Integrating Physiological & Perceptual Assays to Resolve the Effects of Sensorineural Hearing Loss on Neural Place and Time Cues for Pitch

Poster M119

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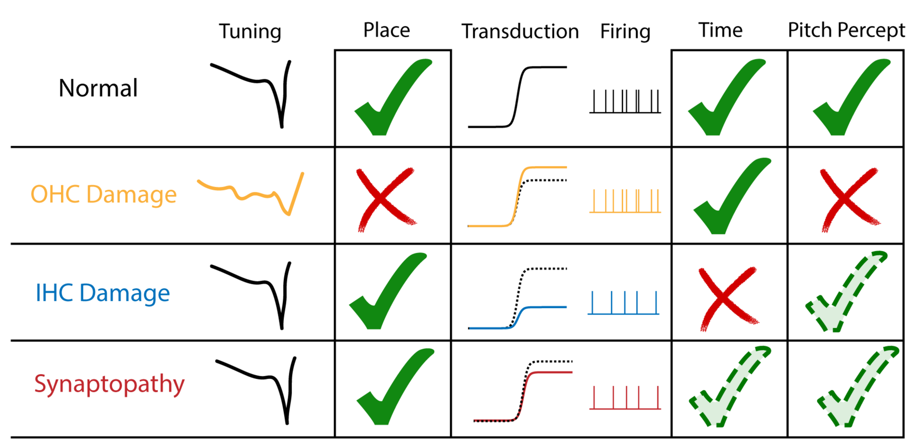
Introduction

How do variations in cochlear physiology result in altered representations of pitch?

- Maintained **tonotopic (place)** and **temporal (time)** representations of periodic sounds are likely important, but place and time deficits may **not necessarily result in the same perceptual consequences**.
- Subtypes of **Sensorineural Hearing Loss (SNHL)** variably impact place and time representation, which could result in a **spectrum of complex pitch perceptual deficits** (below).
- While much pitch literature characterizes perception in normal-hearing individuals, limited studies investigate how pitch processing is affected in hearing-impaired individuals.



The consequences of cochlear hearing loss on pitch perception were explored in a broad population of individuals through:

