Profile analysis and ripple discrimination at high frequencies

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Introduction

- Level discrimination and AM detection vary little as a function of frequency [1, 2]
- However, both of these tasks are simple and can be performed on the basis of cues from a single frequency channel / auditory-nerve fiber
- Whiteford et al. (2020) [3] recently showed that detecting incoherence in the modulator phases of two SAM tones worsened at high carrier frequencies
- Are similar deficits seen at high frequencies in other tasks thought to depend on cross-frequency comparisons?

Overview

Methods

- Measured psychophysical performance at low frequencies and high frequencies in multiple tasks
- Some tasks were designed to be possible using information only from a single channel (level discrimination, ripple detection)
- Other tasks were designed to require information from multiple frequency channels (profile analysis, ripple direction discrimination)
- We then related psychophysical performance to simulations of auditory-nerve responses [3]

Key questions

- Q1: Can listeners perform profile analysis at high frequencies?
- Q2: Can listeners perform ripple direction discrimination at high frequencies?
- Q3: Are patterns of psychophysical performance related to auditory-nerve coding?

Stimuli

Log-spaced complex tones

- Random-phase log-spaced complex tones
- Frequencies spaced from 0.3-0.79 kHz (low freq) or 6 to 16 kHz (high freq)
- Variable number of components (3, 5, 9, or 15)
- Either ...
  - fixed pedestal level of 60 dB SPL (level discrimination)
  - random pedestal level over 50-70 dB SPL (profile analysis)
- 350 ms in duration

Spectrotemporal ripples

- Sum of 300 random-phase SAM tones
- Ripple rate of 2 Hz
- Ripple density of 4 cycles/octave
- Log-spaced carriers from 0.5 18 kHz at 45 dB SPL per-component
- Bandpass filtered from 0.6-1.6 kHz (low freq) or 6 to 17 kHz (high freq)
- 1000 ms in duration

