Poster: R9

Acoustic Spectro-Temporal Modulation Detection in Cochlear Implant Users

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Introduction

- Cochlear implant (CI) user's ability to understand speech is highly variable and in some cases, very poor when compared to normal hearing (NH) individuals[1].
- Speech can be broken down into modulations in the spectral and temporal domains. The ability to detect small spectral and temporal modulations has been linked to greater speech understanding[1-4]. Spectral and temporal modulations in speech are not mutually exclusive events. They often occur simultaneously, producing directional sweeps of frequency over time (Fig. 1). Thus, the ability of a listener to detect small spectro-temporal modulations may be indicative of their ability to understand speech signals that contain similar patterns.
- CI users have relatively poor spectral resolution due to the limited number of electrodes, spread of current during electrical stimulation, and regions neural death or atrophy, but have relatively good temporal resolution. It is unclear how these cues will interact and affect their ability to detect spectro-temporal modulations.
- This experiment compared modulation detection thresholds of various spectral, temporal, and spectro-temporal modulations between NH and CI users and the interaction between spectral and temporal cues.

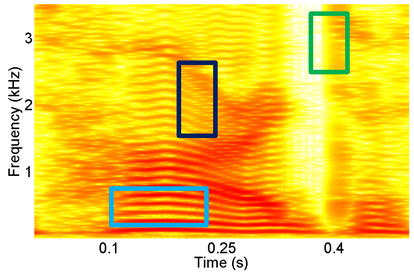


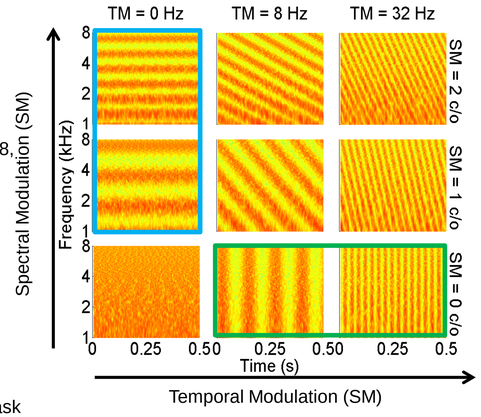
Figure 1. Various spectral (**blue**), temporal (**green**), and spectro-temporal (**black**) modulations seen in the spectrogram of a speech signal

Methods

Stimuli

- Ripple sounds with purely spectral, temporal, or joint spectro-temporal modulations (Fig. 2)
- Bandpassed from 100-8000 Hz
- 500 ms in duration
- Spectral Modulations: 0.5, 1, 2, 4, 8 cycles/octave (c/o)
- Temporal Modulations: 8, 16, 32, 64, 128, 256 Hz

Figure 2. Spectrogram of a 0.5 second window of stimuli with spectral-only (outlined in **blue**), temporal-only (outlined in **green**), and spectro-temporal modulations



Task

- 3 interval, 2 alternative forced choice task
- Subjects heard 2 reference sounds and one target sound per trial, chose sound that was "different"
- Modulation depth (in dB) of target was varied adaptively (Fig. 3)
- Reference sounds were unmodulated
- Modulation depth detection thresholds were calculated.
- Modulation transfer functions were plotted for spectral only (sMTF), temporal only (tMTF), and spectro-temporal (stMTF) conditions.

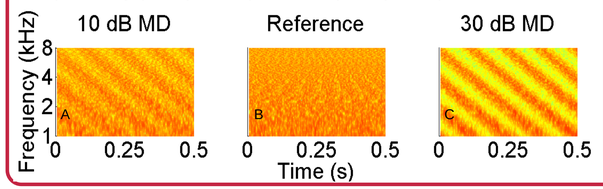


Figure 3. Spectrograms of stimuli showing the reference stimuli (B) as well as shallow (A) and deep (C) modulation depths. In a trial the subject must differentiate the modulated stimuli from two references. This is more difficult with shallow (A) than deep (C) modulation depths.

Subjects

- 9 CI subjects: stimuli presented via auxiliary port (Table 1)
- 9 NH subjects: stimuli presented via ER-2 headphones

Subject	Age	Years CI Experience	Ear Tested	Internal Device	Processor
IAJ	57	15	R	CI24R	N5
IBO	48	5	R	Freedom Contour Advance	Freedom
IBP	62	8	R	CI24M	Freedom
IBQ	80	10	R	CI24R	Freedom
IBY	49	5	R	CI512	N5
IBZ	45	6	R	Freedom Contour Advance	Freedom
ICA	53	11	R	CI24R	N5
ICB	51	11	R	CI24R	N5
ICF	71	3	L	CI512	N5

Table 1. CI subject information

Results

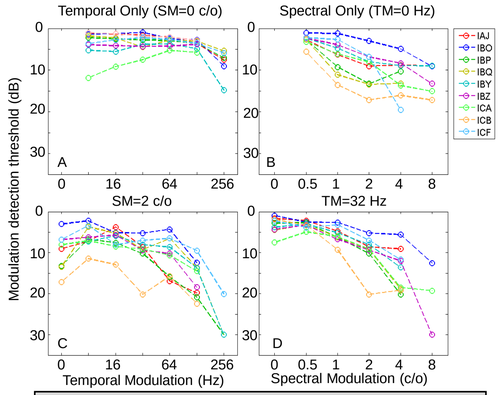


Figure 4. Modulation transfer functions of CI subjects for temporal only (tMTF, A), spectral only (sMTF, B), and various spectro-temporal conditions (stMTFs, C,D).

