Natural acoustic stimuli reveal tonotopic frequency maps in primary auditory cortex

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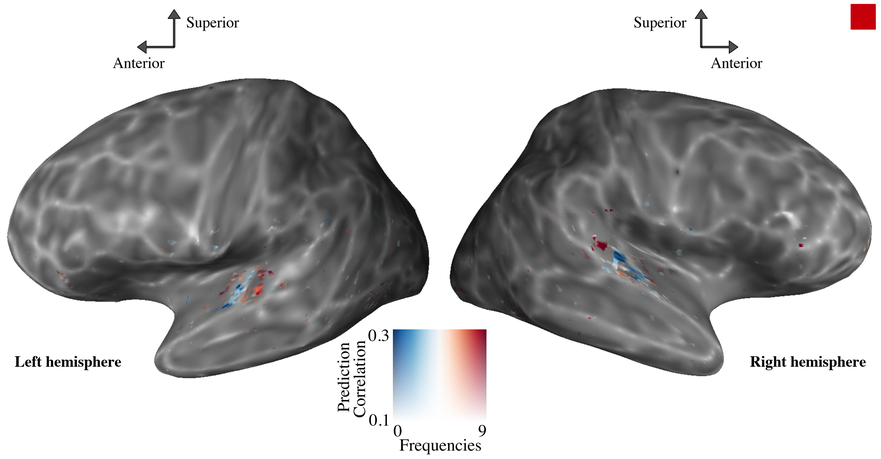
Introduction

Neuroimaging studies have previously shown that frequencies are spatially organized in the primary auditory cortex[1], [2], [3], revealing a tonotopic map that is similar to the spatial organization (retinotopy maps) of the early visual cortex. However, tonotopic maps are neither as consistent across subjects nor as detailed as the comparable retinotopy maps. One possible reason is that most prior studies used synthetically created tones to probe frequency-dependent responses[1]. However, complex natural stimuli are more salient and often result in increased fMRI signal[2], [3], [4]. In this study, we used natural acoustic stimuli (piano music and complex non-linguistic human vocalizations) to reveal tonotopic organization from natural sounds. We first extracted frequency features from the stimuli using two models: (1) a spectrogram of the sound files containing frequency information, and (2) a binary matrix that indexes the occurrences of different frequenciess. We then applied a voxel-wise encoding modeling approach to map these features to each and every unit of activation in the brain. We compared the resulting maps from the full natural acoustic stimuli (piano music) to the natural but controlled stimuli (nonlinguistic human vocalizations) presentation by projecting the model weights onto the cortical surfaces. This procedure revealed a mirror symmetric tonotopic map across Heschl's gyrus in primary auditory cortex. The controlled stimulus probed primary auditory cortex more successfully and revealed a clearer tonotopic map. However, the natural stimulus, as expected, was more salient and illicited a stronger fMRI signal.

Results

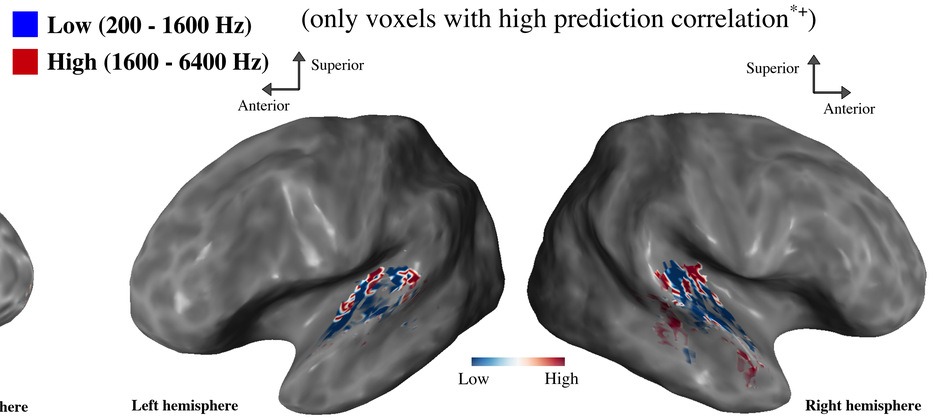
Binary Feature Matrix (controlled)

(only voxels with high prediction correlation*)



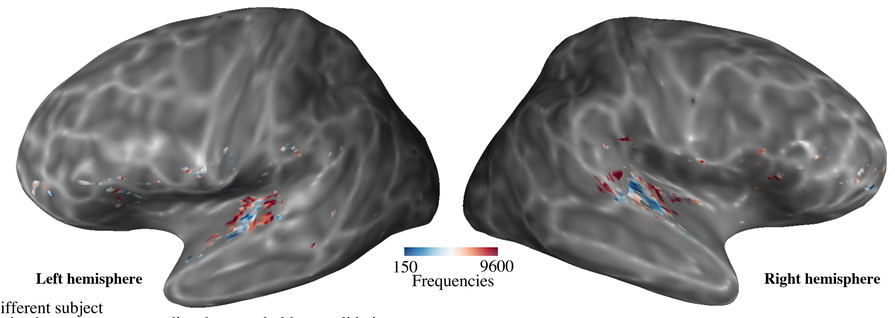
Spectrogram Feature Matrix (music)

(only voxels with high prediction correlation*+)



