Sonifying the Microbiome: 365 days in 360°

Deborah Rudin
deborahrudin079@gmail.com
University of Minnesota Twin Cities
Minneapolis, Minnesota, USA

Andrew Demirjian
ademirji@hunter.cuny.edu
Hunter College CUNY
New York City, New York, USA

ABSTRACT

Scientists are increasingly finding important relationships between mental and physical health and the state of the microbiome. The patterns that emerge from the development of the infant microbiome have intriguing implications for a wide range of mental and physical attributes later in life. However, patterns are not only visual, and utilizing data sonification may yield new results due to human auditory sensitivity and pattern recognition. Data sonification has been used since long before the modern era, and using it on data on the microbiome leads to a new way of perceiving the human body. Results were sonified from the ten most significant taxonomic bacteria families of microbiome data collected from fourteen infants over the course of one year in a prior study. This data generated piece of music was composed using Max MSP and then converted into an immersive 360° experience using Mozilla Hubs. This sonification enriches the breadth of data analysis by expanding the sensory experience, probing the potential for using sonic spatial understanding in data comprehension, creating accessibility for researchers with conditions such as visual disabilities and dyscalculia which make visual and mathematical depictions of data inaccessible, and creating data representations which can be understood and experienced by the general public.

CCS CONCEPTS

• **Human-centered computing** → *Visualization, Sonification*; • **Applied computing** → **Microbiome**; **Sound and music computing**.

KEYWORDS

sonification, auditory display, visualization, immersive media, music, microbiome, pattern recognition

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1 INTRODUCTION

Correlations and connections between mental and physical health and the state of the human microbiome are being increasingly discovered by scientists[7]. As the microbiome develops throughout the course of a being's life, the development of the infant microbiome may lay the formations for different mental and physical attributes later in life. Sonifying the Microbiome: 365 days in 360° develops an exploration of the affordances of sound as an additional tool to help identify patterns and subtle changes in data that are difficult to trace by viewing spreadsheets or graphs. Scientists can now use DNA sequencing to quantitatively monitor all of the different bacteria in a person's microbiome[3]. This project maps data of the evolution and fluctuations of microbes in the microbiome of fourteen infants from the day of their birth until they are one year old into sound. Different aural characteristics like pitch, note duration, timbre and velocity are used to identify variations in presence, quantity and type of bacteria changing over time. The outcome of the research is a 360° listening experience that enables the user to hear the infants in the study simultaneously in an immersive experience in order to compare and contrast differences and similarities in the data.

Sonification is the process of turning non-auditory data or information into sound. Similarly to Data Visualization, this process allows people to interpret data more accurately than if they were simply looking at a set of numbers. Humans possess incredible pattern recognition skills, especially when it comes to sound. Refrains and tunes get stuck in one's brain, and some people even have the ability to mimic or recognize any sound they hear. Additionally, while humans can detect minuscule changes in pitch, minute shifts in color may be indistinguishable to most people, or misjudged due to the lighting of the viewing environment[8].

The idea of using sound to recognize patterns is not new. Heart monitors use both visualization in tandem with sound, with the sounds often the most recognized warnings of something going wrong. Geiger Counters use sound and sonification to identify and warn users of radiation. Much of sonification is currently used to diagnose when something is dangerous, and loud high-pitched noises such as sirens, fire alarms, and heart monitors have become synonymous with danger in society's collective culture. However, sound can be used to convey much more than a sense of danger. Humans are keenly aware of the direction and location of sound, no advanced training in music theory is necessary for a person to understand where a sound is located in a room and comprehend its trajectory as it moves. From listening to traffic on the street to birds in trees, we have gained a complex awareness of sounds in space from urban and rural soundscapes over time. In addition, since infancy we have learned to listen to subtle variations in speech to communicate meaning. This ability to hear nuanced fluctuations in pitch, amplitude and timbre can be utilized in sonifications to reveal intriguing data relationships that may not be caught with other methods of analysis. The spatialization of sound coupled with the sonification of data can be a powerful complement to strictly visual ways of understanding the world. Sonifying the Microbiome:

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365 days in 360° continues to build on understanding the potential of sound in research environments.

2 RELATED WORK

The idea of using sound to communicate and reveal patterns has been around since long before the modern era. Auditing for example, may have had its roots in Ancient Egypt, with auditors listening and comparing the intonations of granary masters in order to prevent the Pharaoh from being cheated[2]. This is an early example of how sound can be used for accurate differentiation between different samples. Later on, Pythagoras used musical terms and knowledge in order to interpret understanding of the celestial bodies: the sun, moon, and planets. There was this idea that these bodies emitted unique sounds as they moved, and he used this as a way to calculate their distances from each other. He used terms such as 'whole tone' and 'half tone' to describe these distances (from the earth to the moon is one whole tone), for a solar system of 7 whole tones, or diapason: a universal harmony[4].

