Binaural Unmasking with Temporal Envelope and Fine Structure in Cochlear Implant Listeners

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Binaural Hearing and Speech Laboratory

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INTRODUCTION

In noisy environments, binaural hearing provides a benefit to speech reception and signal detection. This benefit, known as binaural unmasking, is partially due to the reduction in interaural correlation that occurs in temporal envelope and fine structure when there is spatial separation between sources. Listeners with bilateral cochlear implants (**CIs**) have shown binaural unmasking for signal detection (Long, Carlyon, Litovsky, & Downs, 2006; Lu, Litovsky, & Zeng, 2010). However, the extent of unmasking is limited (Lu et al., 2010; Goupell, 2012) which may be the result of speech processing strategies that present temporal envelope but not temporal fine structure information. This study aimed to determine whether presentation of acoustic temporal fine structure information in the pulse timing would improve binaural unmasking for listeners with bilateral cochlear implants.

GENERAL METHODS

Stimuli

- Masker: 400 ms noise
  - 50 or 125 Hz bandwidth (BW)
  - Interaurally in-phase **(N0)**
- Target: 300 ms tone centered in the noise masker
  - Interaurally in-phase **(S0)** or out-of-phase **(Sπ)**
- Signal-to-noise ratio (SNR) between target tone and noise masker varied
- Hilbert envelope and phase were calculated
- Stimulus portion containing interaural information:
  - Envelope (ENV): The Hilbert envelope was presented with an interaurally synchronized, steady-rate pulse train. The pulse rate was equal to the noise center frequency.
  - Envelope + Fine Structure (ENV+FS): The Hilbert envelope was presented with pulse trains timed to the zeros in the Hilbert phase.
  - Fine Structure (FS): The Hilbert envelope from one side was presented to both sides with pulse trains timed to zeros in the Hilbert phase.

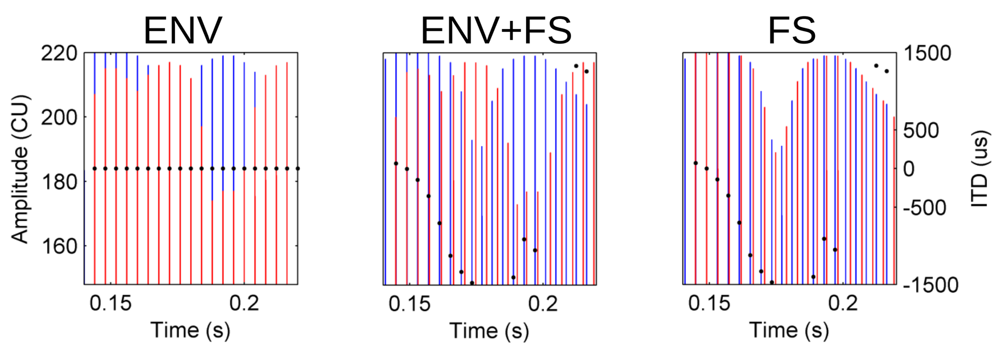


Fig 1. An N0Sπ stimulus in the ENV (left), ENV+FS (middle), and FS (right) conditions at 0 dB signal-to-noise ratio. The left channel is in blue and the right is in red. Black dots show interaural time differences (**ITDs**). The noise had a 250 Hz center frequency and a 50 Hz bandwidth.

Procedure

- 3 interval, 2-AFC
  - Target interval was N0S0 or N0Sπ
  - Non-target interval was N0
- Signal-to-noise ratio varied adaptively (2-down 1-up)
  - 3-5 tracks were collected per condition

Analysis

- The effects of phase (N0S0, N0Sπ), stimulus type (ENV, ENV+FS, FS), and nominal pulse rate were examined using repeated measures ANOVAs.

EXPERIMENT 1: CI listeners

- Participants: 5 listeners with bilateral cochlear implants
  - Implanted with Cochlear devices
  - Single electrode-pair ITD thresholds < 400 μs at 100 pulses per second

Subject	Age (yr)	CI (yr)	Bilateral CIs (yr)
IBF	62	8	6
IBK	73	10	4
IBN	67	13	4
IBY	50	6	2
ICI	55	5	4

- Equipment: Stimuli presented with the Nucleus Implant Communicator and L34 processors
- Stimuli:
  - Noise center frequency (and nominal pulse rate): 125, 250, or 1000 Hz
  - Noise bandwidth: 50 Hz
  - Temporal envelope was compressed between each listeners threshold and maximum comfort levels using a nonlinear compression (Long et al., 2006).
  - ENV, ENV+FS conditions
  - Stimuli were presented to a single pair of interaurally pitch-matched electrodes.

