Evaluating the impact of a simulated mixed-rate cochlear implant strategy on perception of interaural time differences in noise

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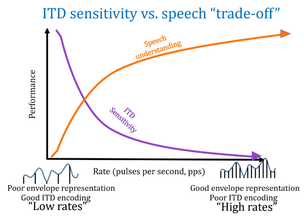
WAISMAN CENTER

Binaural Hearing and Speech Laboratory

2020 ARO MidWinter Meeting
San Jose, CA
Poster # 331

INTRODUCTION

- Normal hearing (NH) listeners rely on low-frequency envelope or fine structure information to locate a sound source using interaural time differences (ITDs) [1].
- Current cochlear implant (CI) technology cannot accurately process ITDs. Bilateral CI listeners show poor sensitivity to ITDs with low-rate stimulation using research processors [2]. Low stimulation rates provide poor speech understanding due to poor encoding of the speech envelope (see Figure 1).



- Previous work has demonstrated that *mixed rates* of stimulation can provide good ITD sensitivity [3] and does not worsen speech understanding [4] in bilateral CI listeners.

Figure 1: Schematic depicting the trade off for low and high rate stimulation on performance in bilateral CI listeners

- However, it is unknown whether a mixed-rate signal is useful in noisy environments. It is also unclear whether the low frequency envelope or low-rate fine structure is more useful for bilateral CI listeners in noise.
  - This study simulated mixed-rate speech in noise to understand the influence of the envelope vs. fine structure ITD of a word in noise in NH listeners.
  - We used a vocoding technique which downsamples the envelope in certain frequency bands (Figure 2) to reflect low-rate fine structure information [5].

Aim: Explore the utility of a *simulated* mixed-rate signal for discrimination of ITDs in noise.

Example amplitude spectra of vocoded words

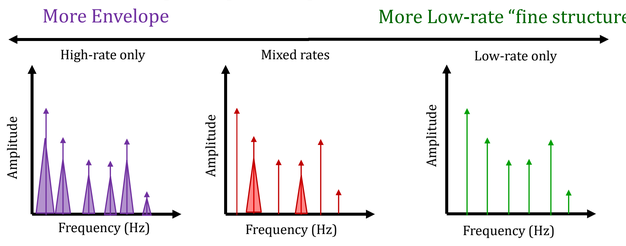


Figure 2: Illustration of "mixed-rate" amplitude spectra of a vocoded word. The reduced bandwidths of some of the frequency bands demonstrate under-sampled bands

Hypothesis: If NH listeners exhibit better performance using high-rate only stimuli, this indicates a reliance on envelope information for utilizing ITDs in noise. While greater performance using low-rate only stimuli indicates a greater reliance on low-rate "fine structure" information.

STIMULI

- Consonant Nucleus Consonant (CNC) words in speech-shaped noise (SSN)*.
- 16-channel tone vocoder (3 configurations):
  1. All-High: no envelope degradation.
  2. Mixed: every odd numbered band was degraded.
  3. All-Low: all bands degraded.
- ITDs applied to CNC Target word: ±25, ± 50, ±75, ±100, ±125 µs.
- ITD applied to SSN noise: 0 µs.
- SNRs: -5 and – 10 dB.

*same stimuli from [5].

High and low rates were simulated by downsampling the envelope in individual frequency bands during the vocoding process

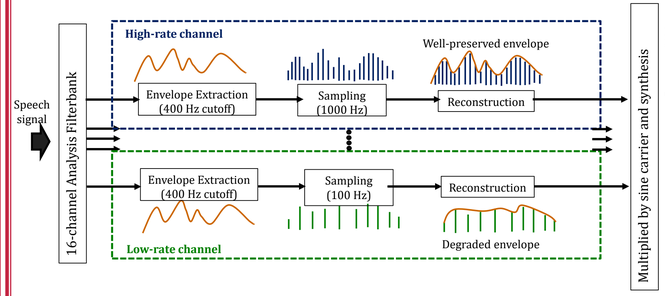


Figure 3: Schematic for vocoding mixed rates. Low-rate channels were implemented by reducing the sampling rate to 100 Hz. High-rate channels were sampled at 1000 Hz. Figure redrawn from [5].

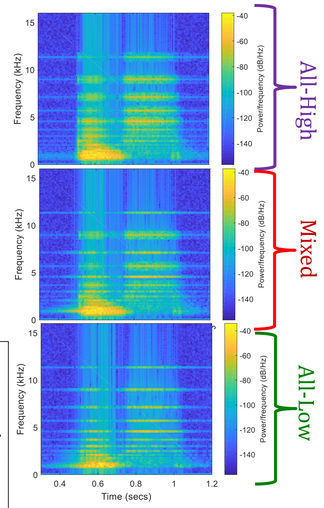


Figure 4: Spectrograms of the word "GOOSE" in quiet.

SUBJECTS & TASK

- 7 NH listeners
  - English native speakers, passed a hearing screening at 20 dB HL.
- Task:
- 2-interval, 2-alternative forced-choice task.
  - First interval: listeners were presented with a single CNC word with a 0 µs ITD.
  - Second interval: the same CNC word with either a left-ward or right-ward ITD.
  - Listeners were instructed to report if they heard the word in the second interval to the left or the right of the first interval.

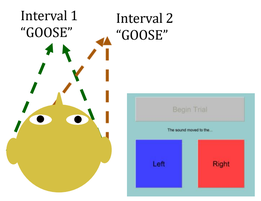


Figure 5: Example trial with a right-ward ITD and response screen.