- Audiological Diagnostics
- Perception
- Electrophysiology

Approach

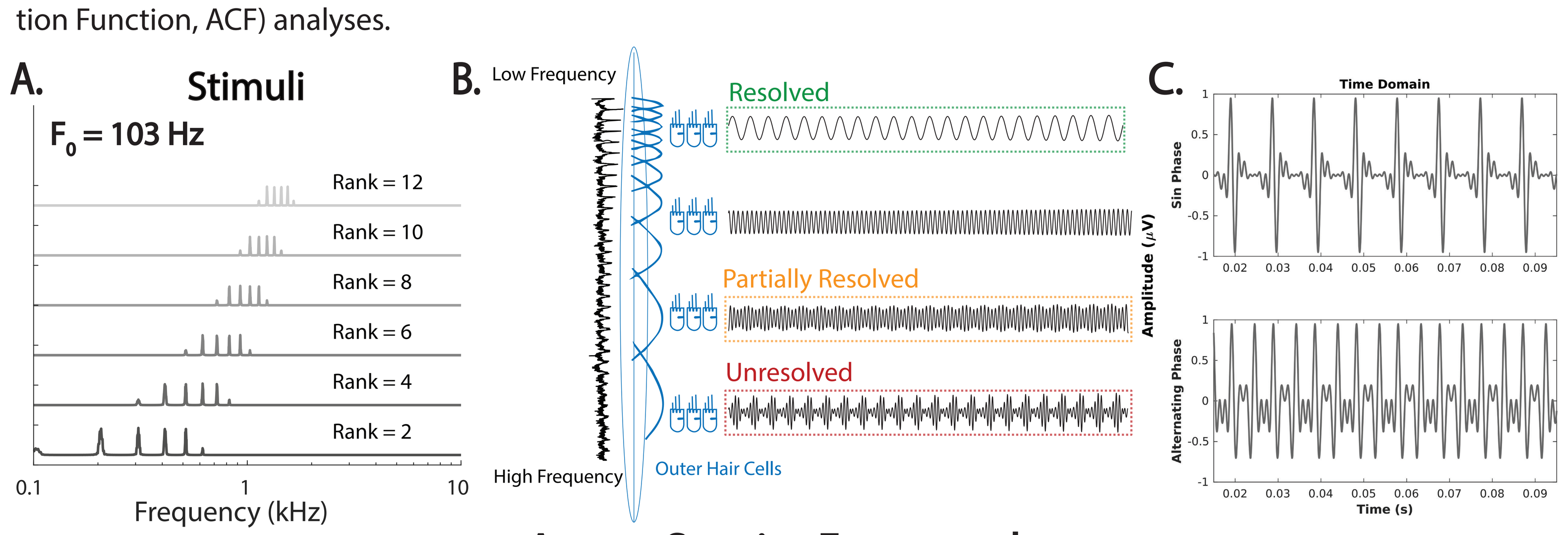
Stimulus Design

Band-limited tone complexes (A) were used to probe the fidelity of cochlear time and place cues through both physiological (Envelope Following Responses, EFRs, Acoustic Change Complex, ACC) and behavioral (Fundamental Frequency Difference Limens, F0DLs) measures.

When the lowest harmonic in the tone complex (harmonic rank) is increased, cochlear filters cannot resolve as many individual harmonics (B), resulting in poorer pitch perception[1].

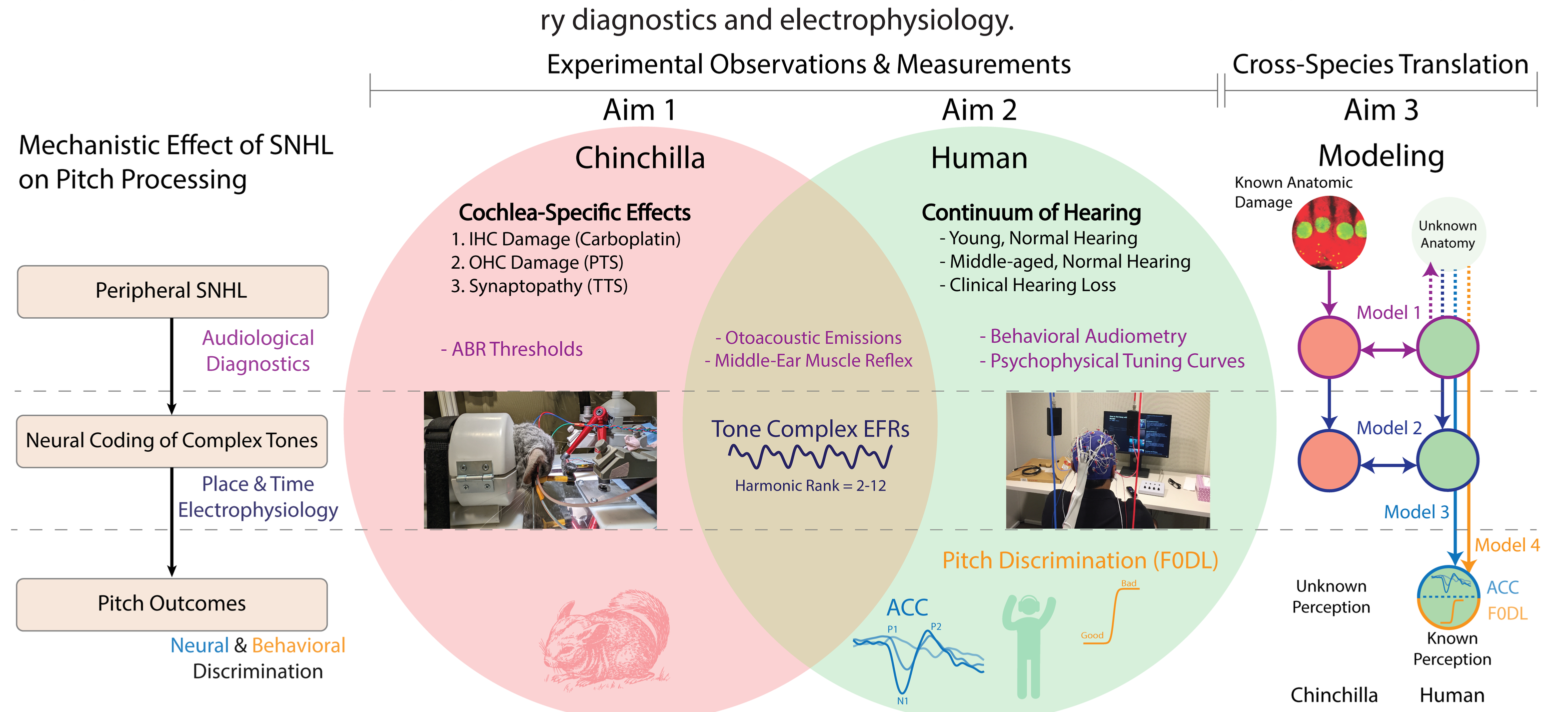
Place-dependent neural coding of complex tones was investigated by presenting harmonic tone complexes in alternating (ALT) phase. This elicits an EFR with a predominant periodicity at 2*F0 when harmonics are unresolved[2] (C).

