Processing of Natural Sounds in the Auditory System of Songbirds

Sloan-Swartz Meeting San Diego - 2003

Is the auditory system tuned to natural sounds?

No to frequency spectrum.

Yes to modulation spectrum.

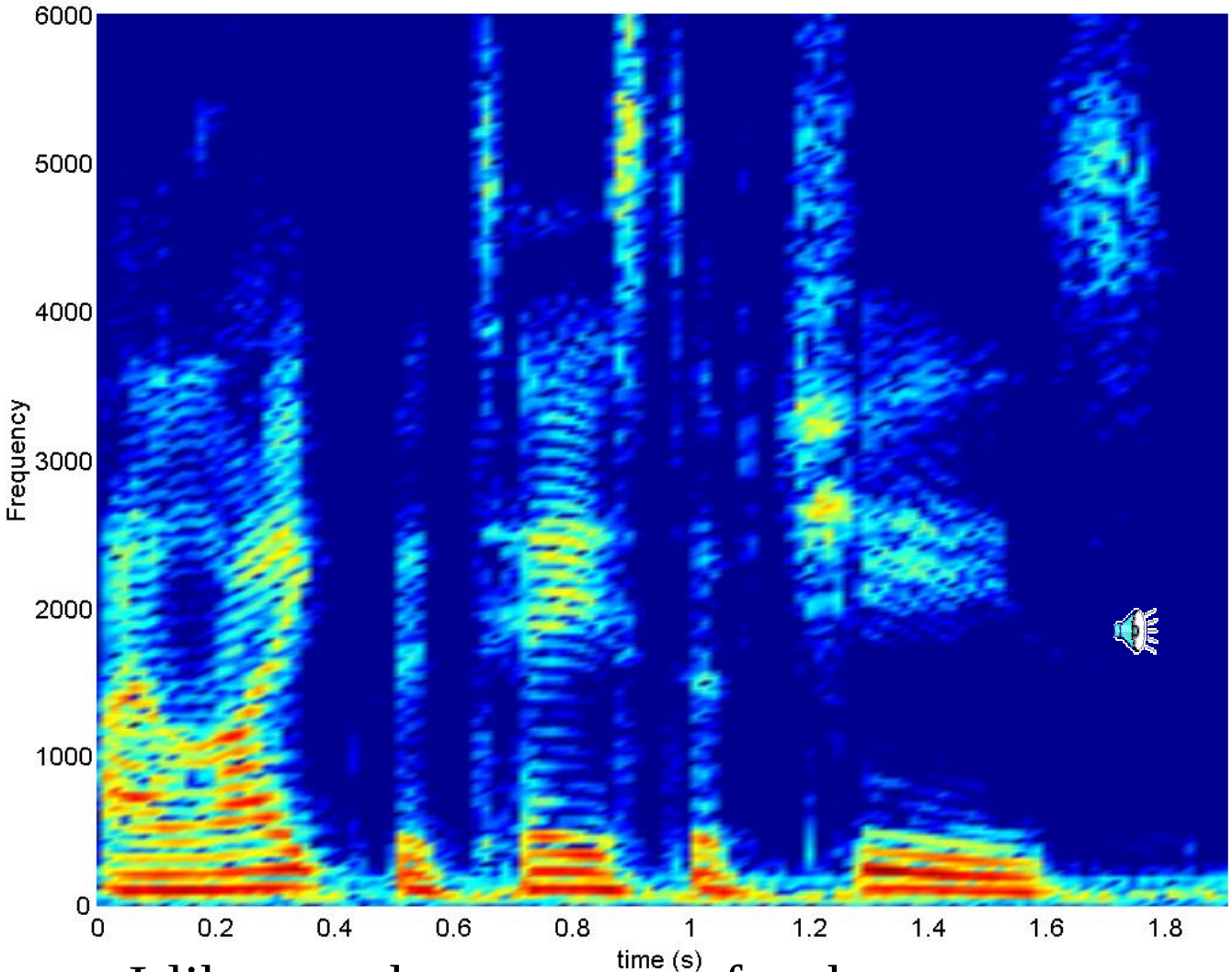
Processing of Natural Sounds in the Auditory System

1. Modulation Spectra of Natural Sounds.

2. Spectro-Temporal Receptive Fields (STRF) and Modulation Transfer Function (MTF).

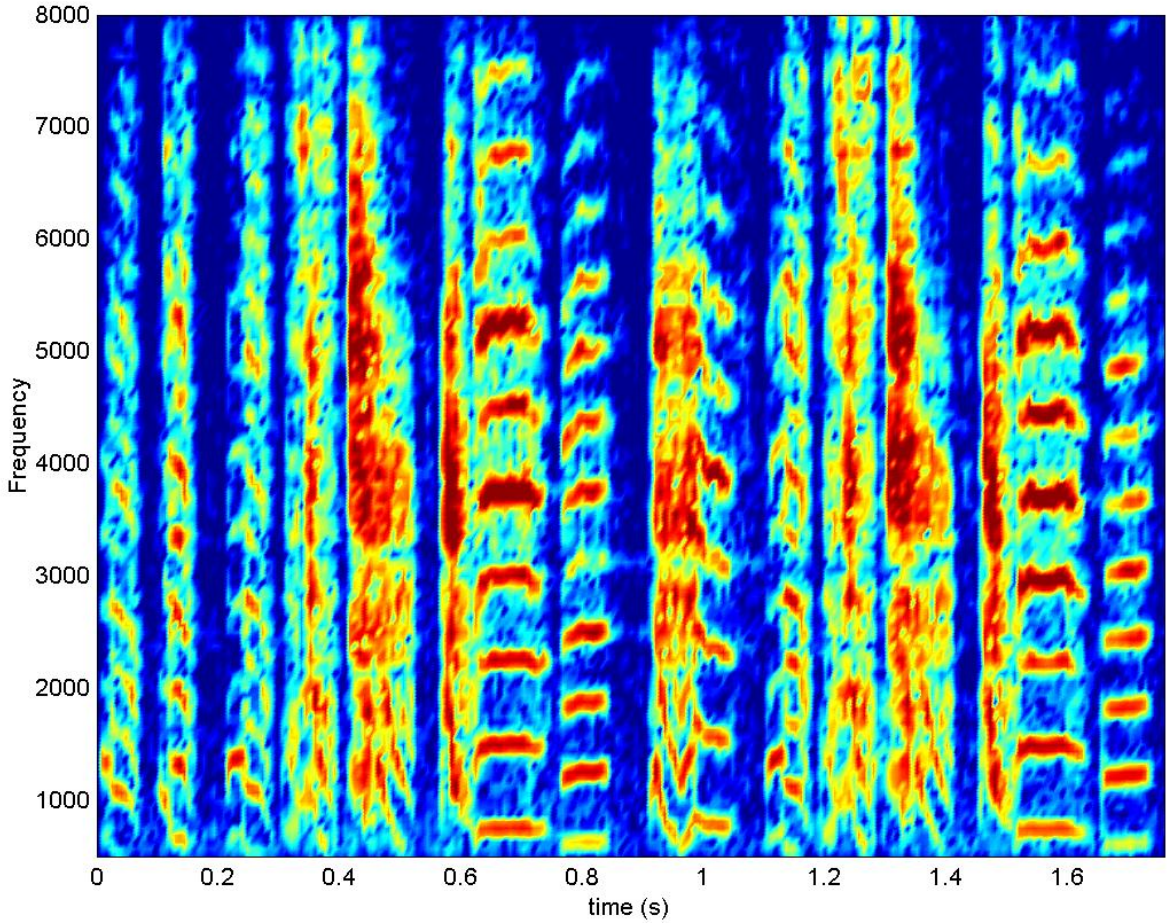
3. MTF Tuning for Modulation Spectra of Natural Sounds

