Simulating effects of contralateral acoustic stimulation using an auditory efferent model

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1 Introduction and model architecture

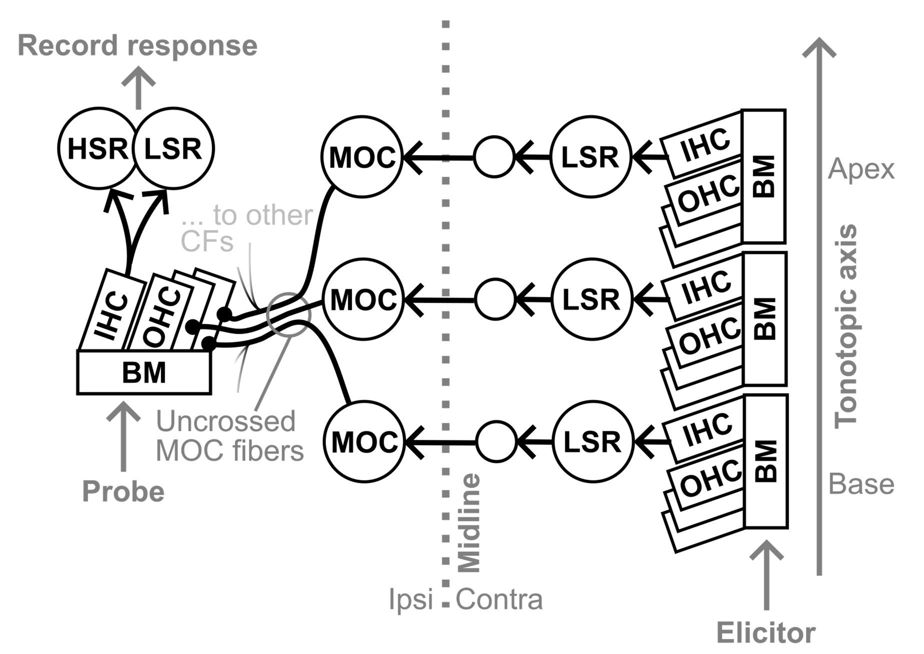
A computational model of the auditory system that includes efferent pathways is necessary for "closing the loop"

One source of data to inform model development is the effects of **contralateral acoustic stimulation** (CAS) on ipsilateral auditory-nerve (AN) responses [Warren1989a]

Contralateral sound excites medial olivocochlear (MOC) neurons that provide efferent innervation to outer hair cells (OHCs) in the cochlea and reduce cochlear gain

Key question: Can our sound-driven efferent model capture general trends in AN CAS experiments?