This envelope periodicity was quantified through spectral (Phase Locking Value, PLV) and temporal (Auto-Correlation Function, ACF) analyses.



Across-Species Framework

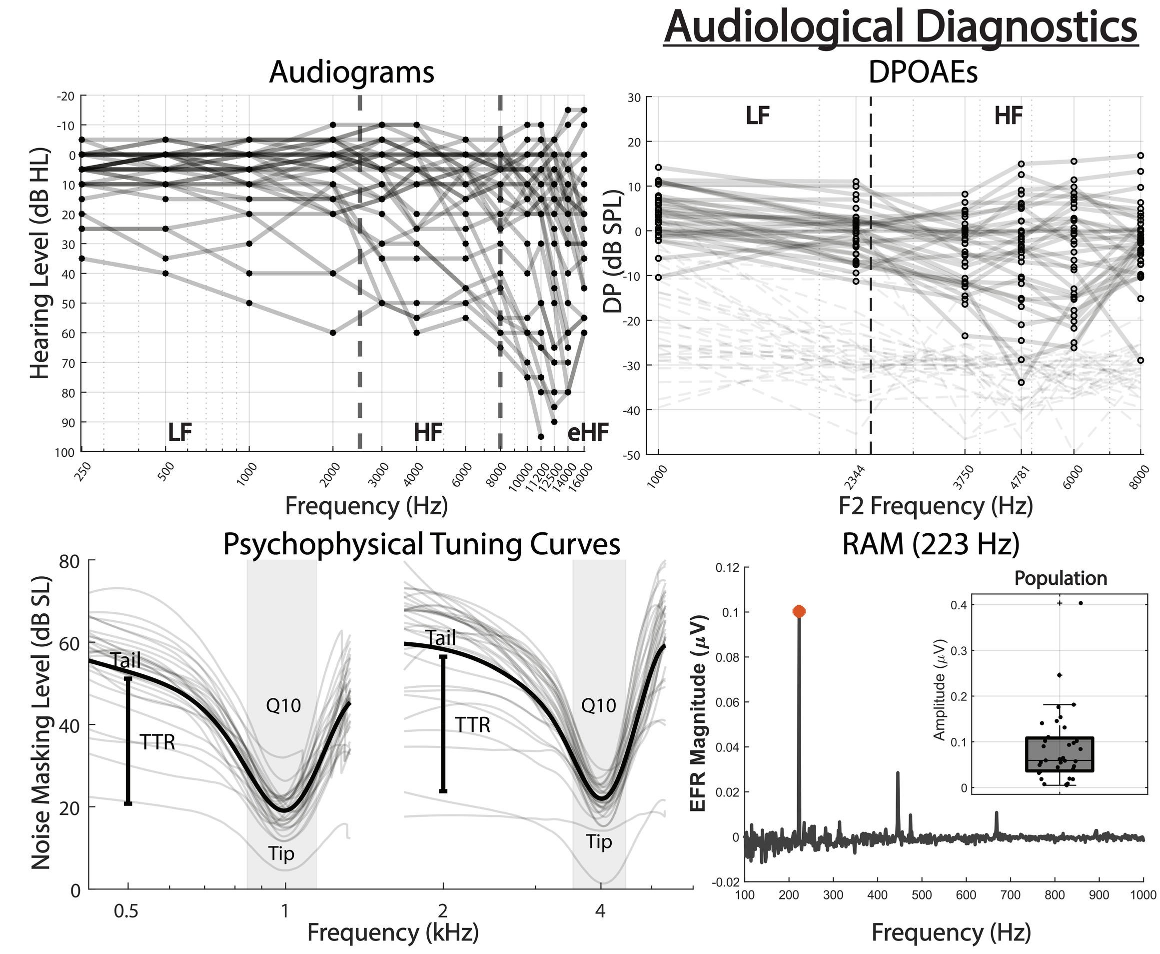
The spectrum of neural and behavioral pitch discrimination ability in a continuum of hearing abilities can be related to underlying subtypes of auditory damage that are well-characterized in animal models of cochlear hearing loss through audiotory diagnostics and electrophysiology.



