NEURODIVERGENCE IN SOUND: SONIFICATION AS A TOOL FOR MENTAL HEALTH AWARENESS

Chihab Nadri[1], Hamza Al Matar[1], Spencer Morrison[1], Allison Tiemann[1], Inuk Song[2], Tae Ho Lee[2], Myounghoon Jeon[1]

Mind Music Machine Lab[1]
Virginia Polytechnic Institute and State University
1185 Perry Street
Blacksburg, USA
{cnadri, hmatar, samorrison20, agtieman, myounghoonjeon}@vt.edu

Department of Psychology[2]
Virginia Polytechnic Institute and State University
109 Williams Hall
Blacksburg, USA
{psyence221b, taehol}@vt.edu

ABSTRACT

The need to build greater mental health awareness as an important factor in decreasing stigma surrounding individuals with neurodivergent conditions has led to the development of programs and activities that seek to increase mental health awareness. Using a sonification approach with neural activity can effectively convey an individual's psychological and mental characteristics in a simple and intuitive manner. In this study, we developed a sonification algorithm that alters existing music clips according to fMRI data corresponding to the salience network activity from neurotypical and neurodivergent individuals with schizophrenia. We conducted an evaluation of these sonifications with 24 participants. Results indicate that participants were able to differentiate between sound clips stemming from different neurological conditions and that participants gained increased awareness of schizophrenia through this brief intervention. Findings indicate sonification could be an effective tool in raising mental health awareness and relate neurodivergence to a neurotypical audience.

1. INTRODUCTION

Advances in neuroimaging techniques have led to a greater understanding of the neural basis of mental health disorders. Functional Magnetic Resonance Imaging (fMRI) allows for the measurement of blood oxygenation level-dependent signals in the brain, making it possible to compare the neural activity of individuals with neurological conditions to that of neurotypical individuals as they perform daily tasks [1]. Each neurological condition affects the brain in a unique way, resulting in distinct fMRI readings. For instance, studies have found that individuals with anxiety disorder have a greater activation of the Frontal Medial Cortex compared to those with bipolar disorder [2].

Individuals with schizophrenia live with neurological processes that disrupt how they act, think, express emotions, interpret reality, and associate with others [3]. Some characteristics include delusion, catatonia, and sensory hallucinations which occur with no prior sensory input [4]. This neurological condition affects roughly 1% of the population, with individuals tending to be diagnosed in their later teenage years or in their twenties [3]. A severe stigma exists surrounding schizophrenia and other neurodivergent conditions [5-7], and those living with this condition can be subject to social isolation or discrimination. The effect of this discrimination also extends beyond social wellbeing to make it more difficult to obtain health care, quality of life, and be perceived as a dangerous individual [7, 8]. As such, raising mental health awareness can serve in supporting individuals with schizophrenia and other mental health conditions.

However, while practitioners can identify patterns in brain function data, the vast amount of data generated by brain imaging techniques can be difficult to interpret and communicate to a broader audience. This could hamper efforts to raise mental health awareness among the general population, especially for conditions such as schizophrenia which involves sensory hallucinations that are unrelatable [3]. Efforts to raise mental health awareness have included education programs [5], workplace training [9], and short ad campaigns [10]. However, these efforts have so far not sought to use fMRI and other brain imaging data, due to the complexity in relating the information to a general audience. One potential solution to this problem is the use of sonification, or the conversion of data into sound, to make the information more accessible and engaging.

Sonification is a method that is used for representing data using sound waves. When sonifying data, distinct elements in the data, such as art style [11] or climate data [12], are mapped to musical elements such as pitch, tempo, loudness, and duration. Sonification has been used to communicate data clearly and effectively, aid the analysis of specific features in the data, and relate scientific concepts to improve science literacy [13]. One of the emerging applications of sonification is the use of sonification for the purpose of raising awareness regarding a topic. In a 2020 study, robot movements were sonified into music to raise awareness about the movement of the robot and improve perceived safety when interacting with a robot [14]. In another study, climate change data and weather patterns were sonified to raise awareness on the phenomenon [15]. Furthermore, the use of sonification in neuroscience has been explored in past research [16, 17], although studies had a higher focus on cognitive state identification and a gap exists regarding sonification's use as a mental health awareness short-term intervention.