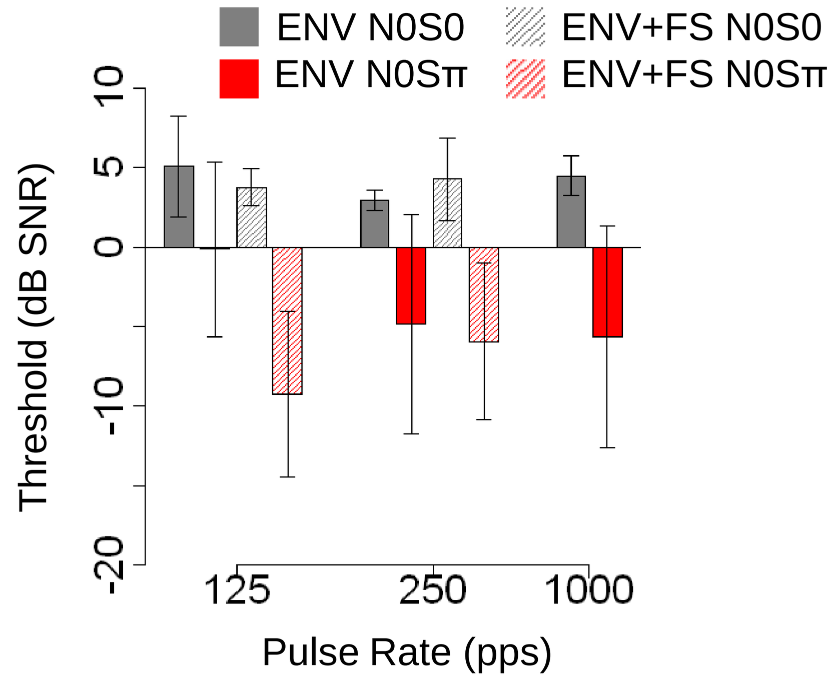


Fig 2. Signal detection thresholds averaged across 5 subjects with CIs as a function of the nominal pulse rate. Error bars show 95 % confidence intervals.

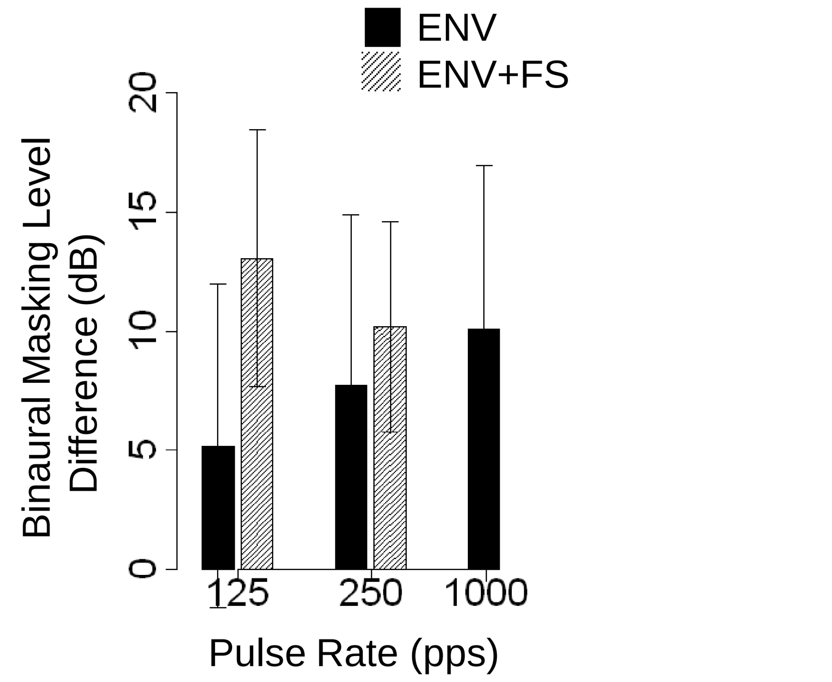


Fig 3. Binaural masking level differences (BMLDs; differences between N0S0 and N0Sπ thresholds) averaged across the subjects with CIs. Error bars show 95 % confidence intervals.