Place & Time Predictors of Pitch Discrimination

Pitch discrimination ability was predicted by audiological diagnostics and assays of place and time coding in 32 listeners with diverse hearing abilities.

Audiological Diagnostics



Three populations of individuals were recruited to sample a **continuum** of listening ability:

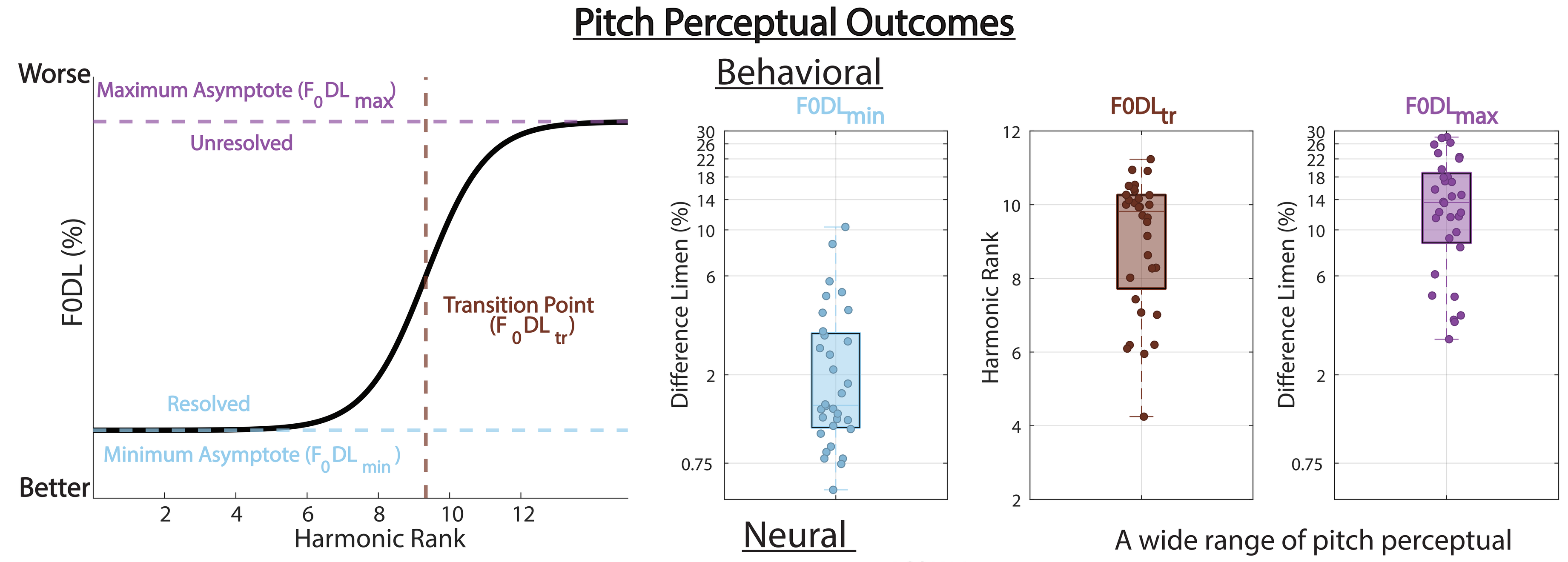
- 22 Normal Hearing (18-65 yrs)
- 10 Hearing-Impaired (18-70 yrs)
  - Clinical thresholds .25-8kHz <65 dB HL