Behavior

Deficits in profile analysis at high frequencies

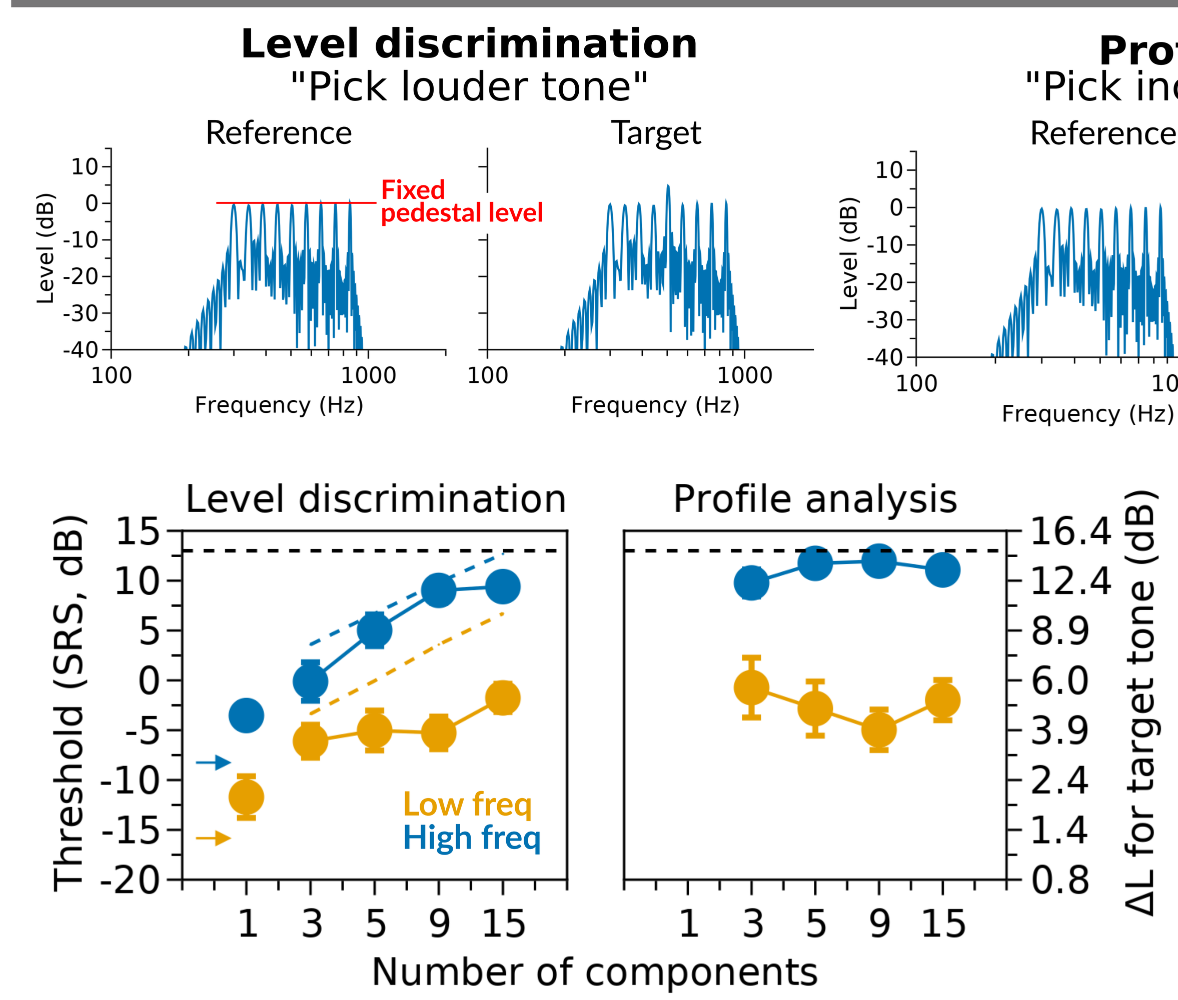


Figure 1: Top panel. Log-power spectra for reference and target stimuli in the level discrimination task (left) or profile analysis task (right). **Bottom panel.** Group-average for the level discrimination task and profile analysis task. Arrows indicate data from corresponding conditions from [1]. Data are reported in units of signal re: standard (SRS; 20 $\log_{10}$ [ΔA/A]; left) and as a level increment (ΔL; right). Dashed colored lines indicate predicted thresholds under the assumption that listeners use changes in overall sound level to perform the task.