Spectrographic Representation of Speech



I-like the taaaste of cheeeeeee se

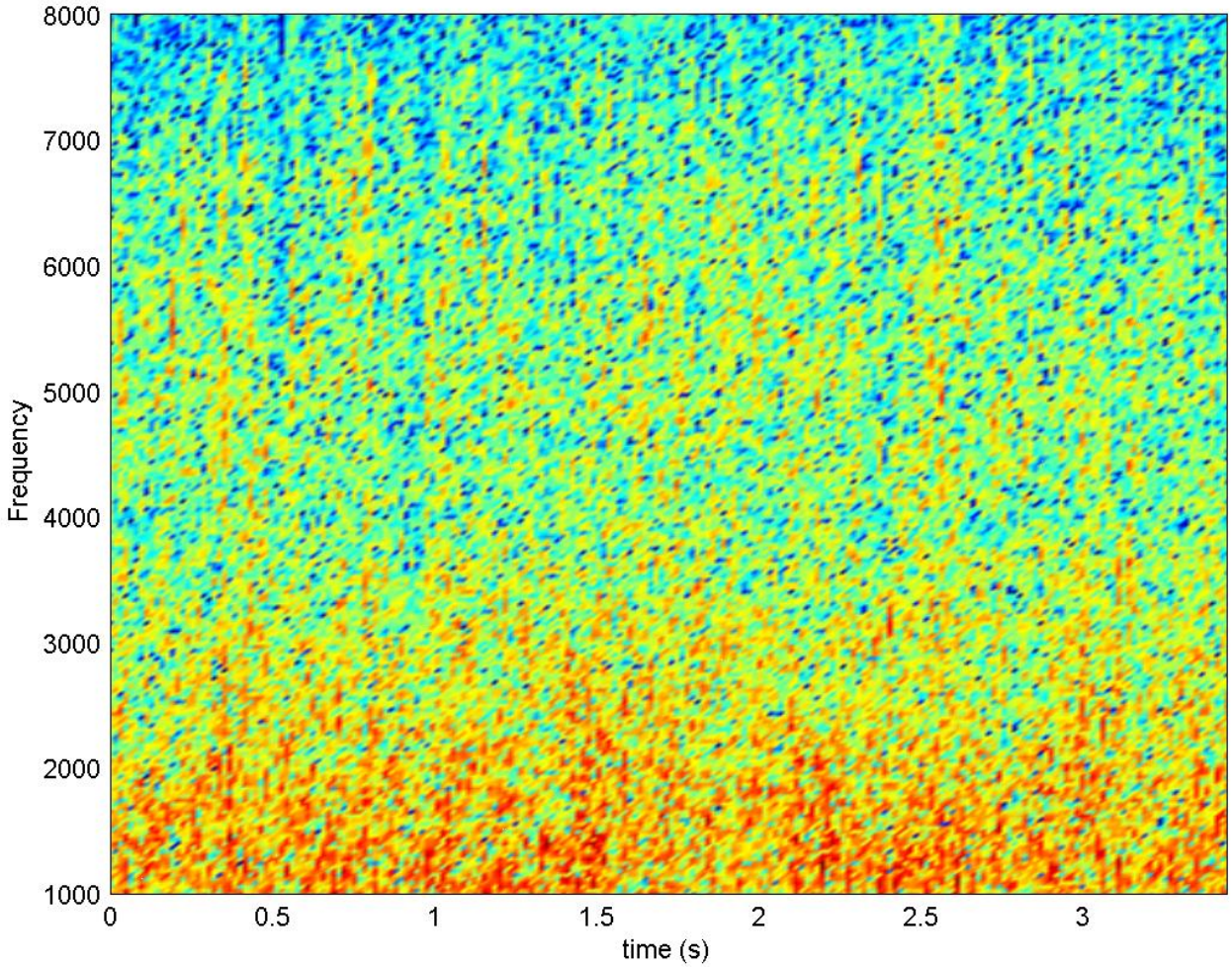
Spectrogram of Zebra Finch Song



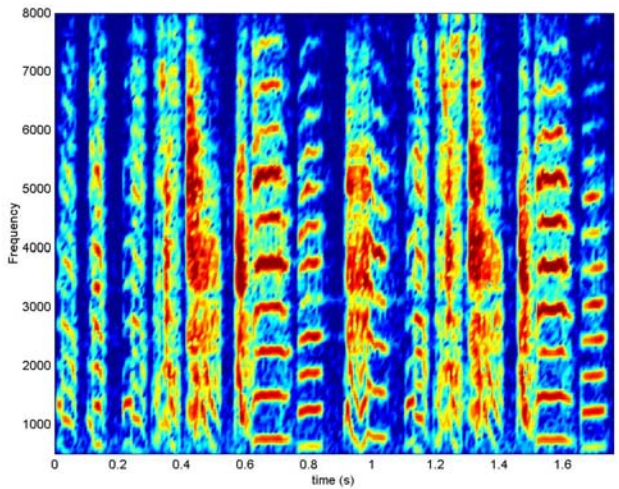
Normal

Slow

Spectrogram of Stream – Environmental Sound



2D Fourier Decomposition of Spectrogram



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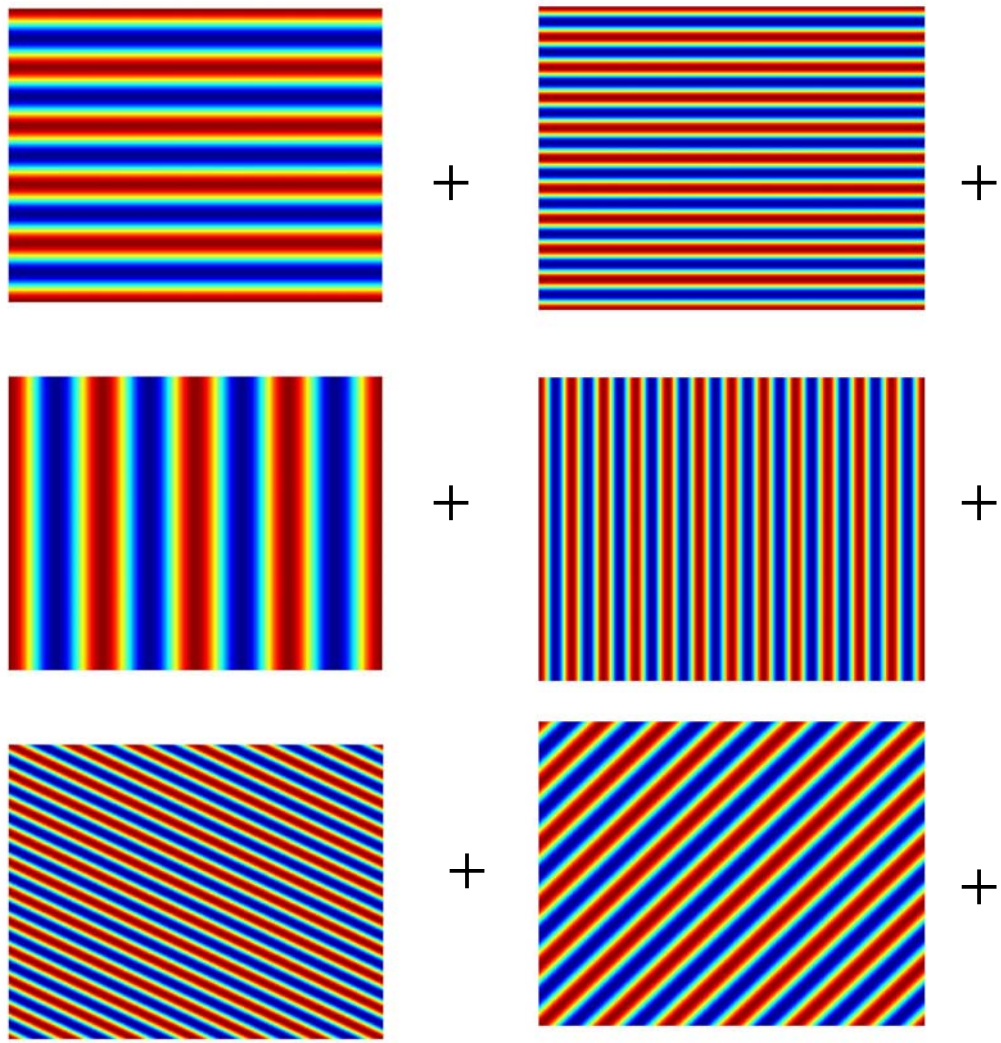
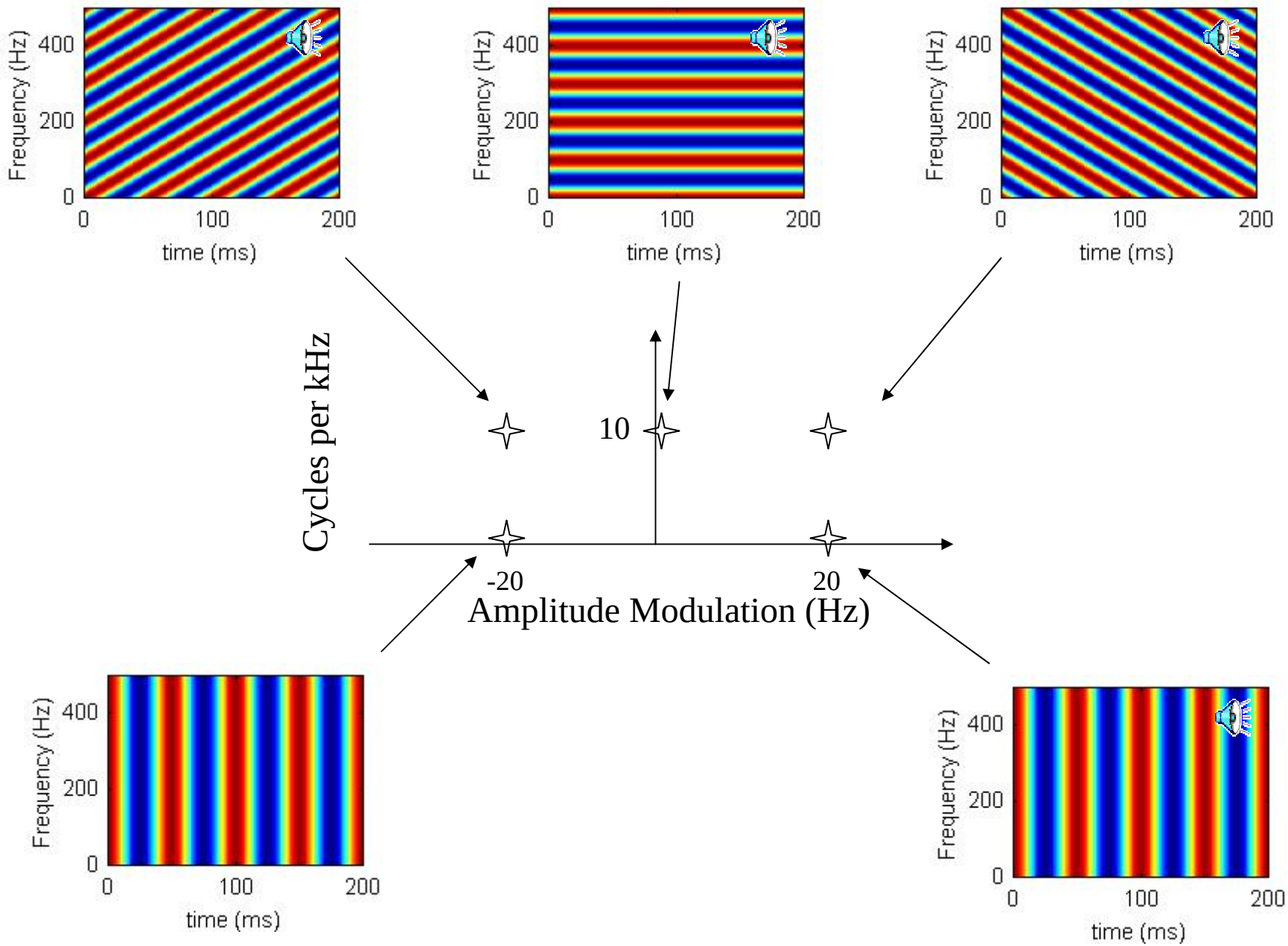
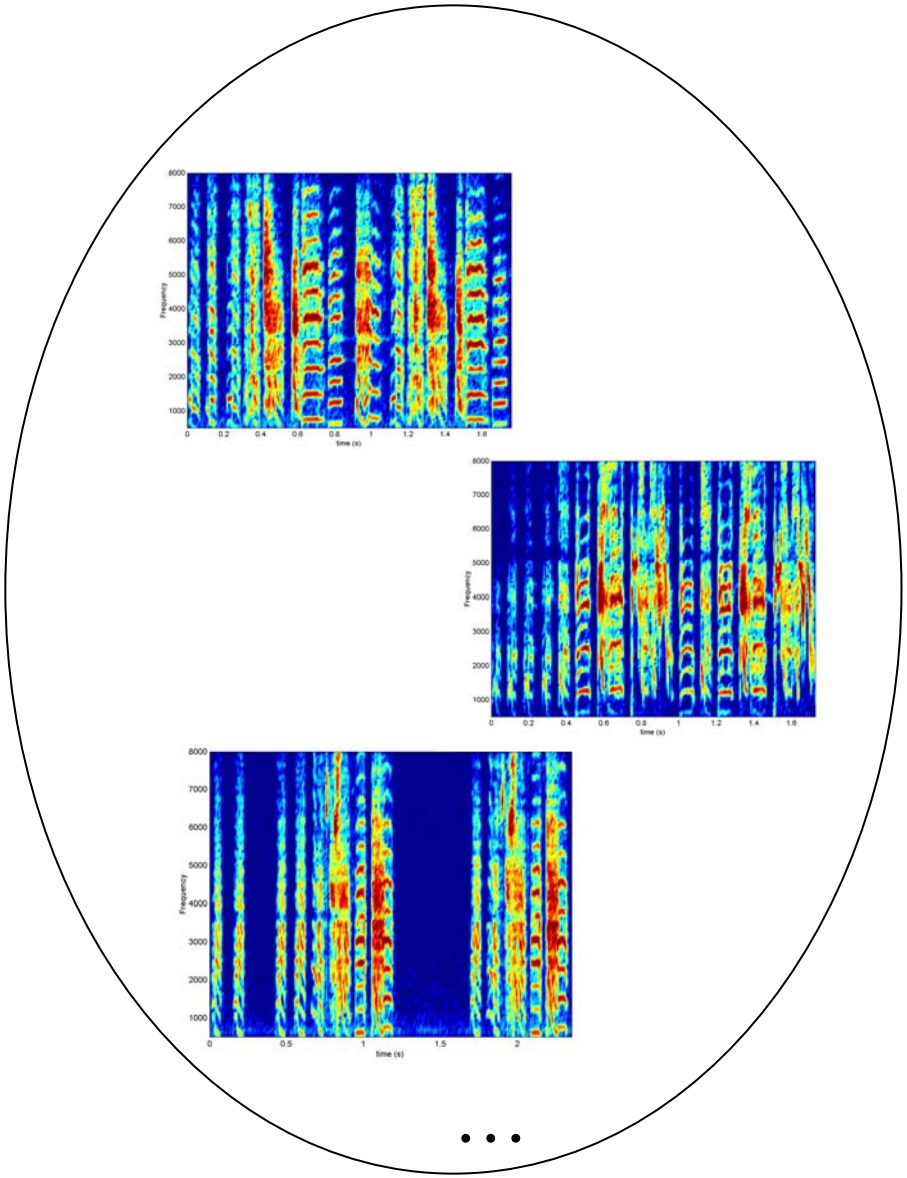
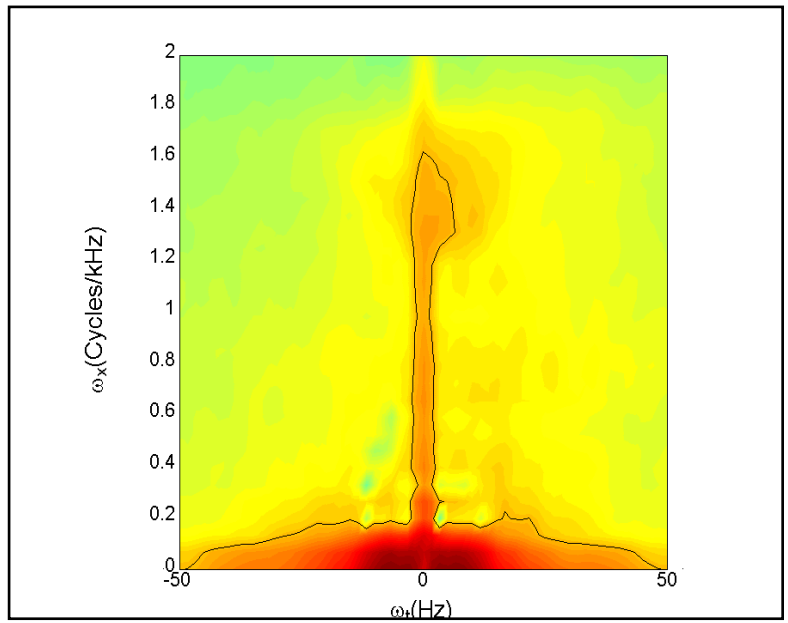
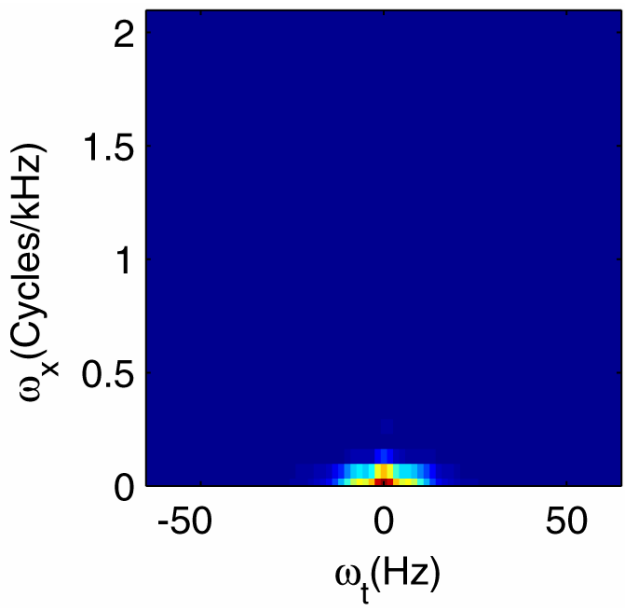


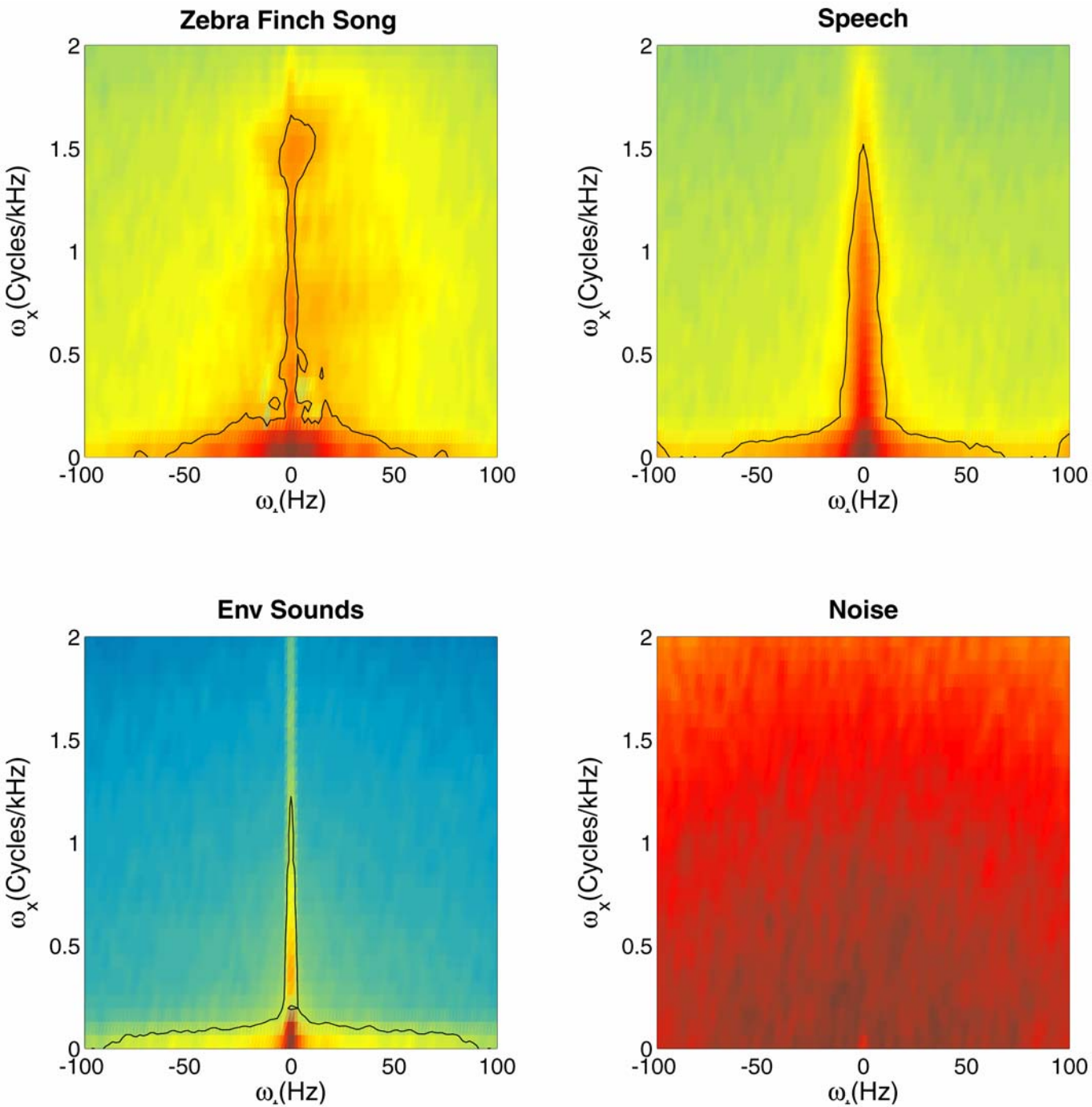

Frequency (Hz)
400
200
0
0
100
200
time (ms)
Cycles per kHz
10
-20
20
Amplitude Modulation (Hz)

