC) messages from the MoCap software into *Max/MSP*. One possibility, then, could be to use real-time sonification during a competition, and it would be interesting to investigate how it could affect the participant’s micromotion. This can be also developed into a performance aspect of the standstill competition rather than pure sonification of data exploration.

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APPENDIX A

This section includes a list of data files of the 2012 stand still competition and a list of rendered audio files from the sonification experiment.

A.1 Data files

nm2012_mocap2.csv
CSV data file of 2012 standstill competition data

nm2012_questionnaireandqom.xlsx
Excel file of questionnaire data for the 2012 Standstill competition

nm2012_mocap.txt
2012 Standstill competition data in text format

A.2 Audio files

A.2.1 Sonification of individual participant data

Example 1.1.wav Displacement of position mapped with white noise for Participant 1 – 100 Hz data playback rate.

Example 1.2.wav Displacement of position mapped with Sine tone for Participant 1 – 800 Hz data playback rate.

Example 1.3.wav Z-Axis values mapped with Sine tone for Participant 1 – 800 Hz data playback rate.

Example 1.4.wav Displacement of position mapped with Sine tone for Participant 1 – 100 Hz data playback rate.

Example 2.1.wav Displacement of position mapped with White Noise for Participant 10 – 100 Hz data playback rate.

Example 2.2.wav Displacement of position mapped with Sine tone for Participant 10 – 100 Hz data playback rate.

Example 2.3.wav Displacement of position mapped with Sine tone for Participant 10 – 200 Hz data playback rate.

Example 2.4.wav Z-Axis values mapped with Sine tone for Participant 10 – 400 Hz data playback rate.

Example 3.1.wav Displacement of position mapped with White Noise for Participant 20 – 100 Hz data playback rate.

Example 3.2.wav Displacement of position mapped with Sine tone for Participant 20 – 100 Hz data playback rate

Example 3.3.wav Z-Axis values mapped with Sine tone for Participant 20 – 800 Hz data playback rate.

Example 3.4.wav Displacement of position mapped with Sine tone for Participant 20 – 400 Hz data playback rate.

A.2.2 Sonification of group average position data

Example A.1.wav Displacement of position mapped with White noise for group A – 100 Hz data playback rate.

Example A.2.wav Displacement of position mapped with Sine tone for group A – 400 Hz data playback rate.

Example A.3.wav Z-Axis values mapped with Sine tone for group A – 1600 Hz data playback rate.

Example B.1.wav Displacement of position mapped with White noise for group B – 100 Hz data playback rate.

Example B.2.wav Displacement of position mapped with Sine tone for group A – 400 Hz data playback rate.

Example B.3.wav Z-Axis values mapped with Sine tone for group A – 1600 Hz data playback rate.

A.3 Video files

This section includes a list of video recording of each sonification modules.

video1.mp4 Demonstration of the sonification module for individual participant data sonification.

video2.mp4 Demonstration of the sonification module for the group average position data.

video3.mp4 Demonstration of the ambisonics sonification module.

A.4 Max patches

Sonification_participants.maxpat sonification module for individual participant data.

Sonification_groups.maxpat sonification module for group average position data.

Sonification_ambisonics.maxpat sonification module with ambisonics audio for individual participant data.

APPENDIX B

This section includes screen shots of Max patches for each sonification module.

