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Effect of Center Frequency on Sensitivity to Interaural Time Differences in Filtered Pulse Trains

DAGA
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Introduction I

- Cochlear implant (CI) listeners are sensitive to interaural time difference (ITD) in the fine structure [Laback et al., (JASA, 2007), Majdak et al. (JASA, 2006)].
- Some listeners up to 800 pulses per second (pps)
- Rate limitation in normal hearing (NH) subjects depends on stimulus
  - High-frequency transients: 256 – 600 pps
  - Pure tones: ≈ 1500 Hz

Introduction II

- In Laback et al. (2007) and Majdak et al. (2006) also NH subjects were tested
- They listened to high-frequency filtered pulse trains (CF=4.6 kHz), representing an acoustic simulation of CI perception
- Question: Was the NH subject's performance underestimated by a potentially unfavorable choice of the CF?
- Hypothesis: If the ringing of auditory filters limits ITD sensitivity at higher rates, the rate limit will increase with increasing CF

→ **Test ITD sensitivity as a function of CF**

Previous Study

- Bernstein and Trahiotis (2002) used transposed tones with constant bandwidth in Hz at different CFs
  - Implies decreasing bandwidth in ERB with increasing CF
- This could unfairly favor lower CFs in terms of the number of stimulated neurons

→ To rule out this potentially confounding variable, we used pulse trains with constant bandwidth in ERB

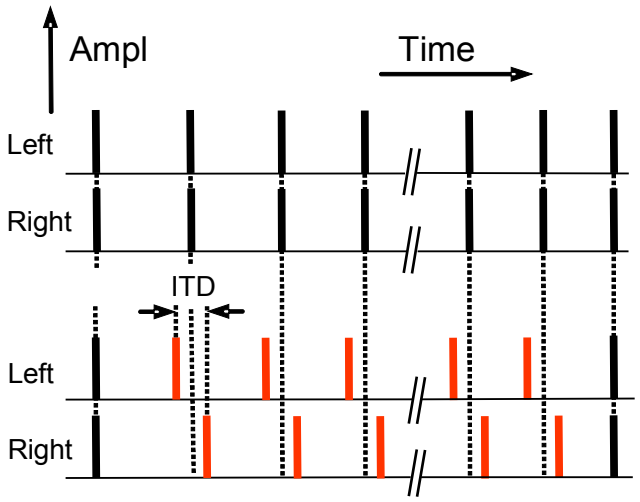
Stimuli I

- Trains of monophasic pulses (pulse duration: 10.4 µs) with total duration of 300 ms
- Bandpass filtered (48 dB/octave) in three frequency regions:
  - 4589 Hz (CF1)
  - 6490 Hz (CF2)
  - 9178 Hz (CF3)
- Constant bandwidths in ERB: 1500, 2121, and 3000
- Level: 66 dB SPL
- Continuous background noise (50-20000 Hz)