In more modern times, the idea of programmed music and applying mathematics to music emerged. At the University of Illinois Champagne-Urbana, strides were taken in this field with the development of a 'rules-based' system used to create Illiac Suite for string quartet in 1957: the first recognized composition created by a computer[11]. This idea of rules to create music laid the foundations for representing data as sound in order to find and interpret patterns. Rules for musical composition have existed since at least 1026[9]. In 1993, CAMUS 3D came into being, using 3D extensions of Cellular Automata to create compositions. This used pattern propagation, with said patterns being transformed over time in strict adherence to the formal rules chosen by the composer[9]. CAMUS 3D uses probability to build it's compositions, but its idea is close to that of using data in sonification. Data fluctuates and has margins of error. If one is using collected data to generate a composition, it will most likely not adhere to one specific pattern. Instead, there will be transformations. This is similar to CAMUS 3D's transformative pattern propagation, with the difference of using data instead of probability generated numbers.

More recently, researchers have delved into the idea of immersive data sonification. Using software synthesis, one can turn data into any imaginable sound. Diass, developed jointly at the University of Illinois and Argonne National Laboratory, uses M4C to do such synthesis in order to turn data into sound. The M4Cave then transforms that sound into a VR visualization in a Cave or ImmersaDesk using one-to-one mapping of the composition as you hear it[6]. This reveals many interesting patterns through the combination of visual and auditory information. However, one could end up distracted by one aspect of the experience - the visualization for instance - and forget to focus on the data synthesis itself. While the span of human vision is generally considered to be 120°[5], our auditory perceptual framework provides 360° of awareness with which auditory scene analysis can be conducted[1]. In this paper the focus will be on the immersivity of the sonification in order to both reveal patterns and create the sensory experience of being surrounded by the human microbiome.

3 METHODOLOGY

Approaching the question of whether data sonification yields different results than data visualization requires first having a data sonification. For this sonification, Max MSP was used. Max MSP is a visual programming language by Cycling '74 which is mainly used for music and multimedia programming. Within Max MSP, one can utilize Ableton, MIDI, Jitter, and other tools with the ability to manipulate them to do precisely what is needed instead of going through an outside application. The first step of the process was taking the data and formulating it such that it would be easily workable through Max MSP. This data came from the study Development of the Human Infant Intestinal Microbiota[10]. This data included data on fourteen infants' microbiomes, measured from stool samples over the course of a year. Also included were samples from siblings, parents, and baby formula. There were ten features – the top ten taxonomic families found in the samples – which were measured based on the quantities found in each sample. Once formatted, the data was put through a coll object and unpacked to get the value of each feature at a certain measurement. Using this, it was possible to iterate through the year of measurements quite easily.

While determining how to denote the data, different factors were considered, including which features were probiotics, which caused disease, and which taxonomic families were Gram-negative or Gram-positive. In an effort to create a valid representation of the data, each feature was set to have a specific note associated with it in a scale. This set the pitch of the note. The value of the data determined the velocity – the volume of the note – such that a smaller quantity of a feature would be quieter, while a larger quantity would be louder. After that, the notes were put through different string instrument synths. While the notes remain the same, the quantities of the features cause some notes to sound loudly and some barely at all, thus creating an interesting and appealing piece of music, completely generated from the collected data. Once the notes were set, the duration was changed to correspond to the time between dates of measurements. This was done in such a way that daily measurements at the beginning are shorter, with the duration increasing as the time between measurements grew louder. As such, the longest note is for the measurement at one year, as it was six months after the last data collection.

In order to make an accessible immersive experience – as not everybody has access to a black box studio – a room was created in Mozilla Hubs. Using existing presets and assets, twelve Grogu (Baby Yoda from the Mandelorian) objects were arranged in a circle, each representing a baby with a corresponding mp3 file on them. Twelve babies, not fourteen, as the twins had a different amount of measurements than the rest of the sample group – which would have thrown of the repetition of the music. When one flies to the center of the circle, Mozilla Hubs' audio panning allows one to experience the sensation of an immersive experience in VR or on one's computer. This made the experience accessible, as just like not everyone has access to a black box, not everyone has access to a virtual reality headset.

4 RESULTS AND DISCUSSIONS

In order to gain an understanding of how well the sonification could be understood, a response form was sent to those who tested the immersive sonification. This form questioned the users on their observations while exploring the experience, and their thoughts on how applicable data sonification is to the field of data analysis. Using the form to gather data was decided on seeing as those who were involved in the creation of the sonification could have a bias towards the project that would skew the data. None of the users had a background in working with the microbiome or in sound production in an attempt to mitigate possible bias. These participants were given basic information on the project: the sonifications were of data collected from the infants' microbiomes over the course of a year, that different notes corresponded to different bacterium, and that the volume corresponded to how much of that bacterium there was at a given measurement.