B.1 sonification_participants.maxpat

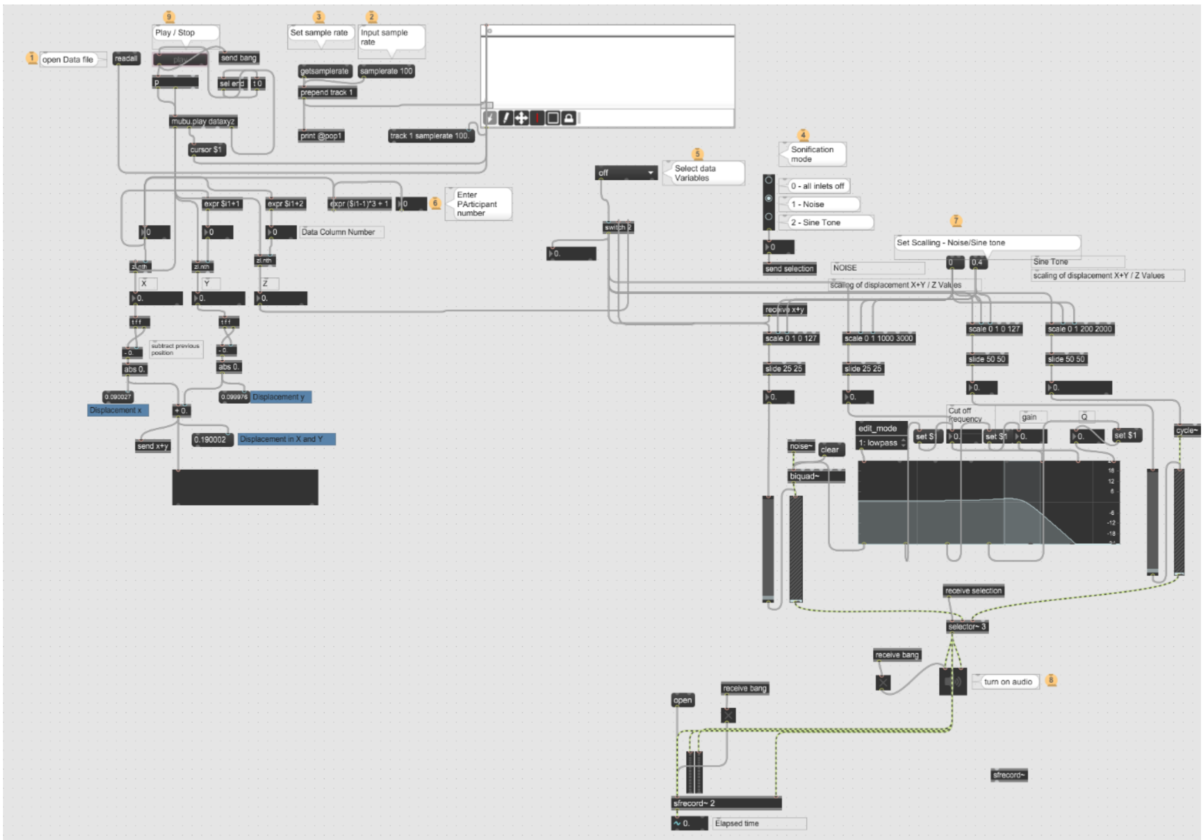

Figure B.1 – Max patch for individual participant data sonification.