An extended, cochlea-focused, diagnostic battery was collected on each individual including:

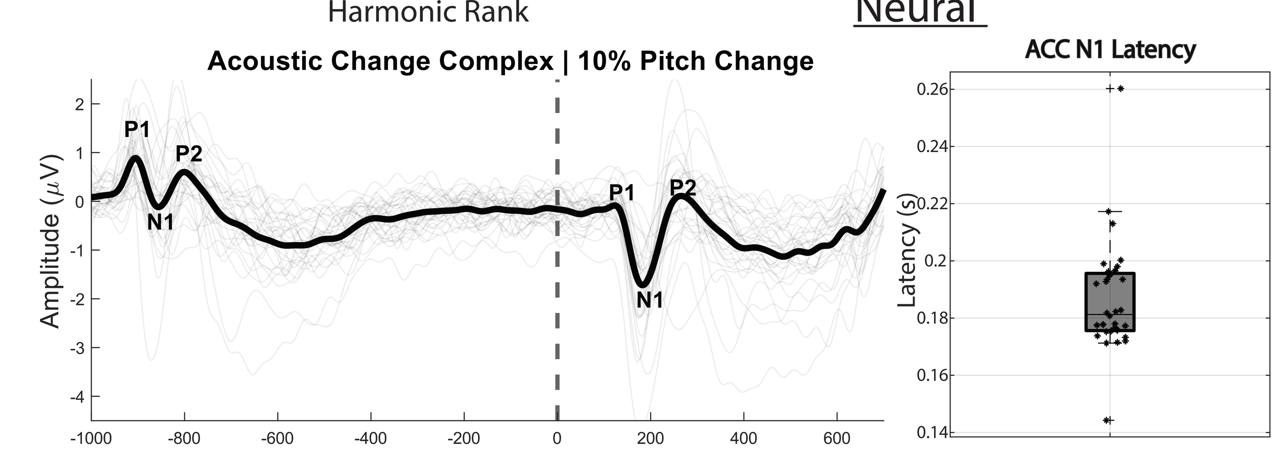
- **Psychophysical Tuning Curves** (PTCs) at 1 and 4kHz [3]
- **Rectangular Amplitude Modulation** (RAM) EEG-based assay of temporal coding [4]
- **Extended HF Audiometry, DPOAEs**
- All measures were collected in the Purdue Audiology Research Diagnostics Core (ARDC, Poster S186)

Pitch Perceptual Outcomes

Behavioral



Neural



A wide range of pitch perceptual (F0DL) and neural discrimination (ACC) abilities were observed in this population.

F0DL performance as a function of harmonic rank was summarized in three variables: $F0DL_{min}$, $F0DL_{tr}$, $F0DL_{max}$.

N1 Latency was the ACC-based metric most predictive of behavioral discrimination (F0DL). ACCs were collected only for Harmonic Rank 4.

