Phoneme categorization with simulated variable cochlear implant insertion depths

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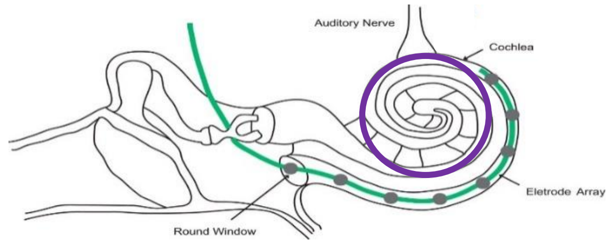
INTRODUCTION

Cochlear implants (CIs) have shallow electrode insertion depth



Shallow insertion depth of the implant causes an upward spectral shift

(Rosen et al., 1999; Svirsky et al., 2004)

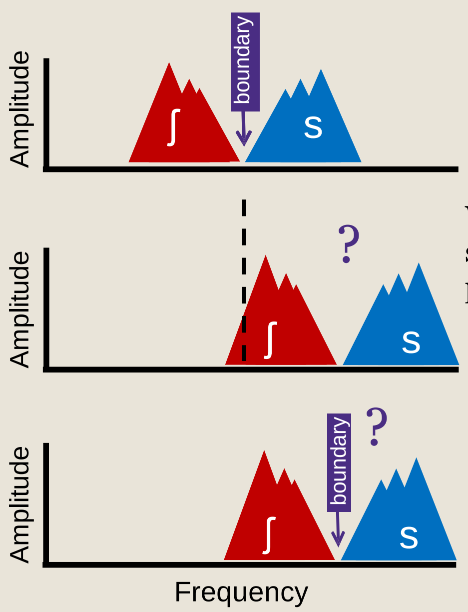
Spectral shifting results in difficulty with phoneme categorization

(Fu & Shannon, 1999; Li & Fu, 2010)

Consonants that differ by place of articulation *should* be affected by a Spectral Shift

Changes in Place of Articulation (PoA) result in changes to the frequency spectrum

Example: /ʃ/ and /s/ are categorized differently due to their spectral differences



With an upward shift, is everything perceived as /s/?

Or does the perceptual boundary shift along with the spectrum?

Questions

1) How does spectral shifting affect phoneme categorization?

Will listeners be biased to hear consonants that naturally have higher frequencies?
(e.g. /s/ rather than /ʃ/, /d/ rather than /b/)

2) Can listeners recalibrate to spectral shifts?

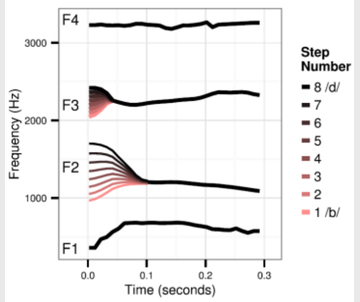
Will some listeners recalibrate better than others?

METHODS

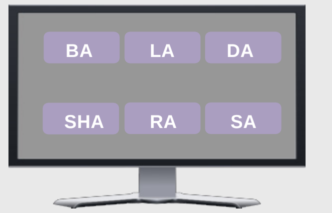
Participants: 15 normal hearing listeners (ages 20-47)

Stimuli: Two phonetic continua and fillers

- /ba-da/: 8-step continuum of formant transitions (Winn & Litovsky, 2015)
- /ʃa-sa/: 7-step continuum of spectral peaks (gradual blending of /ʃa/ and /sa/)
- /ra/ & /la/ tokens added for variability (Winn & Litovsky, 2015)