In this study, we seek to evaluate the effectiveness of sonification as a tool to help differentiate the fMRI readings of neurotypical individuals from individuals with schizophrenia and raise awareness regarding the neurological condition. To do so, we developed a sonification algorithm, modifying the pitch and tempo of given music clips based on fMRI signal characteristics. We also evaluated how participants perform in identifying the two neurological states and whether they can intuitively develop a deeper

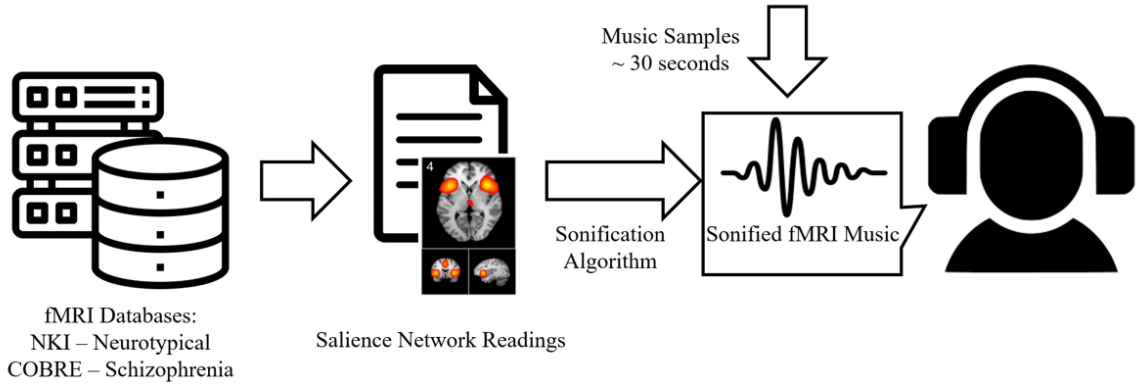

Figure 1: Study process showing data sources and methods used to generate sonifications presented to participants

understanding of schizophrenia with the short sonifications presented (Figure 1).

2. Related Works

2.1. Musical Parameters

A variety of musical parameters can influence user response to sonification [18]. A study performed on the effect of lyrics in music on neural processing found that, when language and music are combined in lyrical music, there was a shift to balancing the processing between the left and right superior temporal gyri [19]. This indicates that lyrics could influence user response to fMRI-based sonifications. As such, the presence of lyrics will be evaluated as an independent variable in this study. Additionally, the paper identified pop and rock as common and salient musical genres [20], which will be evaluated in addition to classical music, a musical genre that has long been evaluated in musical interventions [21-23].

Familiarity is another aspect that factors into music and sonification appreciation. Research has previously found that familiarity plays a crucial role in the engagement of users to music [24]. The study collected fMRI data from participants listening to both familiar and unfamiliar music and found that different processes are engaged depending on the degree of familiarity to music. Exposure to familiar music that matches user expectations can furnish direct access to emotional centers of the brain. In the present study, participants will report how familiar they are with each song they listen to.

2.2. fMRI Data Patterns

fMRI data can provide much information into how neurological states can modify brain patterns. Brain studies found that the salience network plays a crucial role in the regulation of sensory input [26] and abnormal activity patterns in this network have linked to various neurological and mental disorders including Autism Spectrum Disorder (ASD) [25] and Attention-Deficit/Hyperactivity Disorder (ADHD) [26]. The abnormal neural activity in the salience network is also found for individuals with schizophrenia such that schizophrenic individuals display aberrant salience [27, 28], which is reflected in fMRI data patterns. In this context, we will use salience network readings as the source of data that will be sonified in this study.

Past research has explored the sonification of fMRI data using 3D audio [29]. In the study, fMRI data streams were sonified and reflected activity of different areas of the brain using panning. The study, however, only sought to identify the aesthetic qualities of the sonification approach. On the other hand, the application of sonification for schizophrenia has seldom been used in the past. An exceptional study regarding the generation of sound that can reflect auditory hallucinations in individuals with schizophrenia has been conducted [16]. The aim of the auditory intervention was to reflect hallucinated voices an individual with schizophrenia might experience and adjust the tone of the voice to match what was felt by the user. While the study was successful at developing a model for replicating hallucinated voices, the study did not seek to apply the auditory intervention for a wider population that could reflect and learn about the neurological condition, which is a gap we seek to address in this study.