- Time course
- Magnitude
- Threshold
- Trends with CF

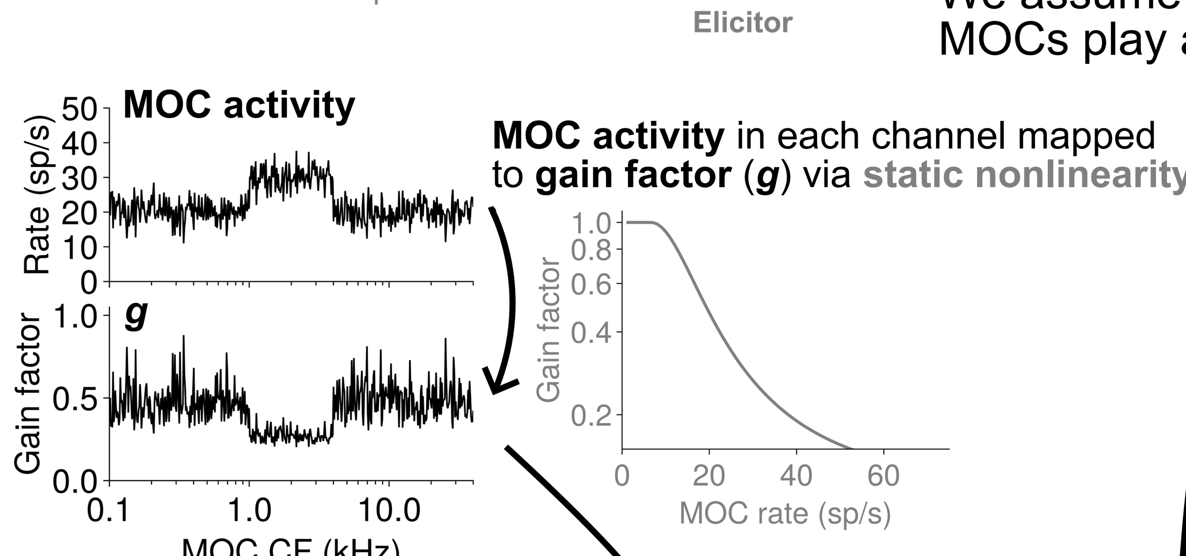


Some MOC neurons innervate OHCs over wide (>1 oct) cochlear spans [Brown2014]

We extended an existing efferent model [Farhadi2023] to simulate CAS with wide-span innervation of OHCs

Our model simulates a tonotopic population of MOC neurons driven by contralateral sound and a single ipsilateral afferent nerve fiber

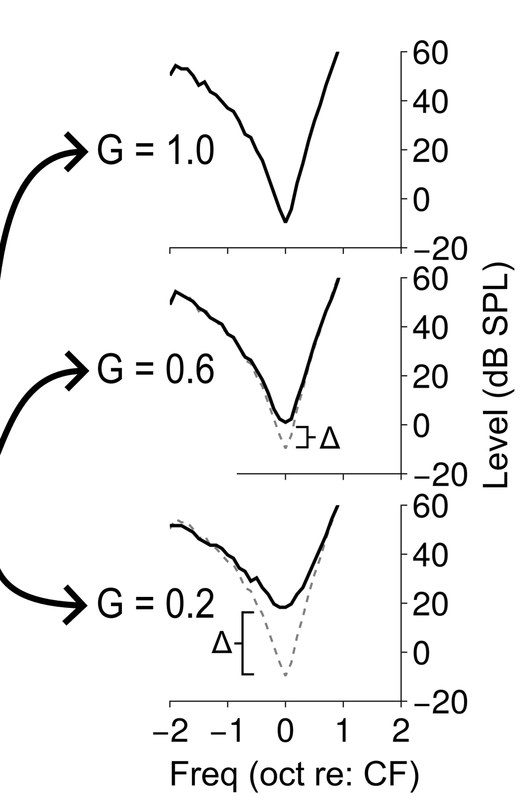
We assume that only uncrossed MOCs play an important role here



MOC activity in each channel mapped to **gain factor** (g) via **static nonlinearity**

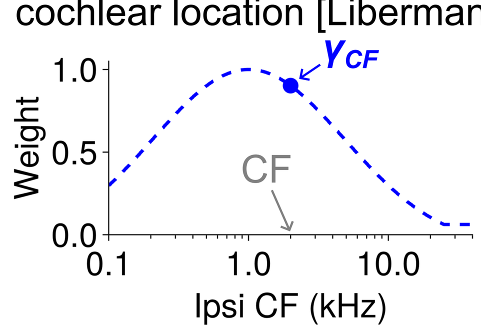
Gain at single cochlear location (G_{CF}), e.g., at **ipsi CF = 2 kHz**, determined by:

$$\gamma_{CF} \frac{1}{\sum_i w_i} \sum_i w_i \log g_i = \log G_{CF}$$

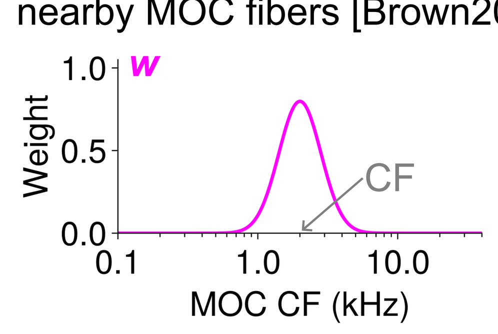


Effects of different gain factors are visible in iso-response tuning curves, as shown above; CF = 2 kHz, HSR fiber