- CI and NH subjects both performed better in temporal-only than spectral-only ($p<0.001$, Fig. 4 A, B, Fig 5 A, B).
- CI subjects performed worse than NH in spectral-only conditions ($p<0.001$, Fig. 5 A, B).
- Both NH and CI subjects performed worse as spectral modulation density and temporal modulation speeds increased. (Fig. 4 C, D. Fig. 5 A, B).
- Temporal modulations of <32 Hz resulted in better performance in CI users than spectral-only conditions ($p<0.05$, Fig. 5 A, B).
- The performance gap between CI and NH listeners was widest with temporally rapid and spectrally dense spectro-temporal modulations (Fig. 5 C).

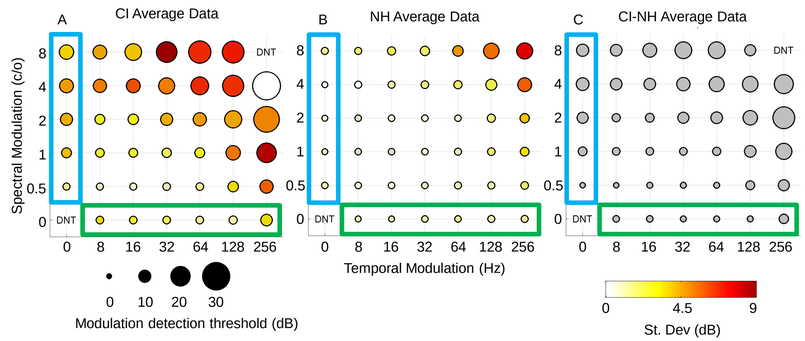


Figure 5. Bubble plots showing the average data of all CI (A), NH (B), and the difference between CI and NH (C) in each condition. Modulation depth detection thresholds are represented by bubble size, and standard deviations for plots A and B are represented by color. Temporal-only conditions are outlined in **green**, spectral-only conditions are outlined in **blue**.

Discussion

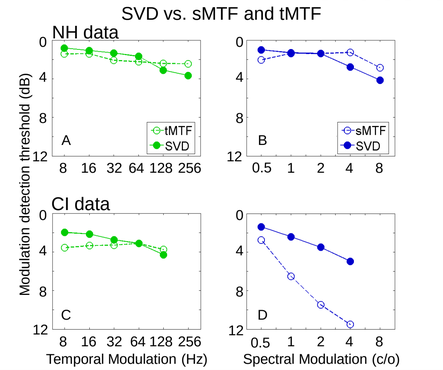


Figure 6. stMTFs were computed as sMTFs and tMTFs using a singular value decomposition (SVD). SVDs for each condition were compared to the actual sMTFs and tMTFs and to see if spectro-temporal modulation detection could be predicted by spectral-only and temporal-only results

Singular Value Decomposition

- For NH listeners, singular value decomposition (SVD) results mimicked sMTFs and tMTFs, showing that spectro-temporal modulation thresholds are correlated to purely spectral and temporal modulations (Fig. 6 A,B).
- For CI users, SVD results were much lower than the sMTF, showing that CI users received a benefit with spectral-temporal modulation over spectral-only modulation (Fig. 6 D).

Spectral Filter Width

- Due to spread a limited number of electrodes and spread of electrical current during CI stimulation, CI users have relatively lower spectral resolution.
- As spectral modulation density increases, temporal modulation cues are lost in the wide spectral filter, but not in the narrow (Fig. 7)
- This may lead to wide spectral filters that cannot adequately capture temporally rapid and spectrally dense spectro-temporal modulations (Fig. 7).

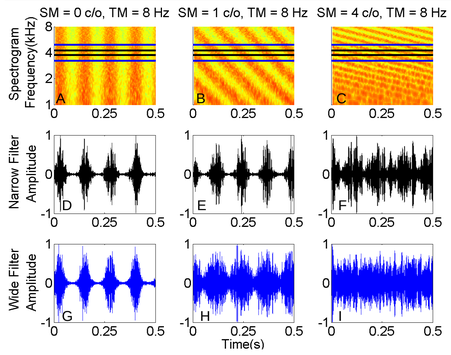


Figure 7. Spectrogram of TM=8 Hz stimuli with various spectral ripple densities. Showing the widths of one ERB-wide (black) and 3mm wide (blue) filters centered at centered at 4 kHz. (A-C). These filters correspond to a NH listeners one-ERB effective bandwidth, and a CI electrode bandwidth with 3mm of current spread. The narrow and wide filters where then applied to the stimuli, and the resulting waveforms are plotted (D-I).

Conclusions

- CI users receive a benefit of spectro-temporal modulation over spectral-only modulation that is not seen in NH listeners.
- With spectro-temopral modulations, dense spectral modulations cause temporal cues to become detectable only within narrow spectral windows .
- Due to their reduced spectral resolution, CI users are not as able to discriminate frequency-specific timing cues.
- Speech sounds that contain dense spectral modulations are likely difficult to discriminate for CI users.

References

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