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Temporal Sensitivity in the Auditory Periphery: Amplitude Modulation Sensitivity to Stimuli Presented to the Same Ear or Across Ears

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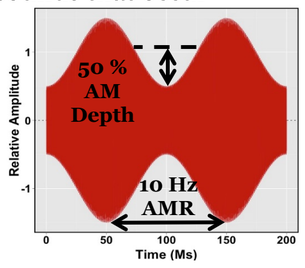
Introduction

- In complex listening environments, listeners use many auditory grouping cues to sort sounds that occur simultaneously [1].
- One example is **amplitude modulation rate (AMR), or the frequency of amplitude modulation** in the stimulus envelope [2].



- Envelope encoding is preserved in stimulation for patients with cochlear implants (CIs), suggesting that concurrent grouping cues in the envelope may be especially useful.
- Sensitivity to other grouping cues for concurrent sounds, like interaural time differences, are predicted by temporal measures at individual electrode locations in CI users [3].
  - Sensitivity to changes in AMR depends on the location of electrodes along the cochlea [4].
- Moreover, the use of electrodes that have lower thresholds in psychophysical tasks relative to other electrodes may improve speech recognition in noise [5], which has useful implications for clinical practice.

Question: How are AMR comparisons affected when the auditory periphery is compromised?

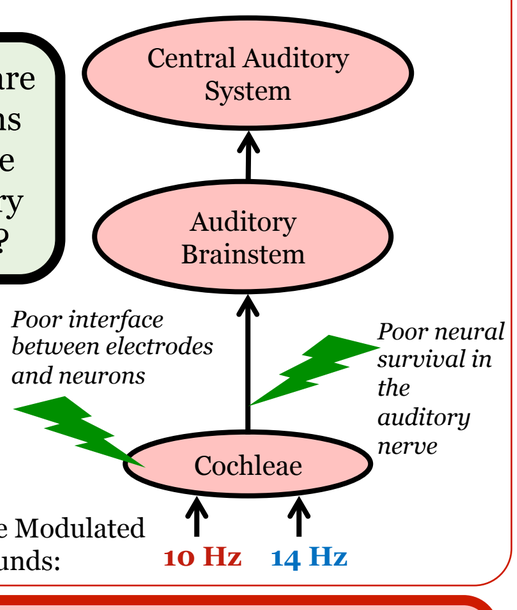


Figure 1: *Factors limiting temporal sensitivity in CI users.* This is a schematic of how amplitude modulation rate information enters the auditory system, and how transmission may be compromised in CI users.

Approach: Simulate electrodes with poor AM sensitivity in CI users by reducing AM depth from 50% to 20% in normal-hearing (NH) listeners, diminishing AMR salience

Methods

Stimuli

- Sinusoidally amplitude-modulated (SAM) tones
  - Carrier: 4000 Hz or 7260 Hz
  - Carriers chosen to simulate spacing of electrodes in Cochlear CI devices
- 600 ms
- Presented at 65 dB SPL(A) via circumaural headphones
- ± 2 dB rove was applied *to each tone* to reduce use of loudness cues
- Subjects (age 22-25)
  - Experiment 1: six NH subjects
  - Experiment 2: five NH subjects
- Thresholds converted to **Weber constants**

$$\text{Weber Constant} = \frac{\text{Just noticeable Difference in AMR}}{\text{Reference AMR}}$$

Experiment 1: Peripheral Sensitivity

Task

- 3 interval, 2 alternative forced-choice task
  - First interval was reference AMR
  - Second or third interval was faster AMR
- 3 reference AMRs (10, 30, and 90 Hz)
- **Subjects chose the fastest AMR**
- Adaptive tracking
  - 3 tracks interleaved for each reference AMR
  - 12 turnarounds

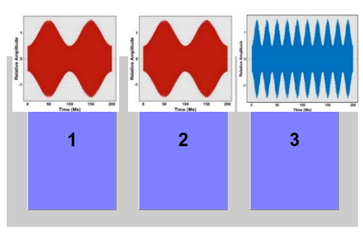


Figure 2: *Graphical user interface and example trial.* Subject initiated trial and stimuli were presented. Two presentations were the slower, reference AMR. The first presentation was always a reference AMR. The faster AMR had a 0.5 probability of occurring on the second or third interval.

Results

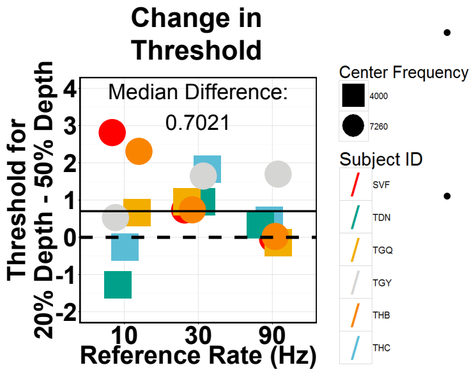


Figure 3: *Peripheral AMR discrimination thresholds.* The y-axis represents threshold for the 20% and 50% AM depth conditions. The black bar represents the median difference between depth conditions.

