SCHIZOSYMPHONY:
FROM SCHIZOPHRENIA BRAINWAVES TO NARRATIVE SOUNDSCAPES

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ABSTRACT

Schizophrenia, a complex and lifelong mental disorder affecting millions globally, poses challenges in understanding, diagnosis, and treatment. To enhance public awareness of the brain imaging data related to this condition, we present two innovative spatial sonification approaches: a tonal approach and a narrative soundscape approach, translating functional magnetic resonance imaging (fMRI) data from schizophrenia patients into spatial sound. Central to our proposal is *Schizosymphony*, an artistic composition incorporating urban soundscapes. Our goal is to present a new perspective on analyzing brain imaging data regarding symptoms and mental states of patients by utilizing artistic sonification technology to represent data through sound. Furthermore, we aim to enhance the connection between the public and data through the artistic potential of data sonification, providing immersive artistic experiences to listeners through spatialized sound. Our fMRI sonification approaches not only facilitate public understanding and support for mental illnesses, but also have the potential to aid expert diagnosis and develop music therapy.

1. INTRODUCTION

Mental disorders such as schizophrenia affect millions of people worldwide [1]. Schizophrenia is a complex chronic disorder characterized by positive symptoms (hallucinations and delusions), negative symptoms (avolition, anhedonia, and social withdrawal), as well as cognitive and behavioral impairment. Considering its high prevalence and lifelong nature, it is important to understand heterogeneous pathological mechanisms, and develop objective diagnostic and therapeutic strategies. With the development of brain imaging techniques, schizophrenia has been further characterized by neurological structural and functional alterations, such as functional dysconnectivity derived from functional magnetic resonance imaging (fMRI) data [2].

Using sound as a means to perceive information highlights the remarkable capability of the human auditory system [3]. Even in complex environments, it is capable of discerning intricate sounds effectively. This emphasizes the potential of leveraging the auditory system as a primary interface for data transmission. The capacity to selectively focus attention on auditory objects and discriminate auditory stimuli through learning reveals the diverse range of opportunities in data sonification. When we listen to audio data, our brains are able to receive, recognize, and process new information [3]. Specifically, brain activity obtained from fMRI scans presents significant challenges in data analysis due to its high-dimensional, sparse, and noisy nature. Spatial sonification, particularly through spatial music, emerges as an appropriate method for representing the complex patterns in brain imaging data [4].

Here, we propose two spatial sonification approaches, including one tonal approach and one narrative soundscape approach, to translate fMRI data from schizophrenia patients into spatial audio. The tonal approach converts the preprocessed and decomposed fMRI signals from time domain to frequency domain through spectrum analysis. The narrative soundscape approach maps the localized brain network activities to audio elements in urban scenes. The key creation of the soundscape method is an artistic composition – *Schizosymphony*. It creates a unified urban soundscape by representing daily life moments typically experienced by schizophrenia patients through urban sounds. Our fMRI sonification methods can be integrated in multimedia installations to promote public understanding and support of mental illnesses through interactive art experiences.

2. BRAIN IMAGING DATA

2.1. Dataset and Data Preprocessing

We used the Functional Biomedical Informatics Research Network (FBIRN) dataset[1] [5] including 160 controls and 151 patients diagnosed as schizophrenia. The resting-state fMRI data in the FBIRN dataset were acquired using a standard gradient-echo echo-planar imaging (EPI) sequence with repetition time (TR) $=$ 2000 ms, echo time (TE) $=$ 30 ms, flip angle (FA) $= 77^\circ$, slice thickness $=$ 4 mm, and slice gap $=$ 1 mm.

The fMRI scans in the FBIRN dataset were preprocessed by the statistical parametric mapping toolbox[2] in MATLAB 2016 programming environment. We first dropped the first five scans for the sake of signal equilibrium. We then performed motion correction, slice-timing correction, spatial registration to the standard Montreal Neurological Institute (MNI) space using an EPI template, and resampling to $3 \times 3 \times 3$ mm^3 isotropic voxels. The resampled fMRI data were further smoothed using a Gaussian kernel with a

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[1] The FBIRN dataset is available at `https://www.nitrc.org/projects/fbirn/`.

