Intensity Dependence of the Auditory STRF

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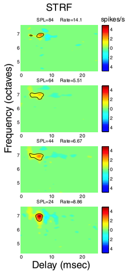
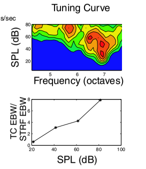
Introduction

The prevailing view of spectral integration is based on studies with pure-tones. Frequency tuning curves (FTC) exhibit a strong dependence in spectral selectivity with increasing intensity. This traditional view holds that spectral selectivity typically decreases with sound level and, somehow, the neural representation must account for this invariance at higher-order auditory stations.

In contrast to pure-tones, natural sounds are often broadband and have complex spectro-temporal modulations that actively engage the entire sensory network. Thus we speculated that dynamic recruitment of excitation and inhibition could potentially stabilize auditory receptive fields. We tested this hypothesis by studying the intensity dependence of the auditory STRF in the central nucleus of the inferior colliculus of cats, during broadband stimulation with dynamic moving ripple noise. Our findings suggest that, during dynamic broadband stimulation, auditory receptive fields are significantly more stable than for narrowband pure-tones. This finding holds significant implications for the representation of broadband environmental stimuli.

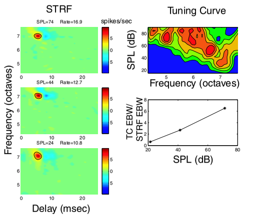
FTC vs. STRF Excitatory Bandwidth: Example 1





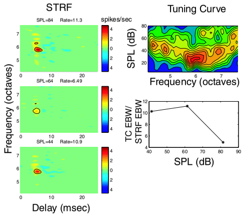
The STRF excitatory bandiwdht (EBW) was mesured by finding the 1/e contour relative to the peak of the STRF (black contour). For a perfectly Gaussion receptive field, this measurment would account for 85% of the STRF energy. The ratio of FTC-EBW versus STRF-EBW increases with SPL.

FTC vs. STRF Excitatory Bandwidth: Example 2



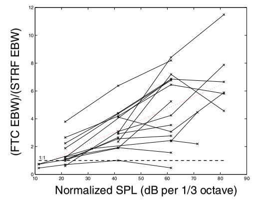
A similar trend is observed for the depicted neuron. The frequency tunning curve is depicted over the same frequency range as for the STRF.

FTC vs. STRF Excitatory Bandwidth: Example 3



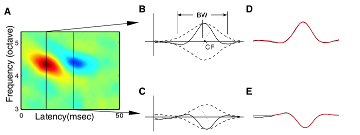
The fraction of STRF- versus FTC-EBW for a non-monotonic neuron initially increases, but decreases at higher SPL.

FTC vs. STRF Excitatory Bandwidth



The ratio of the STRF excitatory bandwidth versus FTC bandwidth increases dramatically with SPL for most neurons. Near threshold, the STRF- and FTC-EBW are very similar. A six-fold increase in the FTC-EBW is observed at 80 dB SPL.

Modeling The Spectral Receptive Field Profile

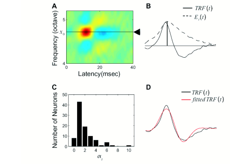


The spectral receptive field (SRF; continuous lines in B and C) is shown for two spectral cross-sections of the STRF (A). Using a Hilbert transform of the SRF (dotted curves in B and C), the SRF is broken down into a carrier (approximately sinusoidal) and envelope component (approximately Gaussian shape; dashed curve; B and C). The SRF is then approximate (D and E) as a spectral Gabor function:

$$G(x) = K\cos(2\pi\Omega_0(x-x_0)+P)\, e^{-[2(x-x_0)/BW]^2}$$

where x=octave frequency, x_0=center frequency, Ω_0=spectral modulation frequency, *BW*=SRF bandwidth, *P*=spectral phase, and *K* is the SRF Energy.