- **Hypothesis: If AM depth is reduced from 50% to 20%, AMR threshold will increase.**
- The median difference between AMR threshold for 20% - 50% was 0.7021 (Fig. 3).
  - Positive values indicate that the AMR threshold was higher for the 20% depth AMRs.

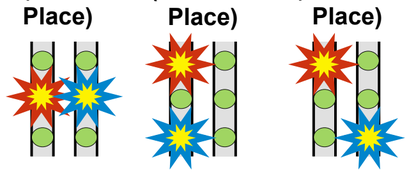
Experiment 2: AMR Comparison

Task

- AMRs were paired:
  - Across or within ears
  - Same or different carrier frequencies
- Subjects discriminated whether the pairs had the **same or different** AMR.
- **The AM depth was reduced to 20% for one SAM tone in pairs for half of conditions.**
- 1 interval, 2 alternative forced-choice task
  - "Same" or "Different"
  - 0.33 probability of being same AMR
- 2 reference AMRs:
  - 10 Hz
  - 90 Hz
- Method of constant stimuli
  - Reference AMRs interleaved

Single Pair AMRs

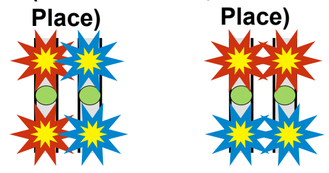
Across Ears (Same Place) | Within Ears (Different Place) | Across Ears (Different Place)



- Single stimulus pairs:
  - One or two different AMRs were presented simultaneously in the same/ different cochlear sites in the left and/or right ear.

Double Pair AMRs

Across Ears (Same Place) | Within Ears (Different Place)

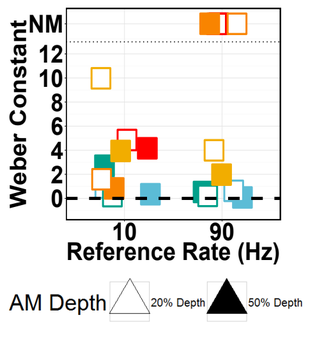


- Double stimulus pairs:
  - Same as single, but with an additional pair of stimuli at two more cochlear locations.

Figure 4: *Illustration of AMR comparisons.* Red stars indicate a reference AMR (either 10 or 90 Hz) and blue stars indicate a variable AMR (which was always a faster rate than the reference), in one or two pairs of stimuli.

Hypothesis: If the AM depth of one simulated electrode in single or double pairs of AMRs was reduced from 50% to 20% depth, then discrimination threshold would increase.

Analyses



- Threshold was defined as the Weber constant for which the subject responded "Different" 71.7% of the time.
  - A logistic function was fit to raw data for each condition to estimate threshold.
- The sensitivity measure d prime was calculated for each point.
- Linear regressions were fit over observed d prime results.

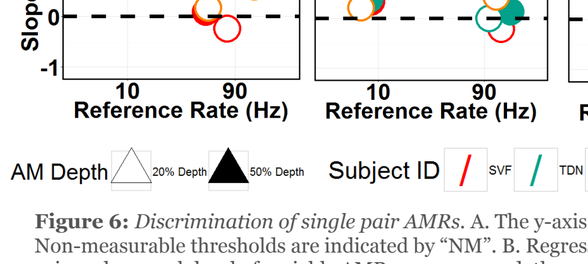


Figure 5: *Analysis techniques.* A. Example data from THB illustrating how threshold was defined. B. Illustration of what the d prime metric represents.

Results – *Single Pair AMRs*

Raw Thresholds

Slope of Regression Over d Prime

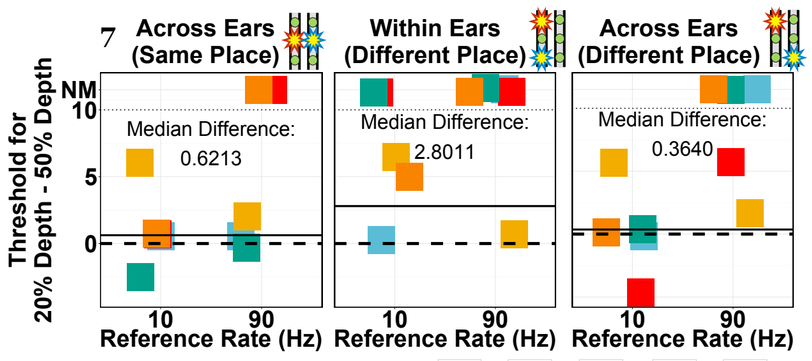
Figure 6: *Discrimination of single pair AMRs.* A. The y-axis represents threshold. Non-measurable thresholds are indicated by "NM". B. Regressions over values for d prime along each level of variable AMR were prepared, the y-axis represents regression slopes.