3. Method

3.1. Participants

A total of 24 participants were recruited for the study (M = 27.96 yrs, SD = 8.18). Participants were recruited from the university population via online advertisement. All participants provided informed consent approved by the university IRB and received monetary compensation of $ 10USD for their time.

3.2. Stimuli

Sound samples that were evaluated in this study were generated on MaxMSP. Data from two neurotypical individuals (from the Nathan Kline Institute – NKI – open-public dataset [30]) and two neurodivergent individuals with schizophrenia (from the Center for Biomedical Research Excellence - COBRE – available at http://openfmri.org/) were used to manipulate the pitch and tempo of short music tracks. The music tracks all lasted around 30 seconds.

Six original music tracks were used in this study. The selection of these music tracks was based on music genre and the presence of lyrics in the sample track (Table 1).

Table 1: Original music tracks manipulated in this study

Music Genre/Lyric Presence	Lyrics present in track	Lyrics not present in track
Classical	Hallelujah Chorus from Handel's Messiah	Daniel Veesey's Sonata No. 1 in F Minor
Pop	Dynamite by BTS	Every Time we Touch by Cascada
Rock	Living on a Prayer by Bon Jovi	Enter Sandman by Metallica

Sonifications were created through the following process:

First, fMRI data were selected from the COBRE and NKI datasets. The fMRI data of four individuals were selected, with two sets coming from the NKI dataset of neurotypical individuals and two sets coming from individuals with schizophrenia in the COBRE dataset. We narrowed the focus of the data to young adult data between the ages of 20 and 30 years old. The LAIRD network atlas [31] was selected in particular, and we utilized mean signals of voxels which were located in the salience network. We chose the salience network, the fourth column of LAIRD data, as research has demonstrated that aberrant salience is a defining characteristic of schizophrenia that can be observed in fMRI studies [27, 28]. Additionally, we sought to determine the viability of sonification as an intuitive tool for fMRI data differentiation. This criterion led us to select saliency as a single data category in this initial study.

In the MaxMSP patch, salience data of individuals were used to manipulate the pitch and tempo of the music track using the pitchshift function, which manipulates both pitch and tempo. The pitchshift values were set to oscillate with a 15% upper and lower limit. This selection was based on past research showing that changes of at least 12% are needed for accurate differentiation in tempo [32]. As the fMRI dataset becomes more sporadic and uneven, as is typical for schizophrenia [27], the music reflects those differences resulting in a distorted sound compared to the original music clip.

Each of the six original music tracks was modified using the data from the four selected individuals in the study, resulting in 24 sonified tracks in total, 12 tracks sonified using neurotypical data and 12 sonified using schizophrenic data.

3.3. Procedure

The procedure for the study began with obtaining informed consent from participants. They were then asked to complete a demographic questionnaire, including their age, gender, and familiarity with fMRI and other brain imaging techniques and/or schizophrenia as a neurodivergent state.

Next, participants listened to the original music samples that had been sonified, as well as all 24 sonifications. They were invited to share their thoughts on the music.

After this initial exposure to the sonifications, participants were presented with an identification task. They were informed that the sonified sound samples they heard were created using fMRI data from both neurotypical and neurodivergent individuals with schizophrenia. Study investigators then played two sonifications of the same original music sample, one created using neurotypical fMRI data and the other using data from an individual with schizophrenia. We counterbalanced the order of presentation of the two sounds for participants. Participants were asked to identify which sample came from a neurotypical individual and which came from an individual with schizophrenia. This process was repeated for a total of 12 pairs of sonifications.

Finally, the study investigators conducted a brief semi-structured interview, asking participants their thoughts on 1) how did they feel about the sonification method and music generated? 2) how did they identify which song was generated from neurotypical data and from schizophrenic data? 3) do they believe they would enjoy listening to songs modified through the sonification of fMRI data? 4) what was their perception of schizophrenia and the experiences of individuals with the condition following the study? 5) which type of song worked best for it in their opinion, and would they change anything with the method used?

4. RESULTS

4.1. Demographics

Out of the 24 participants recruited for the study, 11 were male, 11 were female, and two were non-binary.

In terms of familiarity with fMRI and other brain imaging techniques, 17 participants reported no familiarity with these methods, whereas seven participants reported being familiar with what fMRI and other brain imaging techniques, such as EEG and MRI, consist of.