Results

- The effect of including fine structure (ENV vs. ENV+FS) depended on pulse rate. At 125 pps, ENV+FS resulted in improved N0Sπ thresholds (greater BMLDs; p<.01). This effect was not significant at 250 pps.
- Higher rates were needed in the ENV condition to achieve N0Sπ thresholds (and BMLDs) similar to those in the ENV+FS condition. N0Sπ thresholds in the ENV+FS condition at the lowest rate (125 pps) were not significantly different from those in the ENV condition at the highest pulse rate (1000 pps).

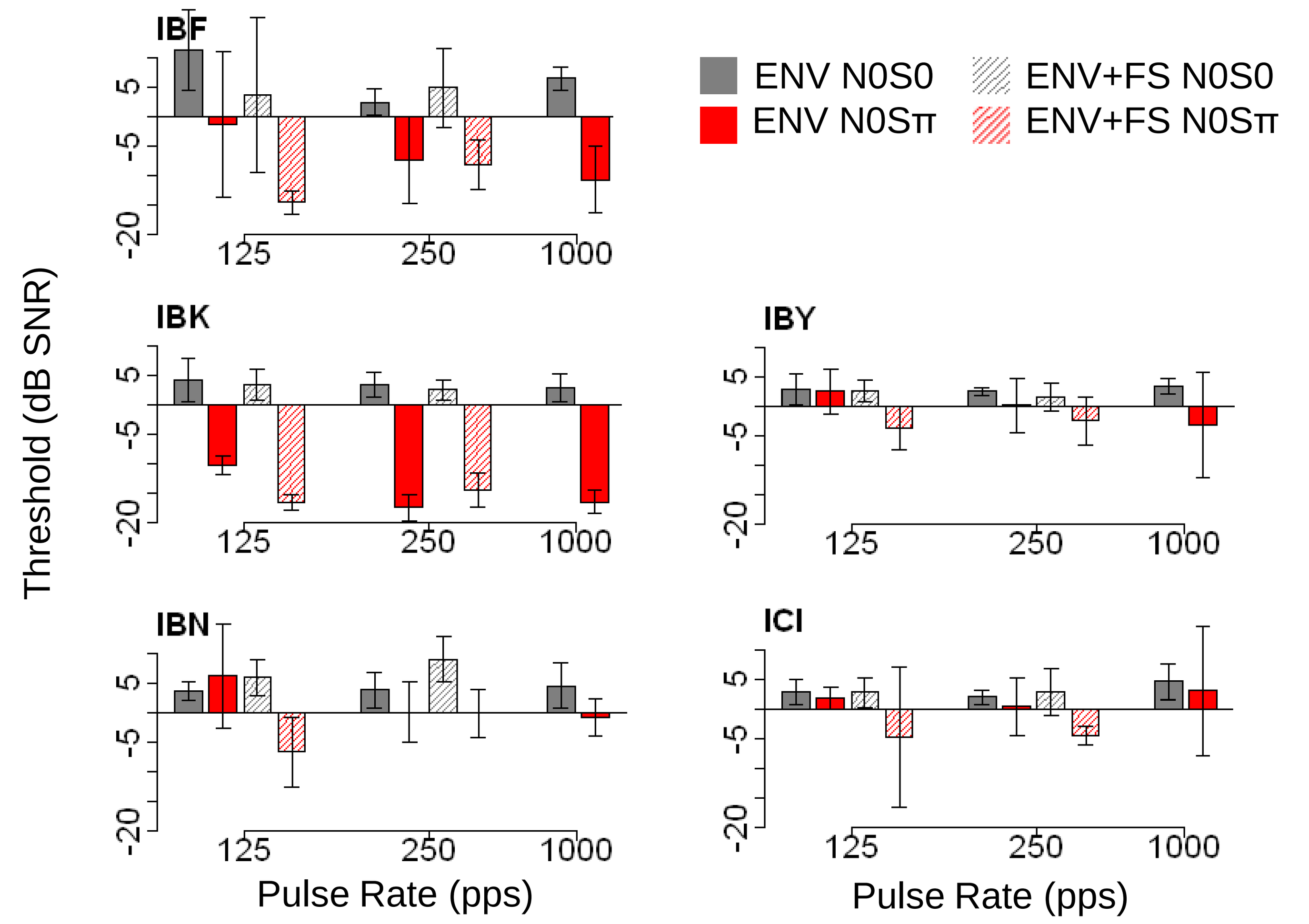


Fig 4. Signal detection thresholds for individuals with CIs averaged over multiple adaptive tracks. Error bars show 95% confidence intervals.