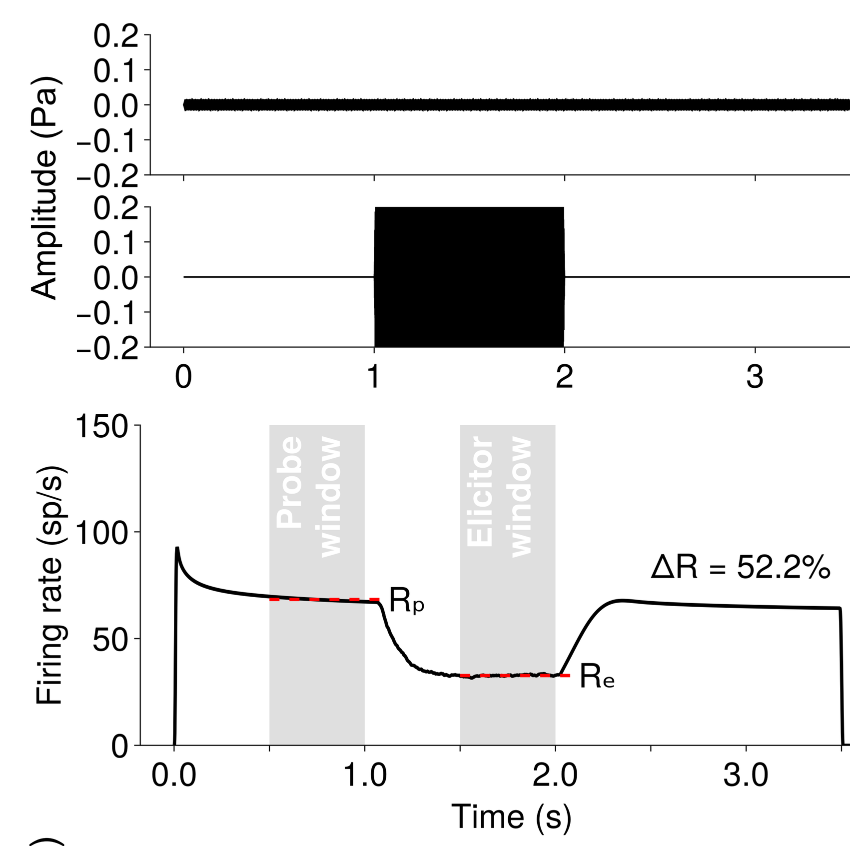
Adjust for innervation strength
Scale result by CF-specific parameter γ, motivated by size/quantity of efferent synapses vs cochlear location [Liberman1990]



Combine across MOC fibers
Inputs averaged with weights w, motivated by overlapping spans of innervation from tonotopically nearby MOC fibers [Brown2014]



