Spectral contrast effects in vowel categorization by listeners with sensorineural hearing loss

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INTRODUCTION

- Phoneme categorization is influenced by *spectral contrast effects* (SCEs), the perceptual magnification of spectral differences between sounds. For example (after Ladefoged & Broadbent, 1957):

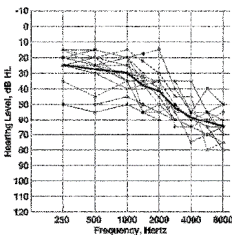
Precursor	More likely to hear
Sentence (unmodified)	/ɪ/ or /ɛ/ vowel target
Sentence with /ɛ/-like (high F_1) frequencies emphasized	/ɪ/ (low F_1)
Sentence with /ɪ/-like (low F_1) frequencies emphasized	/ɛ/ (high F_1)

- SCEs are larger when F_1-emphasized spectral peaks in the preceding sentence are higher-amplitude or broader-bandwidth (Stilp *et al.*, 2015).
- Despite their widespread influence on speech perception for normal-hearing (NH) listeners, SCEs have never been measured in hearing-impaired (HI) listeners.
- Listeners with sensorineural hearing loss (SNHL) may display broadened auditory filter tuning and/or abnormal suppression. This would broaden the effective bandwidths of suprathreshold spectral peaks in speech.
- Given that broader spectral peaks produce larger SCEs (Stilp *et al.*, 2015), we predict that listeners with SNHL will exhibit larger SCEs than NH listeners in a vowel categorization task.

METHODS

Participants

- HI: 14 listeners (ages 51-87) with mild to moderate SNHL from the Greater Lafayette community
  - Mean (thick line) and individual audiometric thresholds for test ear shown
- NH: 25 undergraduates with self-reported normal hearing from the University of Louisville
- All were native English speakers



Stimuli

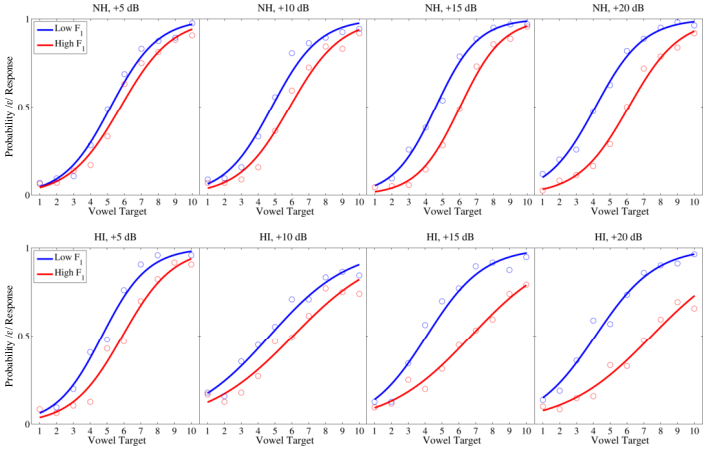
- Precursor sentence: "Please say what this vowel is", spoken by CS (2174 ms) [same as in Stilp *et al.* (2015)]
  - Low F_1 (100-400 Hz) or high F_1 (550-850 Hz) region emphasized by +5, +10, +15, or +20 dB using an FIR bandpass filter
- Target vowels: 10-step series of resynthesized natural tokens varying from /ɪ/ to /ɛ/, spoken by CS (246 ms) [same as in Stilp *et al.* (2015)]
- For HI listeners, stimuli were linearly amplified offline by a hearing aid simulator (Alexander & Masterson, 2015) to scale the output to levels prescribed by Desired Sensation Level *m*(I/O) algorithm v5.0a

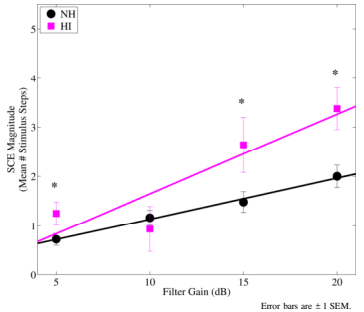
Procedure

- Each trial presented a precursor sentence then a vowel target (50-ms ISI) monaurally (SNHL) or diotically (NH) over circumaural headphones
- NH listeners completed 160 trials/level of filter gain, HI listeners did 200

ANALYSES

- Results from 5 NH and 2 HI listeners were excluded from analyses due to an inability to consistently identify unambiguous vowel endpoints, making the final samples 20 NH and 12 HI listeners.
- For both listener groups, the first two repetitions of each stimulus were treated as practice trials and are not included in analyses.
- For each listener, for each level of filter gain, logistic regressions were fit to vowel identification data associated with each precursor (low- vs. high-F_1 filter peak). 50% points (equal probability of responding "ih" and "eh") were calculated from the regression equations.
- SCE = difference in 50% points across the regressions (*i.e.*, translation of psychometric function along the abscissa).