Modulation Spectrum of Zebra Finch Song

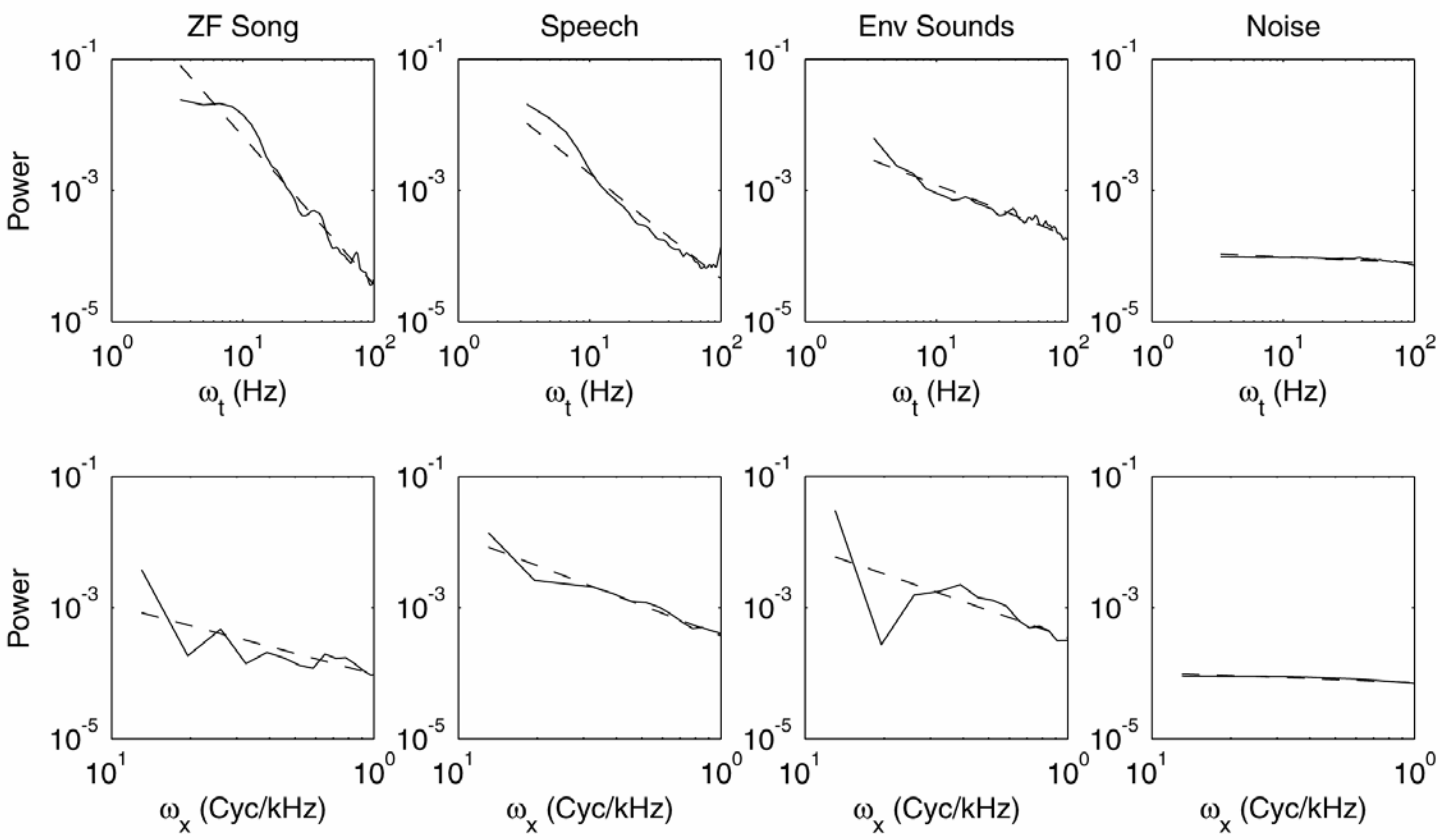




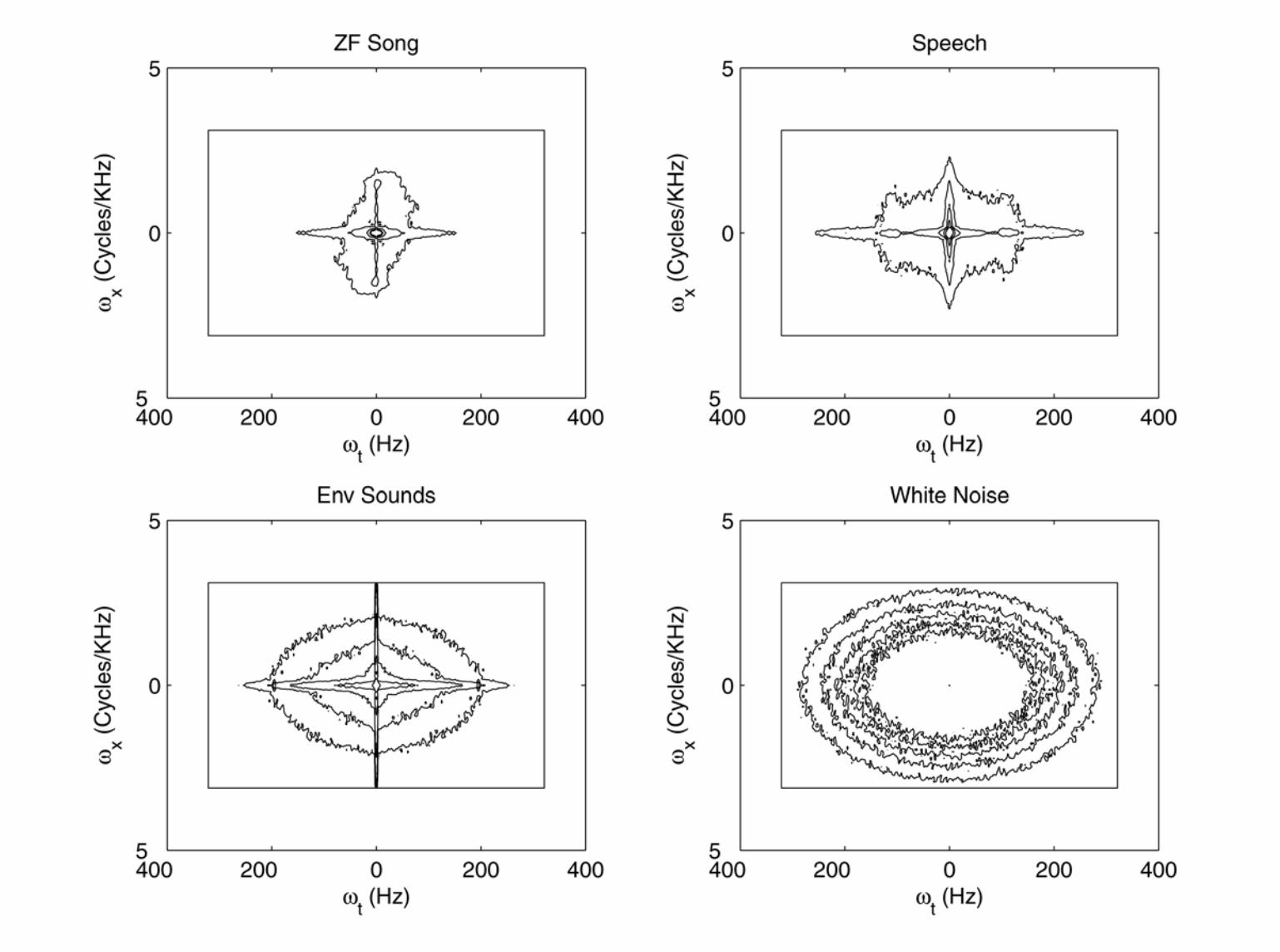



Zebra Finch Song
Speech
Env Sounds
Noise
ω_x(Cycles/kHz)
ω_t(Hz)
0
0.5
1
1.5
2
-100
-50
0
50
100

Modulation Spectra of Natural Sounds are low-passed



Natural Sounds Have a Star-Shaped Modulation Spectrum



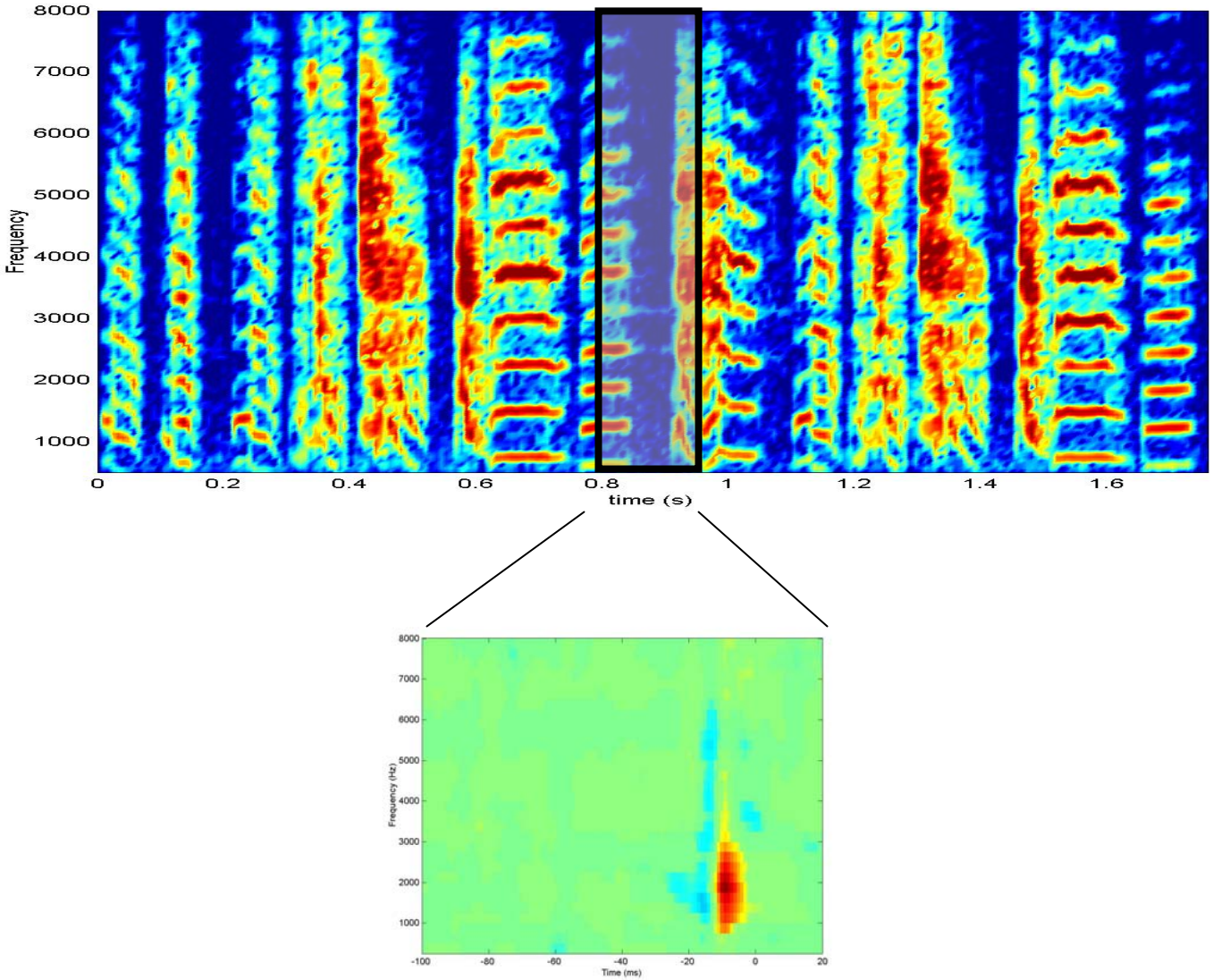
Processing of Natural Sounds in the Auditory System

1. Modulation Spectra of Natural Sounds.
- Natural Sounds have a low-pass modulation spectrum.
- In animal vocalizations, spectral modulations are found mostly at low temporal modulations.
- Ethological theories of auditory coding: Matched, Whitening, Selective.

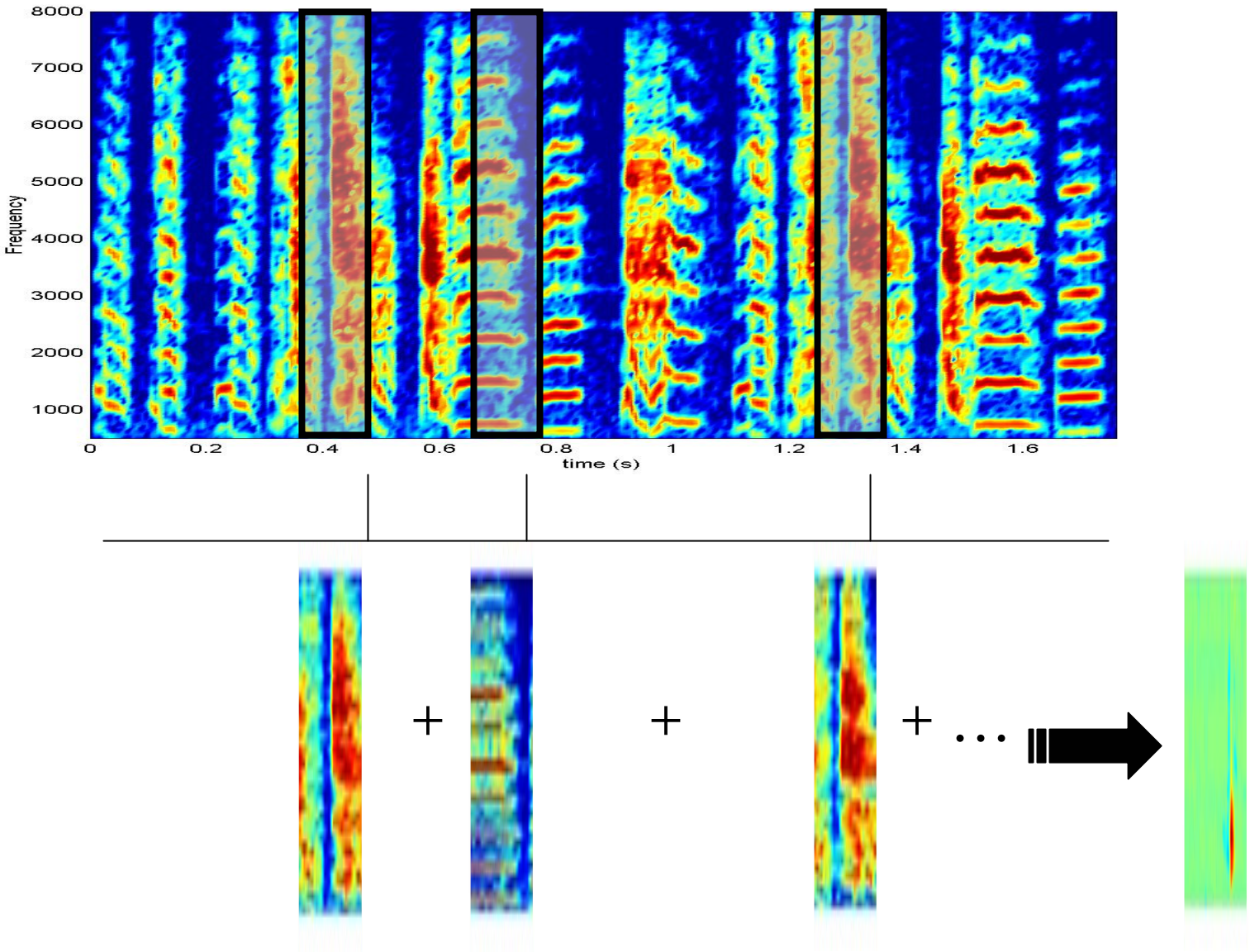
2. Spectro-Temporal Receptive Fields (STRF) and Modulation Transfer Function (MTF).