EXPERIMENT 2: NH listeners

- Participants: 8 listeners with normal hearing (NH; 19-32 yrs old)
  - Pure tone thresholds within 20 dB HL at 8000 Hz
- Equipment: Stimuli presented using ER-2 insert earphones
- Stimuli:
  - Noise center frequency (and nominal pulse rate): 125, 250, 500 Hz
  - Noise bandwidth: 50 Hz (and 125 Hz at the 500 Hz center frequency)
  - Single channel Gaussian-enveloped tone vocoder (CI simulation)
  - 9.2 kHz carrier
  - -3 dB bandwidth was 1660 Hz
  - FS, ENV, ENV+FS conditions
  - Uncorrelated pink-noise background from DC to 20 kHz

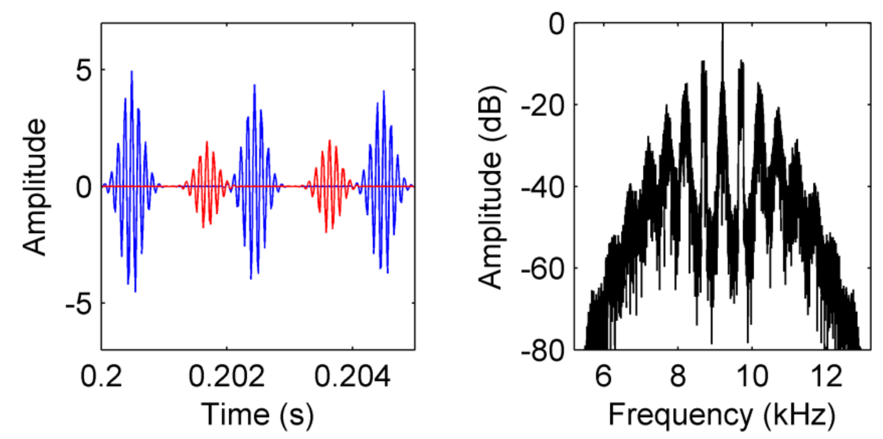
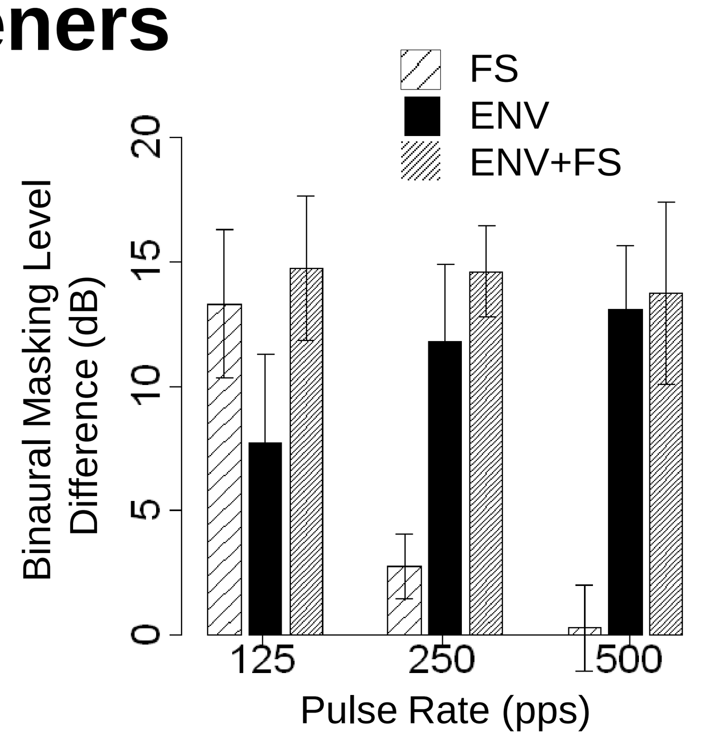