No deficit in ripple detection/discrimination at high frequencies

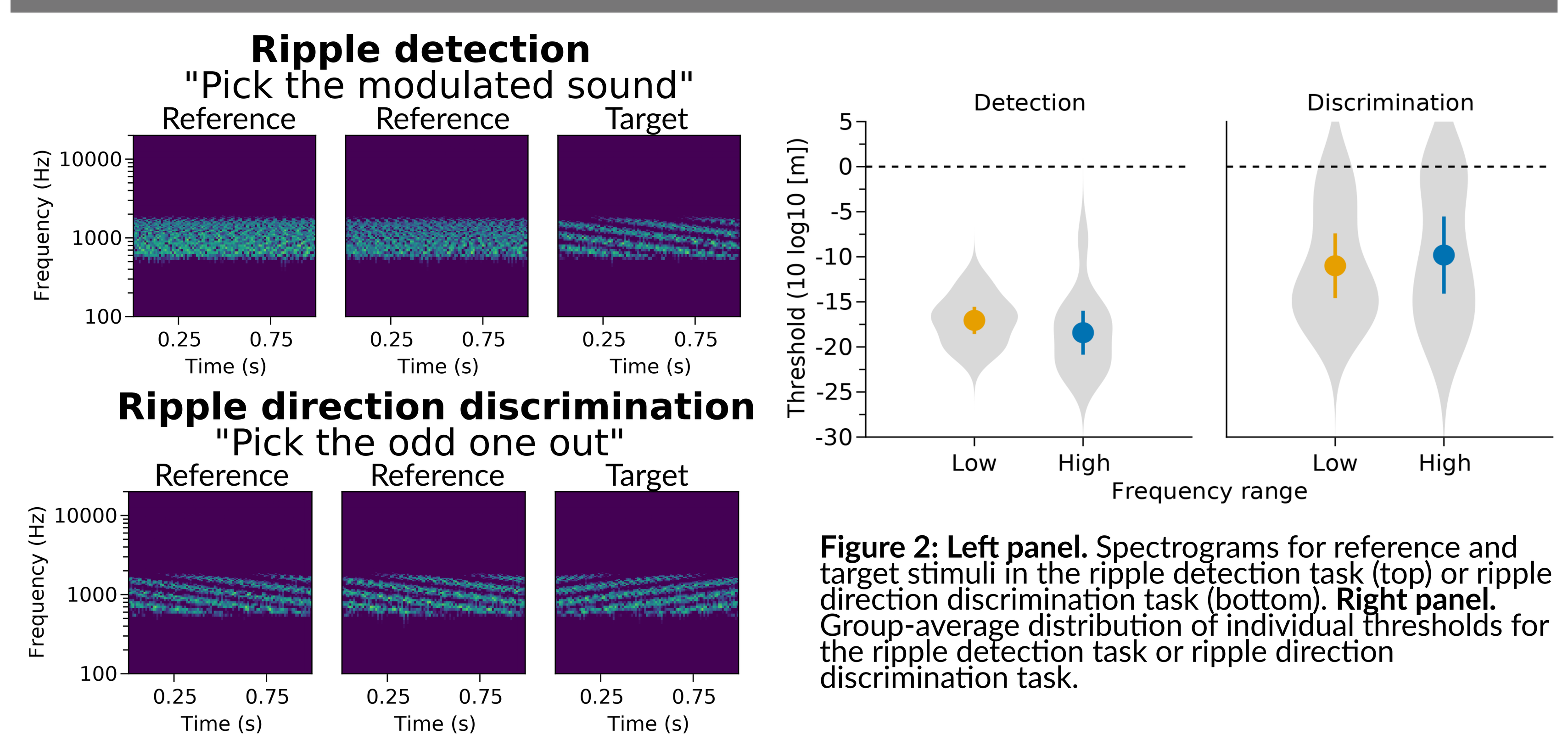
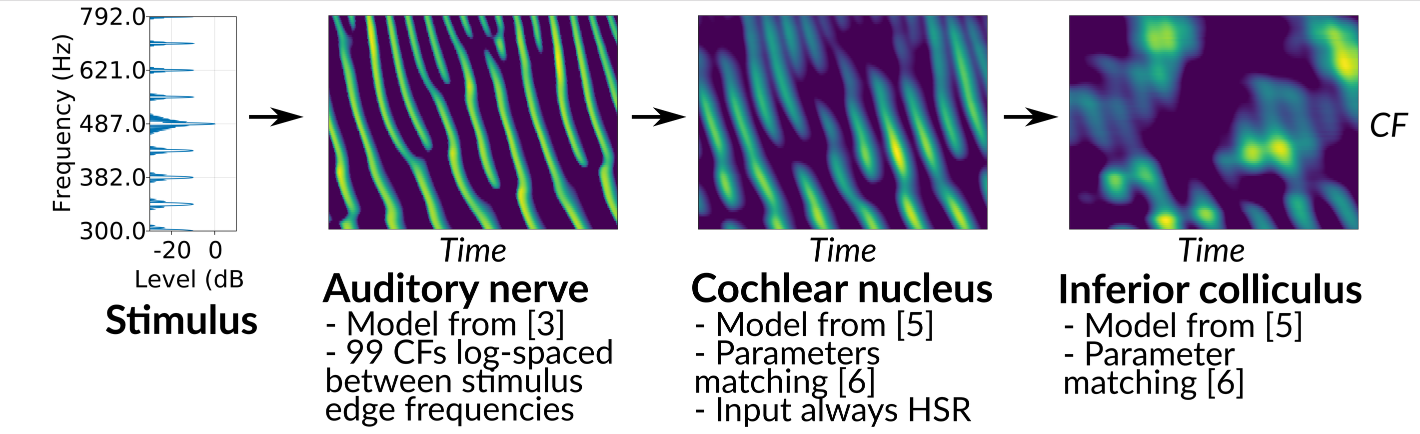


Figure 2: Left panel. Spectrograms for reference and target stimuli in the ripple detection task (top) or ripple direction discrimination task (bottom). **Right panel.** Group-average distribution of individual thresholds for the ripple detection task or ripple direction discrimination task.