3. MTF Tuning for Modulation Spectra of Natural Sounds

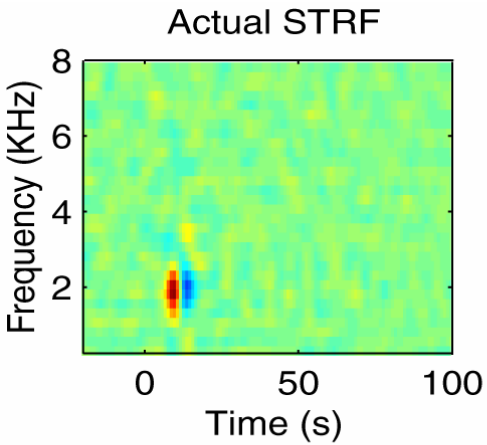
Spectro-Temporal Receptive Fields

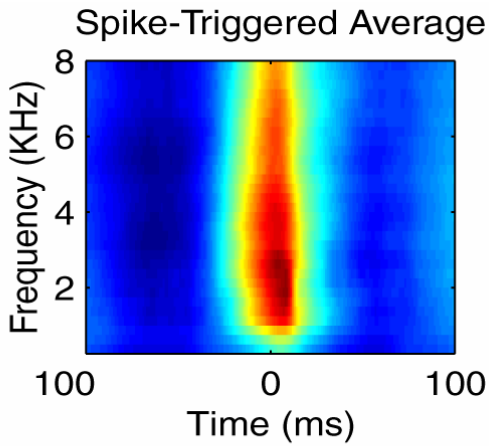


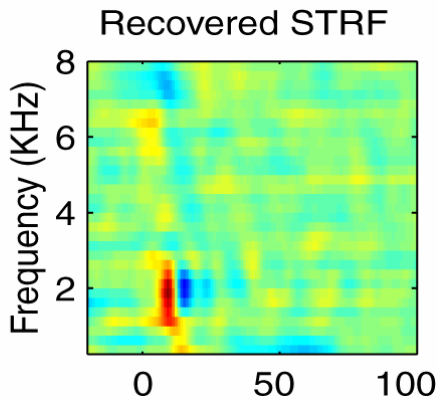
Estimating STRFs – Modified Reverse Correlation

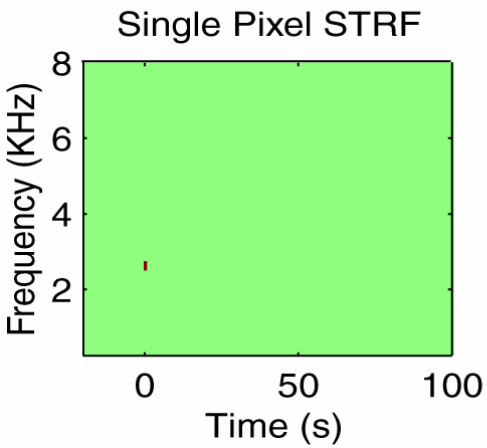


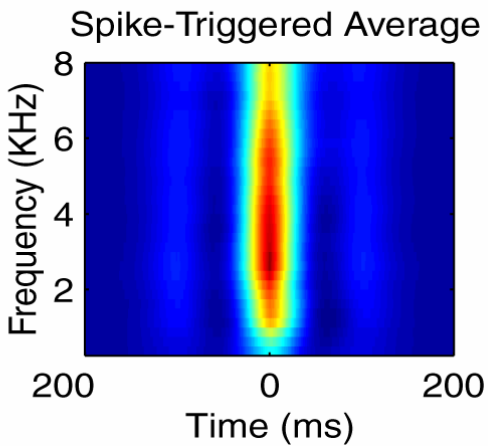
Estimating STRFs – Removing Correlations











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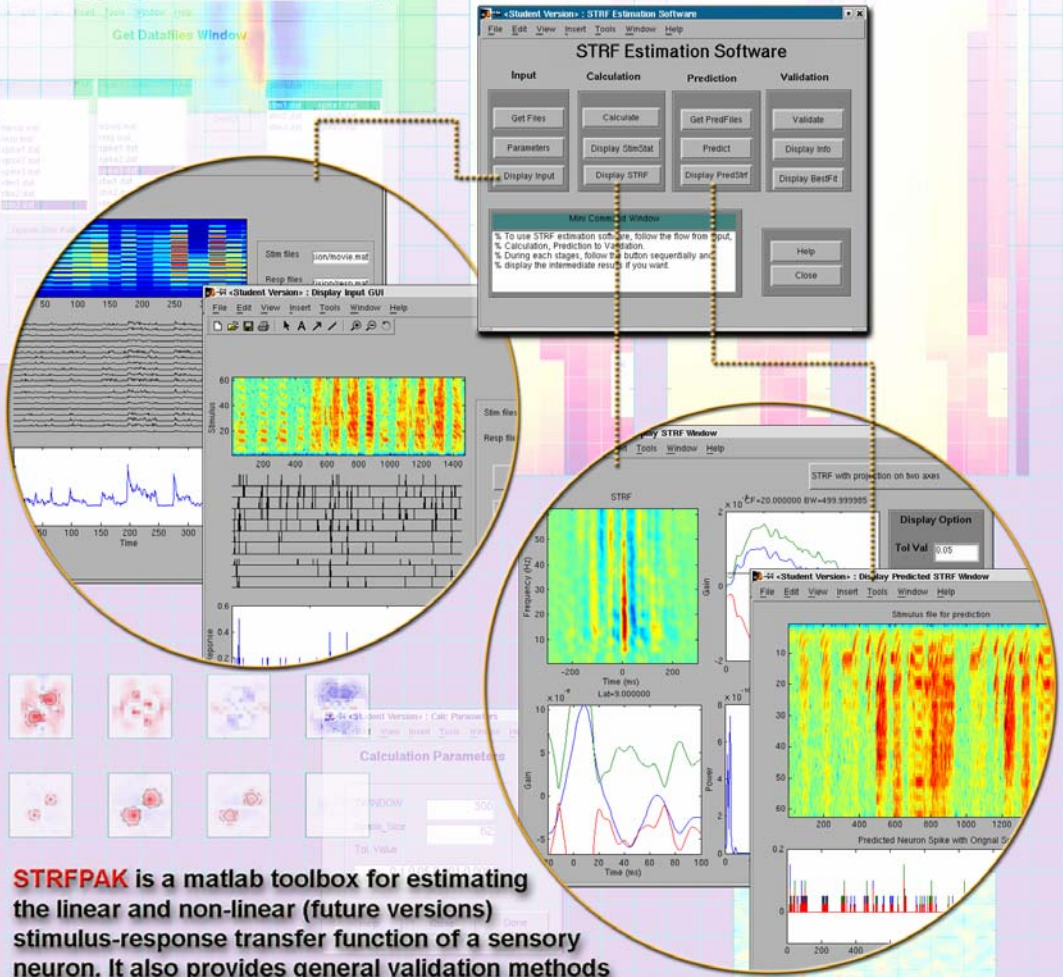
STRFPAK

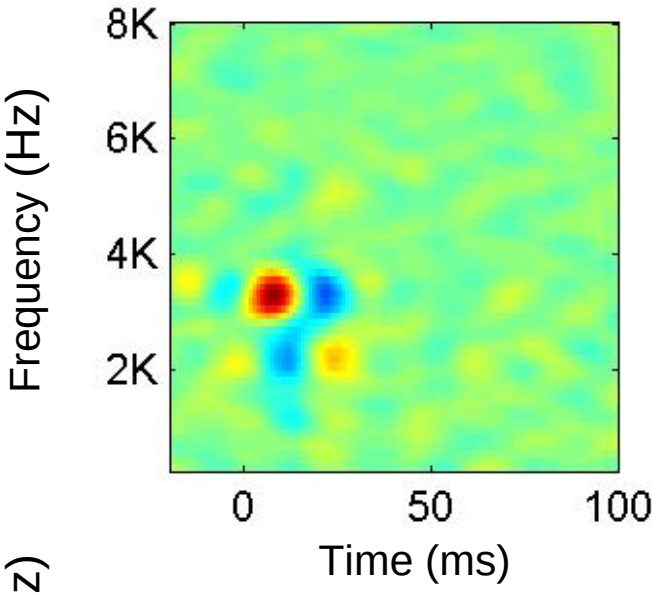
Spatio-Temporal Receptive Field Estimation Software

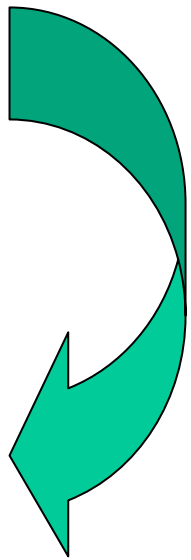


STRFPAK is a matlab toolbox for estimating the linear and non-linear (future versions) stimulus-response transfer function of a sensory neuron. It also provides general validation methods to estimate goodness of fit. The matlab GUI programs with point-and-click features are designed for ease of use.