Stimuli II

- Pulse rates from 200 – 588 pps
- ITD in ongoing pulses only

Schematics of Pulse Train

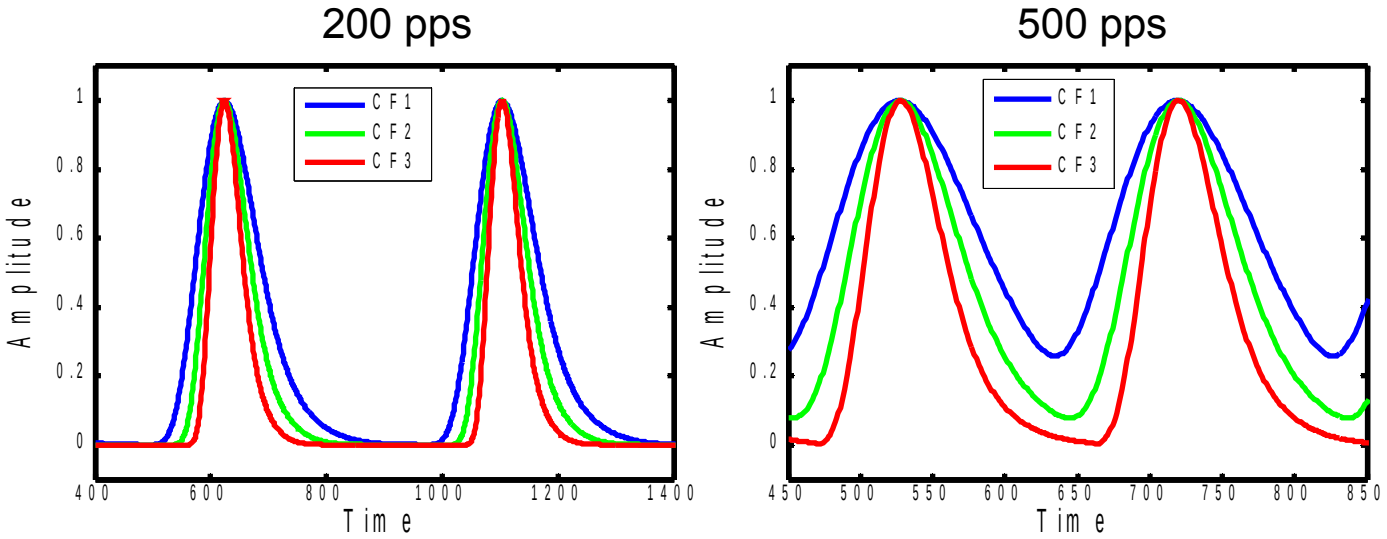


No ITD
(reference)