Modeling

Responses to profile-analysis stimuli simulated in multiple loci



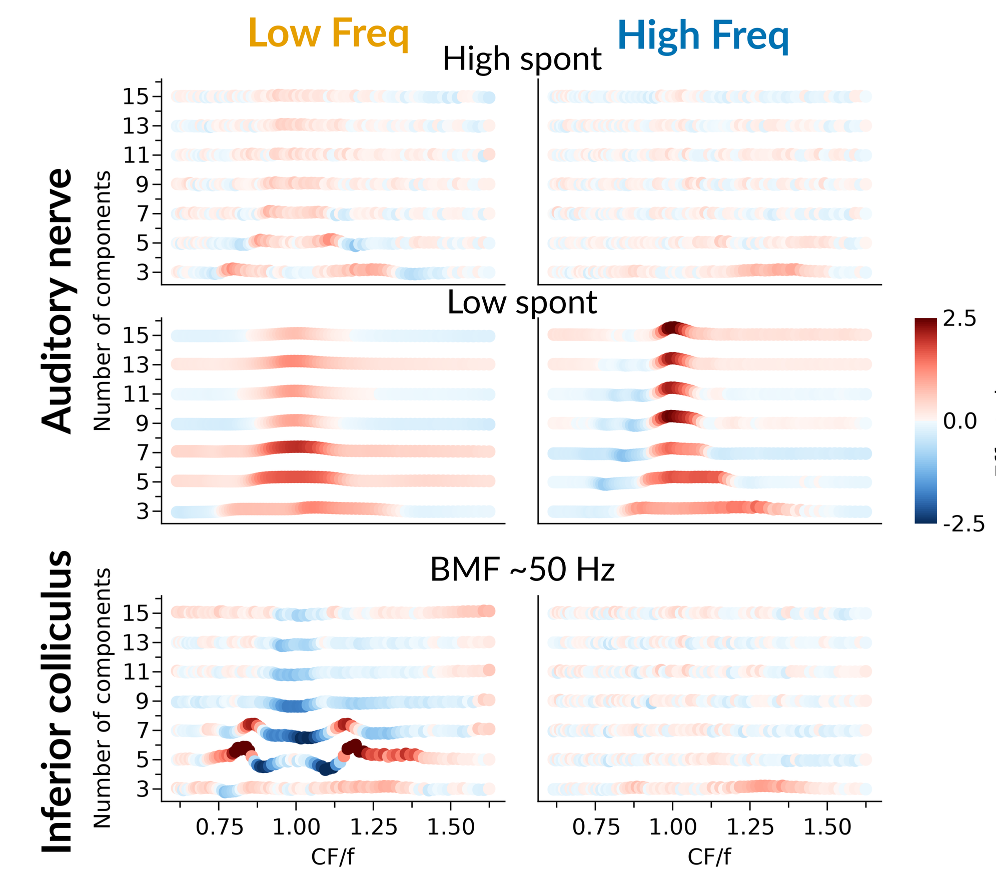
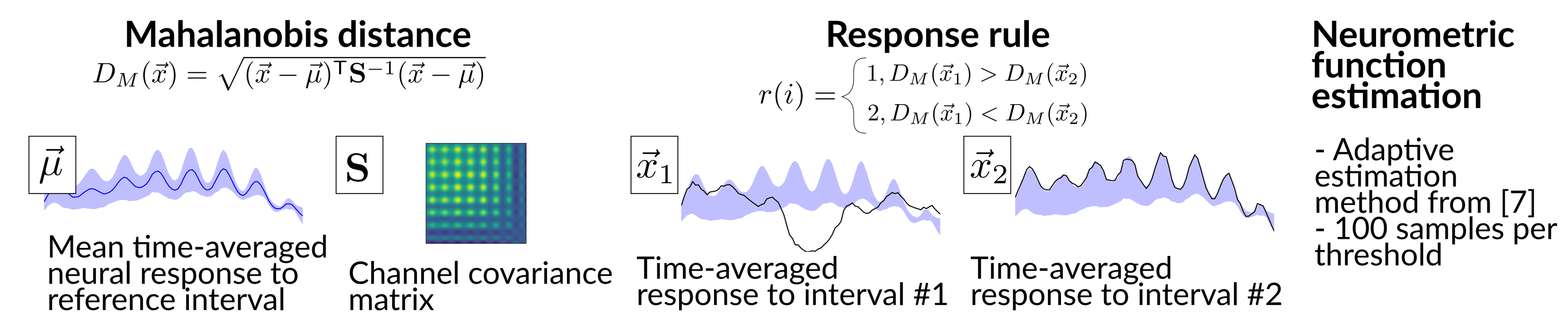


Figure 3: Simulated average-rate responses to the profile-analysis stimuli. Color and height indicate average difference between target and standard divided by the standard deviation of the standard (effect size).