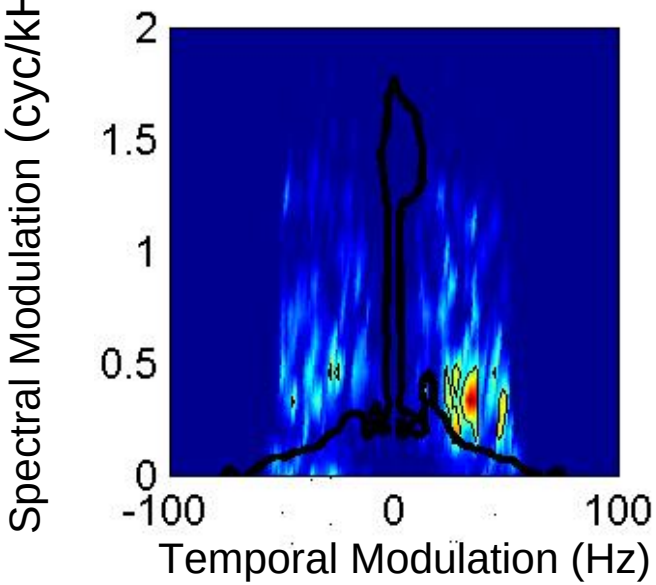
http://strfpak.berkeley.edu

Obtaining the Modulation Transfer Function (MTF) from the STRF

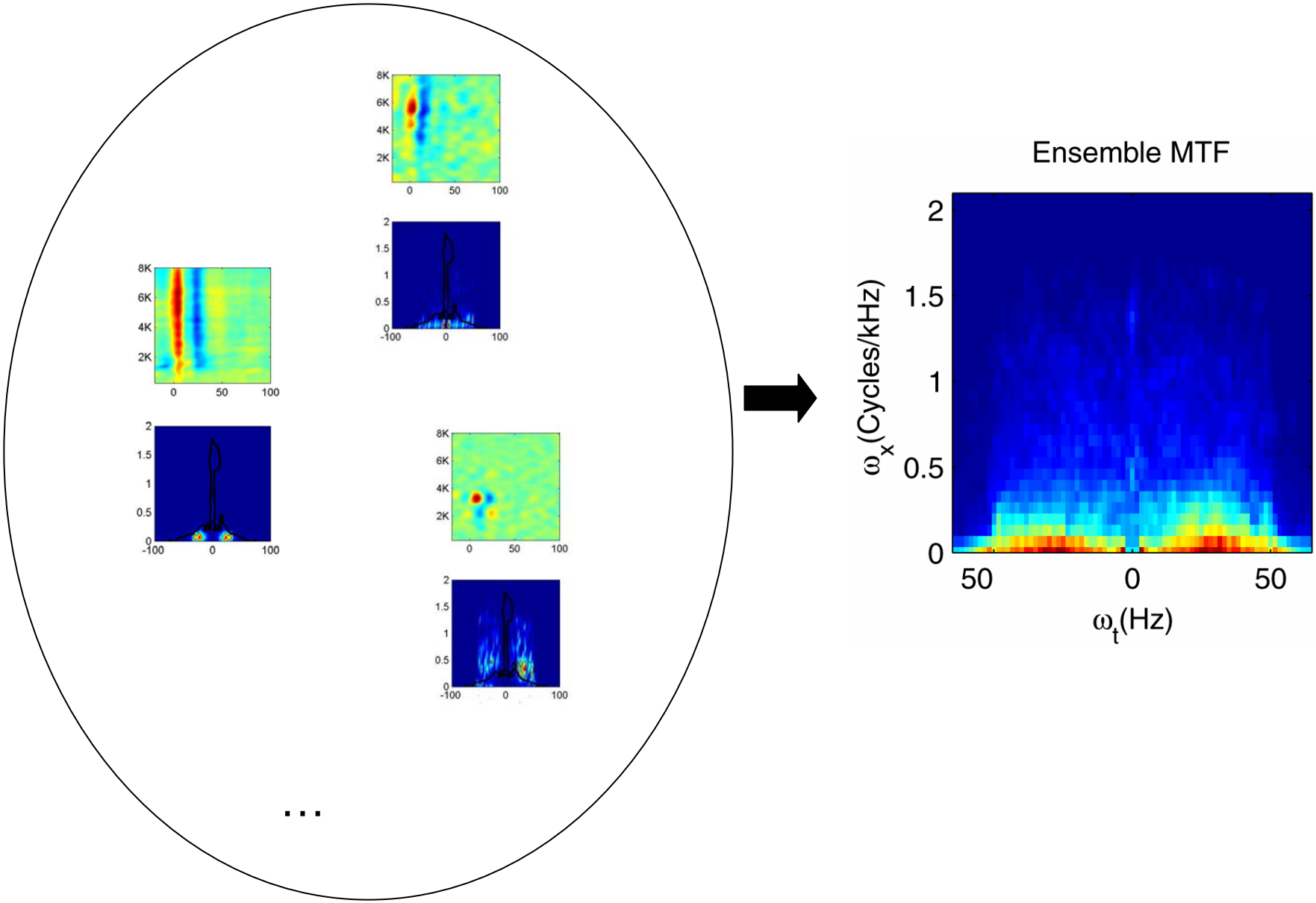




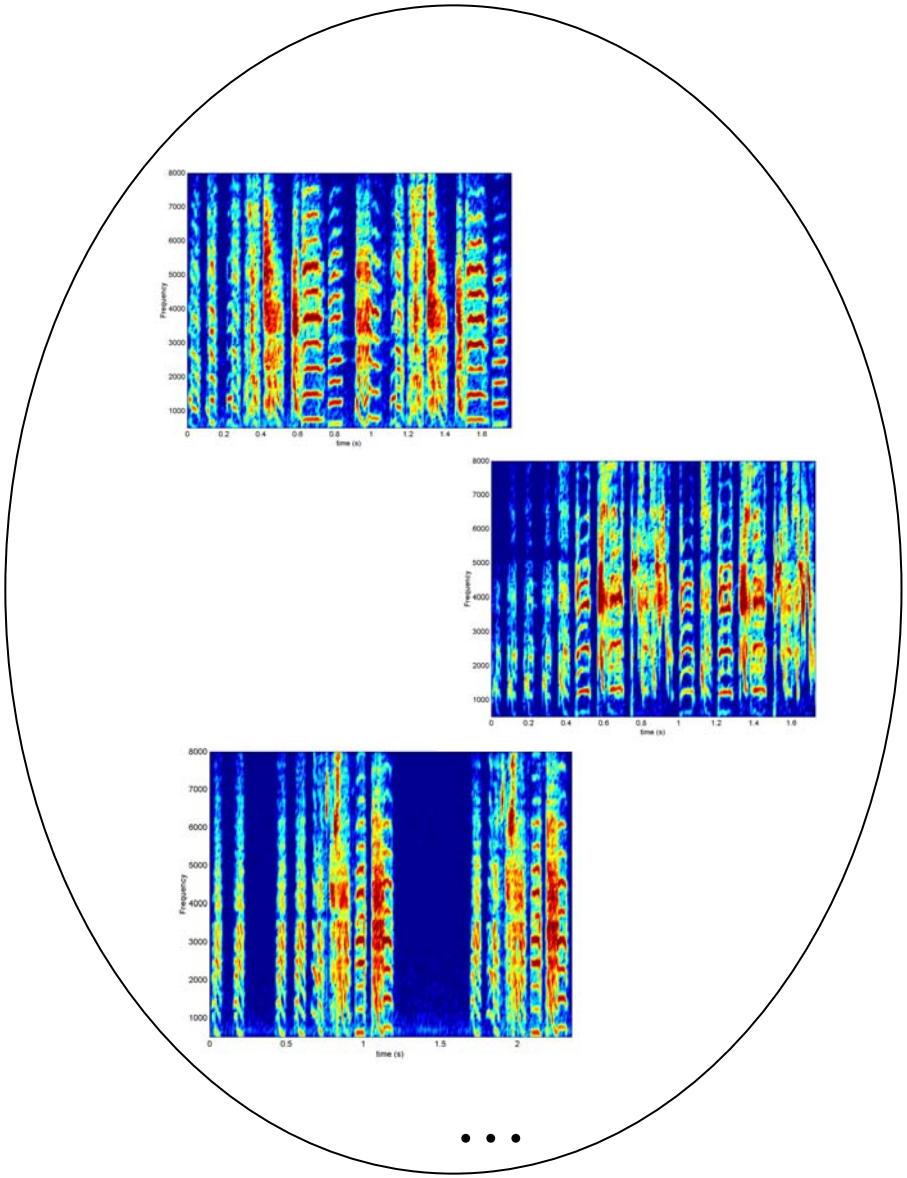
2D FFT

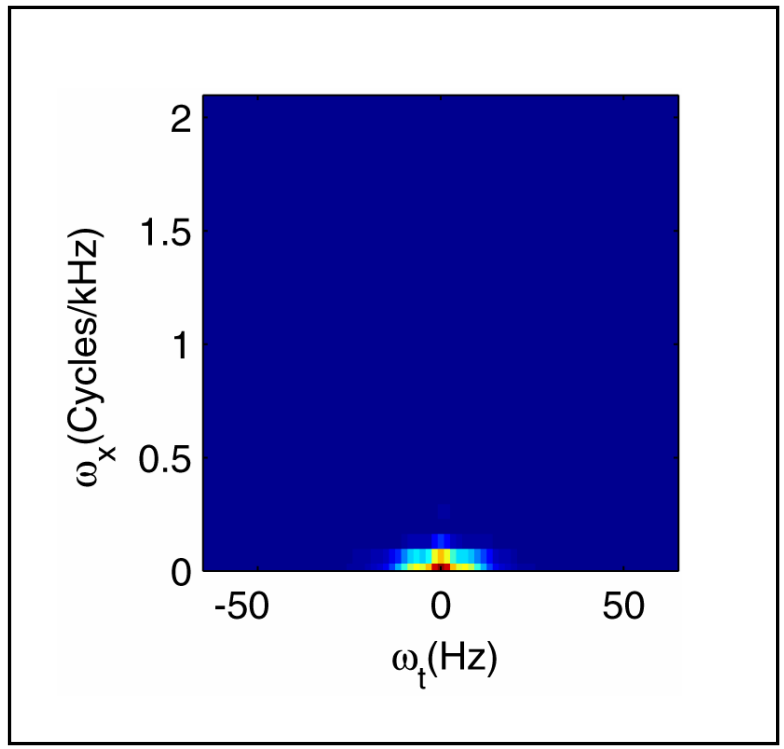


Ensemble MTF for Neural Assembly



Modulation Spectrum of Zebra Finch Song





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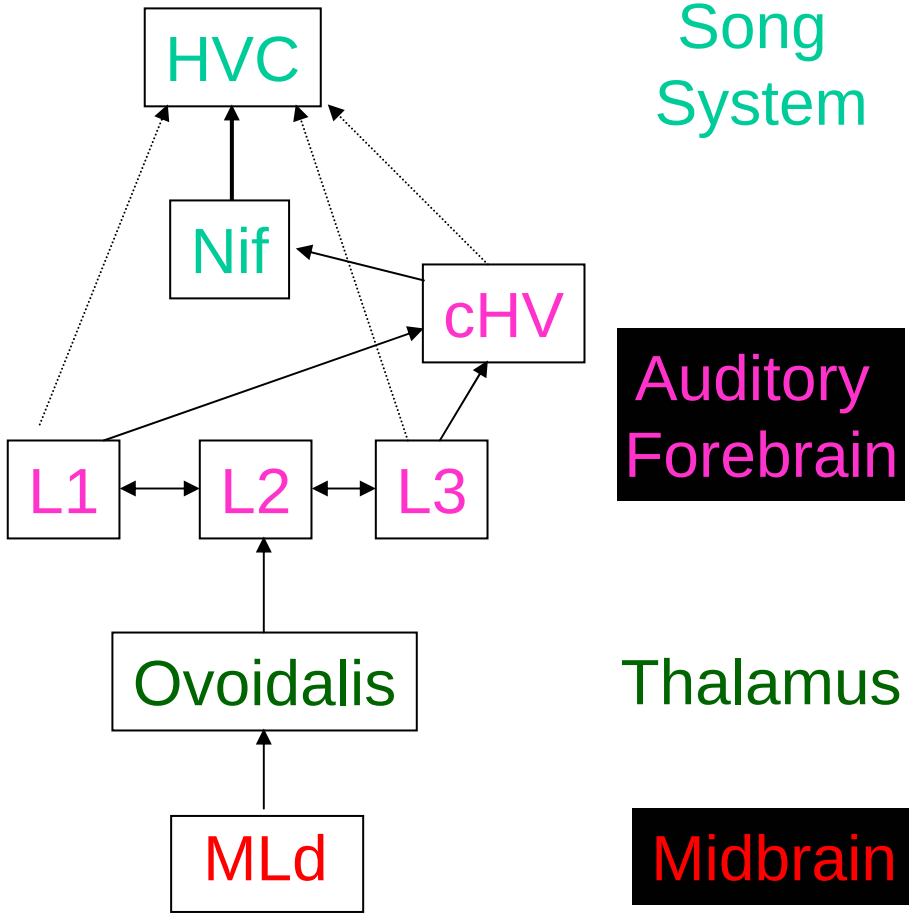
- Spectral modulations are mostly found at low temporal modulations In animal vocalizations.
- Ethological theories of auditory coding: Matched, Whitening, Selective.

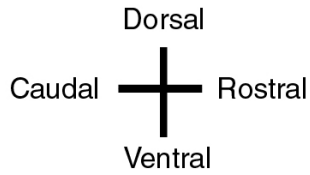
2. Spectro-Temporal Receptive Fields (STRF)
and Modulation Transfer Function (MTF).

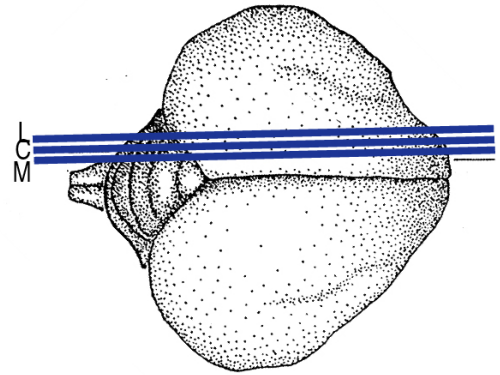
- STRFs can be obtained from responses to complex sounds by regularized linear regression methods.
- MTF shows the modulations that are coded by single neurons or neuronal ensembles.

3. MTF Tuning for Modulation Spectra of Natural Sounds

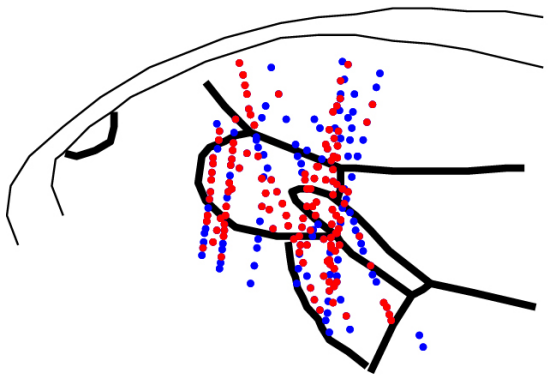
Avian Auditory System and Relation to Song System



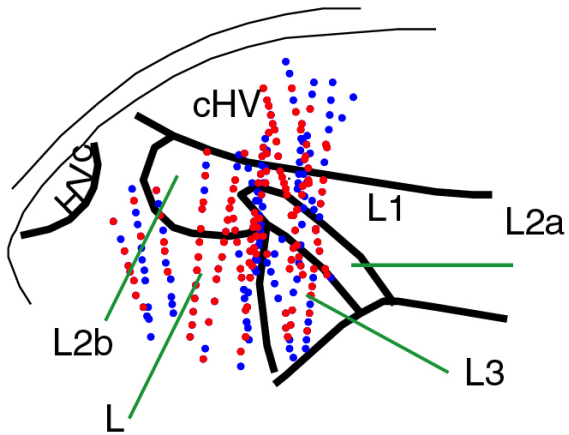




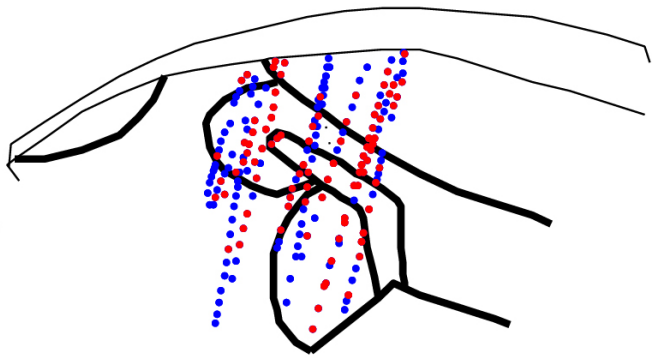
medial slice (M)

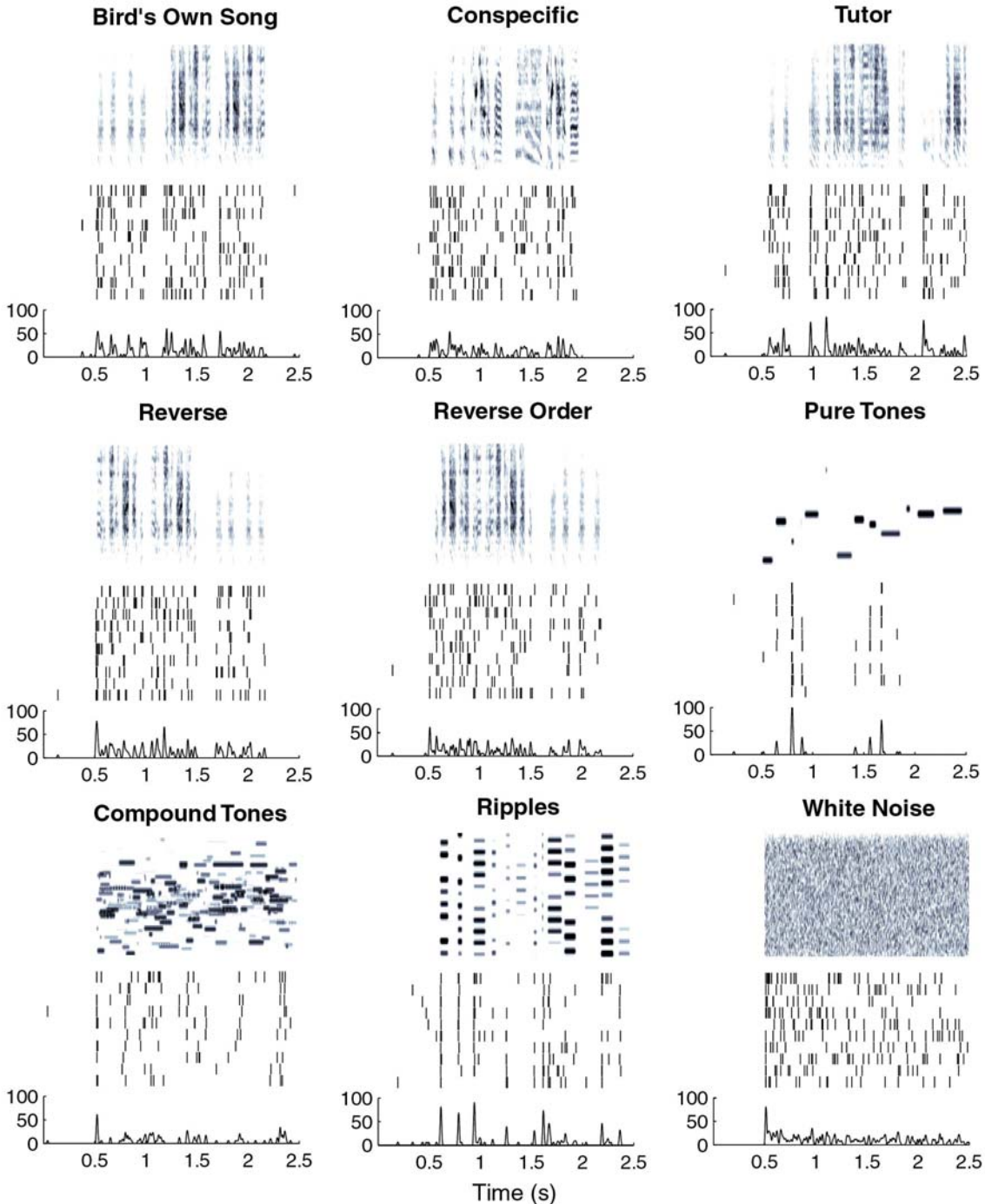


central slice (C)

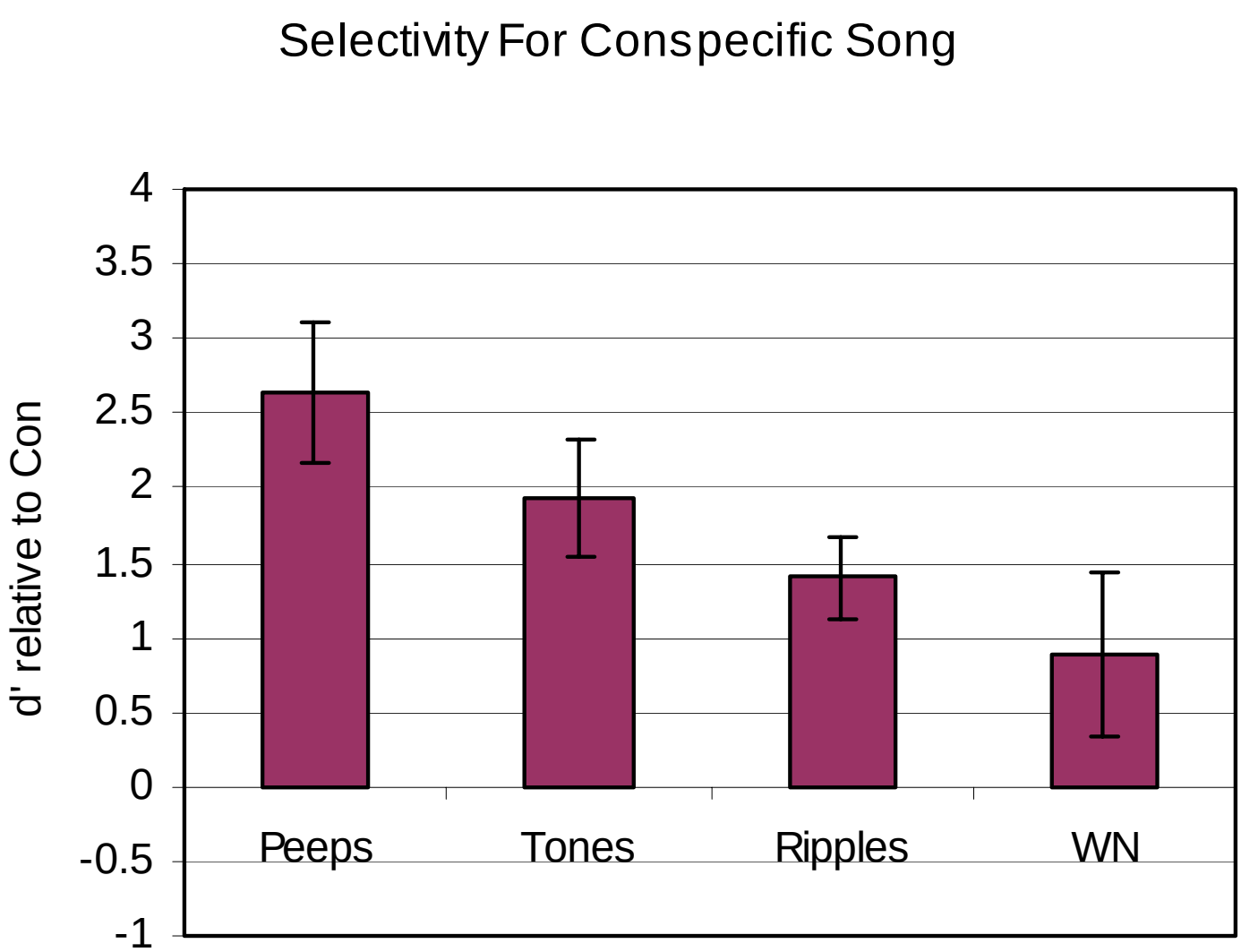


lateral slice (L)




Bird's Own Song
Conspecific
Tutor
Reverse
Reverse Order
Pure Tones
Compound Tones
Ripples
White Noise
100
50
0
0.5
1
1.5
2
2.5
Time (s)