In terms of familiarity with schizophrenia, 14 participants were not familiar with the neurological condition, and ten participants indicated they were familiar with schizophrenia.

4.2. Sonification Effectiveness: Accuracy

We compared the performance of individuals with identifying the neurological state of a given music sample when compared in pairs of neurotypical and neurodivergent data from individuals with schizophrenia. Since the score was based on a binary scoring system, performance data were analyzed with a binomial logistic regression.

It was found that music genre significantly influenced the likelihood of right guesses in the comparative task $\chi 2(2) = 13.21$, $p = 0.0014$. According to the odds ratios, classical music as opposed to pop music increased the likelihood of a right guess by a factor of 3.83, $p = 0.0002$. Classical music, when compared to rock music, also increased the likelihood of a right guess by a factor of 2.37, $p = 0.0218$ (as seen in Figure 2). For 96 neurological state guesses with classical music samples, participants made 83 correct guesses – 86.46%. For 96 neurological state guesses with pop music, participants made 60 correct guesses – 62.5%. As for rock music samples, out of 96 state guesses, participants made 70 correct guesses – 72.92%.

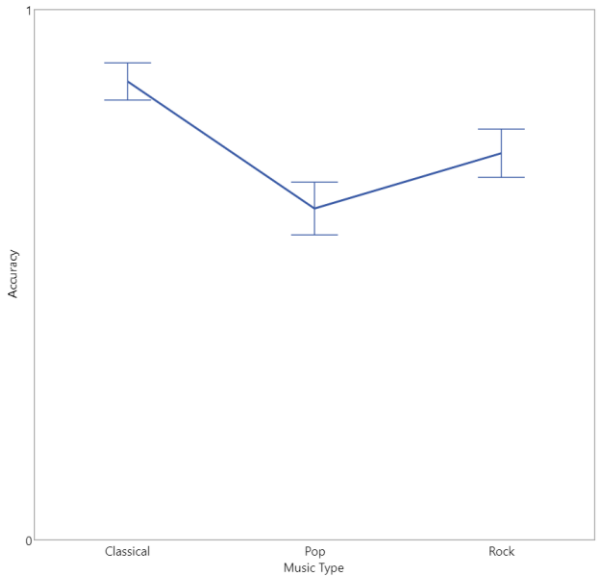

Figure 2: Identification Accuracy score based on music type

4.3. Semi-Structured Interview Results

4.3.1. Opinions on sonification

Participants expressed a wide range of opinions regarding the sonification method used in the study. Overall, 16 participants liked the music and approach used, five participants held neutral views, whereas three participants did not like the music generated.

Participants who liked the sonification method indicated great interest, such as P3 who mentioned: “It was really interesting to see the difference in the two types of sonification that was used. Overall, I think it was great to hear the differences”. Participants who held neutral views on the sonification indicated they were able to accurately guess the neurological state of different sound samples, such as P19 who said: “I feel the distortions generated in the songs really impacted the outlook of the original song”. On the other hand, reasons for disliking the sonification method were due to the distorted nature of the music, which was unpleasant, with P5 saying: “The music that was generated based on the perception of schizophrenic made me feel uneasy and uncomfortable”.

Participants were able to accurately understand the difference between neurotypical and neurodivergent sound samples and all indicated so in the semi-structured interviews. Participant views on songs they believed worked best were mediated based on sonification purpose and enjoyment:

- Classical music was noted as a music genre where differences between the neurotypical and neurodivergent samples were easy to recognize, albeit less enjoyable as a result: “Classical music worked best because it was easiest to distinguish whenever it did not sound right… Schizophrenic version of classical music was very difficult to listen to” (P5).
- Sonifications made using rock music were noted as enjoyable to listen to by participants who said: “I believe I would enjoy modified songs, especially the 'rock' type of songs as in such songs, there's a huge window of modification through the sonification of fMRI data” (P19); “Sandman song easily the best. Might try putting it in a very different key, that would make it interesting.” (P24).

When asked whether they would enjoy listening to more sonifications of fMRI data, 15 participants indicated further interest in the method as is, whereas nine individuals indicated either indifference or a desire to change the sound output of the sonifications before further usage, such as P9: “I don't think I'd enjoy that, since the notes and speeds were mostly changed for the worse, not for better. However, some metal heads might enjoy listening to them, due to the unique feeling they create”.

