Pressure vs. decibel modulation in spectrotemporal representations: How nonlinear are auditory cortical stimuli?

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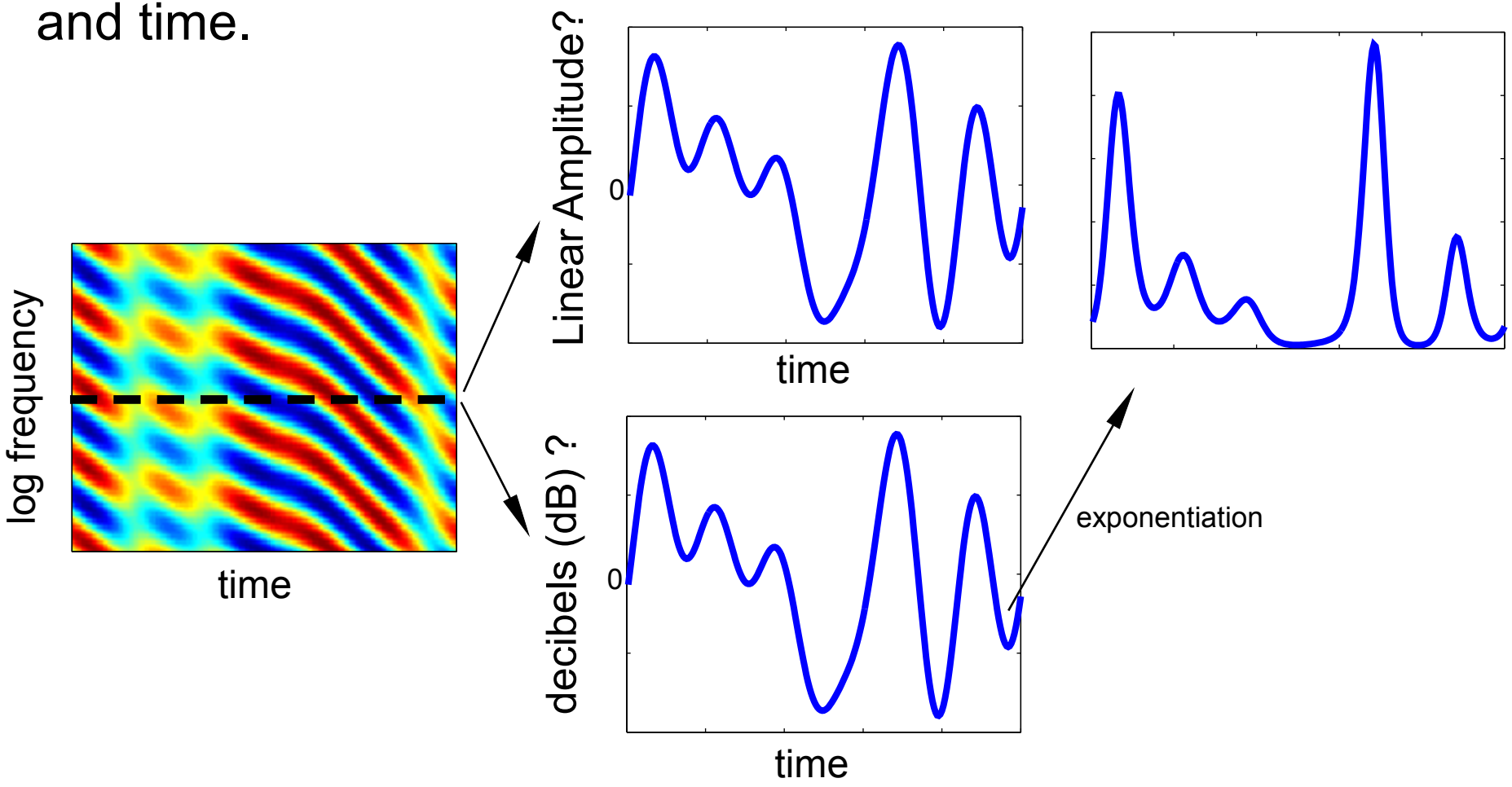