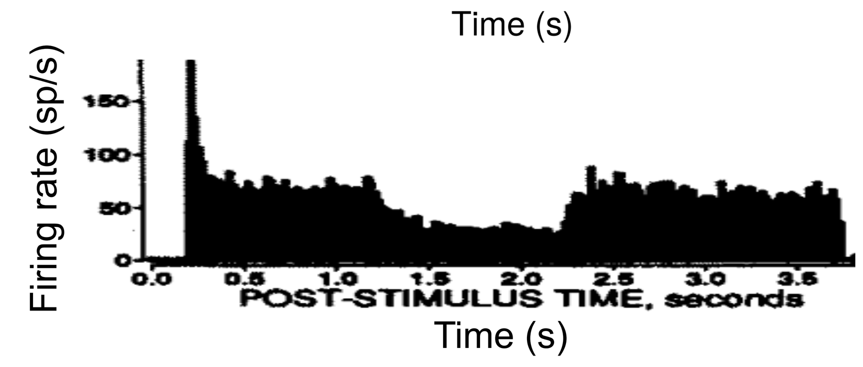
2 CAS time course example



Ipsi stimulus (probe)
Pure tone at CF
Level = rate-level function midpoint

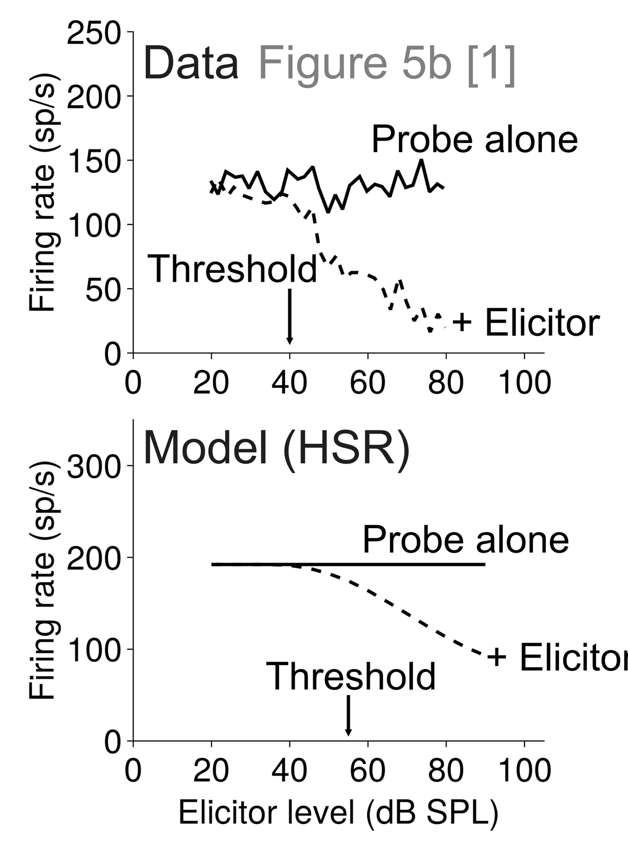
Contra stimulus (elicitor)
OR (1) Broadband Gaussian noise
(2) Pure tone
+20–30 dB re: ipsi probe level

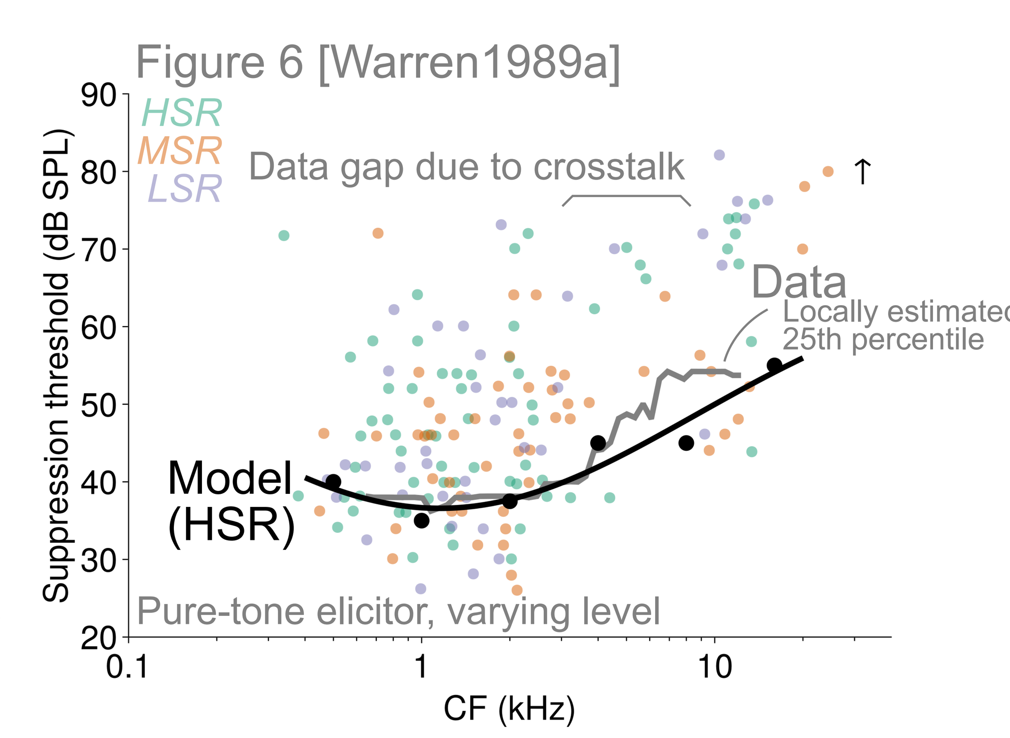
Ipsi response (simulated)
LSR fiber, CF = 4.37 kHz
Gaussian-noise elicitor
R_p rate in probe-alone window
R_e rate in +elicitor window
$\Delta R = 100 \times ([R_e - R_p]/R_p)$