Template-based models used to estimate thresholds



Neither AN nor midbrain rate decoding captured all trends

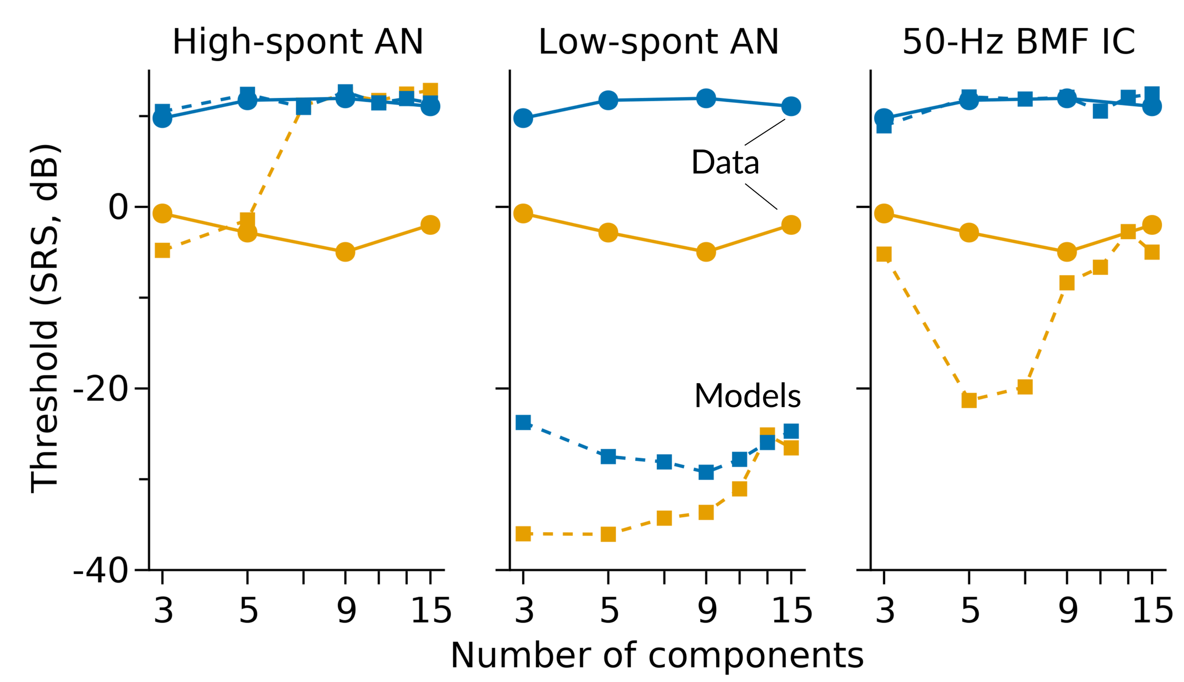
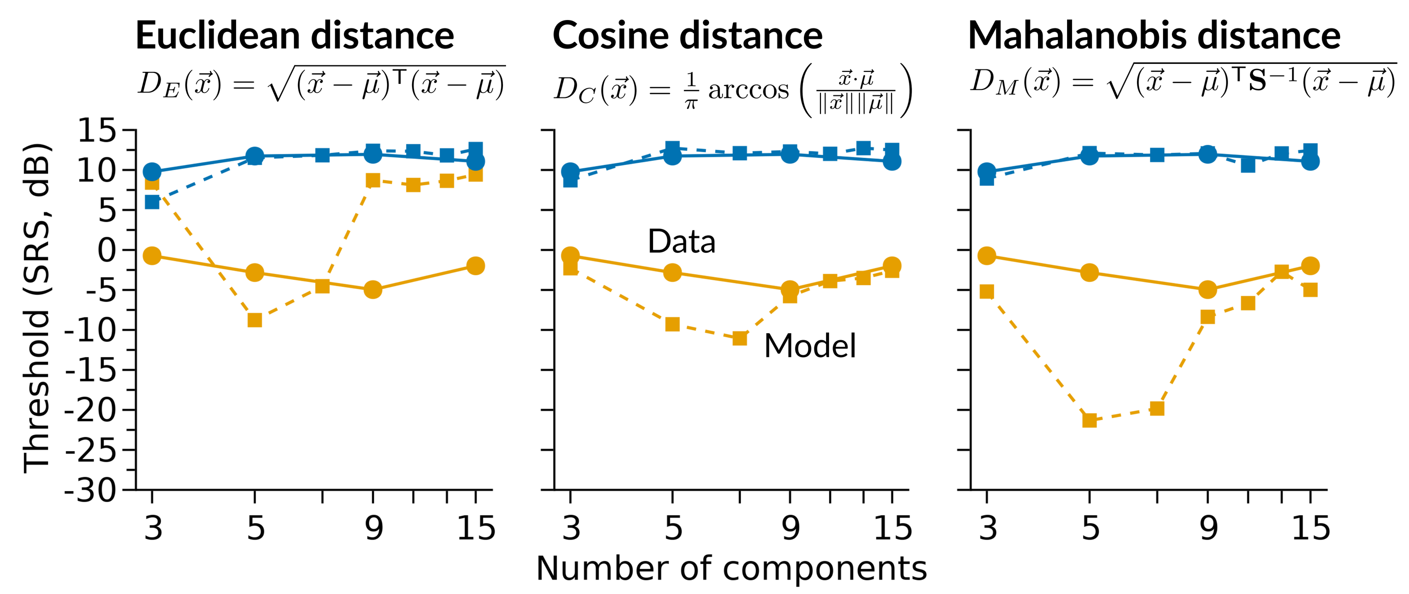