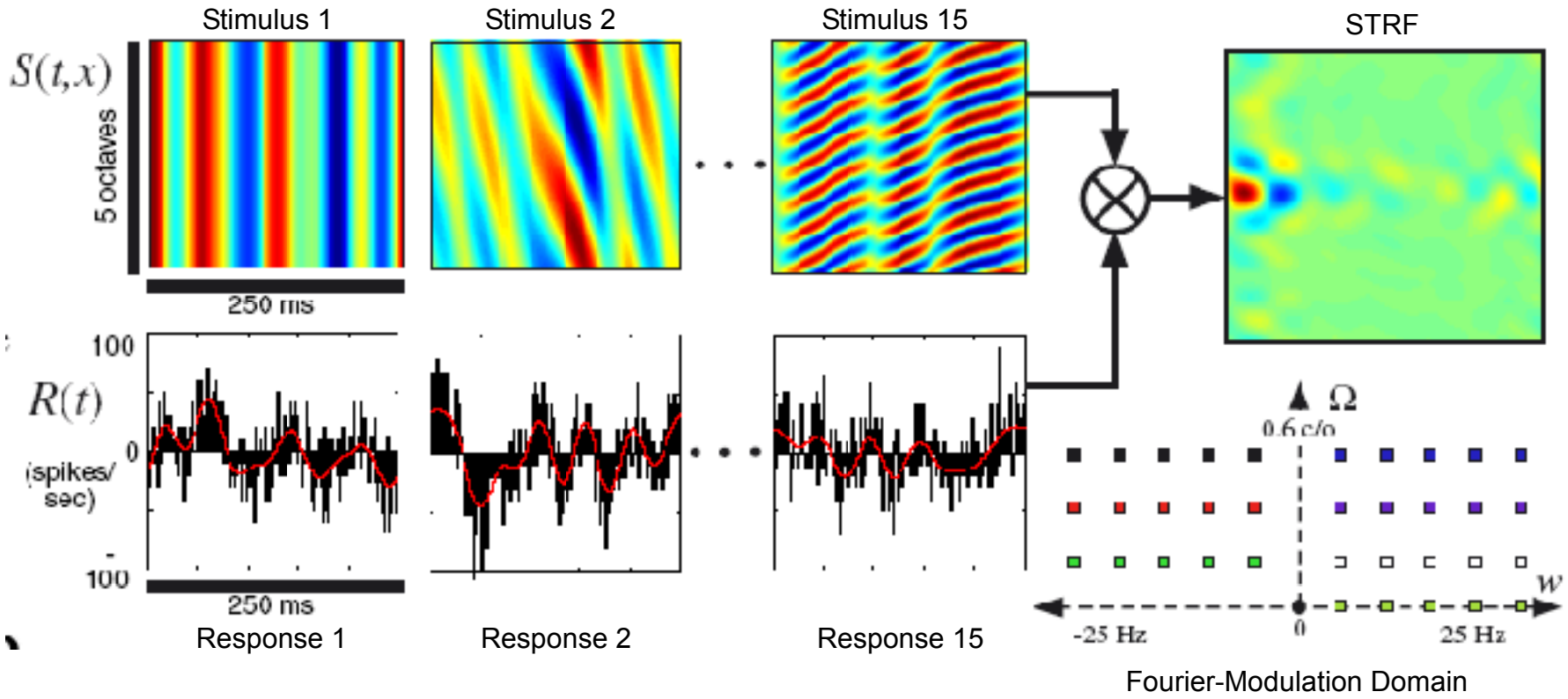
The spectrotemporal envelope of a stimulus represents how stimulus amplitude is modulated as a function of log-frequency and time.

