Effects of NAL-R on Consonant Vowel Perception in Hearing Impaired Subjects

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Introduction

Consonant vowel (CV) identification experiments in speech weighted noise
- Two gain conditions; Flat-Gain (FG) and NAL-R (compensation for hearing loss)
- 16 hearing impaired (HI) ears are tested at 4 SNRs
- Subjects are tested at their most comfortable loudness (MCL)

Audibility of CVs (at MCL)?
- Audibility based on pure tones and long term average speech spectrum are not appropriate
- Rigorous definition of audibility based on token entropy

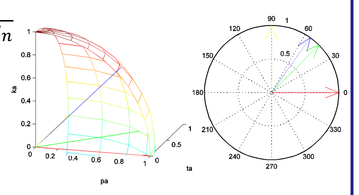
Effects of NAL-R?
- Are the CV recognition rates higher with NAL-R? Do the confusions change?

Key Findings
- *Most comfortable loudness* (MCL) testing works -> sounds are audible
- Spectral correction (i.e. NAL-R) decreases the entropy of the responses
- Spectral correction makes listeners respond more consistently on a token level

Methods

Cosine Direction: Every confusion matrix defines a vector space. The angle between responses can be calculated, with the help of the Hellinger distance metric:

$$\cos\theta_{pq} = \vec{p}\cdot\vec{q} = \sum_{n=1}^{N}\sqrt{p_n}\sqrt{q_n}$$



Entropy: Measure of randomness of response

$$\mathcal{H}(p) = \sum_{n=1}^{N} p_n \log_2\left(\frac{1}{p_i}\right)$$

- 16 HI ears (8 subjects, all with post-lingual hearing loss), age μ=74 year (σ = 7year)

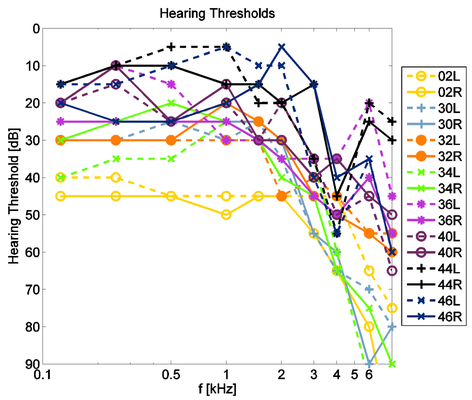


Figure 1: Pure Tone Thresholds of the 16 ears

- 14 consonants (/p,t,k,f,s, ʃ, b, d, g, v, z, ʒ, m, n/) followed by the vowel /a/
  - Two talkers per consonant (male & female)
  - All stimuli have < 3% error (i.e. 1 error /38 trials) for normal hearing (NH) ears at ≥ -2dB SNR
- Four noise levels Quiet, 12dB, 6dB, 0dB (speech weighted noise)
- Max entropy task (14 possible responses (/p, t, k, f, s, ʃ, b, d, g, v, z, ʒ, m, n/ + /a/)
- Two conditions
  - Flat-Gain (FG), no spectral correction presented at MCL
  - Spectral Correction (NAL-R), spectral correction according to hearing thresholds also presented at MCL
- For each subject, the number of trials per token and SNR varies between 5 and10, depending on the error rate of the first 5 trials

Results

- Categorization (first arrow indicates what happened to the error with NAL-R, second what happened to the entropy)

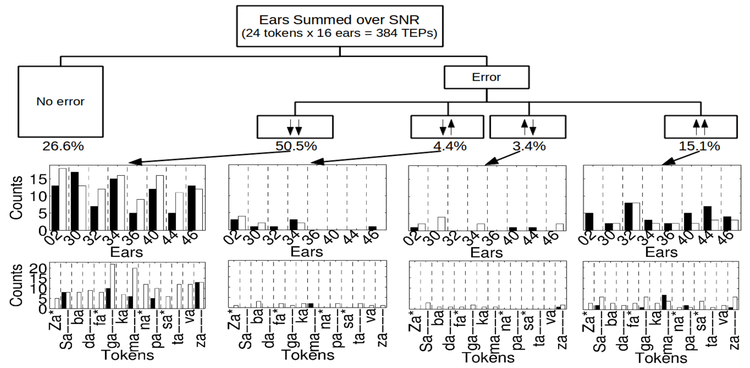


Figure 2: Categorization of token-ear pairs

- Confusion Bars collapsed over SNR (proportion correct indicated by white space, confusions indicated by color, see legend)

