Sensitivity to Spectral Peaks and Notches in Cochlear Implant Listeners

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INTRODUCTION

To localize sounds in the vertical plane, spectral peaks and notches are necessary. The necessary frequency range is typically accepted to be 4-16 kHz. This could be problematic for cochlear implant (CI) users because the frequency range is typically limited to approximately 10 kHz, thus omitting half of the relevant frequency range.

Particularly important spectral features for sound localization may include:

- Front: 1-oct. notch with lower cutoff from 4-10 kHz
- Back: small peak from 10-12 kHz
- Increasing frontal elevation: increasing lower cutoff of 1-oct. notch

However, broadband rather than narrowband cues are most relevant (Mcpherson and Middlebrooks, 2003). Given the crude spectral resolution of CIs, this is a promising and necessary result for implementing a CI sound localization strategy.

This study measures CI listeners' sensitivity to spectral peaks and notches in a "flat" background with different bandwidths and at different tonotopic places. The results will be compared to the normal hearing (NH) thresholds (Moore et al., 1989).

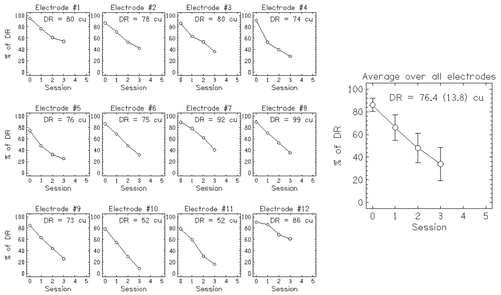
LOUDNESS BALANCING

All 12 electrodes are balanced to an equal loudness using an iterative loudness balancing procedure.

1. Determine a comfortable level (CL) for each electrode separately
2. Present all electrodes simultaneously at CL, reduce level to an overall comfortable level (OCL)
3. Balance level of individual electrodes at CL adjusted by the offset found from the OCL
4. Present all electrodes simultaneously at new levels, reduce level to an overall comfortable loudness (OCL)
5. Repeat steps 3 and 4 until all electrodes are presented at an equal loudness and can be presented simultaneously at a comfortable loudness

Listeners needed 2-4 iterations to reach an overall equal-comfortable level.

Fig. 1: Iterative loudness balancing results for an example listener. The levels at all twelve electrodes were balanced to the same overall loudness.



METHODS

1. Listeners

- 6 Med-El C40+/Pulsar Implants
- 1515 pps stimulation rate per electrode (direct stimulation research interface)

2. Procedure

- 3I-2AFC oddity task
- 2 down – 1 up staircase
- 16 turnarounds (first 4 omitted from calculation of mean and stand. dev.)

EXPERIMENT 1: AMPLITUDE DETECTION

Conditions

- Tonotopic place = low (electrodes 4-6), mid (7-9), high (10-12)
- Bandwidth = 1, 2, 3 electrodes
- Peaks and notches
- No roving and roving (±5 cu)
- Band only (no background)

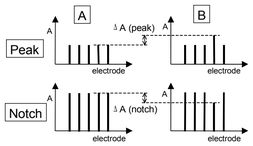
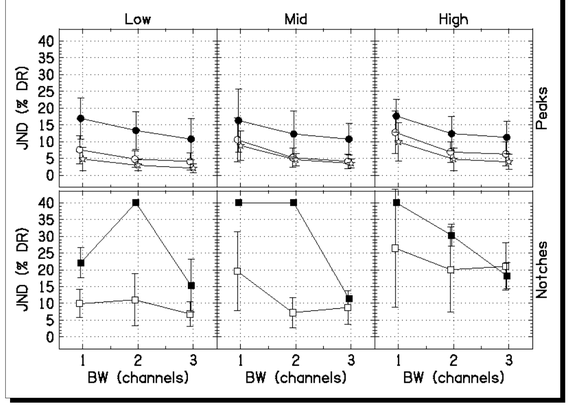
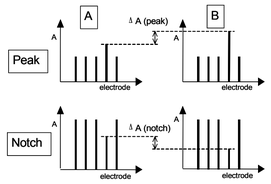


Fig. 1: Peak and notch thresholds averages (N = 6) as a function of the percentage of the dynamic range (% DR). Indeterminable JNDs are set to 40%.



Amplitude detection could be determined for all peak conditions, but only 75% notches without roving and 13% with roving. Notches were more difficult than peaks, consistent with NH data. It was found that a bandwidth of 1 electrode was worse than 2 and 3 ($p < 0.001$) and that the high place was worse than the low and mid places ($p < 0.001$). The place effect is consistent with the NH data (see individual data handout for specific tendencies), however there was no bandwidth effect in the NH data. Thresholds for CIs, in general, were worse than NH listeners who have a peak without roving JND = 2-3 dB (assuming 100 dB dynamic range for NH and 100 cu range for CI). The "band only" data correlates very well with the peak without roving data, suggesting the sensitivity is limited by intensity discrimination.