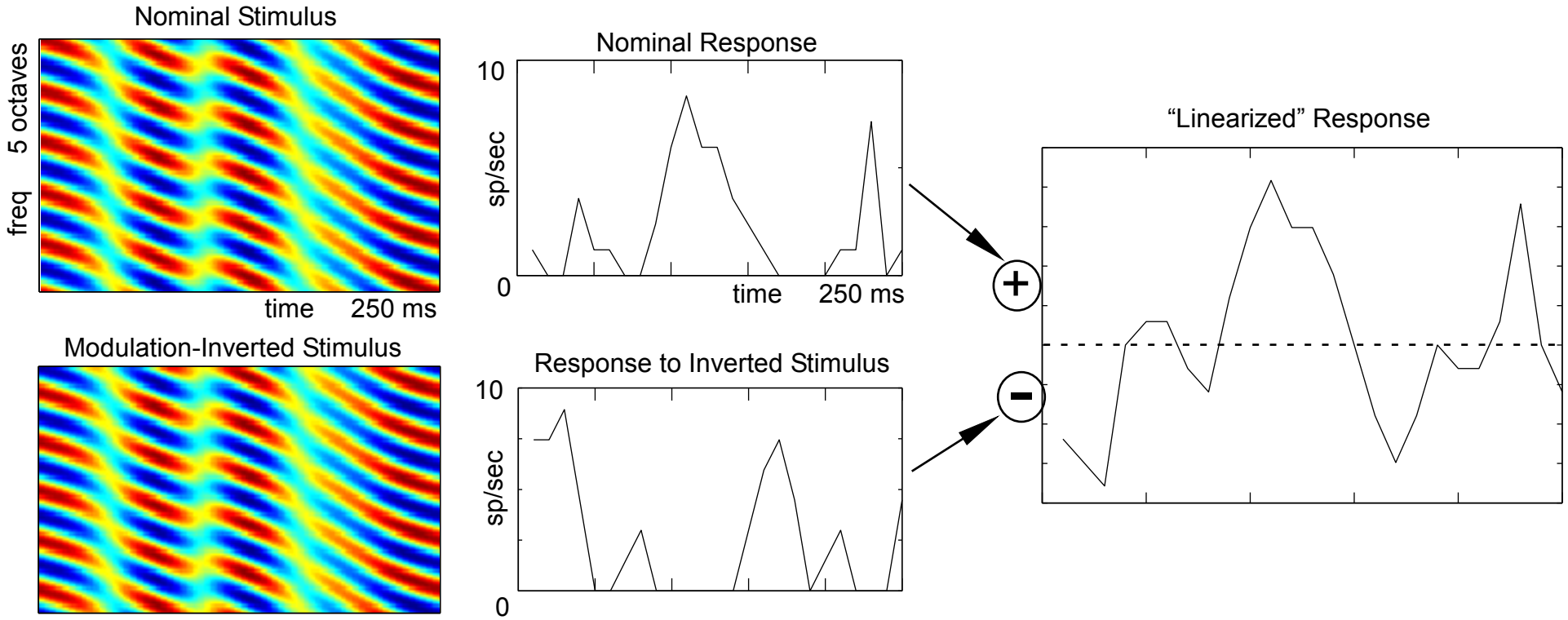


In this study we are investigating how the functional relationship between the spectrotemporal envelope and the response in primary auditory cortex differs when stimulus amplitude is represented in linear or decibel (dB) units.

We measured the spectrotemporal sensitivity of AI neurons using stimulus-response cross-correlation (i.e. reverse correlation) using stimuli spanning the modulation preference of AI neurons. This provides the linear relation between the spectrotemporal envelope and the response: the spectrotemporal receptive field (STRF).



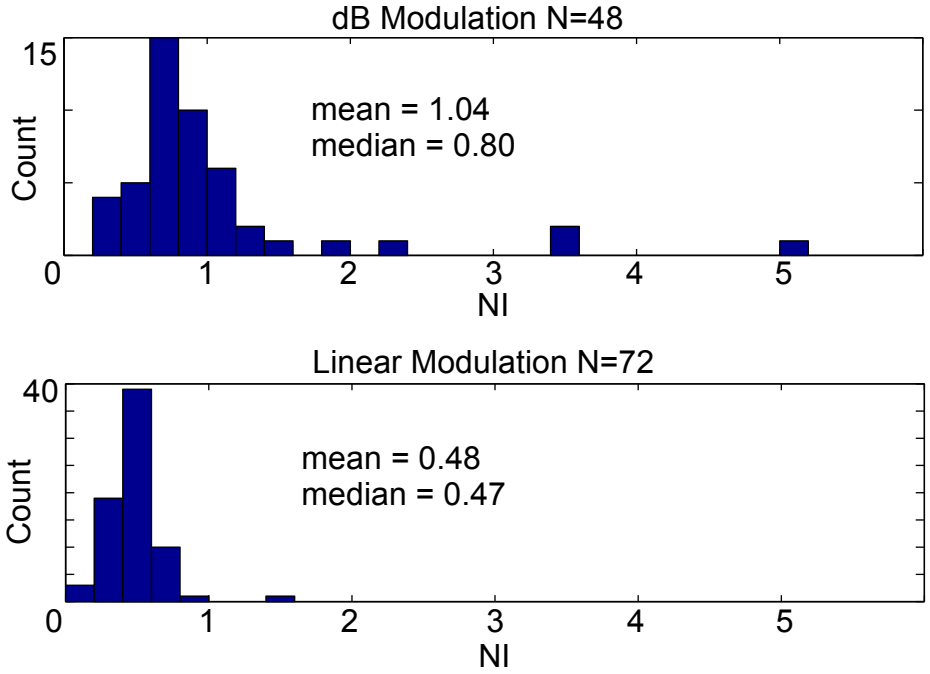
To better measure the STRF, the interfering effect of static nonlinear contributions to the responses (e.g. half-wave rectification) are minimized using inverse-repeat stimuli.