Procedure: 6-alternative forced choice for each sound



Conditions: Normal, vocoded with 0, 2, 4, 6mm shift

Trials: 9 trials per continuum step in each condition

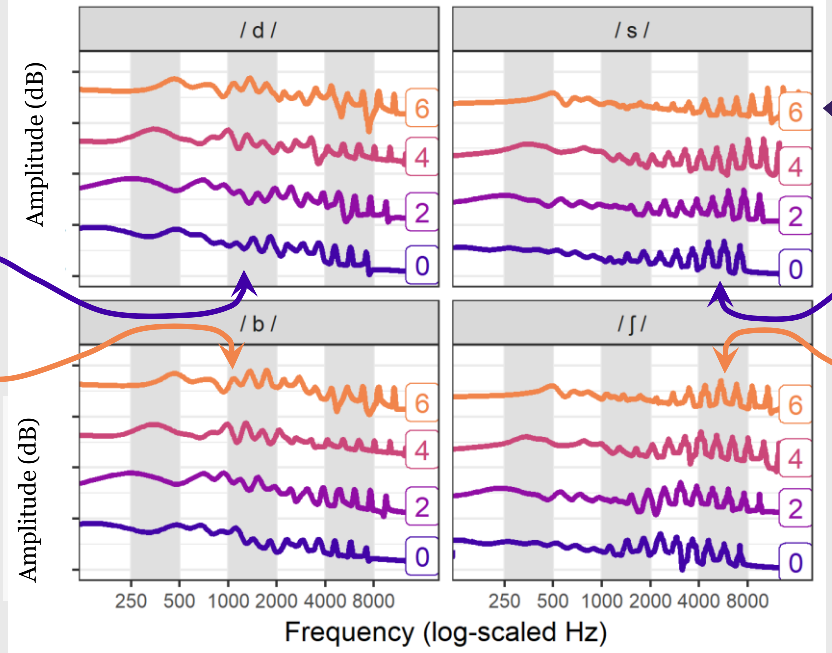
Word Intelligibility: 50 CNC words/condition

Vocoder and Spectral Shifting

Vocoder:

- 16 spectral channels between 100Hz - 8000Hz
- Sine wave carrier
- Envelope LPF at 600Hz

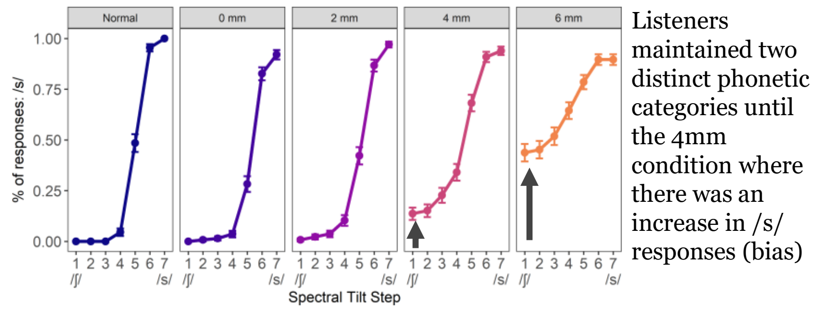
Shifting: Stimuli were spectrally shifted in varying amounts of cochlear space (using the Greenwood (1990) function) to simulate shallow implant insertion depths.



CNC Group Scores	Condition	Normal	0mm	2mm	4mm	6mm
	% Correct	100	94	91	67	21
	Std. Error	0	1	1	7	3

RESULTS

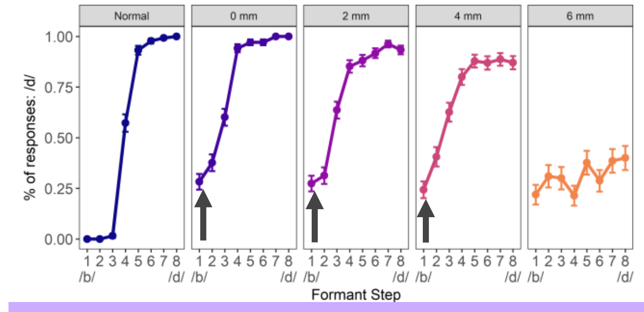
/ʃa/-/sa/ bias due to spectral shifting



Listeners maintained two distinct phonetic categories until the 4mm condition where there was an increase in /s/ responses (bias)

As spectral shifting increased there was a bias in perception towards /s/ (arrows)

/ba/-/da/ bias due to vocoding



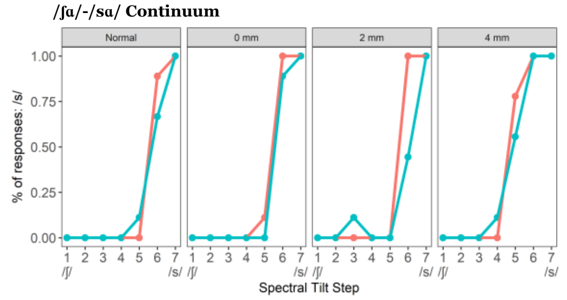
Categorical bias was seen with signal degradation (arrows) while categorization broke down in the 6mm condition

