Within-Consonant Perceptual Differences in the Hearing Impaired Ear

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**Objective:** Understand how hearing impaired (HI) ears perceive the acoustic cues in speech.

**Methods:** 14 Consonant Vowel stimuli ("zero-error," unambiguous)
/b, d, f, g, k, m, n, p, s, f, t, v, z, z+/a/ (in plots: Z=ʒ, S=ʃ)
2 talkers for each consonant (1 male, 1 female)
Speech Weighted Noise at 4 SNRs (0, 6, 12 dB, Q)
*Token* - 1 talker & 1 consonant

**Results:**
1) HI errors can be contained to a small subset of tokens

2) Tokens of the same consonant can be perceptually different for HI listeners (noise-robustness/confusions)

3) Consistencies are observed across NH and HI ears in terms of noise robustness and confusion groups
Audiogram and Average Error - 17 HI ears

14 Miller-Nicely Consonant Vowel stimuli,
2 talkers per consonant (1 male, 1 female)

/b, d, f, g, k, m, n, p, s, j, t, v, z, z/+, a/, Speech Weighted Noise (SWN)
Audiogram and Average Error - 17 HI ears

14 Miller-Nicely Consonant Vowel stimuli
2 talkers per consonant (1 male, 1 female)

/b, d, f, g, k, m, n, p, s, j, t, v, z, z+/+α/, Speech Weighted Noise (SWN)
Error Overview

Overview of Token Errors, Quiet, Listener 40L

- 6 dB
- Quiet

Tokens, No Sorting

Sorted Tokens
Error Overview

Overview of Token Errors, Quiet, Listener 40L

Overview of Token Errors, 6 dB, Listener 40L

Overview of Token Errors, 12 dB, Listener 40L

Probability of Error

Sorted Tokens
Error Overview - 6 HI ears

Concentration of error to a subset of tokens observed across HI ears, in both Quiet and Noise.

Implications for understanding an average. Or planning a training program.
HI Within-Consonant Differences: Noise Robustness
Probability of Error, Listener: 40L

- Probability of error for different consonants:
  - ba: SNR vs. Avg. P_{error}
  - da: SNR vs. Avg. P_{error}
  - fa: SNR vs. Avg. P_{error}
  - ga: SNR vs. Avg. P_{error}
  - ka: SNR vs. Avg. P_{error}
  - ma: SNR vs. Avg. P_{error}
  - na: SNR vs. Avg. P_{error}
  - pa: SNR vs. Avg. P_{error}
  - sa: SNR vs. Avg. P_{error}
  - ta: SNR vs. Avg. P_{error}
  - va: SNR vs. Avg. P_{error}
  - Sa: SNR vs. Avg. P_{error}
  - Za: SNR vs. Avg. P_{error}
  - za: SNR vs. Avg. P_{error}

N=40-80 per consonant
2 tokens per consonant
Individual token differences in noise robustness

Trevino, Allen, JASA 2013 (In Review)
HI Within-Consonant Differences: Noise Robustness

\[ \overline{\Delta P_e} = \frac{1}{n(S)} \sum_{s \in S} (P_e^M(s) - P_e^F(s)) \]

\[ S = \{ s \in \{0, 6, 12, Quiet\} : s \leq s^* \} \]

Trevino, Allen, JASA 2013 (In Review)
Differences in noise-robustness are observable across 17 HI ears
Consistencies across HI ears suggest that each token's acoustic cues play a role

Trevino, Allen, JASA 2013 (In Review)
Characterizing Token Variability with Normal-Hearing (NH) psychoacoustic data

The psychoacoustic noise-masked threshold (NH SNR$_{90}$) is correlated with the intensity of the token’s acoustic cue region (Régnier, 2008). Compare the 2 tokens of each consonant.

Trevino, Allen, JASA 2013 (In Review)
HI vs. NH Noise Robustness

Average Error Difference, 17 HI Ears

\[ \Delta P_e \]

Hearing Impaired data

Normal Hearing data

SNR\textsubscript{90} Difference between tokens, NH Listeners

\[ \text{SNR}_{90} \]

Trevino, Allen, JASA 2013 (In Review)
HI vs. NH Noise Robustness

Implies that natural variability of cue intensity, characterized by the NH-listener noise-masking data, is strongly related to the HI within-consonant differences in noise-robustness.

Trevino, Allen, JASA 2013 (In Review)
Conclusion

There is a correlation between HI and NH consonant perception.

Supports the hypothesis that the HI and NH listeners are using the same primary cues.
HI Within-Consonant Differences: Confusion groups
Token-Specific Confusions /ba/

Avg Recognition Data, all 17 HI ears, Female /ba/ Token

Avg Recognition Data, all 17 HI ears, Male /ba/ Token
Summary

Multiple tokens of the same consonant can be perceptually different for HI listeners in terms of noise-robustness and confusion groups.

Systematic behavior on a token basis:
- HI and NH listeners show agreement in noise-robustness
- Different HI listeners share token-dependent confusions

Systematic responses suggest that common cues are being used.

Consistent (low-entropy) token-specific confusions imply that the HI ears are not guessing.
Conclusions

- The average error can have large amounts of underlying individual token error

- Analysis at the token level reveals systematic patterns in the HI confusions

- NH psychoacoustic data can characterize the cue variability of individual tokens, providing tools for understanding HI perception

- The role of naturally-occurring conflicting acoustic cues remains unknown (Li et al. 2010, 2012)
Thank you
Token-Specific Confusions /ba/

Talker 1

Listener: 36L 36R

SNR and Listener

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Large proportion of /da, ga, va/ confusions

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Talker 1: Large proportion of /da, ga, va/ confusions overall

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Talker 2: Large proportion of /fa, va/ confusions overall

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

Talker 2: Large proportion of /fa, va/ confusions overall

Trevino, Allen, JASA 2013 (In Review)
Token-Specific Confusions /ba/

SNR and Listener
Analysis must be done at the token level

Trevino, Allen, JASA 2013 (In Review)