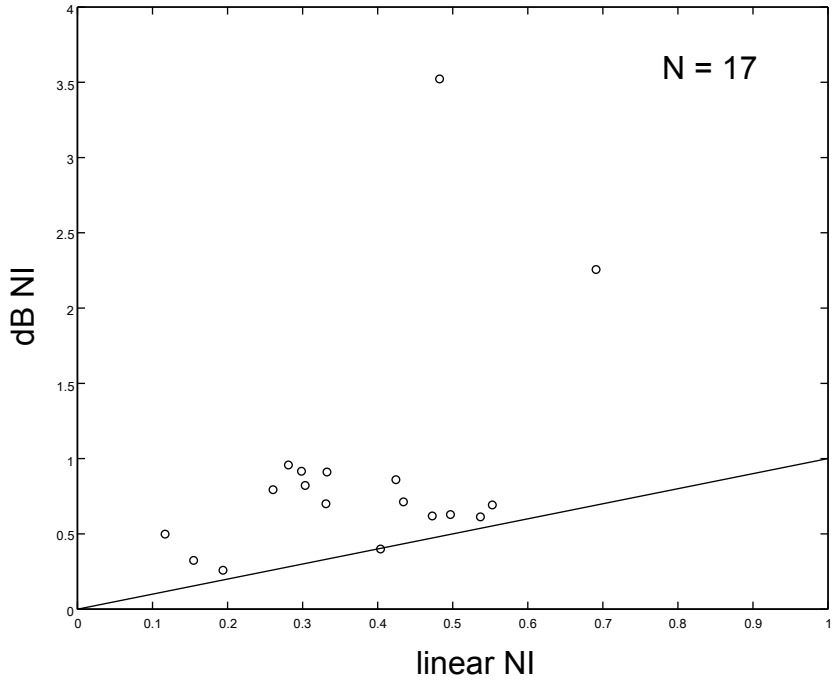


A **Nonlinearity Index (NI)** was computed as the total power of the nonlinear portion of the response (removed by the inverse-repeat method) relative to the that of the linearized response.

We compared the Nonlinearity Index (NI) with linearly modulated stimuli and dB-modulated stimuli.

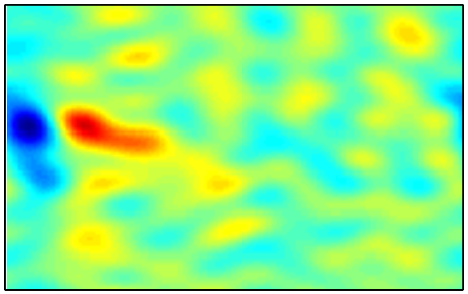
Across the population and in individual neurons, the NI was higher for the dB-modulated stimuli, occasionally much higher.