[2] SPM12: `http://www.fil.ion.ucl.ac.uk/spm/`.

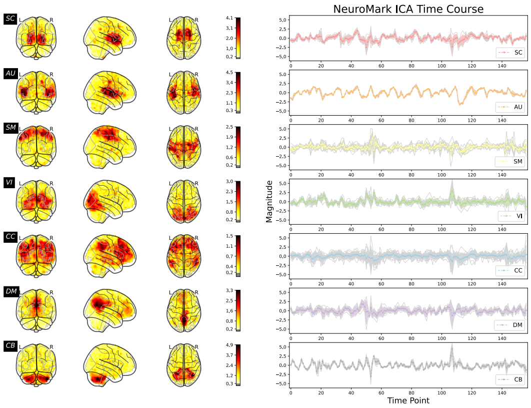

Figure 1: NeuroMark ICA spatial maps (left) and time courses (right) of intrinsic connectivity networks for one schizophrenia patient. Left: The red areas highlight the spatial components from each functional domain. Right: The gray solid lines are the time courses corresponding to 53 ICNs. The colored dashed line and shaded area indicates the mean and standard deviation of the time courses for each of 7 functional domains, respectively.

full width at half maximum (FWHM) = 6 mm. There are 157 scans for each subject after the preprocessing steps.

2.2. NeuroMark Pipeline

The preprocessed fMRI scans were further processed by the NeuroMark pipeline[3] [6]. Specifically, we estimated 53 spatial components and corresponding time courses using the spatially constrained independent component analysis (ICA) [7] for each subject. The spatial components are the spatial maps of intrinsic connectivity networks (ICNs). These 53 ICNs can be grouped to 7 functional domains (FDs) according to their functional properties, including the subcortical (SC), auditory (AU), sensorimotor (SM), visual (VI), cognitive control (CC), default mode (DM) and cerebellar (CB) domains [6]. For each ICN, we obtained the voxel location corresponding to the highest absolute intensity in the three-dimensional coordinate system of the standard MNI space. Next, we performed four postprocessing steps on the estimated time courses, including detrending, removing head motions, dispiking, and filtering with 0.15 Hz low-pass filter. Figure 1 visualizes the spatial map of all ICNs from each FD (left), and the corresponding time courses for all ICNs and the average time course within each FD (right) for one schizophrenia patient.

3. SONIFICATION APPROACHES

3.1. Tonal Approach

The tonal approach was inspired by previous research on fMRI data sonification. While there has been ongoing interest in sonifying brain data, most efforts have focused on electroencephalogram (EEG) data [8, 9, 10], with attempts at fMRI data sonification being exceedingly rare. A parameter-mapping sonification approach was introduced in 2011, which generated harmonic and texture-based sounds from fMRI data [11]. This was followed by *Neurospaces* in 2014, a musical composition employing spectralism techniques and spatial composition to transform fMRI data into music [12]. However, further aesthetic exploration of fMRI data sonification remains very limited.

Table 1: Frequency ranges (Hz) for seven functional domains.

Functional Domain	Frequency Range (Hz)
SC	440 – 469.73
AU	469.73 – 482.18
SM	482.18 – 542.41
VI	542.41 – 610.17
CC	610.17 – 762.09
DM	762.09 – 835.15
CB	835.15 – 880.00

Our tonal approach began with an analysis of the previous work, aiming to implement a tonal method suitable for the fMRI data of schizophrenia patients. This sought to aesthetically transform the parameter-mapping approach from the perspective of microtonality [13] and enable a more artistic tonal approach through object-based spatialization [14] of the resulting abstract sounds.

To sonify the time course from each ICN, we generated waveforms based on the principles of musical scale generation which show the numeric characteristics of the data. Starting with a fundamental frequency of 440 Hz, we proportionally calculated the frequency range for each of 7 FDs based on its respective range, resulting in the acquisition of the frequency range. We then established a new scale proportionally based on the size of the group of ICNs within one octave around the unique value of the fundamental frequency set for the 7 FDs (see Table 1). The pitch method is based on the characteristics of the data, specifically the time series data extracted from the 53 distinct ICNs within the 7 FDs.