Ipsi response (data)
Figure 3 [Warren1989a]
Anesthetized cat
Severed middle-ear muscle
LSR fiber, CF = 4.37 kHz

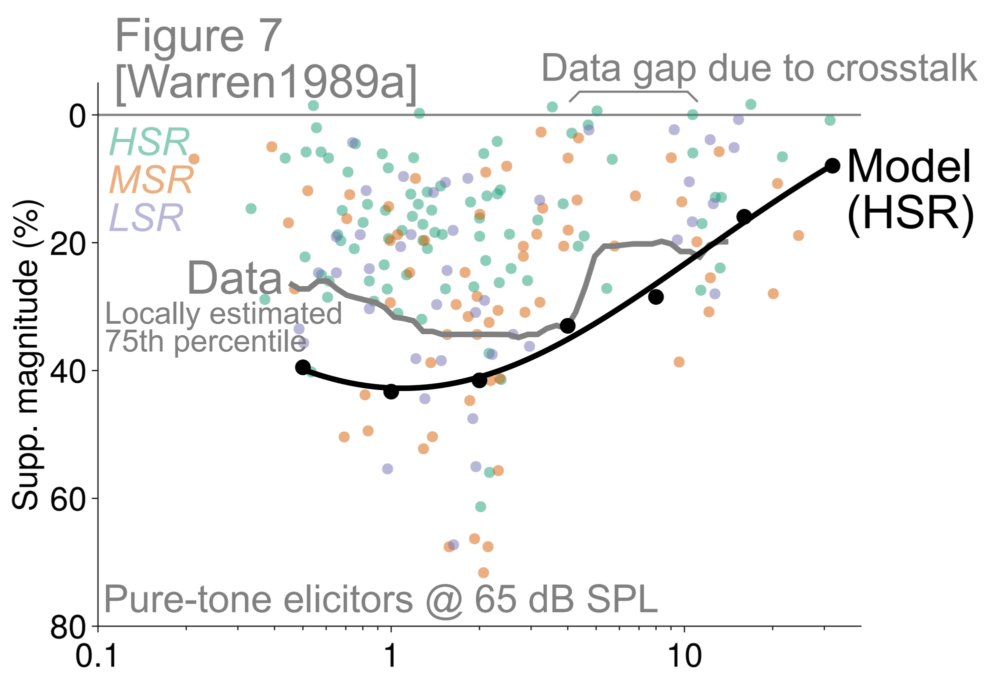
3 CAS thresholds vs CF





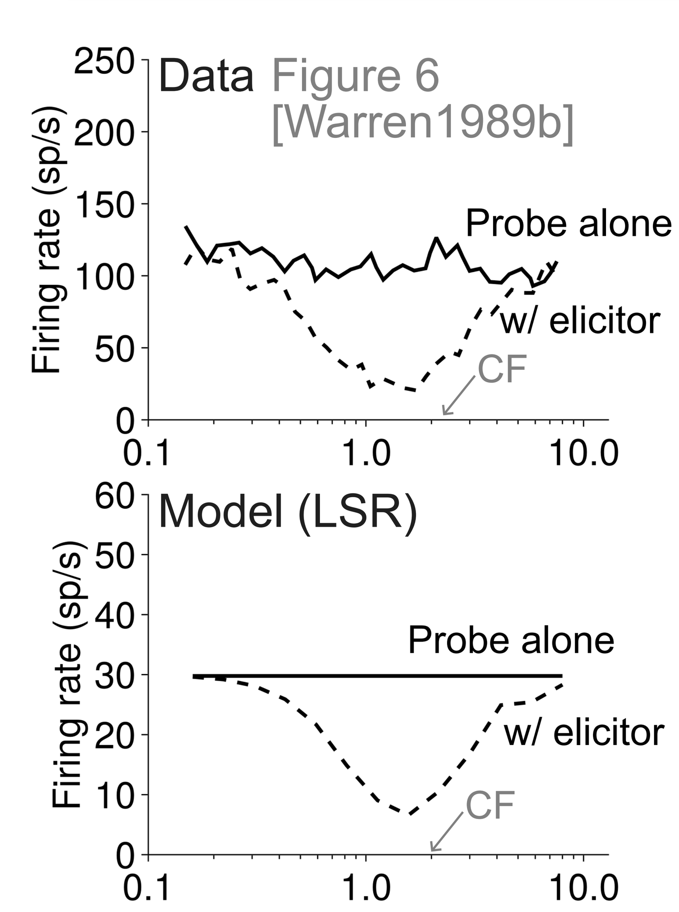
A CAS threshold is the elicitor level at which significant reductions in probe rate are first observed (criterion for model = 5%, left). CAS thresholds vary with CF (right), and a **CF-specific innervation strength** (γ) was needed in the model to account for elevation of thresholds at higher CFs.