Pitch Discrimination Modeled by Place and Time Predictors

Place-Time Model

$$\underbrace{F_0DL_{min,max,tr}}_{\text{or } ACC_{latency}} \sim Age + \underbrace{Q10_{1k,4k} + TTR_{1k,4k}}_{\text{Place}} + \overbrace{RAM}^{\text{Time}}$$

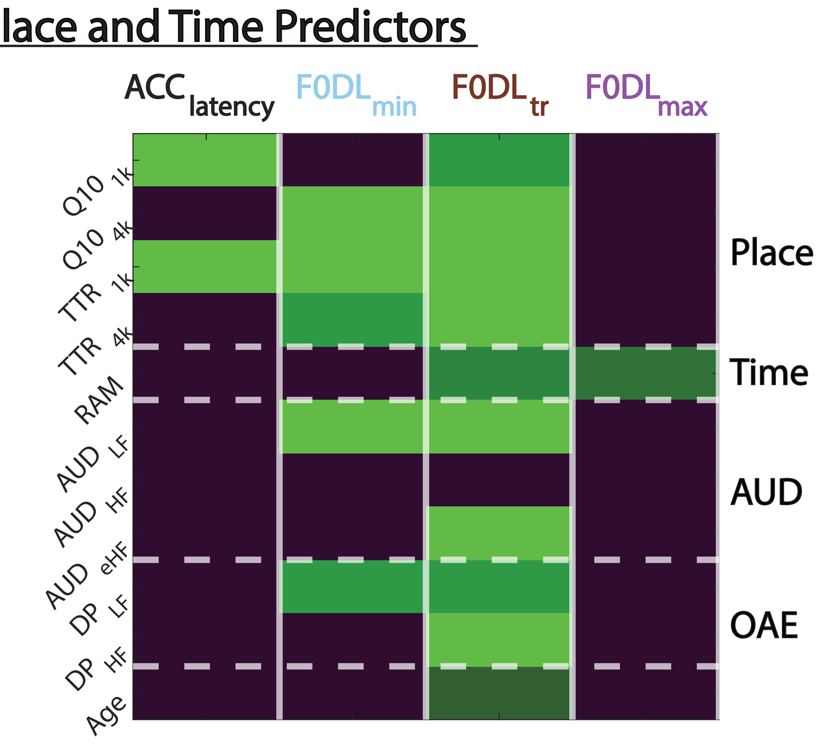
Diagnostic Model

$$\underbrace{F_0DL_{min,max,tr}}_{\text{or } ACC_{latency}} \sim Age + \underbrace{AUD_{LF,HF,eHF}}_{\text{Audiometric Threshold}} + \overbrace{DP_{LF,HF}}^{\text{OHC Function}} + \underbrace{RAM}_{\text{Temporal Coding}}$$

Backward stepwise regression was used to relate potential audiological and place-time predictors of pitch processing outcomes in two models.

Bright green indicates terms that were significant ($p<0.05$) predictors, duller green indicates terms that were included but not significant, and black indicates terms absent from the optimal models.

Generally, $ACC_{latency}$ (Rank 4), $F0DL_{min}$, and $F0DL_{tr}$, are best explained by assays of **place coding**, while $F0DL_{max}$ is only explained by **temporal coding fidelity**.