B.2 Sonification_groups.maxpat

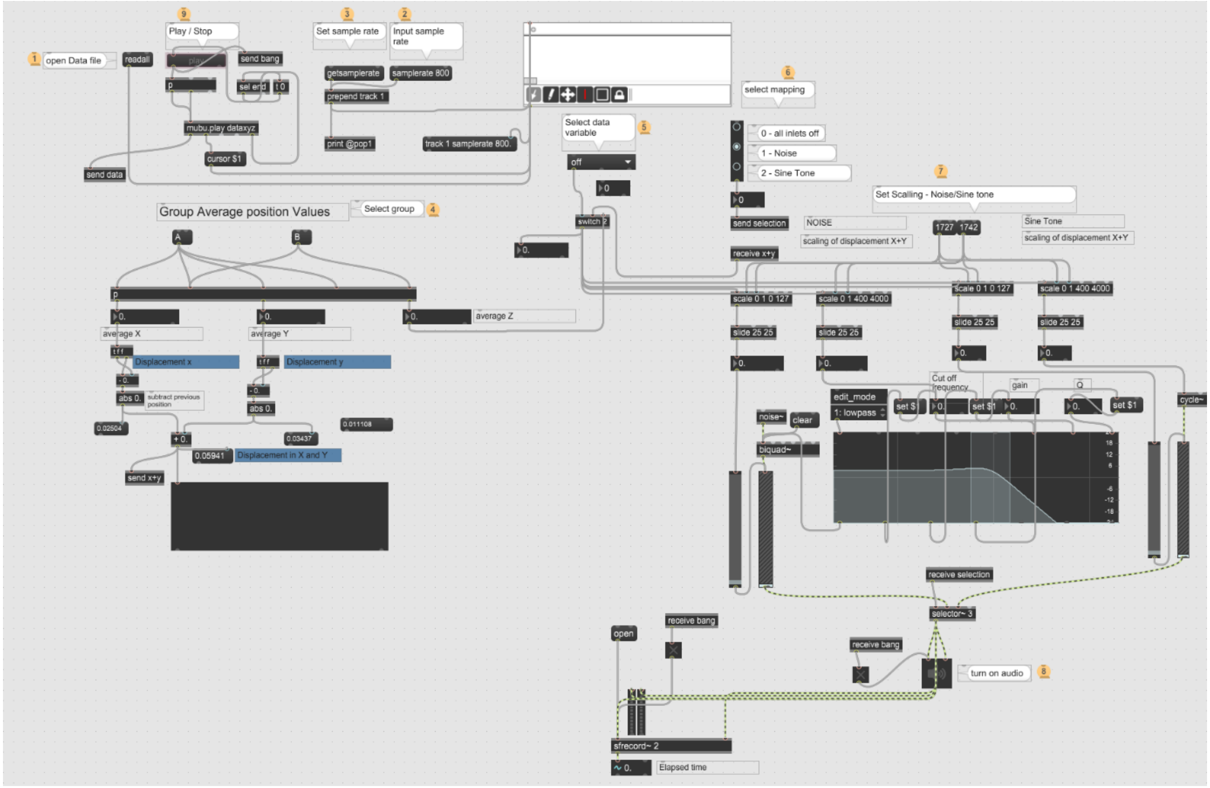

Figure B.2 – Max patch for group average position data sonification.

B.3 Sonification_ambisonics.maxpat

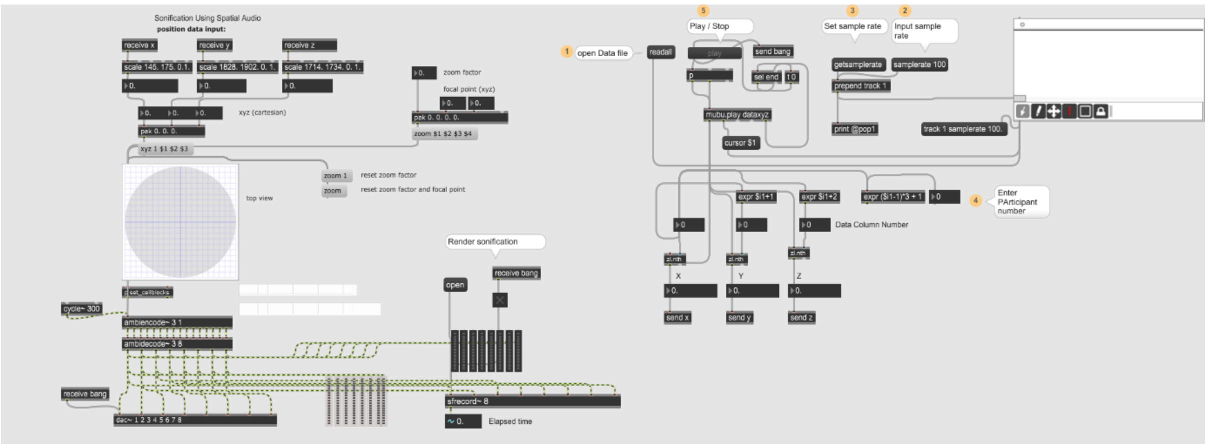

Figure B.3 – Max patch for sonification with ambisonics audio.