Measuring spectral resolution for speech: Implications for cochlear implants

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INTRODUCTION

Spectral resolution

Major limitation of hearing with a cochlear implant

Important for distinguishing speech sounds

We want:

A way of measuring spectral resolution for speech sounds

* To see if it has been improved

6-alternative forced choice

Target sounds: /ba/, /da/, /pa/, /da/, /pa/, /ma/ (for variability)

Filler sounds: /ba/, /da/, /pa/, /ra/, /na/ (for variability)

Interpersed with other listening tasks including open-set word recognition

HOW DO WE CREATE SPEECH STIMULI APPROPRIATE TO MEASURE SPECTRAL RESOLUTION?

Natural utterances were decomposed into global source and vocal tract filter using linear predictive coding (LPC) inverse-filtering.

High-frequency energy (normally lost in LPC) was restored following re-synthesis.

Stimuli maintained excellent natural quality with full bandwidth

RESULT

7 listeners showed improvement with interleaved maps (blue above red),
while 8 showed decline (blue below red).

HOW DID WE ATTEMPT TO IMPROVE SPECTRAL RESOLUTION?

Electrode interaction is a major source of spectral degradation.

It can be reduced by:

- Current focusing
- Increasing space between electrodes

Inter-electrode space can be increased by disabling alternating electrodes

If the listener is a bilateral CI user, missing channels in one ear can be represented by active channels in the other ear, creating desirable non-overlapping spectral profiles in the two ears.

This is dichotic / interleaved / zippered channels

* There is no guarantee that the interleaved channels will be aligned by pitch percept, but the listener suffers no loss of information.

PARTICIPANTS

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ANALYSIS

1. /ba/-/da/ responses summarized for each continuum step to create a perceptual psychometric function

2. Functions modeled with logistic regression (1.83

3. The metric for spectral resolution is logit coefficient for the spectral cue (either in “less-weighting” or “more-weighting”)

4. Coefficients are compared. Improvement is when: interleaved coefficient > normal coefficient.

CONCLUSIONS

- Spectral resolution can be measured using speech stimuli that are explicitly controlled in the spectral domain.
- Accurate and robust use of spectral cues in speech is the operational metric for spectral resolution.
- Performance with these stimuli is related to open-set word recognition.
- This method of testing could be used to evaluate ways to improve spectral resolution (e.g. current focusing).
- Improvement in spectral resolution can be validated using tests of listening effort, including pupilometry.
- Improving spectral resolution generally results in less pupil dilation, which is a sign of reduced listening effort.

RESULTS

Spectral Resolution

Formant coefficient = log odds of perceptual change resulting from a change of the formant cue (higher number = better use of the spectral cue).

NIH listeners: average around 1.0

Changes in word recognition with their basic maps (wide range of red values)

7 listeners showed improvement with interleaved maps (blue above red),
while 8 showed decline (blue below red).

Spectral resolution and word recognition

LISTENERS WITH BETTER SPECTRAL RESOLUTION TEND TO SCORE HIGHER ON WORD RECOGNITION.

However, variance in word recognition is also explained by other factors (temporal resolution, etc.,)

Spectral resolution and listening effort

Quantified using pupil dilation during an IEEE sentence repetition task.

Pupil size measured with a Tobii 2150 eye-tracker between sentence & repetition.

Listeners who benefited from interleaved channels also showed benefit in terms of listening effort as indicated by less pupil dilation while listening with interleaved channels.

Change in effort with interleaved channels was better predicted by the spectral resolution test than by word recognition.

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Binaural Hearing and Speech Laboratory

Landsberger et al., 2009. Analysis of categorical response data: Use logistic regression rather than endpoint correlation with:

Pupil size

\[
\Delta \text{Pupil size} = r \times \Delta \text{Perceptual change} + \text{constant}
\]

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