Once the responses were gathered, they were then analyzed. Some responses were much more in depth, while others were very short and uninformative. Unfortunately, due to the time frame, the sample size was quite small - only ten participants. As such, while the information gathered is important and informational, more research should be done on data sonification for data analysis.

However, there was much to be gathered from the response form. 100% of participants answered yes to the question 'Do you think that data sonification is a promising avenue for data analysis?' while only 70% percent answered yes to the question 'Did listening to the data give you a different understanding of the data?'. This is intriguing and brings into question the personal experiences and biases of the participants. Did it fail to bring a different understanding because the sonification wasn't clear enough, or did the user simply prefer mathematical representations of data to auditory ones?

Throughout the responses was a theme of users clearly recognizing the fluctuations in the data and the changing note duration. As such, it can be inferred that data sonification does clearly convey a sense of time in measurements. They also correctly identified how the stronger, more common notes were the more commonly encountered bacteria. The spacial format of the sonification encouraged deeper engagement with the users as well. One user even spent an entire hour in the space, taking in the sonification. Being able to roam throughout the virtual space was an aspect that was found especially pleasing, with one participant commenting that they "like the idea of roaming the room full of babies and hearing what they have to 'say'". Interestingly, many participants noted how the different babies would sync up with each other at times, and harmonize with each others at other times. Several participants mentioned that they were deeply engaged in the music, or that it sounded beautiful. A quote from one response to the question 'Did listening to the data give you a different understanding of the data and how did that understanding inform your experience and observations?' was "All of the data shares similarities and differences, despite being exposed to different microbiomes. Although they are similar, there are still differences that cause them to be unique". This response was very enlightening, as it really got to the point that human beings are unique, despite having many similarities throughout. All the data samples have the same features recorded, but there are different quantities in each measurement and no sample was the same. Yet the untrained human ear was able to pick up on this, which definitely sheds light on how data sonification increases the understanding of data to the general public. Additionally, 80% of participants responded that they thought that data sonification increases the accessibility of data analysis.

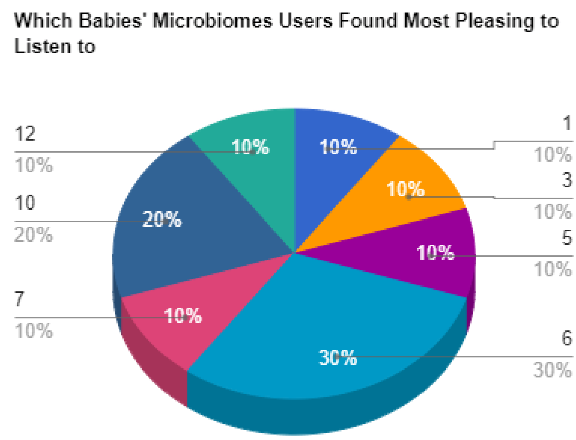

Figure 1: Pie Chart of User Responses to the question 'Which baby was the most pleasing or interesting for you to listen to?'.

5 CONCLUSION

Just as each being is unique, so is every microbiome. That this distinction is evident in a data sonification without an accompanying visual or mathematical representation confirms that data sonification is able to convey complexities in the shifts of data. While further research is needed to solidify data sonification's place within the field, participants' abilities to distinguish the harmonies and individual pitch changes agrees with prior understanding of human auditory processing skills, and indicates that future forays into data sonification for data analysis would be successful.

This 360° listening experience enabled the users to utilize their spacial understanding in a way which allowed a fuller perception of their senses while exploring the data. Not only did this spacial sonification encourage deeper and longer interaction with the data (which may nurture a heightened analysis of said data), but the majority of participants also agreed that data sonification increases the accessibility of data analysis. As is, the field depends heavily on visual and mathematical analytics. This not only alienates those who have visual or mathematical processing disorders, but also those who may not have as much experience interpreting data. An issue that has popped up throughout history is lack of transparency in studies. This can be misleading, and often harmful. Often, data to back up the claim is never shown to the public, but when it is there is the issue of the data being uninterpretable to those who aren't the researchers. While this could be brushed off as an academic issue, it's really a way to keep information out of the hands of the public, intentionally or unintentionally. Having a representation like data sonification which is more accessible in tandem with more traditional representations of data can increase transparency in studies and allow non-researchers to develop a fuller understanding of data analysis.

Academically, this widens a branch of data analysis and also opens the field to interdisciplinary thinking and collaboration. Researchers could work with those in the music and audio production fields to gain a fuller comprehension of their data. Working in one specific field can limit worldview, and adding an interdisciplinary aspect can increase that understanding. Drawing from millennia old knowledge such as music can create new avenues for exploration in the modern age. Data sonification opens the field of data analysis up to interdisciplinary thinking and increased accessibility, allowing for innovation and discovery by utilizing the power of the human senses.

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