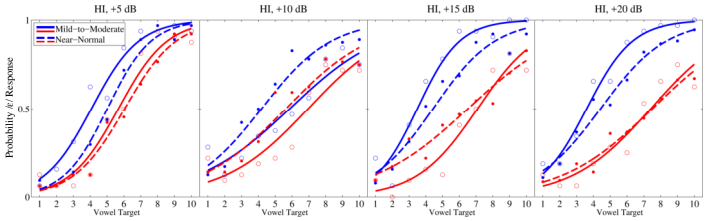


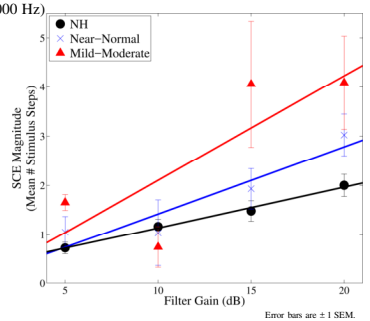
2 (listener group; between-subjects) x 4 (filter gain; within-subjects) mixed ANOVA:

- Main effect of listener group ($F_{1,30} = 7.12$, $p < .025$): HI listeners exhibited larger SCEs than NH listeners
- Main effect of filter gain ($F_{2.42,72.50} = 21.28$, $p < .001$): larger filter gains produced larger SCEs
- Significant interaction ($F_{2.42,72.50} = 4.08$, $p < .05$): HI listeners exhibited larger SCEs at +5, +15, and +20 dB

Audiometric data suggests the 12 HI listeners formed two subgroups:

- n=8 with near-normal low-frequency hearing (< 25 dB HL at 250 & 500 Hz, < 35 dB HL at 1000 Hz)
- n=4 with mild-to-moderate low-frequency hearing loss (25-55 dB HL at 250 & 500 Hz, 35-55 dB HL at 1000 Hz)





Trends suggest that hearing loss in F_1 frequency regions may be responsible for larger SCEs (mild-to-moderate mean SCE = 2.63, near-normal mean SCE = 1.76), but small sample sizes and intersubject variability limit statistical power (independent-samples *t*-test on HI subgroups: $t_{10} = 1.55$, $p = .15$).

DISCUSSION

- SCEs are reported in HI listeners' speech perception for the first time
  - SCEs were larger for HI listeners than for NH listeners
  - Like NH listeners, SCEs increased with larger spectral peaks in the preceding sentence, but grew more quickly for HI listeners
- This extends previous speech perception research with HI listeners, which focused on *intrinsic* cues to vowel identity (*e.g.*, fundamental frequency, F_1, F_2, *etc.*). Here we report HI listeners' sensitivity to *extrinsic* cues to vowel identity (*e.g.*, long-term average spectrum of preceding sounds).
- Results were suggestive of differential processing of spectral context depending on the degree of hearing impairment (near-normal low-frequency hearing vs. mild-to-moderate low-frequency hearing loss), but further study with larger samples is needed to confirm this.
- What are the potential mechanisms behind larger SCEs for HI listeners?
  - Broadened tuning of auditory filters. Broadened filtering would result in broader spectral peaks in the precursor sentence, which produce larger SCEs (Stilp *et al.*, 2015).
  - Steeper growth of loudness in F_1 regions
- Why is it bad to exhibit larger SCEs than NH listeners?
  - If category boundaries are far apart, perception is biased toward one response option.
    - NH listeners correctly labeled vowel target 10 (/ɛ/ endpoint) irrespective of whether the +20 dB peak in the preceding sentence was in low-F_1 or high-F_1 frequencies.
    - HI listeners became less accurate as high-F_1 filter gain increased. Following a +20 dB high-F_1 peak, HI listeners labeled this vowel as /ɛ/ only 65% of the time.
  - Previously unambiguous vowels became more ambiguous when SCEs were overly large, increasing confusions in speech sound categorization.
- Relevance to DSP in hearing aids and cochlear implants:
  - Speech sound recognition by HI listeners is influenced by both short-term and long-term properties of the listening context (Alexander & Kluender, 2009).
  - This argues strongly against the exclusive use of short time constants in hearing aid filtering (*e.g.*, Van Dijkhuizen *et al.*, 1987, 1989).

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