RESULTS: Group Data

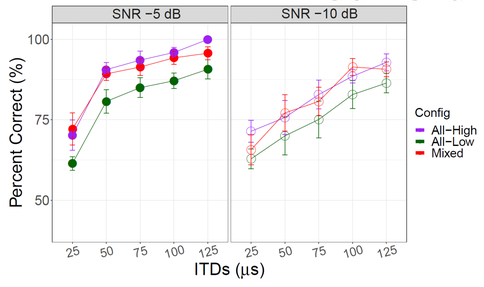


Figure 6: Average percent correct scores as a function of ITD. Error bars represent standard error of the mean.

Do simulations of a mixed-rate speech signal provide better low rate ITDs over a high-rate only signal?

- Group data show a significant effect of ITD [F (1, 4) = 48.89, p<0.01], Configuration [F (1, 2) = 29.291, p<0.01], and SNR [F (1, 1) = 14.81, p<0.01].
- A pairwise comparison showed that score in the Mixed and All-High were significantly different from "All-Low," but not from each other.

RESULTS: Individual Data

Both percent correct scores and just-noticeable difference (JND) thresholds show that the introduction of <u>only</u> low-rate ITDs results in worse performance than a signal having channels with "All-High" or "Mixed" rate ITDs.

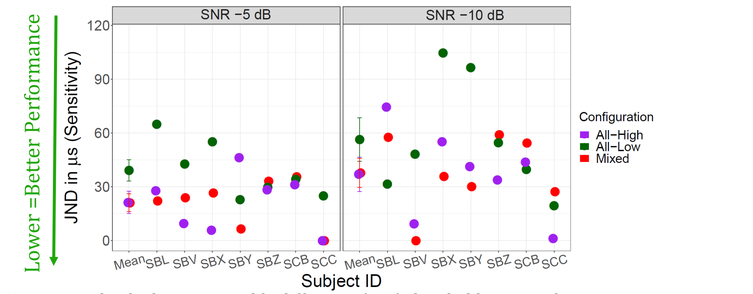


Figure 7: Individual just-noticeable difference (JND) thresholds per configuration. Lower values indicate better ITD sensitivity. Error bars represent standard error of the mean.

Implementing a mixed-rate strategy for CI listeners

Applying mixed rates *after* a target word and masker are combined

<u>The order of processing matters:</u>

- To represent both the envelope and low-rate ITDs the mixed rates need to be applied *prior* to mixing a target and masker.
- Unlike the NH system, information in a CI is discretized into pulses, leading the output to represent a pulse from either the target and masker but not both simultaneously.

Applying mixed rates *before* a target word and masker are combined

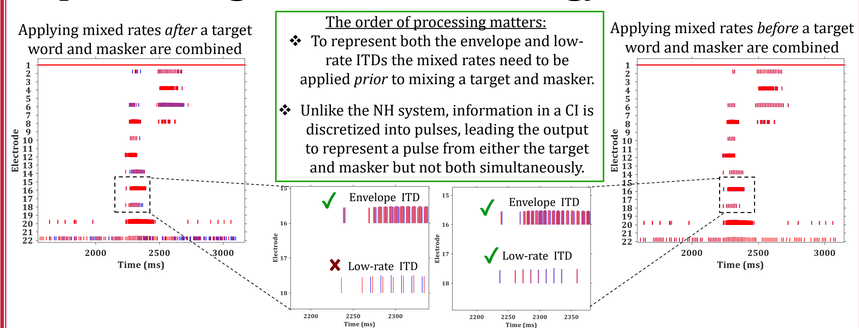


Figure 8: Electrodogram of the word "GOOSE" in +12 dB SNR SSN with a 1000 µs ITD. Stimulus was processed using two different methods in a CIS-like strategy.

SUMMARY

- **This study investigated the effect of mixed-rate simulations on the ability of NH listeners to discriminate ITDs of words in noise**.
  - Worst performance occurred in the All-Low configuration, while best performance occurred with All-High or Mixed.
  - This suggests that low-rate "fine structure" may be detrimental for ITD discrimination of a word in noise. This is clear from the decrease in performance in the All-Low configuration compared to All-High or Mixed.
- Among NH listeners, having a well-represented envelope may be more important for relaying an ITD of a word in noise. It remains unclear whether BiCI listeners use the envelope or low rate cue under a similar paradigm

REFERENCES

1. Wightman, F. L., and Kistler, D. J. (1992). "The dominant role of low-frequency interaural time differences in sound localization," J. Acoust. Soc. Am., 91, 1648–1661. doi:10.1121/1.402445
2. Kan, A., and Litovsky, R. Y. (2015). "Binaural hearing with electrical stimulation," Hear. Res., 322, 127–37. doi:10.1016/j.heares.2014.08.005
3. Thakkar, T, Kan, A, Jones, HG, and Litovsky, RY (2018). Mixed stimulation rates to improve sensitivity of interaural timing differences in bilateral cochlear implant listeners. The Journal of the Acoustical Society of America, 143, 1428-1440.
4. Leclère, T, Kan, A, Litovsky, Y, (in prep). Speech intelligibility of unilateral cochlear implant patients with a mixed-rate strategy.
5. Leclère, T, Doyle, S, Kan, A, Litovsky, Y, (2019). Binaural Intelligibility Level Difference with a Simulation of a Mixed-rate Strategy for Bilateral Cochlear Implants. Presented at the 42nd ARO Mid-winter Meeting Baltimore, MD

ACKNOWLEDGEMENTS

WAISMAN CENTER UNIVERSITY OF WISCONSIN-MADISON
Printing courtesy of the Friends of the Waisman Center

We would like to thank all our participants and Cochlear Ltd for providing equipment. This work is funded by NIH-NIDCD (R03DC015321 to AK and R01DC003083 to RYL), and NIH-NICHD (U54HD09256 to Waisman Center).