- Raw thresholds for AMR vary by subject (Fig 6A).
- Some thresholds were not measurable (NM) because 1) subjects' "Different" responses never went below 71.7% or 2) could not discriminate between the AMRs presented.
- Coefficients for d prime regressions near zero explain why some thresholds could not be measured (Fig 6B).

Experiment 2 Results

Single Pair AMRs (cont.)

Change in Threshold

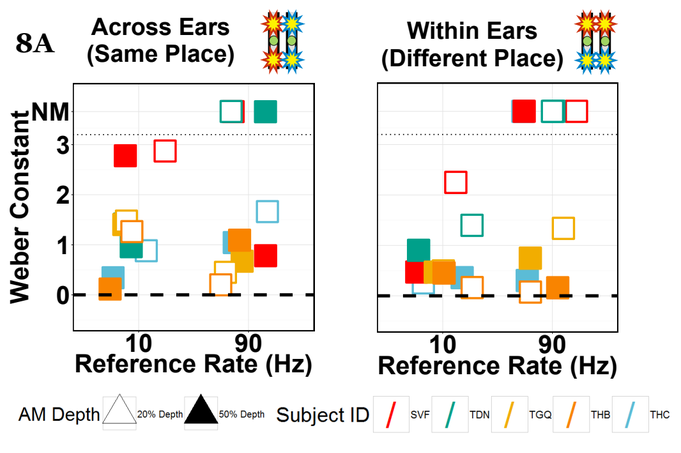


- For single pair AMRs, the median difference between 20% and 50% AM depth conditions was higher than zero (Fig. 7).
- There was considerable inter-participant variability.

Figure 7: *Discrimination of single pair AMRs.* The y-axis represents change in threshold between the 20% and 50%. Non-measurable thresholds are indicated by "NM".

Double Pair AMRs

Raw Thresholds



Change in Threshold

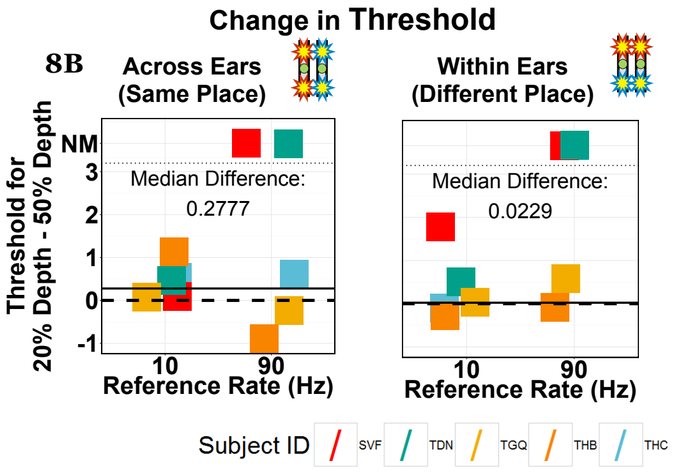


Figure 8: *Discrimination of double pair AMRs.* Non-measurable thresholds are indicated by "NM". A . The y-axis represents threshold. B. The y-axis represents change in threshold between the 20% and 50%.

- In general, thresholds were lower and measurable for two pairs of AMRs (Fig. 8A) compared to one pair of AMRs (Fig. 6A).
- For double pair AMRs, the difference between 20% and 50% AM depth conditions were nearer to zero than single pair AMRs (Fig. 8B).

Summary

- Discrimination of the grouping cue AMR was tested, where reduced AM depth was used to elicit increased thresholds, homologous to electrode sites with poor temporal sensitivity in CI users.
- **Peripheral discrimination thresholds** for AMR tended to increase when AM depth was reduced.
- **Thresholds for comparison of single and double pairs of AMRs** tended to increase when AM depth in one tone was reduced for one pair of AMRs, but not two, and varied across listeners.
- This paradigm allows us to simulate poor temporal sensitivity in the auditory periphery by reducing AM salience in NH listeners.
- Future work in CI users is aimed at investigating if their ability to make use of grouping cues may be limited by factors in the auditory periphery, which can be tested using simple psychophysical tasks.
- The development of simple tests for temporal sensitivity in the auditory periphery may be useful to clinicians in determining the efficacy of information transfer at each electrode site.

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Acknowledgements

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