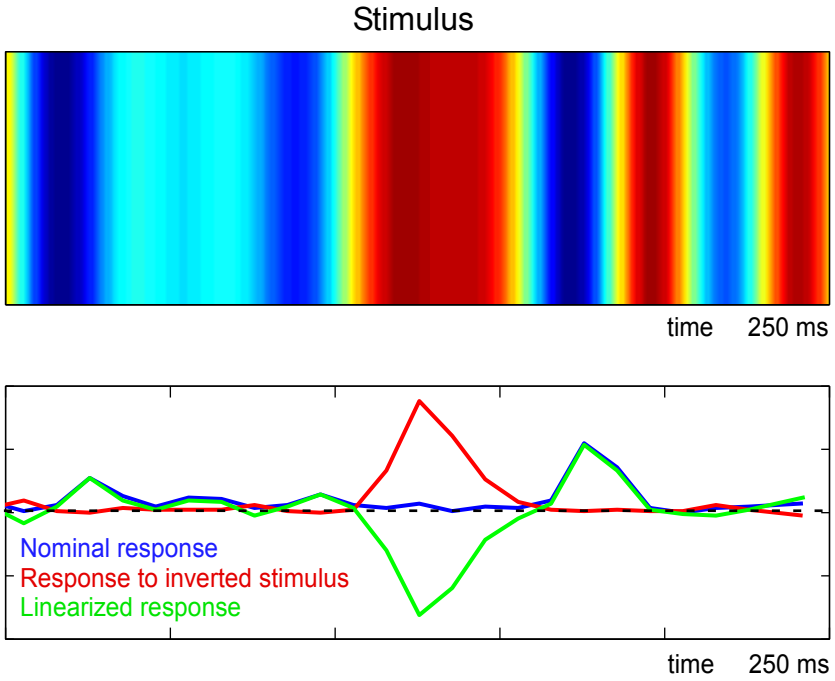


A closer examination of the most nonlinear responses to dB-modulated stimuli revealed that the nonlinearity was consistent with an (expansive) exponentiation of the spectrotemporal envelope, which would be required to transform the dB modulation pattern back into units of linear amplitude.