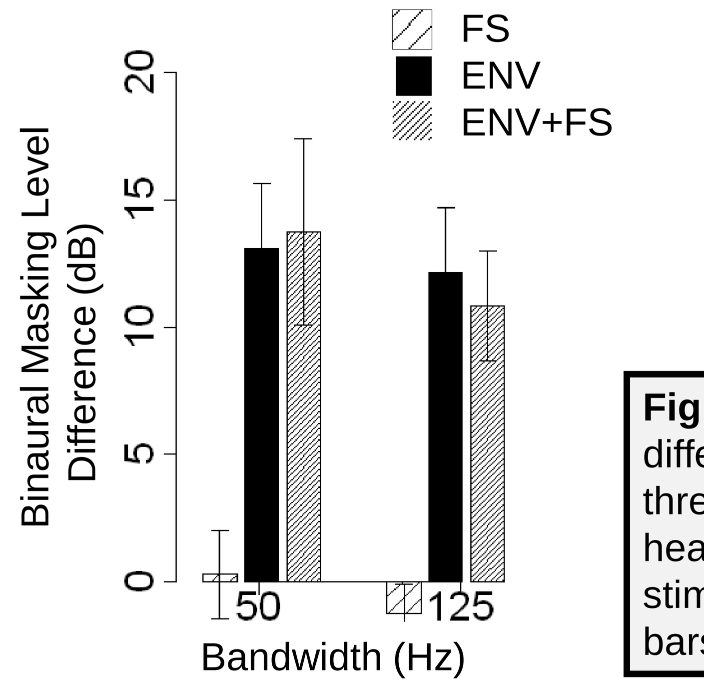
Fig 5. An ENV+FS stimulus in the N0Sπ condition at 0 dB signal-to-noise ratio. The left channel is in blue and the right is in red. The noise had a 500 Hz center frequency and a 125 Hz bandwidth.



Results

- FS resulted in binaural unmasking (BMLDs > 0) only at lower pulse rates (125, 250 pps; p<.01).
- ENV+FS resulted in improved N0Sπ thresholds (greater BMLDs) compared to the ENV condition at the lower pulse rates (125, 250 pps; p<.01).
- Higher rates were needed in the ENV condition to achieve N0Sπ thresholds (and BMLDs) similar to those in the ENV+FS condition.

Fig 6. Binaural masking level differences (BMLDs; differences between N0S0 and N0Sπ thresholds) averaged across 8 listeners with normal hearing as a function of the nominal pulse rate for noise with a 50 Hz bandwidth. Error bars show 95 % confidence intervals.



Results

- FS did not result in binaural unmasking (BMLDs > 0) at either bandwidth.
- ENV+FS did not improve N0Sπ thresholds (or BMLDs) compared to the ENV condition for either bandwidth.

Fig 7. Binaural masking level differences (BMLDs; differences between N0S0 threshold and N0Sπ thresholds) averaged across 8 listeners with normal hearing as a function of the noise bandwidth for stimuli with a nominal pulse rate of 500 pps. Error bars show 95 % confidence intervals.

SUMMARY & CONCLUSIONS

- This study examined whether the binaural benefit for signal detection could be improved for listeners with cochlear implants from encoding temporal fine structure (i.e., interaural time differences) in the electrical pulse timing (Fig. 1).
- Listeners with cochlear implants showed greater binaural unmasking from encoding temporal fine structure only at the lowest nominal pulse rate examined (125 pps; Fig. 3). Performance with fine structure was never significantly better than performance with only temporal envelope at the highest rate tested.
- Similarly, listeners with normal hearing (listening to a CI simulation) showed improved binaural unmasking when fine structure was presented in the pulse timing at low nominal pulse rates (125, 250 pps; Fig. 6), but performance did not exceed that of performance at steady pulse rates at the highest rate tested.
- For both groups, the inclusion of fine structure information in the pulse timing eliminated the detrimental effect of lower pulse rates on thresholds for binaural signal detection (Fig. 3 and 6).
- Despite the aperiodic rate of the pulses (due to encoding the noise fine structure), presenting fine structure information in the pulse timing did not provide a benefit to binaural unmasking at high pulse rates (Fig. 7). This result does not match previous findings that aperiodic pulse timing can improve sensitivity to interaural time differences at high rates (Laback and Majdak, 2008; Goupell, Laback, and Majdak, 2009). Further research is needed to determine whether this discrepancy is due to the temporal envelope modulation of the pulse trains used in the present experiment.

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