After data preprocessing, we obtained NeuroMark ICA time courses from 53 ICNs, each with 157 time points. These neuroimaging features were transformed into waveforms through spectral conversion based on the magnitude of its changes. Therefore, waveforms are mapped to predetermined frequency ranges as described in the proportional scale generation method. Within the scale, the variations in the data freely depict changes in tonality. To achieve this freedom, the data within each region is endowed with uniqueness through microtonality. However, these attempts had limitations in musical expression due to the sharp changes in the time points inherent in fMRI data, which restricted the aesthetic realization of the sound. These limitations led to the conception of another artistic approach capable of overcoming the nonlinear constraints inherent in the characteristics of fMRI data.

3.2. Soundscape Approach

3.2.1. Narrative Soundscape Sonification

Based on the narrative soundscape theory [15], we propose an aesthetic and creative data-driven sonification approach using fMRI data from schizophrenia patients.

The soundscape approach uses the sounds from daily life to form an audio scene with the symptom characteristics of schizophrenia, assigning spatial sounds using the 7 FDs and 53 ICN locations as the basis for sonification. Each of the 7 FDs

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[3] The NeuroMark pipeline can be found at `http://trendscenter.org/software`.

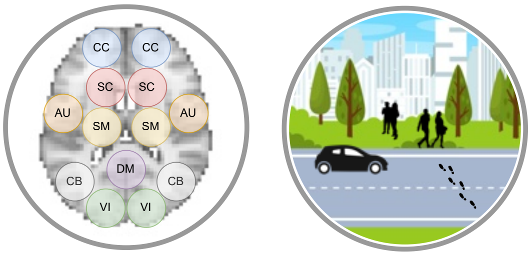

Figure 2: Relative axial location of brain functional domains (left) and the corresponding visual elements in the urban scene (right).

forms a sound theme based on its location, and each of the 53 ICNs is assigned an individual sound within the theme. The loudness and movement in the sounds change over time, aurally revealing the temporal variations in the data. Each of the 7 FDs also uses an additional pair of sounds associated with positive and negative values based on the theme. These sounds are located at a central point in each FD and are used to represent specific data points in the analysis to illustrate patient idiosyncrasies or to highlight data trends. The narrative soundscape sonification opens up the possibility of understanding the neuroimaging characteristics associated with schizophrenia in the context of the tangible world. Furthermore, immersion strategies [15] can be implemented through spatial audio, offering a new pathway to utilize trained auditory abilities connected to everyday sounds [3].

3.2.2. *Schizosymphony*

Central to our narrative soundscape proposal is *Schizosymphony*[4], an artistic composition incorporating urban soundscapes. The sonification of the narrative soundscape is implemented by assigning different audio elements to 53 ICNs based on the top categories allocated to 7 FDs. Overall, it creates a unified urban landscape by connecting moments from daily life typically experienced by a patient to construct a single sound scene. Moreover, additional sounds associated with positive and negative values separately for each category to further demonstrate the data trends.

In order to implement a dynamic and realistic soundscape, a different sound is assigned to each of the 53 ICNs based on the theme assigned to the respective FD. The 7 FDs are mapped to visual elements in the urban soundscape [16], according to Table 2. Each visual component in the urban scene is selected according to the relative spatial location of brain functional networks (Figure 2), clearly revealing spatial relationships such as above and below or effectively illustrating directionality amidst the urban landscape.

3.3. Spatialization for FMRI Data

Spatialization is utilized as a key element to reveal the characteristics of the tonal data. The tonal data is transformed into 53 individual sound sources based on the location data of ICNs. These sound sources are then grouped into 7 higher-level regions, determined by the coordinated locations of 7 regions. The locations of these 7 regions are calculated based on the minimum and maximum values of the grouped subregion location data.

Table 2: Audio elements based on visual components for seven functional domains.

