# Sonification of Harmonic Signals in the Brain

Emily Wertheimer '20

Faculty Advisor: Dan Lloyd, Ph.D. Departments of Neuroscience and Philosophy

Trinity College
HARTFORD CONNECTICUT

## Abstract

This study was conducted in order to determine the validity of data sonification as it pertained to resting-state functional magnetic imagine (rsfMRI) data. Particular attention was paid to the sonification of harmonic signals present in these fMRI scans. To achieve this aim, a thorough review of the literature pertaining to data sonification was conducted, followed by the creation of a YouTube video that contained an animated graphic of the density of harmonic signals in a resting-state scan. The sonified rsfMRI scans assisted us in perceptualizing the data, while the "musified" data began to clarify the pulsing patterns of harmonic activity as revealed by the fMRI scans.  This result is significant due to its novel, sonic approach to observing and classifying harmonic brain signals.

## Introduction

Sonification is defined as the use of non-speech audio to perceptualize data (Flowers, 2005). More specifically, sonification is "the transformation of data relations to perceived relations in an acoustical signal for the purposes of facilatating communication or interpretation" (Kramer et al., 2005). This technique confers many benefits compared to conventional data analysis, specifically enhanced temporal, spatial, amplitude, and frequency resolution by taking advantage of humans' high level of perceptual auditory resolution (Flowers, 2005).  Previous sonfication endeavors have focused on using sound to aid in ECG, EKG, pulse oximeter monitoring, and advanced patient monitoring display (Krather et al., 2017) (Sag et al., 2017). Furthermore, multidimensional auditory displays have  proven to outperform conventional methods of data perceptualization (Pollack & Ficks, 1954). This project sought to sonify resting-state fMRI data in order to determine the degree of harmonicity of neural signals in the resting-state. As there has been no previous research in this specific area of neuroscience, the project sought to exploit the aforementioned benefits of sonification to perceptualize the data.

**Definitions**

- The **resting state fMRI** is an experimental condition in which the subject remains idle while in the fMRI scanner. Thus, resting state fMRI scans measure spontaneous neural activity. Previous research has discovered that the resting state features organized patterns of oscilations distributed along the brain's cortical regions (Atasoy, 2017).
- **Harmonic signals** (see *Figure 1*)  are those that are comprised of a fundamental frequency combined with larger integer multiples to form a harmonic signal (Atastoy 2017). Previous research has suggested that harmonics for patterns that are the basis of neural activity (Atasoy, 2017).
- **Parameter mapping** (see *Figure 2*) is an approach to sonification in which an singular characteristic of the fMRI signal is directly represented by a sonic feature (Flowers, 2005).

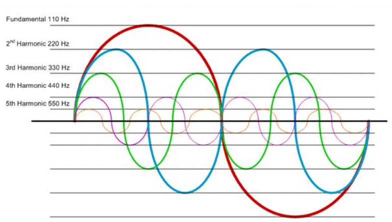


*Figure 1 details the fundamental frequency (top) followed by its corresponding integer partials, or harmonics (Peters, 2018).*

## Methods

These methods were adapted from The Temporal Connectome: From stationary modes to musical moments, authored by Dan Lloyd (2018).

*Obtaining Data*

- Resting state fMRI data of 180 subjects with 900 brain images each were obtained from the Human Connectome Project (HCP). These images were scanned at 7 Tesla at the University of Minnesota and were received for secondary analysis.

*Preprocessing*

- The HCP processed this data beforehand by removing spatial distortions and errors from subject motion by using their minimal preprocessing pipeline. Resting state images were also normalized to a global mean before being used for analysis.

*Analysis*

- The rsfMRI preprocessed data yielded signals from approximately 96,000 voxels, where one image per second was rendered to ultimately yield 900 images.
- To determine the harmonicity of the rsfMRI signals, each signal was assumed to be noisily periodic and was analyzed using the continuous wavelet transfrom.
  - Wavelets are rapidly-decaying, wavelike oscillations with a mean of zero that exist in several shapes and sizes (Ricker, 1953).
  - The continuous wavelet transfrom was used to capture momentary changes in the original, continuous signal over time. This transformed reavealed the frequency component from second to second for the duration of the signal.
- Harmonic signals are a subclass of periodic signals and are comprised of the fundamental frequency and its larger integer multiples. To determine if harmonic signals were present, calculations were performed to test for subfrequencies existing in integer relationships. The harmonic frequencies that exceeded the 95th percentile in amplitude were selected for further analysis.
  - Voxels containing multiple harmonic components were given a "harmonic score," or the sum of the harmonic hits.
- All harmonic scores were summed for each of the 900 seconds to create an aggregate signal of these harmonic voxels. Fourier analysis was then performed on this aggregate signal to determine its component frequencies. These component frequencies were then examined for harmonic relationships from which the top 14 in amplitude were selected.
- All harmonic voxels were then matched to the best-fit frequency time course. The top fifty of these pairings were kept and averaged while also noting the which voxels were mapped to the original frequency.