Bias towards /d/ due to vocoding; no systematic effect of spectral shifting

Individual Differences: Listeners

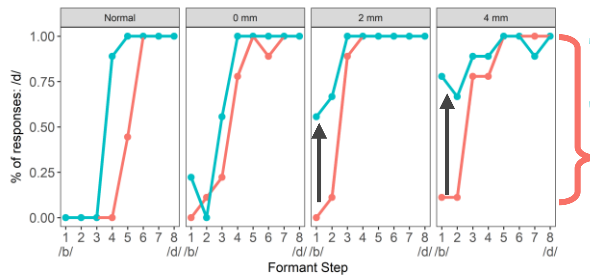
N267 N273

/ʃa/-/sa/ Continuum



Both listeners maintained two distinct phonemic categories as indicated by the upper and lower asymptote of the response function

/ba/-/da/ Continuum

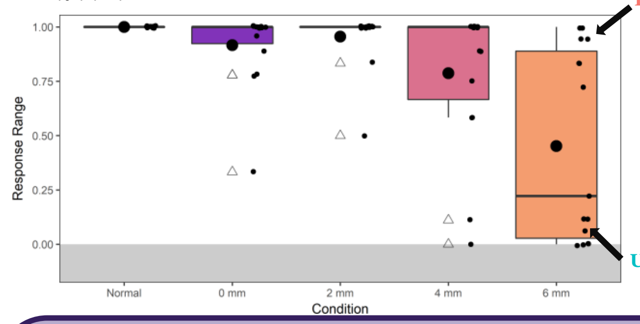


Listener could not recalibrate to the spectral shift; only perceived one consonant reliably.

Listener recalibrated to the spectral shift and maintained two categories

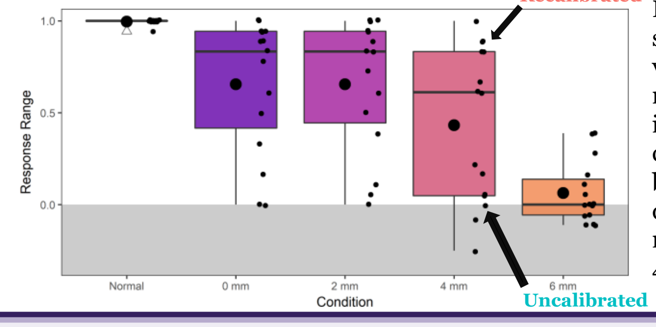
Differences of Calibration: Bimodal distribution of responses

/ʃa/-/sa/ Continuum



Responses indicate some listeners could recalibrate to the spectral shift and others could not

/ba/-/da/ Continuum



Listeners showed greater variability of response range in the stop contrast and a bimodal distribution of responses in the 4mm condition

CONCLUSIONS

1) Phoneme categorization was affected by spectral shifting with listeners showing a bias in categorization from /b/ towards /d/ and from /ʃ/ toward /s/. This bias manifested differently among the two contrasts:
   - /ʃ/ - /s/was systematically affected by greater amounts of spectral shifting resulting in larger bias
   - /b/-/d/was affected by signal degradation regardless of the spectral shift
2) Some individuals recalibrated to maintained two phonetic categories after shifting; while others perceived everything as roughly the same sound.
3) CI listeners struggle to perceive place of articulation, which may be partially explained by spectral shifting.

1 Rosen, S., et al. (1999). Adaptation by normal listeners to upward spectral shifts of speech: Implications for cochlear implants. *JASA*
2 Svirsky, M, et al. (2004). Long-term auditory adaptation to a modified peripheral frequency map. *Acta Ooto-Laryngologica*
3 Fu, Q. J., & Shannon, R. V. (1999). Recognition of spectrally degraded and frequency-shifted vowels in acoustic and electric hearing. *JASA*
4 Li, T., & Fu, Q. J. (2010). Effects of spectral shifting on speech perception in noise. *Hearing Research*
5 Winn, M.B., & Litovsky, R. Y. (2015). Using speech sounds to test functional spectral resolution in listeners with cochlear implants. *JASA*
6 Greenwood, D. D. (1990). A cochlear frequency-position function for several species—29 years later. *JASA*

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