"Fine Structure" ITD

Stimuli III

- Envelopes of pulse trains after passing auditory filters at the three CFs

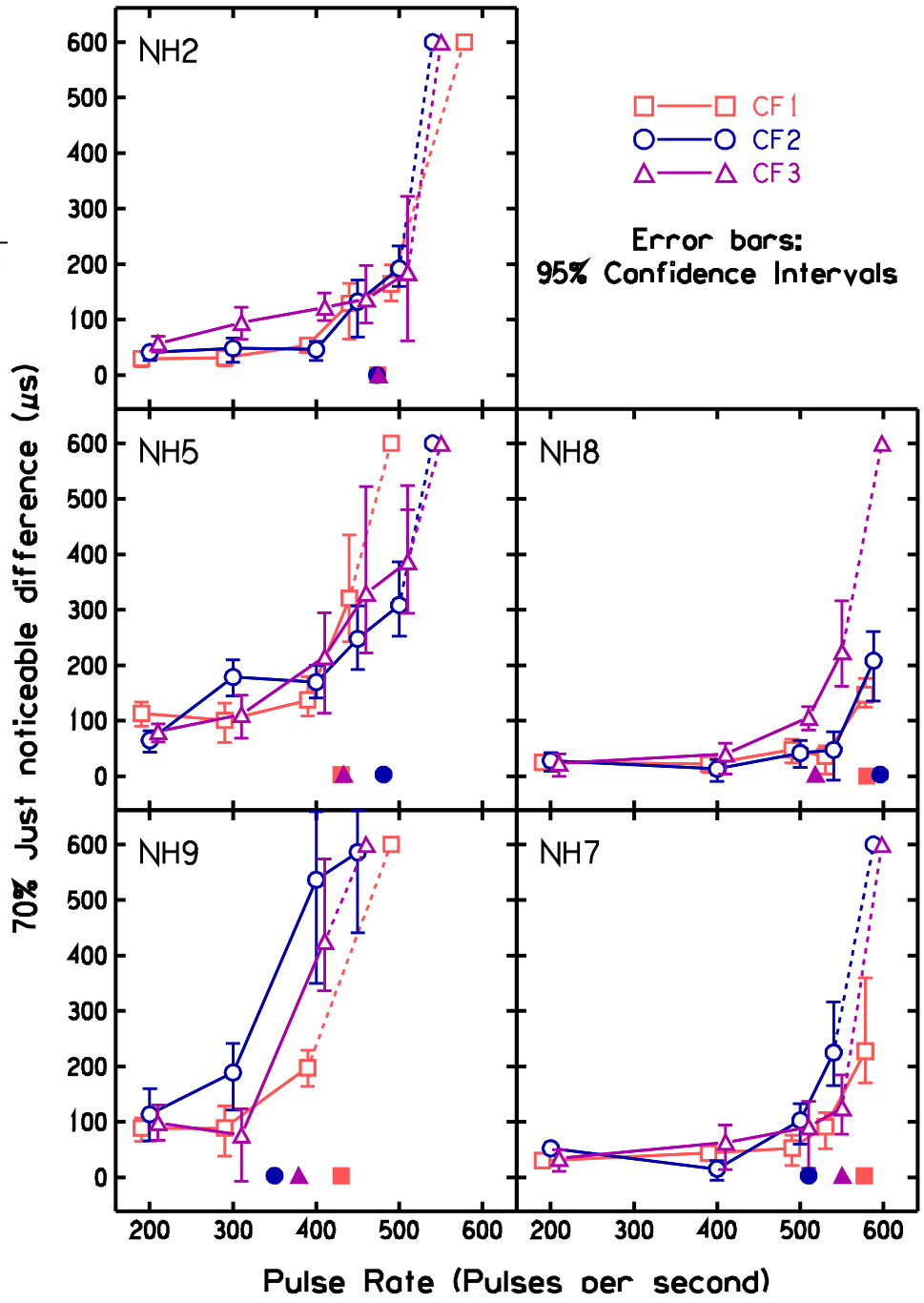


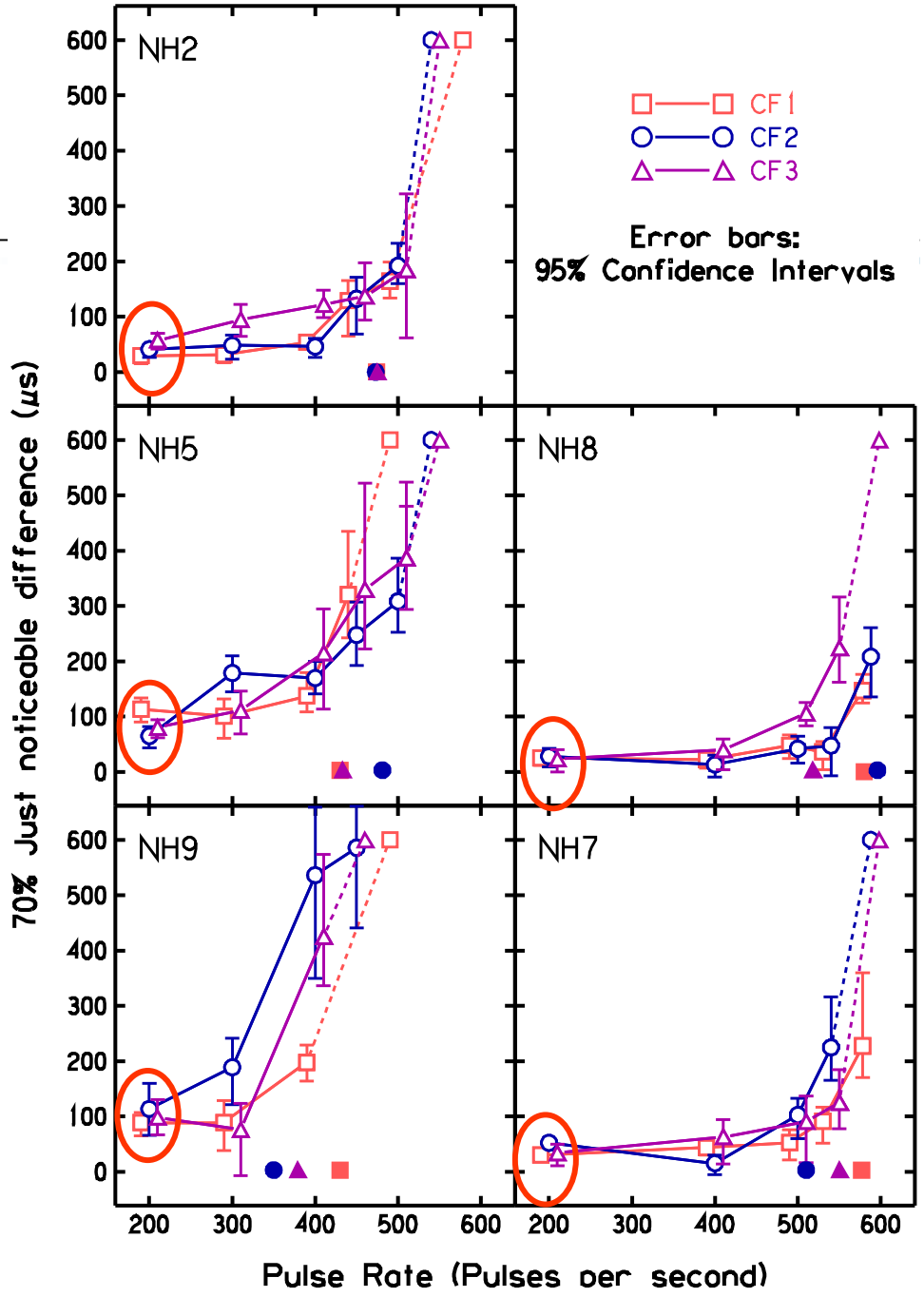
- With increasing CF, the amount of modulation increases, in particular at the higher pulse rate