*Video creation*

- Voxel locations were converted into a video that displayed these varying amplitudes. The amplitude of each frequency was mapped onto 20 notes of a pentatonic scale so that signal intensity was paired with pitch. Each of the 14 channels allowed by the Midi synthesizer could thus be represented by separately synthesized instruments and, in doing so, represent the whole of cortical activity during the rsfMRI scans (see *Figure 2*).

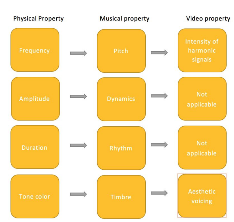


*Figure 2 shows the transformation of the four cardinal musical properties of music to the four cardial perceptual properties of music. These properties were then used as mapping parameters for the creation of the video.*

## Results

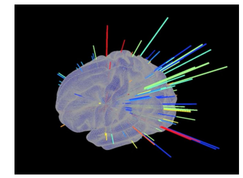

*Figure 3 shows an example of an image rendered from the sonified video. The color of each of the bars represents a different spatial location in the brain while the length of each of the bars represents the magnitude of the signal.*

*Please refer to video on screen.*

## Conclusions

*General Conclusions*

- The original aim of this study was to assess the validity of data sonification as a means of perceptualizing rsfMRI data with particular respect to harmonic signaling in the brain. The results of this project revealed that sonification and musification confer additional advantages to conventional data representation. For example, sonification allowed for the easy identification of outliers and general trends in the data set, while musification allowed for easy identification of patterns in the dataset. These results adhere closely to previous research into auditory data representation in which it was found that sonified data is capable of being accurately and precisely perceptualized via the human brain (Flowers, 2005) (Krather et al., 2017).

*Remaining Questions and Future Directions*

- One potential area of research to pursue could be the definition of the appropriate usage of musification versus sonification. We believe that this area is ripe for future research given the potential power of auditory data representation.
- Parameter mapping remains another area of interest. This aspect of sonification is novel to rsfMRI auditory display and future research is needed into which properties of sound should represent which properties of neural activity.

## References

Flowers, J. H. (2005, June 6). Thirteen Years of Reflections on Auditory Graphing: Promises, Pitfalls, and Potential New Directions. Retrieved July 24, 2018, from http://sonify.psych.gatech.edu/ags2005/pdf/AGS05_Flowers.pdf

Walker, B. N., & Nees, M. A. (2005). Theory of Sonification. In *Principles of Sonification: An Introduction to Auditory Display*. Retrieved July 24, 2018, from http://sonify.psych.gatech.edu/~ben/references/nees_theory_of_sonification.pdf

Kather, J. N., Hermann, T., Bukschat, Y., Kramer, T., Schad, L. R., & Zöllner, F. G. (2017, March 20). Polyphonic sonification of electrocardiography signals for diagnosis of cardiac pathologies. Retrieved from https://www.nature.com/articles/srep44549

Sag, N. (June 2017). Proceedings from the Journal of Acoustical Science. Retrieved from https://asa.citation.org/doi/10.1121/1.1917759.

Pollack, I. Ficks, L. (1954, March). Information of Elementary Multidimensional Auditory Displays. 26(2): 155-158.

Atasoy, S., Kringelbach, M. L., & Pearson, J. (2017). Harmonic Brain Modes: A Unifying Framework for Linking Space and Time in Brain Dynamics. *The Neuroscientist.* Advanced online publication doi:10.1177/1073858417728032

Harmonic. (n.d.). Retrieved July 26, 2018, from http://www.cchrispeters.com/SynthesisTerms/Harmonic.htm

Ricker, N. (1953). "Wavelet Contraction, Wavelet Expansion, and the Control of Seismic Resolution." *Geophysics* 18(4).

## Acknowledgements

I would like to thank Professor Lloyd for his guidance and assistance throughout this project. I would also like to thank my lab partner, Rachel Fox, for her assistance and support throughout this project.