Modeling The Temporal Receptive Field Profile

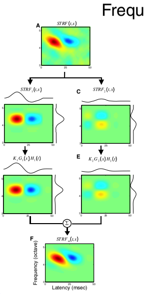


The same fitting procedure (as for the SRF) is applied to the temporal receptive field (TRF). The TRF is modeled as a temporal Gabor of form:

$$H(T) = K\cos(2\pi F_m(T-T_0)+Q)\, e^{-[2(T-T_0)/D]^2}$$

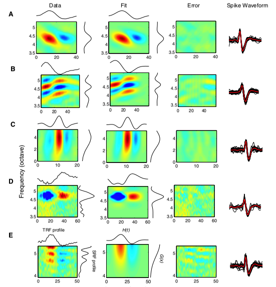
where the time axis is skewed according to T=2 arctan(βt), in order to account for asymmetric transient envelopes (B) observe in all neurons (C shows asymmetry statistics). Relevant parameters include: T_0=Peak Latency, F_m=temporal modulation frequency, *D*=response duration, *Q*=temporal phase, and *K*=TRF Energy.

Modeling the STRF with Separable Time-Frequency Gabors

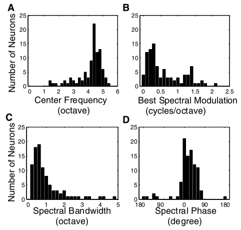


Pannels 2 and 3 show that TRF and SRF can be individually fitted by Gabor functions. Does this generalize for the entire STRF? To fit the STRF by Gabor functions, we first break it down into a series of time-frequency separable STRF components (B; shown for the first two components only). This is done by applying a sigular value decomposition to the receptive field in (A). Each component receptive field in B, is then fitted by a separable time-frequency Gabor (D). The Modeled receptive field (F) is obtained as a weighted sum of the component Gabors in (D).

Example STRF Fits

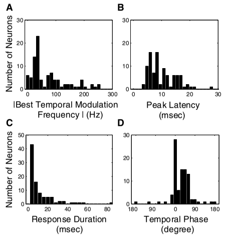


Spectral Receptive Field Parameters



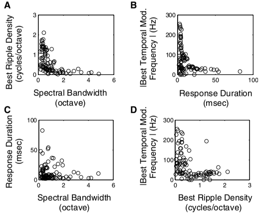
Distributions of spectral receptive field parameters derived from the Gabor STRF model.

Temporal Receptive Field Parameters



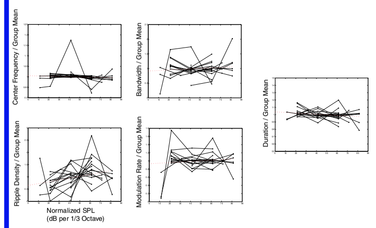
Distributions of temporal receptive field parameters derived from the Gabor STRF model.

Time-Frequency Integration Tradeoffs



Spectro-temporal parameters show distinctive trends in receptive field size and modulation filtering resolution. (A and B) Receptive field bandwidths and durations limit the number of modulation cycles. (C) There is a spectro-temporal tradeoff in receptive field size and (D) modulation filtering resolution.

STRF Parameters vs. SPL



The STRF parameters of the Gabor Model are relatively constant with SPL.

Conclusion

1. Broadband timulation with dynamic moving ripple appears to stabilize the auditory receptive field. In contrast, pure-tone response profiles are significantly more affected by the stimulus intensity.

2. We hypothesize that this intensity invariance is due to active recruitment of excitation and inhibition across the entire sensory epithelium. Encoding of natural broadband signals could benefit from such a strategy, because the representation at higher levels of processing would be invariant with intensity.

3. Spectral and temporal parameters show distinct time-frequency resolution tradeoffs in receptive field size and modulation filtering.

4. These findings may help explain the perceptual constancy of numerous spectro-temporal integration phenomena.

Reference

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