4.3.1. Opinions on sonification

Out of 24 participants, 21 participants expressed views showing an increased understanding of schizophrenia as a neurological condition.

Participants, who expressed views that show a greater understanding of schizophrenia, were able to intuit that individuals with schizophrenia may perceive the world differently than neurotypical individuals, with participants mentioning: “I think they perceive sounds in different tones and different speeds compared to a neurotypical” (P13) and “They have different perception from normal people” (P1). While P13 reported being familiar with schizophrenia, P1 was not familiar with the condition. Additionally, participants who were initially unfamiliar with schizophrenia were able to understand that neurological differences in brain function led to schizophrenia-induced sensations, as some mentioned: “Inferring from the increased distortion, the brain waves are much more irregular than a neurotypical person” (P17).

As for participants who did not show an increased understanding of schizophrenia, they mainly reported on the distorted nature of the music generated. The participants mentioned: “I think even listening to music can be painful for them” (P9), and “It seems real issue, I mean those sounds seemed really disturbing” (P14). These views show a limited understanding of the condition.

5. DISCUSSION

Our study aimed to explore the potential of sonifying fMRI data as a tool for raising awareness of neurodivergent conditions, particularly schizophrenia, and the influence of parameters such as music genre and lyric presence. We analyzed performance in an identification task and received feedback via semi-structured interviews.

Results showed that participants were able to identify the neurological condition of sonified clips with high accuracy. This was particularly the case with classical music, with an 86.46% accuracy rate. Results showed that music genre had a significant impact on participants' ability to distinguish neurotypical from neurodivergent fMRI data. Participants also expressed a preference for classical music and found unfamiliar music less disturbing. This preference to modify unfamiliar music instead of familiar music is an effect to investigate further, as past research indicated that familiar music could increase activity in different brain regions [24]. This effect could be due to an adverse effect of user expectations with the music not being met, as the sonified

output of familiar music sounds wrong and keeps being compared to the original music piece. This suggests that future sonifications may benefit from using unfamiliar music, though further comparison is needed.

With regards to subjective feedback regarding musical preference, people preferred classical music samples. Participants also indicated they liked or were less disturbed by unfamiliar music and this goes in line with performance findings, as a significant change in music that is recognizable would make it sound significantly worse. On the other hand, the preference for classical music over rock and pop music could be attributed to classical music having a positive physiological effect on therapy and other activities [33]. Another aspect is that the structure and keys of the provided classical music songs in this study could have influenced how participants perceive the sonifications.

With regards to participant opinions on the sonification method, the method we used was shown to be effective at conveying differences between neurotypical and schizophrenia. Participants mostly responded in a way that showed a greater understanding of the condition. This matches with performance scores achieved in the study, as participants correctly guessed the neurological state of the sonification samples we presented, especially in the case of classical music.

When asked about their understanding of schizophrenia following the study, participants expressed sympathetic views and generally agreed they could understand and relate better to individuals with schizophrenia. Results show that sonification could help reduce mental health stigma by helping contextualize the experience of schizophrenia, and thus, help reduce feelings of social alienation [6, 8]. Furthermore, the study showcased the potential of sonification as a tool for increasing mental health awareness in a short-term intervention. Study findings suggest that sonification could be implemented in short-term settings as an effective primer on schizophrenia. Conducting such an activity as part of a STEAM (STEM + Arts) education program could spark participant interest in science. Past research has shown that music technology and art can help motivate students [34, 35] and lead to positive academic outcomes. However, further work is needed to evaluate whether sonification could convey a wider variety of neurological states, such as ASD.

6. CONCLUSION

In this study, we evaluated the effectiveness of sonification as a tool to help differentiate the fMRI brain activities of neurotypical individuals with individuals with schizophrenia and raise awareness regarding this neurological condition. While further design work is needed to refine the methodology used, the study develops a new way to raise awareness of neurological states and mental health. The findings of the study would integrate well with STEAM education principles as an effective delivery method to instruct students and the wider population on the reality of living with different neurological conditions. In this study, auditory hallucinations and salience network disturbances typically experienced by individuals with schizophrenia were conveyed to participants. Future work could seek to evaluate how effective sonification could be in conveying aspects of other neurological conditions, such as ASD.

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