Neural Coding of Complex Tones

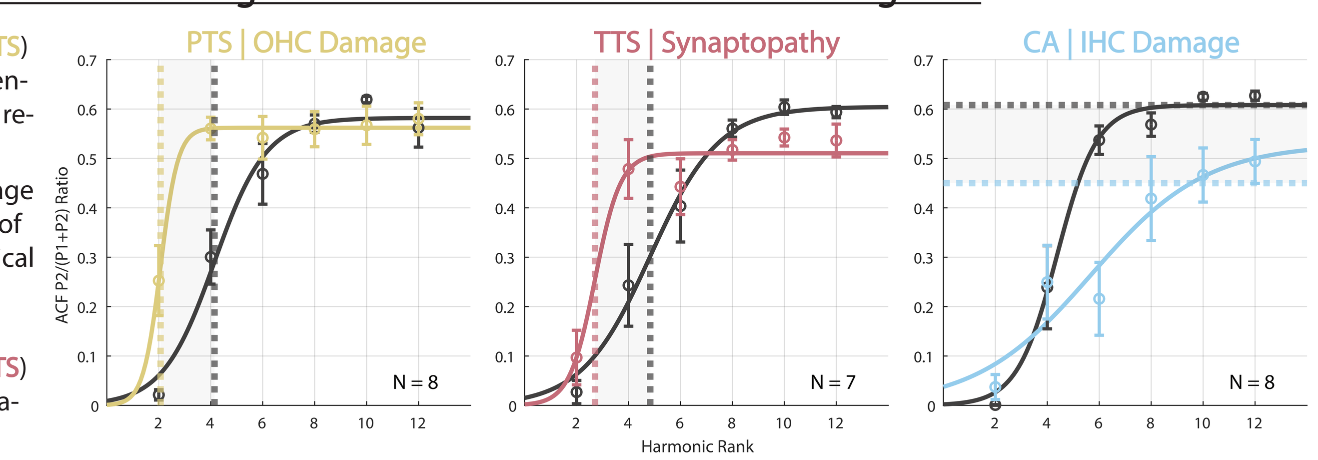
Subtypes of cochlear hearing loss alter the neural representation of envelope and may explain abnormal pitch discrimination patterns.

Mechanistic Insights from Chinchilla Models of Hearing Loss

Permanent Threshold Shifts (PTS) result in envelope over-representation due to poorer harmonic resolvability.

Carboplatin-induced IHC damage (CA) diminishes the sharpness of temporal envelope coding critical for the representation of unresolved harmonics.

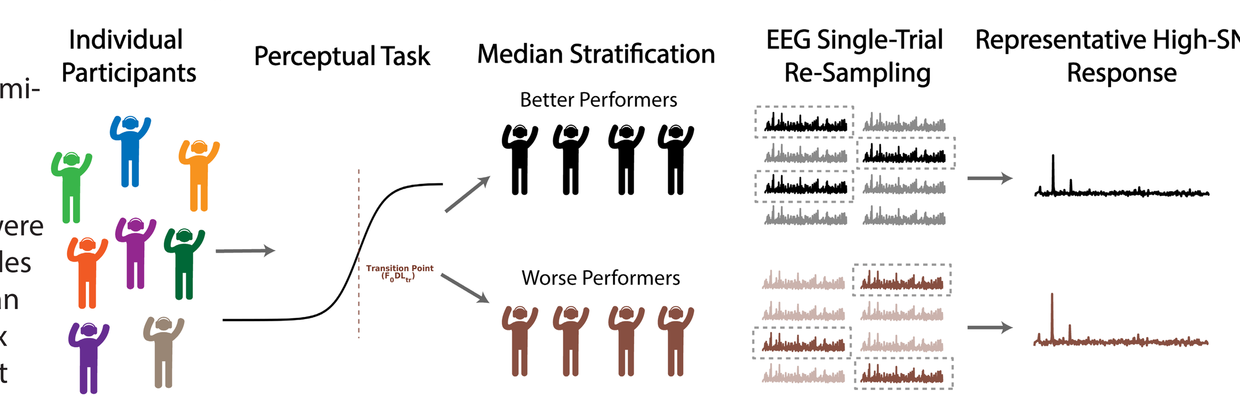
Temporary Threshold Shifts (TTS) result in a more subtle combination of the two effects.