Field L Neurons are Selective for Conspecific Song

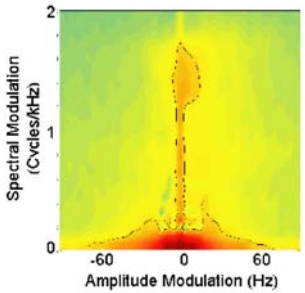


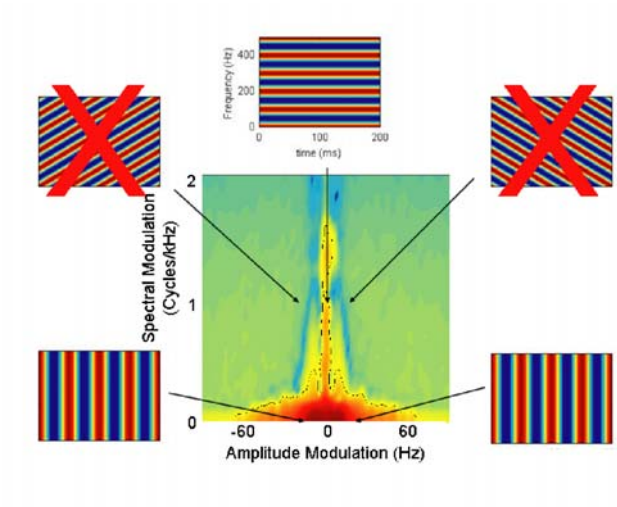
Grace, Amin & Theunissen, *J. Neurophys*, 2003

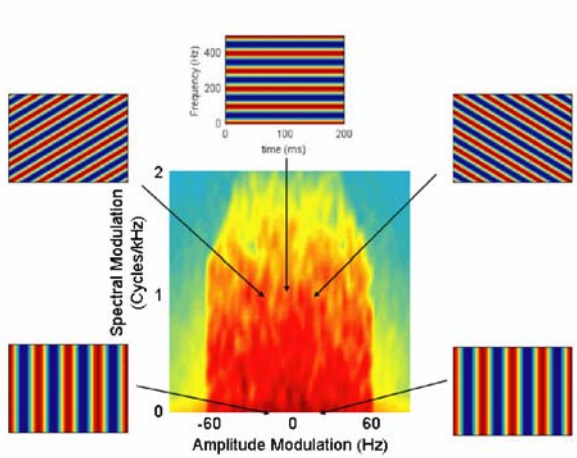
Song

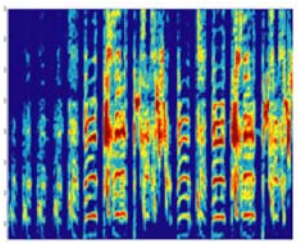
Song Ripples

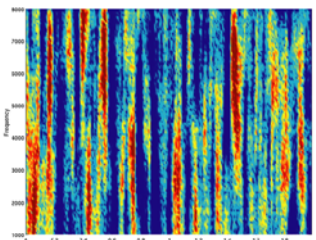
Flat Ripples

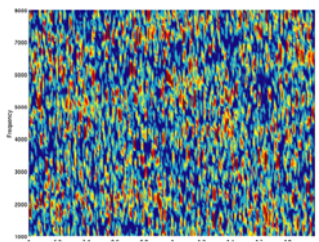






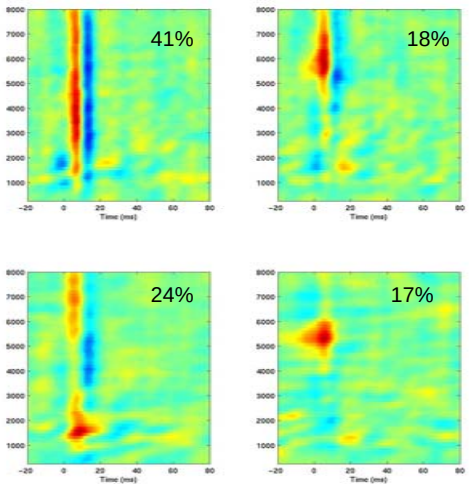




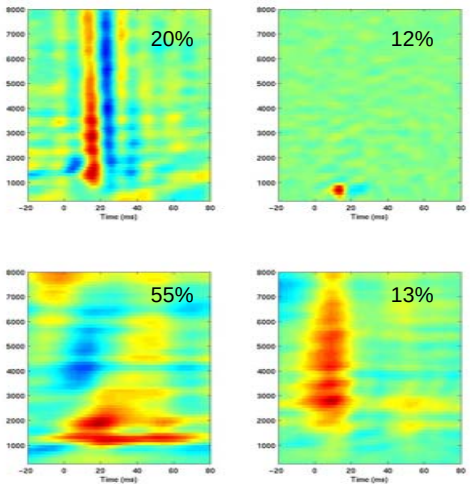


~Four Types of STRFs

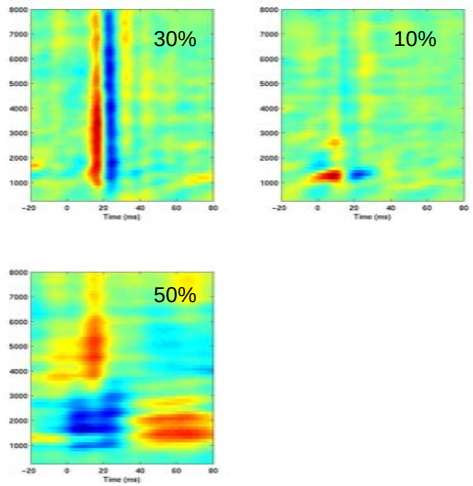
MLd



Field L



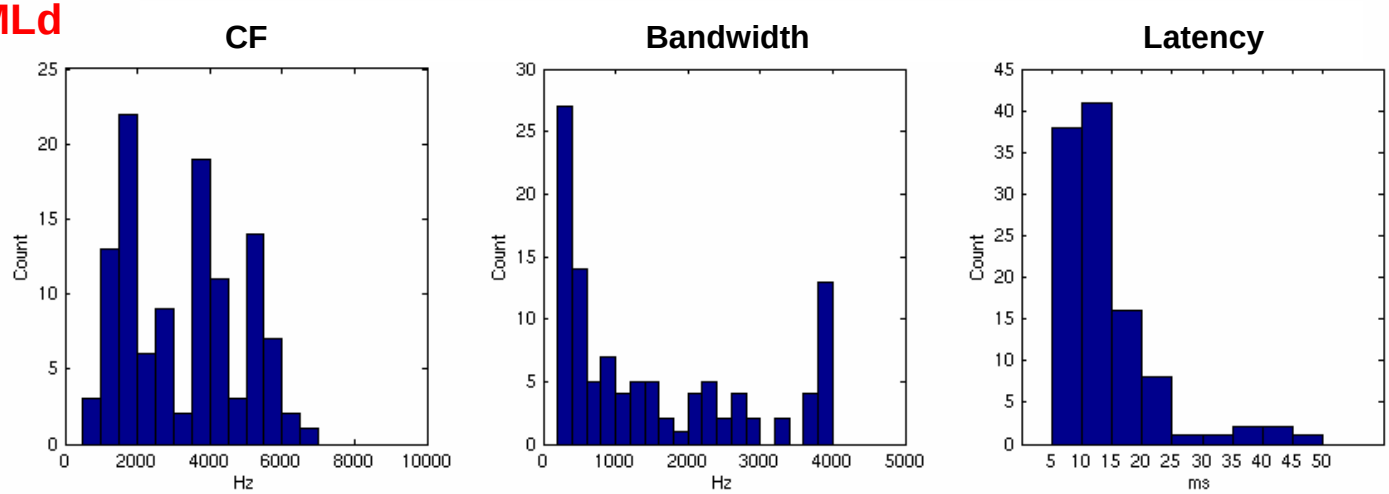
cHV



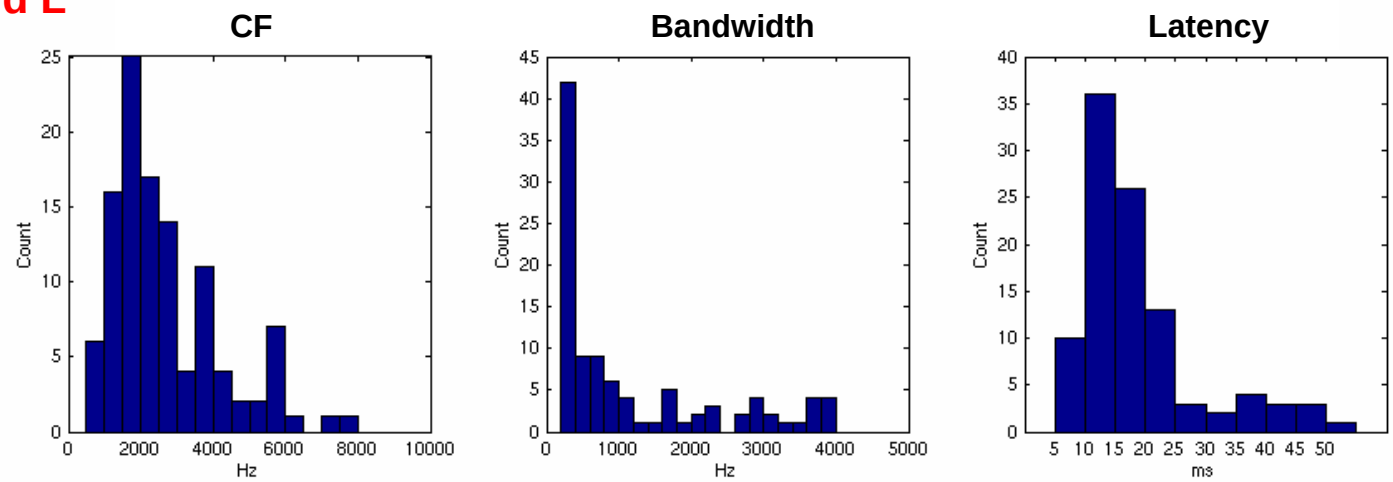
Does the frequency tuning extracted from the STRF match the frequency power spectrum of song?