Functional Domain	Visual Component	Audio Element
SC	Open Space	Air
AU	Building	Construction
SM	Green Space	Trees
VI	Road	Footsteps
CC	Sky	Wind
DM	People	Chatter
CB	Vehicle	Cars

3.3.1. *Dynamic Spatialization*

To enable a more intuitive understanding based on the positioning of the brain, we sought to reveal the magnitude based on location. For this purpose, we created sound movements based on the locations of 7 regions set according to actual brain areas. The 7 regions have 53 individual subregions, with each of the 53 virtual sound sources being assigned a unique initial position. These allocated positions serve as starting points for spatial movement, acting as reference points to prevent data confusion and to delineate spatialization more clearly by constraining the range of movement. When expressing the movement of sound based on the location data, cross-movement within the regions is generated to reveal the correlation of functional brain activity. The extent of such cross-movement is determined within the range of brain activity, based on the ranking system of intra-region activity, derived from the fMRI data, determining the magnitude of movement within the scope of brain activity.

3.3.2. *Interpretation of Dynamic Changes*

In the tonal approach, dynamic changes generate movements of sounds using position data generated for 53 regions as starting points and 157 time points as peak points, along with amplitude changes. Combining spatial audio with different tonalities can enhance the effectiveness of conveying information in the process of sonifying data, including positional information. Through the process of inducing auditory focus on specific data, sound not only becomes spatially distinguishable but also effectively reveals the highs and lows of the data through the movement generated by its variation. This can serve as a means of implementing visual perception of movement in auditory concepts, thereby increasing individual listening opportunities for subtly implemented tonalities within the 7-scale range.

In the soundscape approach, dynamic changes are associated with variation in the presence of sound, providing greater freedom in the way various sounds are blended, following the theory of narrative soundscape. The manner in which the presence of various sounds in a sound scene is adjusted along with spatial audio effects such as reverb, effectively showcasing the quality of the sound. Simultaneously, spatial effects are generated within 7 constrained ranges based on characteristics to seamlessly integrate sound into the sound scene. This enables listeners to naturally focus on sonified data while gaining an overall understanding of the scene. Each individually assigned sound undergoes pre-mixing before amplitude modulation by the data, ensuring the initial balance is set for configuring the whole sound, with the size of the sound changing sequentially according to the data variation. The application of

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[4] The link for the sound demo is publicly available at the GitHub repository: `https://github.com/L42i/Schizosymphony`

sonification may require composers to manually adjust parameters for transforming location information and applying audio effects to enhance musical persuasiveness. Additionally, scaling adjustments may also be necessary to convert the data into Ambisonics format for implementing spatial audio representing the location information of 7 FDs corresponding to the 53 ICNs. It is advisable to limit alterations to the sound itself when changing parameters for individual sounds in sonification, in order to maintain the fundamental background of the sound scene while ensuring clarity in data representation. Therefore, alongside proposing sound editing techniques such as amplitude modulation and tempo adjustment, it is important to adhere to the essence of the sonification task and the compositional background of the sound scene.

4. DISCUSSION

There are several limitations in the current methods. One limitation of the tonal approach is that it maps the ICN time courses to the sounds directly. The generated sound might not be smooth or continuous due to the spikes in the ICN time courses. To address this issue, we may further perform smoothing on the brain time-series data prior to sonification. A limitation of the soundscape approach is that the sound scene itself might be abstract compared to the real ambience sound, because the location of the brain region is not exactly identical to the urban soundscape.

Moreover, the future directions of Schozosymphony include audio evaluation and therapy development. Aesthetics and effects of sonification results can be evaluated by questionnaire feedback collected from listeners. Additionally, soundscapes generated from fMRI data can be linked to narrative soundscapes designed for therapeutic purposes in patient care. This could aid in understanding symptomatic manifestations in schizophrenia patients, potentially assisting in diagnosis. Specifically, creating narrative soundscapes from fMRI data can create a perceivable auditory scene, which could be utilized in the Bonny Method of Guided Imagery and Music (GIM), a branch of music therapy that harnesses the patient's imagination, or solely its use in music and imagery for relaxation [17].

5. CONCLUSION

We present two spatial sonification approaches to generate spatial audio from neuroimaging data of individuals with schizophrenia. The tonal approach transforms temporal features from fMRI scans into waveforms via spectral conversion. The narrative soundscape approach constructs audio scenes using daily sound elements in an urban setting. Our proposed methods aim to understand the complex mental states of schizophrenia patients from an auditory perspective, and to promote public understanding of mental illnesses.

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