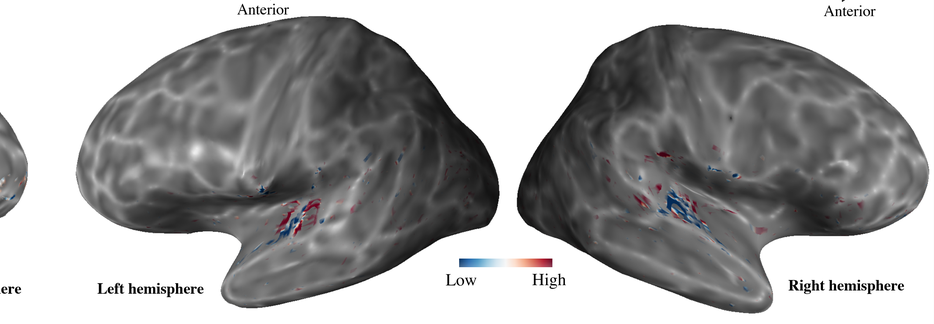
Binary Feature Matrix (controlled)

(only significant** voxels)



Spectrogram Feature Matrix (controlled)

(only voxels with high prediction correlationǂ)



\+ Different subject
* Trained on seven runs, predicted on one hold-out validation set
** Significance threshold of less than or equal to 0.05
ǂ Trained on six runs, predicted on one hold-out validation sets

Methods

Experimental Design

One human subject for each stimulus

Stimuli

~ 134 minutes of classical piano music
~ 60 minutes of band-pass filtered non-linguistic vocalizations

fMRI Parameters (music)

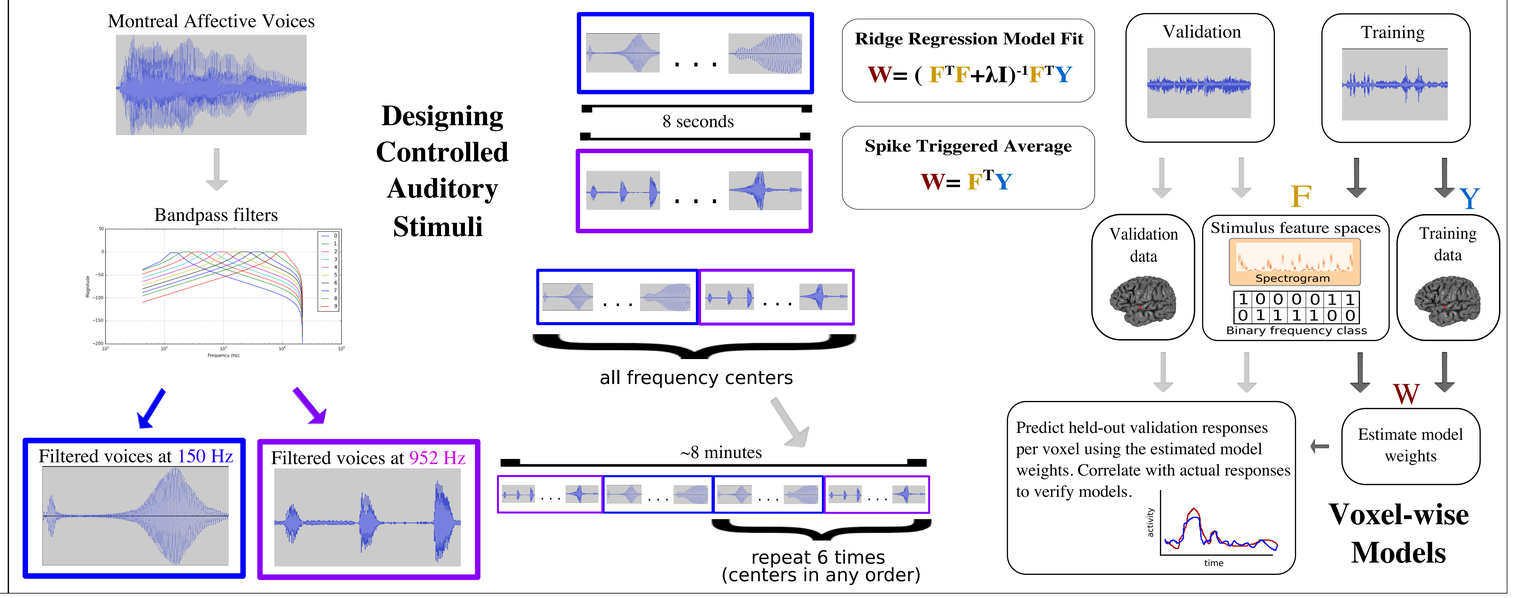
TR: 2.0045 seconds
Voxel size: 2.24 x 2.24 x 3.5 mm^3
Full brain

fMRI Parameters (vocal)

TR: 2.0 seconds
Voxel size: 2.11 x 2.11 x 2.0 mm^3
Oblique slice

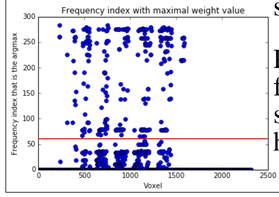
Bandpass Filter Frequency Centers (Hz)

150	1512
238	2400
378	3810
600	6048
952	9600



Future Directions

In order to fully compare the two different stimuli, more data must be collected from more subjects using both stimuli.



Preliminary analysis of frequency selection suggests grouping low and high frequencies differently.

References and acknowledgements

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