Classical Tuning Properties extracted from the STRFs

MLd

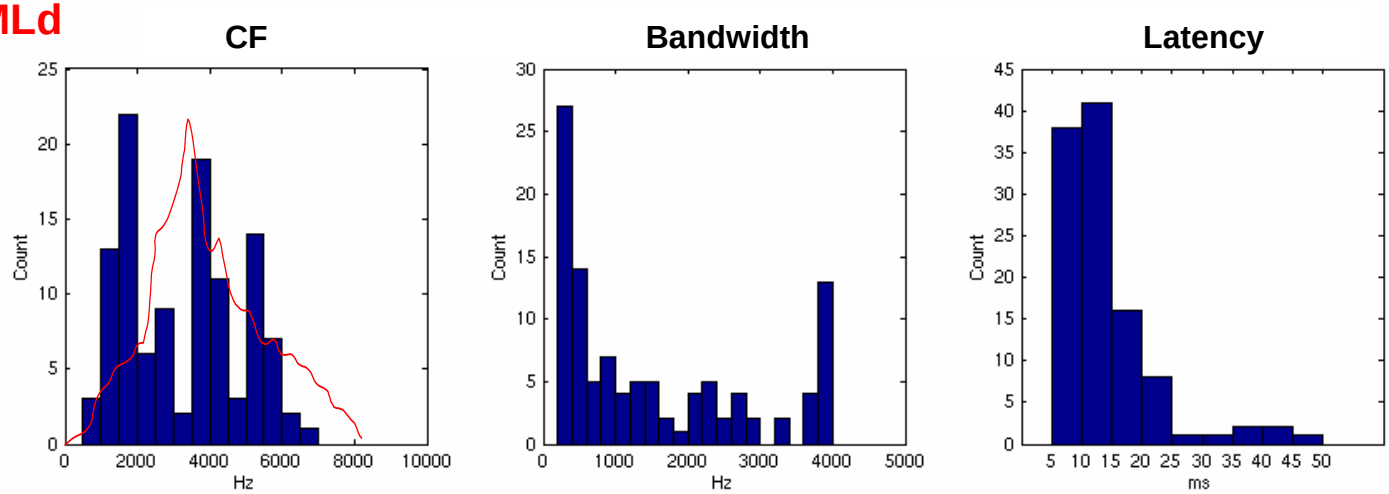


Field L

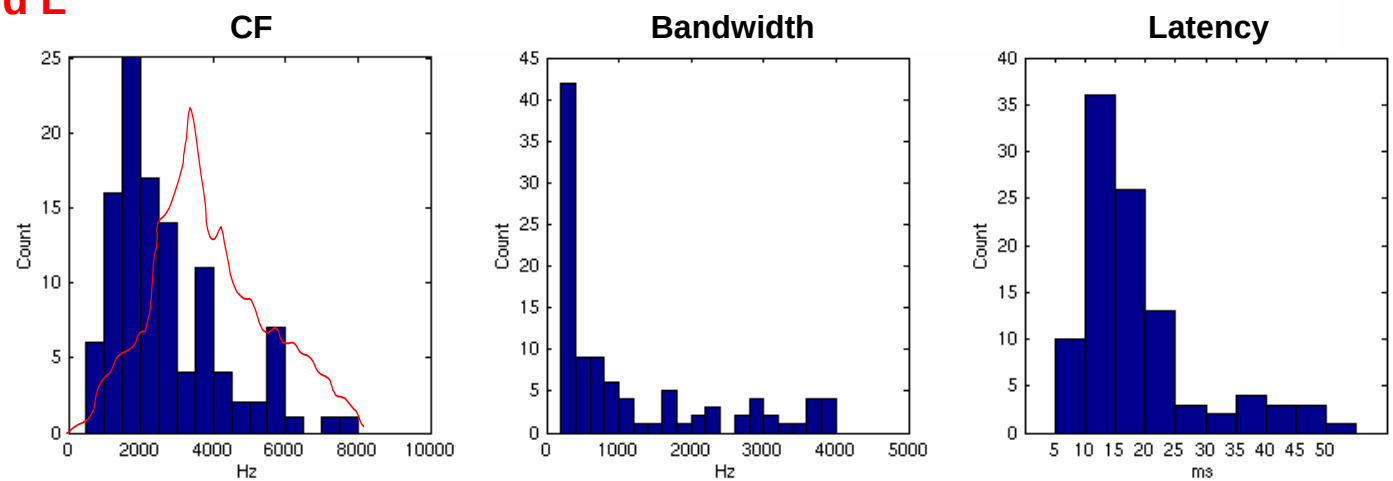


Classical Tuning Properties extracted from the STRFs

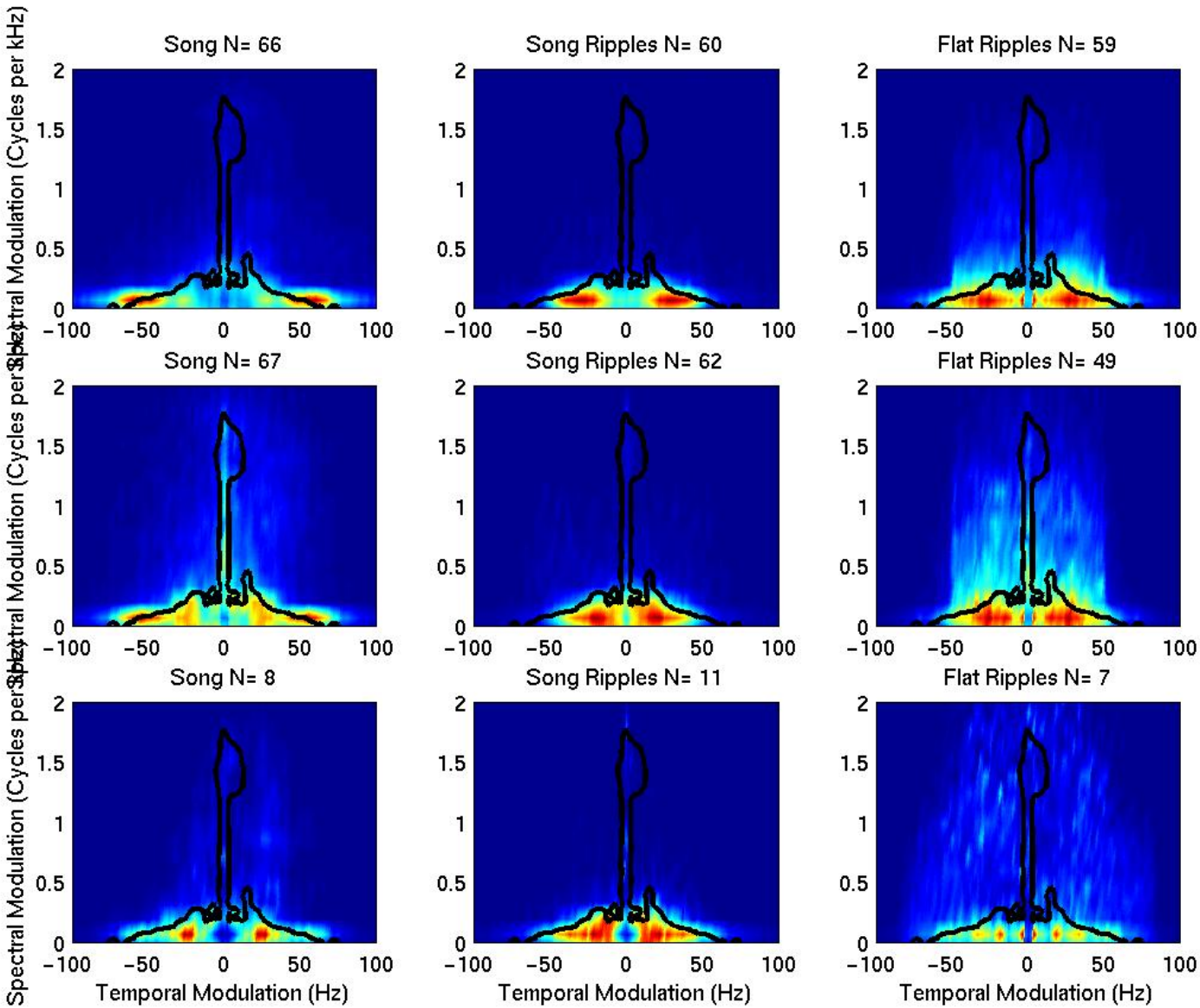
MLd



Field L



Ensemble Modulation Transfer Function



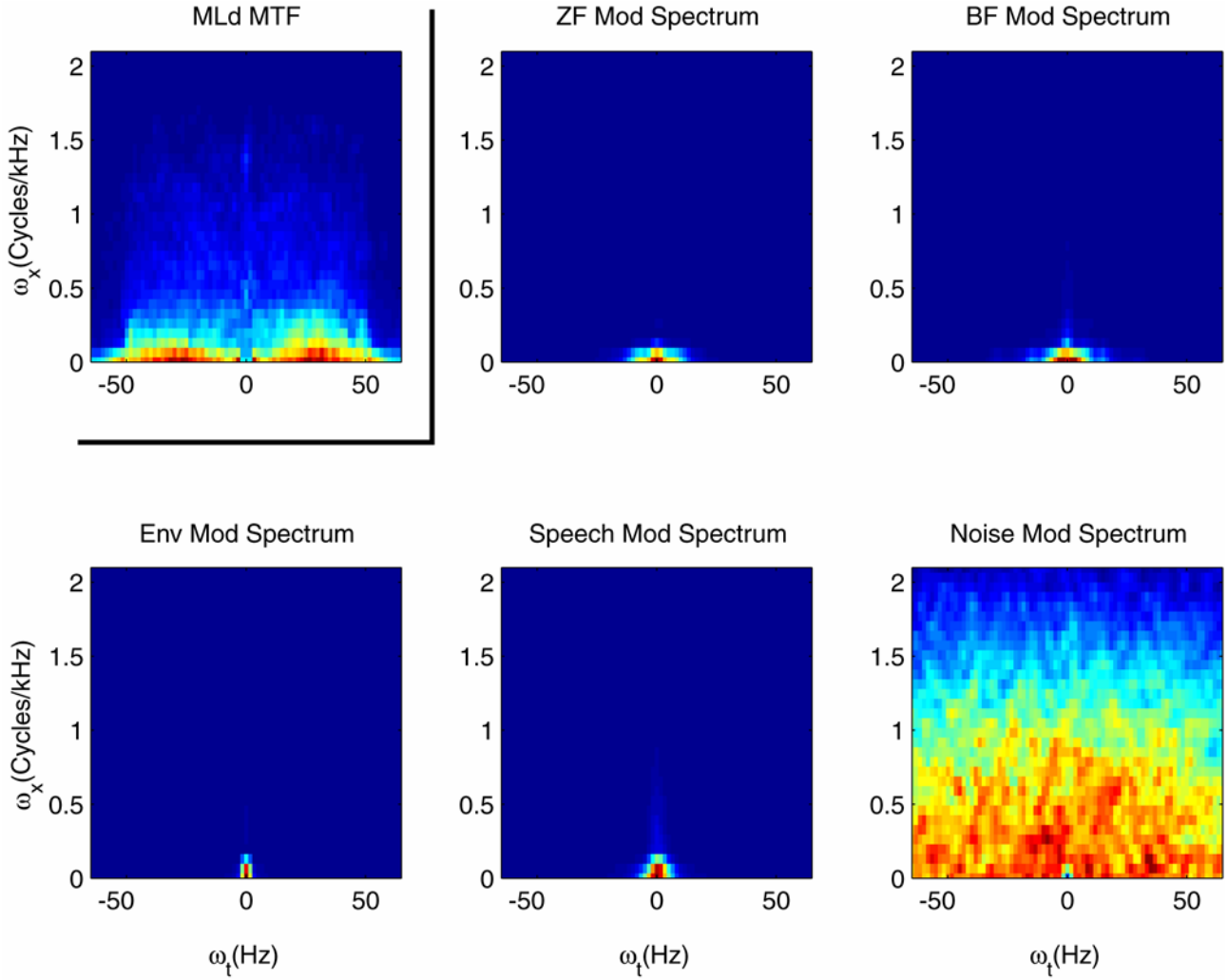
MLd

Field L

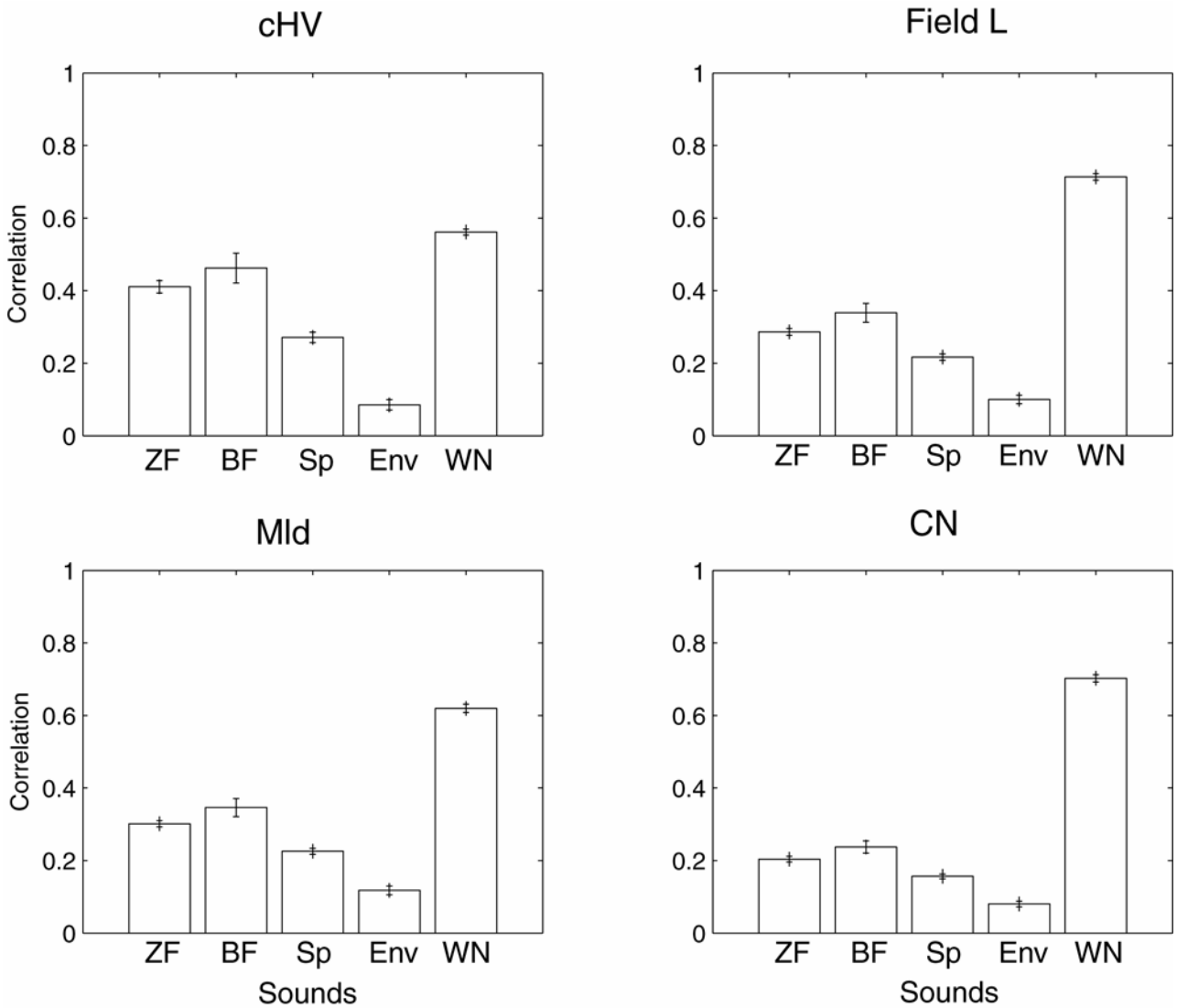
cHV

Modulation Tuning Matched Hypothesis: The ensemble MTF matches the modulation power spectra of natural sounds.

Match between the ensemble MTF and the Modulation Spectra of Natural Sounds



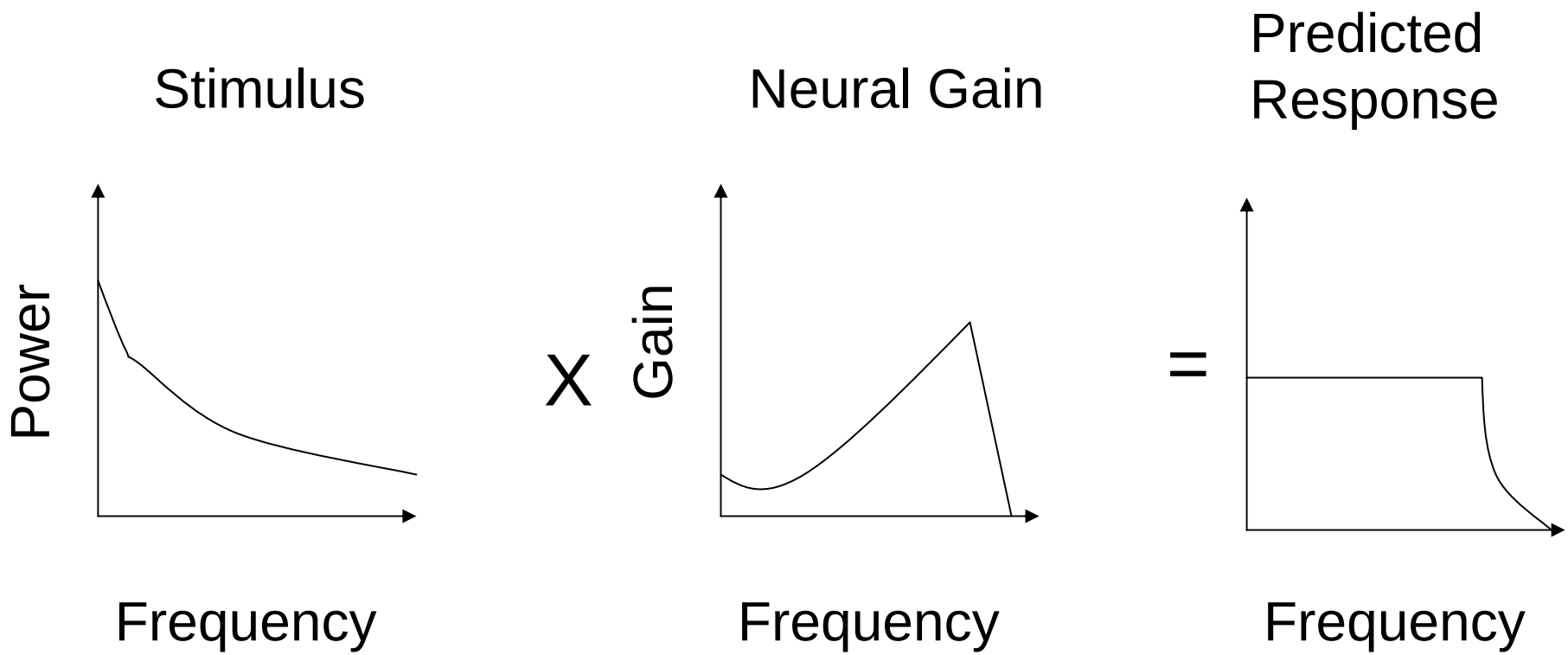
Match between the ensemble MTF and the Modulation Spectra of Natural Sounds



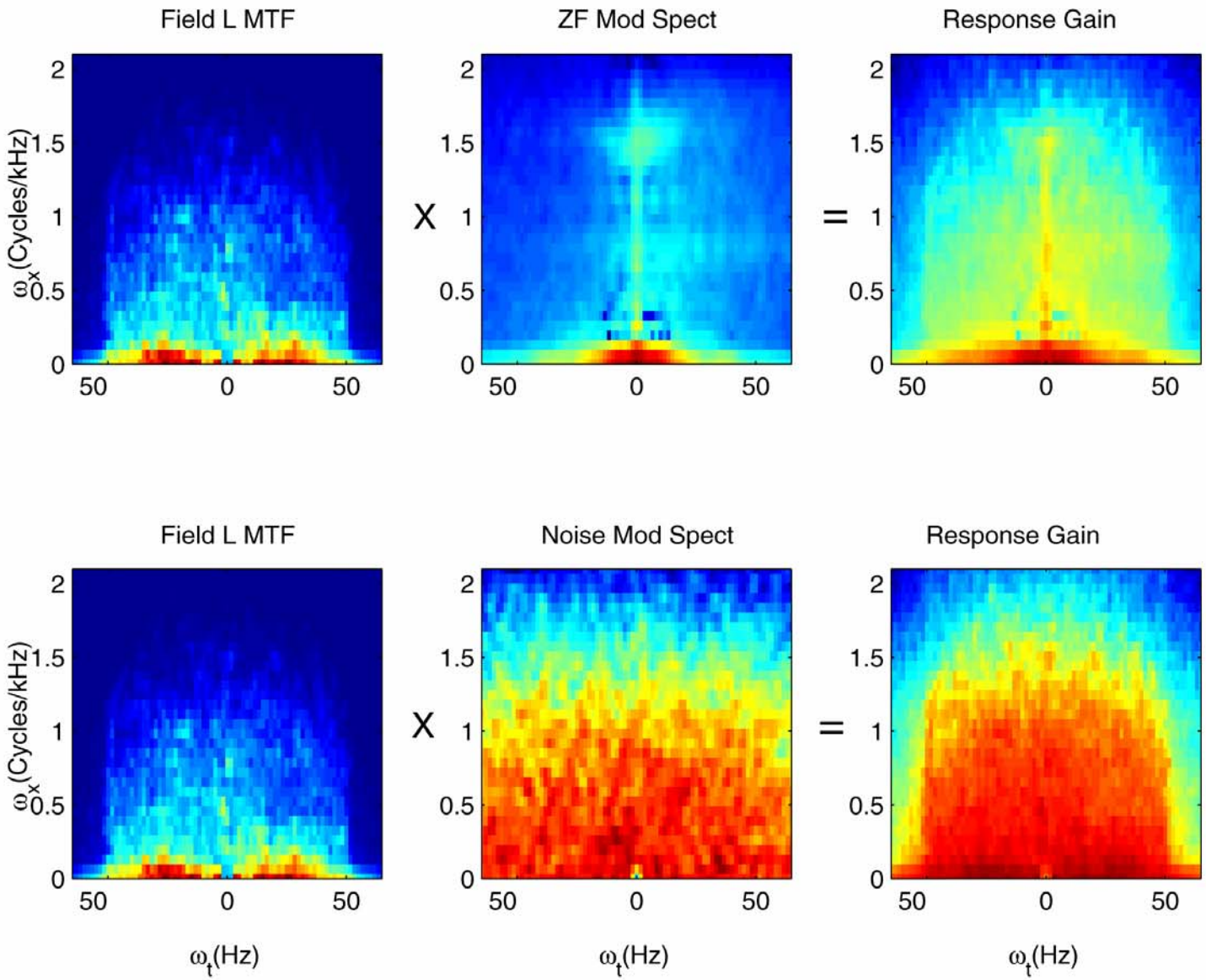
Modulation Tuning

Whitening Hypothesis: The ensemble MTF decorrelates the modulation power spectra of natural sounds emphasizing modulations with little power and attenuating modulations with high power