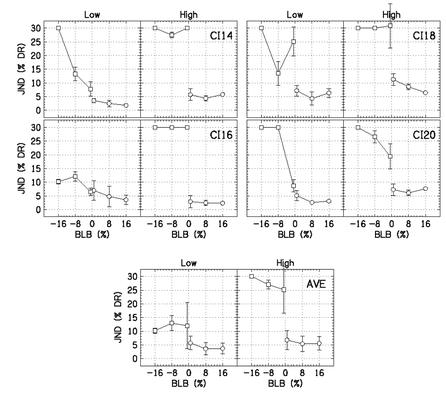
EXPERIMENT 2: AMPLITUDE DISCRIMINATION



Conditions

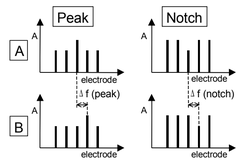
- Tonotopic place
  - low = electrodes 4-5
  - high = 10-11
- Bandwidth = 2 electrodes
- Peaks and notches
- Band-level re: background (BLB) = 8 and 16% of the dynamic range of electrodes

Fig. 2: Amplitude discrimination JNDs for references with ±8 and ±16% BLB calculated as a percentage of the dynamic range. Peaks are shown by circles, notches by squares. Indeterminable JNDs are set to 30%.



Amplitude discrimination was slightly better for detecting peaks with a non-zero BLB, and thresholds were slightly better at the low place. All peaks could be determined, but only 50% of notches could be determined. The reason for this is that the wideband, equal-loudness stimuli were presented at levels often close to the thresholds of the CI listeners making deeper notch threshold impossible to determine. The trends in the data for the peaks correspond well to NH data (≅2 dB) although slightly worse.

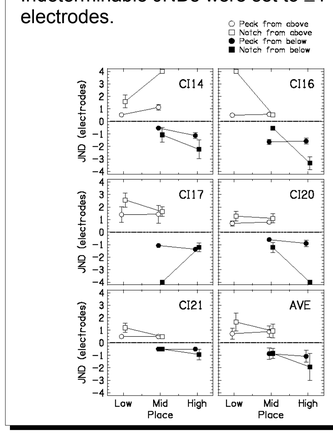
EXPERIMENT 3: FREQUENCY DISCRIMINATION



Conditions

- Tonotopic place
  - low = electrodes 4-5
  - mid = 7-8
  - high = 10-11
- Bandwidth = 2 electrodes
- Peaks and notches
  - Height-depth = 12% of dynamic range

Fig. 3: Frequency discrimination JNDs. Indeterminable JNDs were set to ±4 electrodes.



All peaks could be determined and 80% of notches could be determined. Compared to the NH data, CI listeners are over 10 times worse at frequency discrimination. Also, there is a larger difference between peaks and notch thresholds (>50% increase) as compared to NH listeners (33% increase). This can be explained by course spectral resolution of CIs. Another explanation could be the lack of temporal cue for this task. Like NH listeners, there was little effect of place for this task.

CONCLUSIONS

Three types of spectral sensitivity were tested in CI listeners. Specific results are:

- Peak sensitivity without roving (2-3 electrodes) is less than 8% DR (≈50 μA)
- Level roving increased peak thresholds by 7% DR (≈40 μA)
- Sensitivity to notches is much worse, 17% DR (≈80 μA)
- A bandwidth of 1 electrodes was significantly worse than 2 or 3 electrodes
- The high place was worse than the low and mid places (but listeners had large individual tendencies)
- Discrimination of peaks became better with increased peak height from background
- Discrimination of notches became worse with deeper notch depth from background
- Frequency discrimination thresholds were approximately 1 electrode

Compared to NH listeners, CI listeners showed most all the same effects, however they are worse at the tasks. Amplitude detection seems limited by intensity discrimination thresholds (similar to NHs) and frequency discrimination is limited by the number of electrodes (resolution) of the electrode array. However, it should be possible to implement a vertical plane sound localization strategy from these results.

Macpherson, E. A., and Middlebrooks, J. C. (2003). "Vertical-plane sound localization probed with ripple-spectrum noise," J. Acoust. Soc. Am. 114, 430-445.

Moore, B. C. J., Oldfield, S. R., and Dooley, G. J. (1989). "Detection and discrimination of spectral peaks and notches at 1 and 8 kHz," J. Acoust. Soc. Am. 85, 820-836.

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