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Relation between temporal envelope coding, pitch discrimination, and compression estimates in listeners with sensorineural hearing loss

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Introduction
Recent physiological studies in animals showed that noise-induced sensorineural hearing loss (SNHL) amplified the amplitude envelope coding in single auditory-nerve fibers [1, 2]. As pitch discrimination of unresolved complex tones is assumed to rely on temporal envelope coding mechanisms, the present study investigated pitch-discrimination performance in listeners with SNHL. Additionally, peripheral loss of compression was considered as a potential factor in envelope coding enhancement. In experiment 1, pitch discrimination was investigated in normal-hearing (NH) and hearing-impaired (HI) listeners for complex tones of varying harmonic resolvability. Envelope processing was assessed in the same listeners in a behavioral amplitude-modulation detection task (experiment 2). Basilar-membrane input/output functions were estimated to assess individual compression ratios (experiment 3).

Method
- Participants: 14 NH listeners, 10 HI listeners with SNHL.

Experiment I: Pitch discrimination
- Stimuli: Sinusoidal and random phase complex tones filtered in either a low (LF: 0.3-1 kHz) or a high (HF: 1.5-3.5 kHz) frequency region to vary the resolvability of the harmonics [3].
- Paradigm: 3 AFC, two intervals contained a reference complex tone with a fixed F0, and one interval contained a deviant complex tone with a larger F0.

“Which tone has the highest pitch?”

Results

Figure 3 Pitch discrimination thresholds as a function of F0 for complex tones filtered either in a low (white squares) or high (black circles) frequency region. Left panel: Musicians, right panel: Non-musicians.

**NH listeners (sine phase)**

- 6 musicians
- 8 non-musicians

**NH vs. HI listeners (sine phase)**

**Musicians**

**Non-musicians**

- Pitch discrimination thresholds were dependent on musical training (see Fig.3)
- Unresolved conditions (gray-shaded regions in Fig.3):
  - 8 HI performed as well as NH for sine-phase complexes
  - 6 HI performed significantly worse than NH for random-phase complexes.
- The ratio between the random-phase and the sine-phase threshold for unresolved complex-tone can be considered as an indicator of envelope processing that is independent of musical training (see Fig.6).

- Experiment III: Cochlear compression estimates
- Experiment II: Amplitude-modulation detection

Discussion

As pitch discrimination thresholds were found to depend on musical training, the ratio between random-phase and sine-phase thresholds (FODL ratio in Fig. 6) of unresolved complex tones was used as an indicator of envelope processing, independent of musical training. Nine HI listeners showed FODL ratios larger than NH listeners, suggesting that changes in envelope coding play a role in pitch-discrimination of unresolved complex tones. Figure 8 shows that there is a trend for the increase of auditory filters bandwidth and loss of cochlear compression to consistently vary with the increase of FODL ratios (panels A) and decrease of modulation thresholds (panels B).

Conclusions and perspectives

Overall, these findings suggest that changes in temporal envelope coding in HI listeners affect pitch discrimination of unresolved complex tones. Such changes seem to be partly ascribed to auditory filters broadening and loss of cochlear compression. Future modeling work will consider the effects of degraded frequency selectivity and loss of compression on the modulation power at the output of the auditory filters to clarify how each factor contributes to pitch-discrimination performance in HI listeners.

References

Figure 4 The transition point (F0,DL) depicts the point on the fitted sigmoid for which the harmonics start to get resolved.

Figure 5 Pitch discrimination thresholds as a function of F0 for HF-filtered complex tones. Black squares: Mean of NH listeners; colored circles: Individual HI thresholds. The gray-shaded region depicts the region where the complex tones are unresolved for both NH and HI.

Figure 6 Ratio of random-phase and sine-phase pitch-discrimination thresholds for NH (black squares) and HI listeners (colored circles).

- 8 HI listeners showed lower modulation thresholds than NH, when the sidebands were unresolved (i.e., for F0 < 200 Hz).
- Auditory filter bandwidth (BW) at 2 kHz was estimated from the TMTF curves (at the F0 corresponding to the 10-dB point n the maximum threshold).

Figure 7 Amplitude-modulation thresholds for NH (black squares) and HI listeners (colored circles).

- Effect of filter BW
- Effect of loss of compression