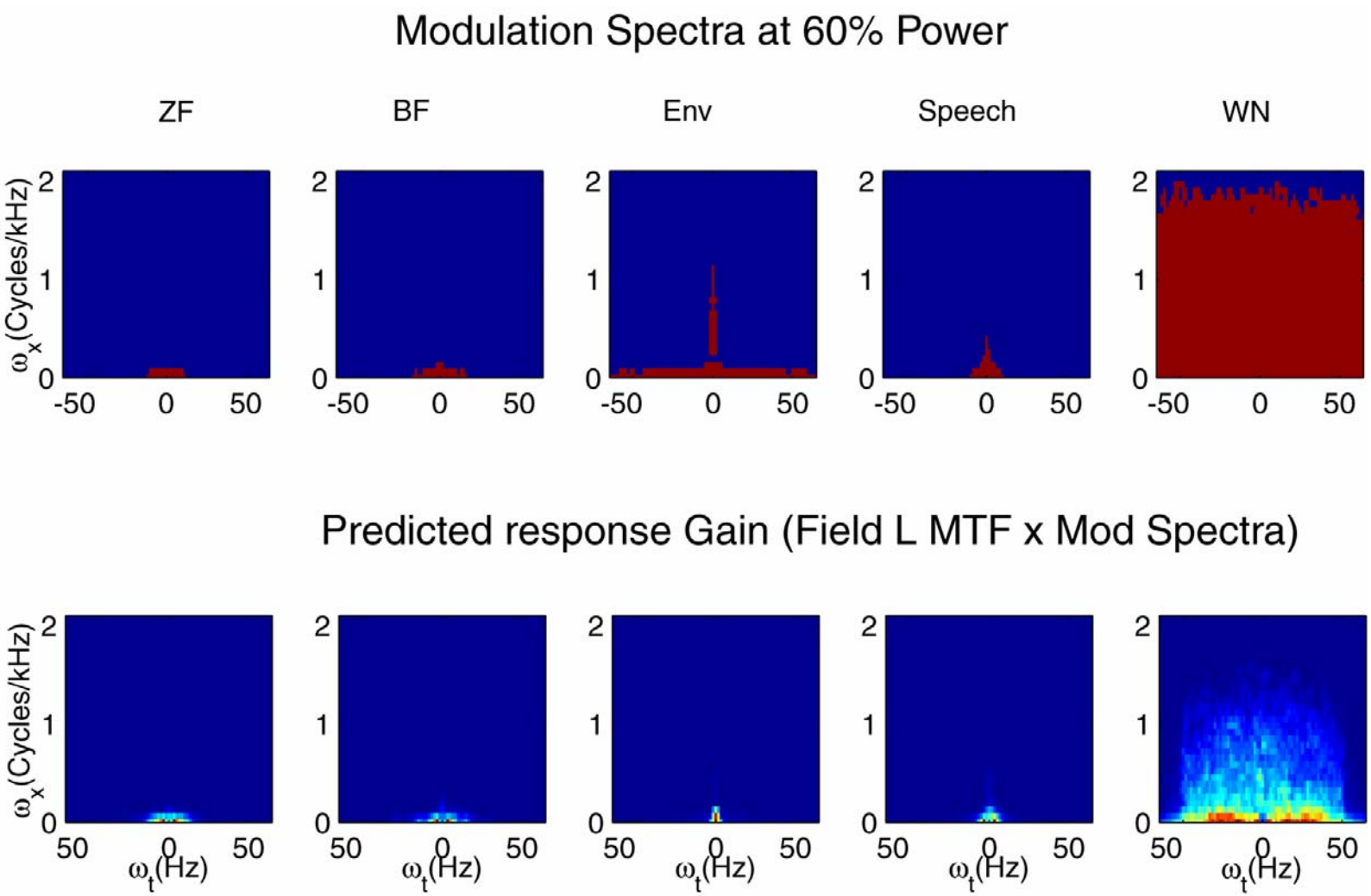
The Whitening Hypothesis



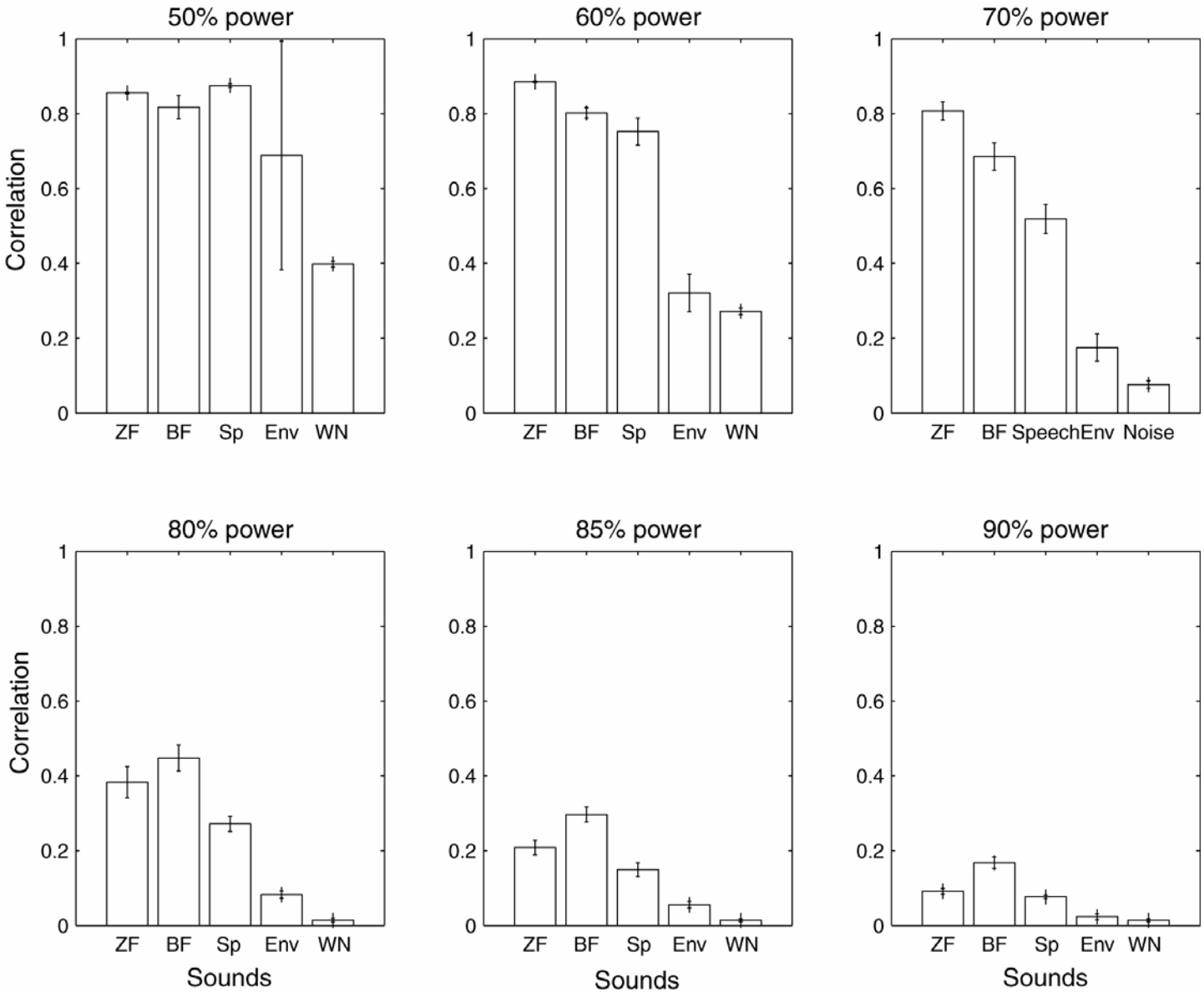
Calculating the Predicted Response Gain



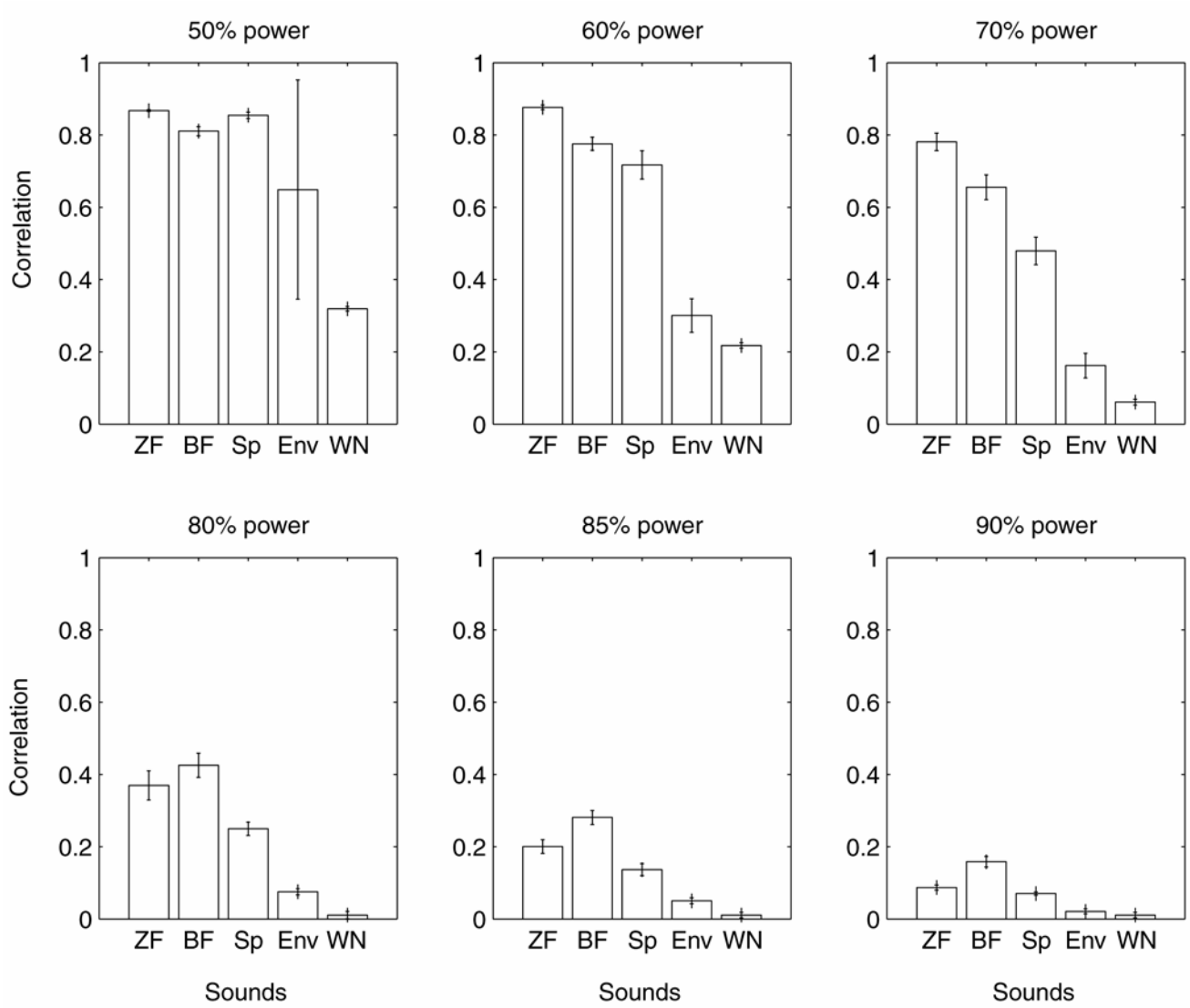
Whitening in the Forebrain
Comparison between Predicted Response and Flat Power



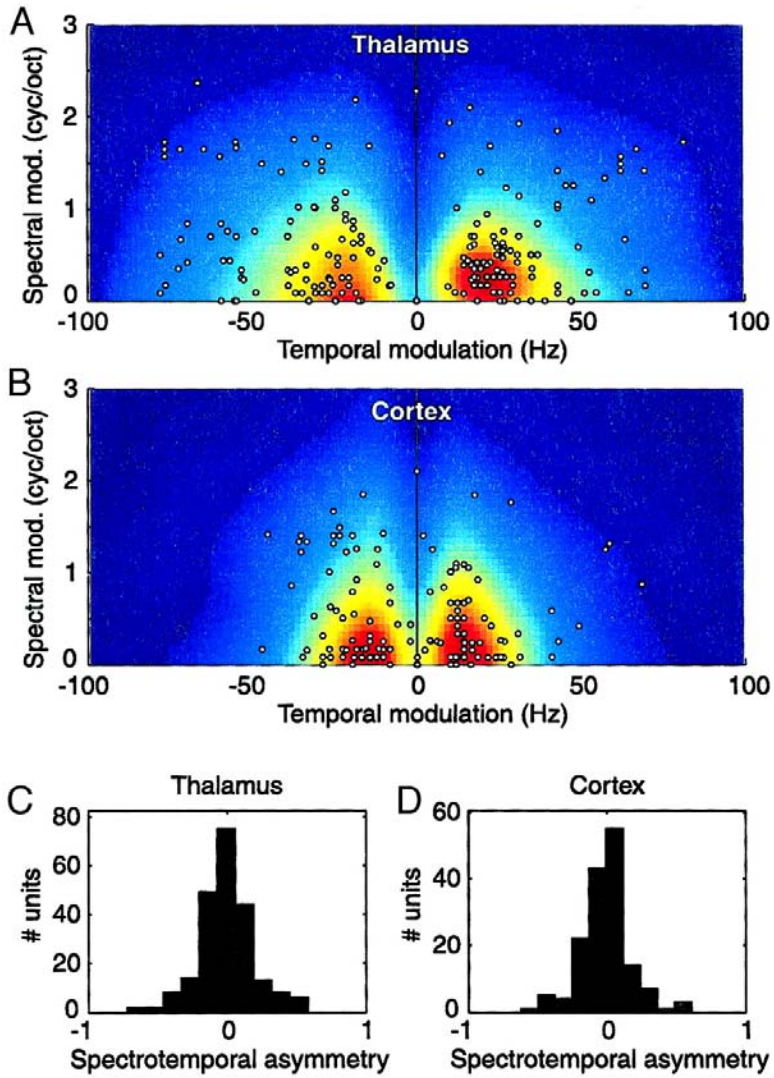
Whitening in the Forebrain (Field L)
Correlation between Predicted Response and Flat Power



Whitening in the Midbrain (Mld)
Correlation between Predicted Response and Flat Power



Modulation Transfer Functions in Cat Auditory Thalamus and Cortex



Miller, Escabi & Schreiner *J. Neurophys* 2002

Processing of Natural Sounds in the Auditory System

1. Modulation Spectra of Natural Sounds.

- Natural Sounds have a low-pass modulation spectrum.
- Spectral modulations are mostly found at low temporal modulations In animal vocalizations.
- Ethological theories of auditory coding: Matched, Whitening, Selective.

2. Spectro-Temporal Receptive Fields (STRF) and Modulation Transfer Function (MTF).

- STRFs can be obtained from responses to complex sounds by regularized linear regression methods.
- MTF shows the modulations that are coded by single neurons or neuronal ensembles.

3. MTF Tuning for Modulation Spectra of Natural Sounds

- Auditory system of song birds is tuned to the modulation spectra of natural sounds and in particular bird vocalizations. The form of the tuning is that of a whitening filter which emphasizes sounds that are less common but more informative.

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Quantifying the Goodness of Fit of the Linear STRF