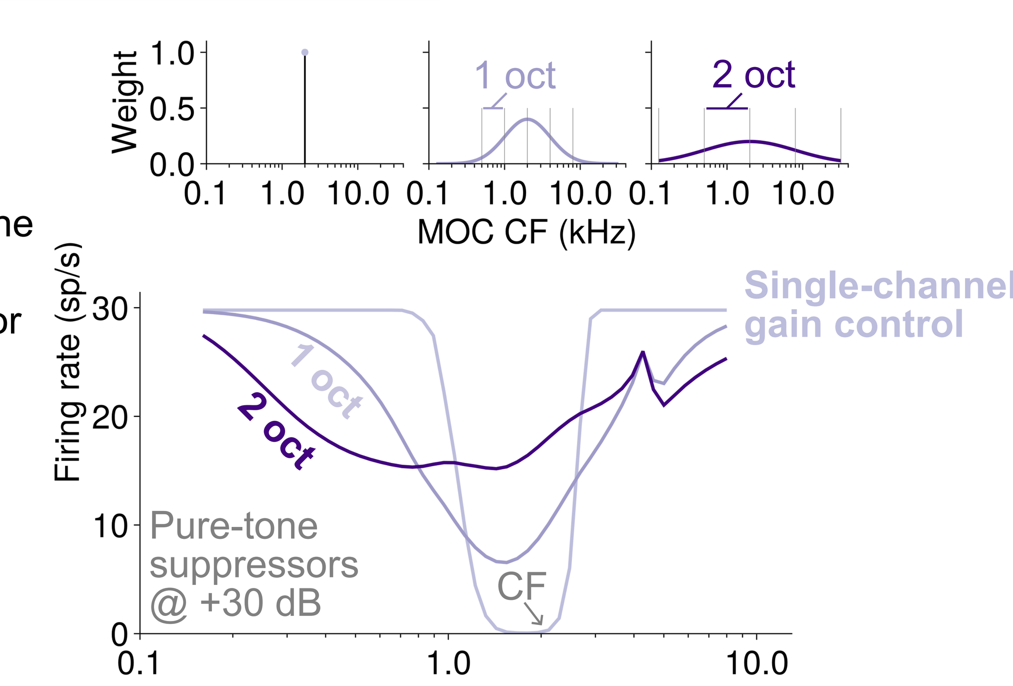
4 CAS magnitude vs CF



The magnitude of CAS effects (ΔR, as measured in Panel 2, measured for elicitors at 60–70 dB SPL) varies with CF, peaking at ~2 kHz. Using the same **CF-specific innervation strength** (γ) as before, we observe weaker efferent effects at higher CFs, as in the data. Significant heterogeneity in the data complicates quantitative assessment of the model fit.

5 CAS frequency tuning





Elicitors swept in frequency produce broad patterns of suppression (left); simulating this requires **combination of MOC inputs** over fairly wide tonotopic range (> 1 oct) and cannot be explained purely by spread of excitation (right).

6 Conclusions

Our sound-driven efferent model can simulate trends in CAS data: Thresholds (Panel 3), magnitudes (Panel 4), tuning (Panel 5)

Two key ingredients are needed:
[1] A CF-weighting function that tapers off at high CFs, possibly reflecting biases in efferent innervation [Brown2014, Liberman1990]

[2] Convergent input from multiple MOC neurons spanning a wider CF range than the afferent AN fiber itself

7 Bibliography, acknowledgements

References
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