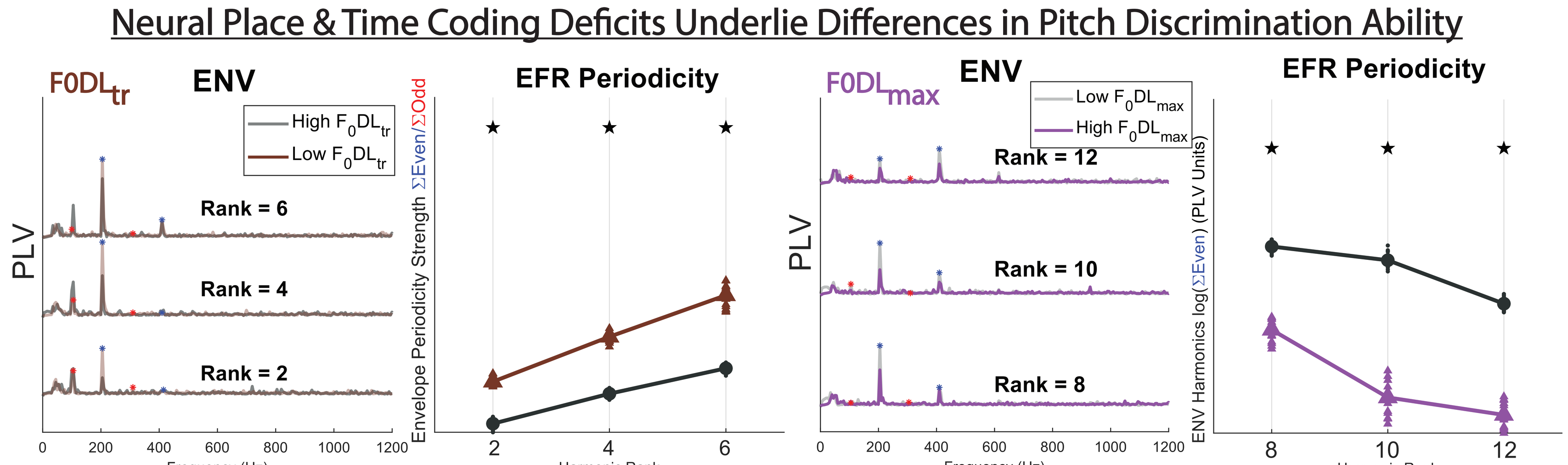
Stratified Resampling Improves Measurement SNR in Human EFRs

Single-trial EFRs were stratified based on individual pitch discrimination ability ($F0DL_{min}$, $F0DL_{tr}$, $F0DL_{max}$) and pooled together.

The EFR-based metrics below were computed on 20 random samples (with replacement) to acheive an acceptable response SNR (~2.5x the number of trials collected at the individual level).



Neural Place & Time Coding Deficits Underlie Differences in Pitch Discrimination Ability



Envelope periodicity was assessed based on the phase-locking value (PLV) spectra of stratified EFR responses. A ratio of even/odd harmonics was used to assess harmonic resolvability (left), while the sum of envelope-driven (even) harmonics (right) was used to assess the fidelity of temporal envelope representation. Stars represent significant differences ($p<0.005$).

Worsened place representation and poorer harmonic resolvability in subjects with lower $F0DL_{tr}$ lead to envelope over-representation.

Temporal coding deficits in subjects with poorer $F0DL_{max}$ lead to an underrepresentation of envelope driven by unresolved harmonics.

Conclusions

Variability in the fidelity of place and time cues relayed by the cochlea explain different aspects of pitch perception in a broad group of listeners.

- **Patterns in pitch discrimination (F0DL) are not entirely explained by audiometric thresholds.** Rather, a combination of place (PTCs, DPOAEs) and time (RAM) assays paint a more complete picture.
- **Good place coding appears to be most important for the discrimination and neural coding of resolved tone complexes.**
- **Good temporal envelope coding likely helps extract pitch from unresolved tone complexes.** Though this weaker sense of pitch is less useful for discrimination, envelope could carry information useful for timbre or other auditory cues.
- Comparison of findings across species suggest that **damage to OHCs and IHCs lead to deficits in place and time coding**, respectively.

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