Figure 4 (left): Model predictions for the Mahalanobis-distance template observer vs behavioral data. The left two columns show auditory-nerve predictions, while the right column shows predictions for an example inferior-colliculus population.

■ **Model prediction**
● **Behavioral data**

Figure 5 (below): Model predictions for same inferior-colliculus population, but as a function of different decoding schemes (Euclidean, Cosine, or Mahalanobis distance).



Conclusions

- A1: Listeners could not perform profile analysis at high frequencies (Figure 1)
- A2: Listeners could perform ripple direction discrimination at high frequencies (Figure 2)
- A3: Template-based decoding of AN rates did not match behavioral trends in profile analysis (Figure 3)
  - Both ANF spontaneous rate and decoding strategy strong influenced predictions
  - Midbrain-rate decoding could offer alternative account of behavioral performance

Supporting materials

Poster available at:

https://guestdaniel.github.io/download/GuestOxenhamASADenver2022.pdf

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Open source code/software:
- AFC [8]
- Julia (Parameters, Chain, Makie, DataFrames, Algebra of Graphics, DrWatson)
- Inkscape

References

[1] Florentine, M., Buus, S. R., & Mason, C. R. (1987). Level discrimination as a function of level for tones from 0.25 to 16 kHz. *The Journal of the Acoustical Society of America*, *81*(5), 1528-1541.

[2] Sek, A., & Moore, B. C. (1995). Frequency discrimination as a function of frequency, measured in several ways. *The Journal of the Acoustical Society of America*, *97*(4), 2479-2486.

[3] Whiteford, K. L., Kreft, H. A., & Oxenham, A. J. (2020). The role of cochlear place coding in the perception of frequency modulation. *Elife*, *9*, e58468.

[4] Zilany, M. S., Bruce, I. C., & Carney, L. H. (2014). Updated parameters and expanded simulation options for a model of the auditory periphery. *The Journal of the Acoustical Society of America*, *135*(1), 283-286.

[5] Nelson, P. C., & Carney, L. H. (2004). A phenomenological model of peripheral and central neural responses to amplitude-modulated tones. *The Journal of the Acoustical Society of America*, *116*(4), 2173-2186.

[6] Maxwell, B. N., Richards, V. M., & Carney, L. H. (2020). Neural fluctuation cues for simultaneous notched-noise masking and profile-analysis tasks: Insights from model midbrain responses. *The Journal of the Acoustical Society of America*, *147*(5), 3523-3537.

[7] Kontsevich, L. L., & Tyler, C. W. (1999). Bayesian adaptive estimation of psychometric slope and threshold. *Vision Research*, *39*(16), 2729-2737.

[8] Ewert (2013). AFC - A modular framework for running psychoacoustic experiments and computational perception models. *Proceedings of the International Conference on Acoustics*. 1326-1329.