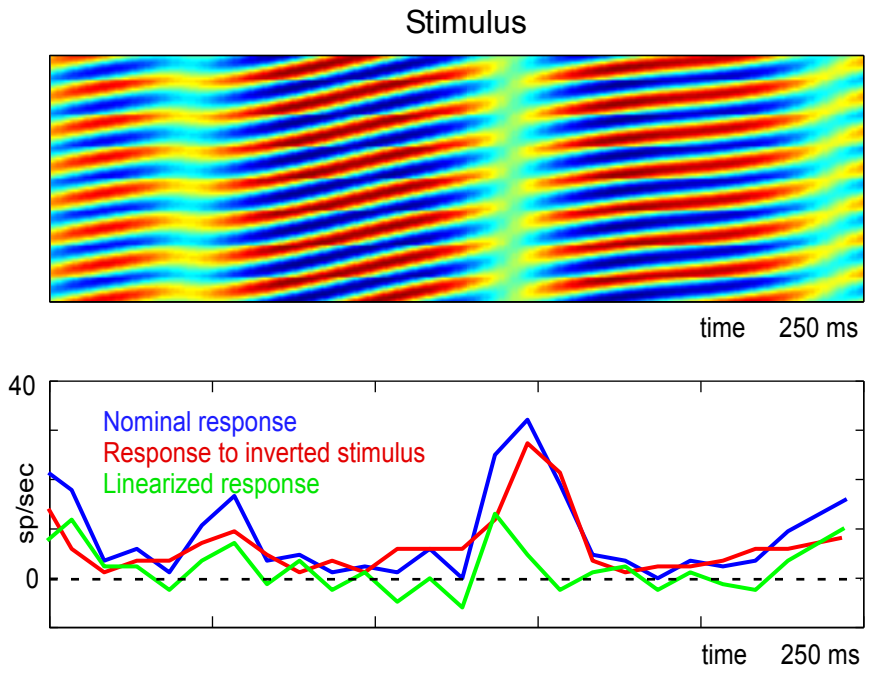
STRF



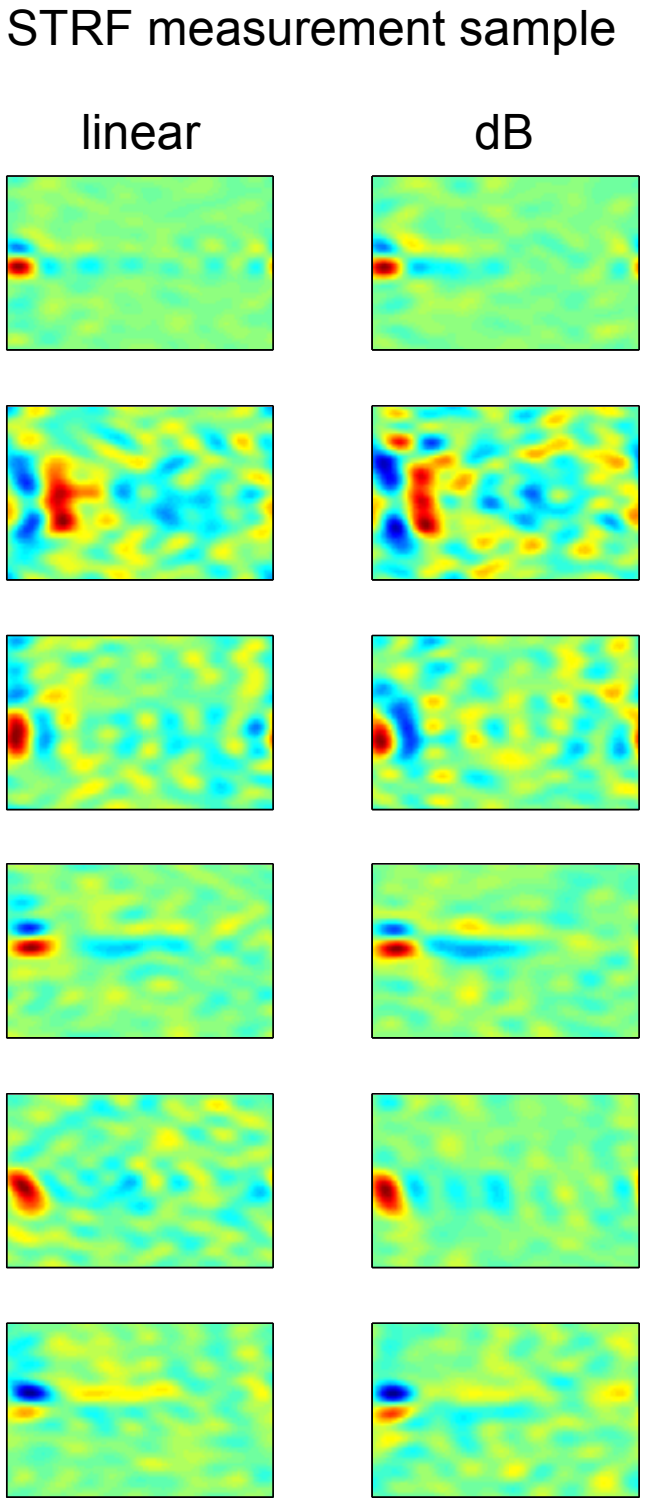
The STRF indicates the neuron responds preferentially to offsets of broadband spectral features. The neuron's response to stimuli containing such features is consistent.



However, the neuron also responds strongly to decreases in contrast of fine-scale spectral features, while the STRF indicates the linear response to such features should be weak Also, the responses to the nominal and inverted stimuli are similar. This nonlinear behavior (NI = 3.5) can be explained by an expansive nonlinearity, which emphasizes intensity increments over decrements.



Although dB-modulated stimuli make the AI response appear more nonlinear, the final STRF measurement (the linear part of the response) usually looked very similar for both dB modulation and linear modulation. Additionally, AI neurons respond more strongly to dB modulation (average gain in spike rate was 1.81), resulting in a more reliable STRF measurement (average gain in signal-to-noise ratio was 3.89).



Summary

- AI neurons exhibited more nonlinearity in their responses when the stimulus modulations were represented in terms of dB modulation.
- The nature of the nonlinearity was expansive, which is required to transform decibels back to linear amplitude.
- With respect to linear amplitude modulations, the STRF provides a good description of the AI response.
- The degree of nonlinearity evident depended upon the stimulus and the neuron's spectrotemporal sensitivity (STRF).
- dB modulations resulted in higher spike rates and more reliable STRF measurements

Implications

- Representing dynamic spectrotemporal envelopes in terms of decibels may provide an inaccurate view of the input to AI.
- AI responses may appear more nonlinear if the stimulus is represented in this way.
- The STRF is a robust descriptor of AI neurons
- The firing rate statistics of AI neurons should be linearly related to the amplitude statistics of natural sounds, rather than being a compressive function of them.