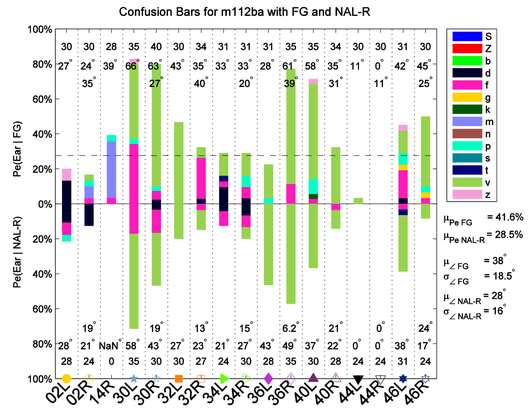


Figure 3 (a): Confusion bars for male token of /ba/

Conclusions Figure 3 (a):
- Average error decreases by 13%
- Dominated by /va/ confusions
- /fa/ confusions decrease with NAL-R
- Angle to correct answer decreases with NAL-R by 10°
- Entropy decreases with NAL-R

Conclusions Figure 3 (b):
- Average error decreases by 2%
- Dominated by /da/ confusions
- /ga/ confusions increase with NAL-R
- Angle to correct answer decreases with NAL-R by 3°
- Entropy stays high with NAL-R

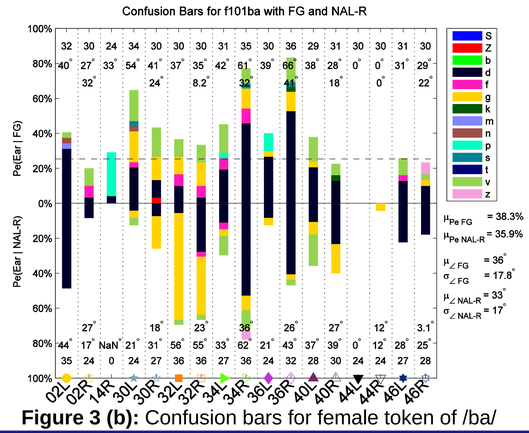


Figure 3 (b): Confusion bars for female token of /ba/

- Audibility is not an issue despite MCL testing

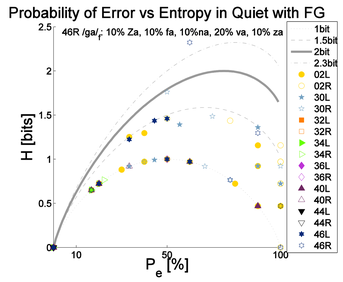


Figure 4: Error vs. Entropy in quiet, proposed audibility threshold (2-bit curve). All tokens for all ears are audible except, female /ga/ for ear 46R.

- Entropy in quiet is a rigorous measure for audibility
- 2-bit curve is a reasonable threshold , since the average Miller and Nicely confusion group is 3.

Reasons why PTTs are inappropriate:
- CV perception is binary (Singh and Allen [2012])
- Natural wide band speech is much more complex than pure tones, with non-linear effects like forward masking playing an important role.
- Average speech spectrum is irrelevant when it comes to CV perception, since it is dominated by vowel energy

- Angle between conditions (FG and NAL-R)

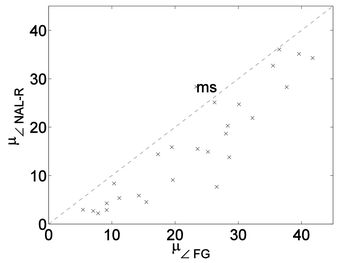


Figure 5(a): Scatter plot of mean angles between responses and correct answer. Angles with NAL-R decrease for all tokens but the male /sa/ token (ms).

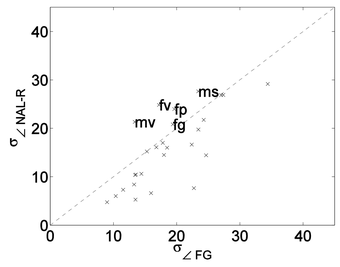


Figure 5(b): Scatter plot of standard deviation of angles between responses and correct answer. The standard deviation is a measure of listener consistency. It increases for all tokens but the ones labeled (fv: female /va/).

Conclusion

The data from the two experiments showed:

- Despite the uncommon approach of measuring CV confusions at MCL, we demonstrated with the low entropy in quiet that audibility was not an issue.
- We defined a more rigorous definition for audibility in high-entropy recognition tasks
- Hellinger Distance is a powerful tool to analyze confusion matrices
- NAL-R in general, decreases the entropy of the responses; this is true for all listeners and all tokens
- NAL-R makes the responses on a token level more consistent across all ears

Summary: NAL-R in general helped and listeners are consistent on a token basis; however, specific listeners have problems with specific tokens, implying that tailored training could help

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