Experimental Procedure

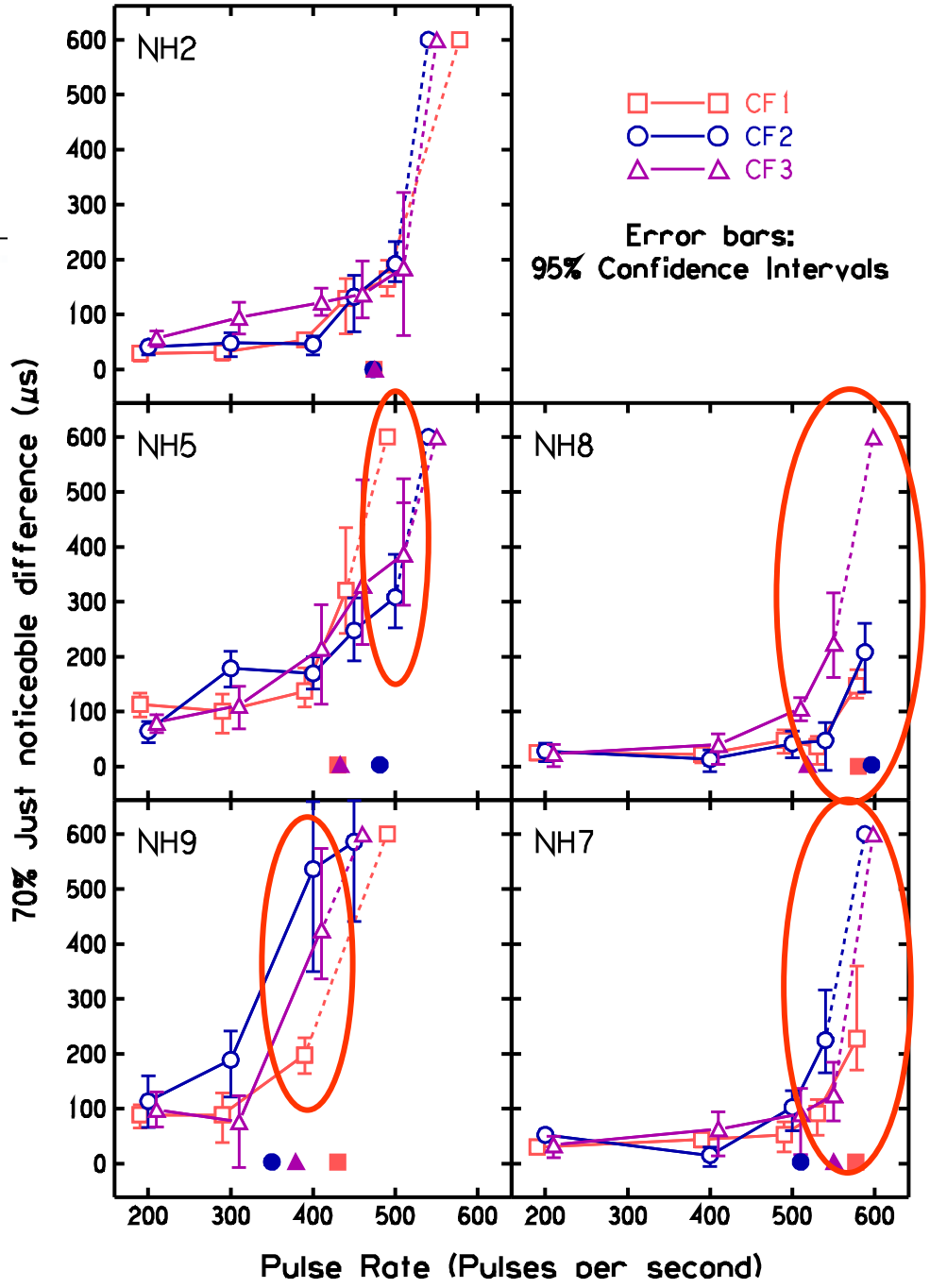
- Left/right discrimination of a target sound containing ITD
- Preceding reference stimulus with 0-ITD
- Visual response feedback after each trial
- Each combination of three CFs and up to seven ITD sizes in a separate test block
- Each block containing 70 repeat presentations of four predefined ITD sizes
- At least two blocks per condition
- Determination of 70% JND from pooled %scores

  (560 items)


NH2
NH5
NH8
NH9
NH7
CF1
CF2
CF3
Error bars:
95% Confidence Intervals
70% Just noticeable difference (µs)
Pulse Rate (Pulses per second)
0
100
200
300
400
500
600



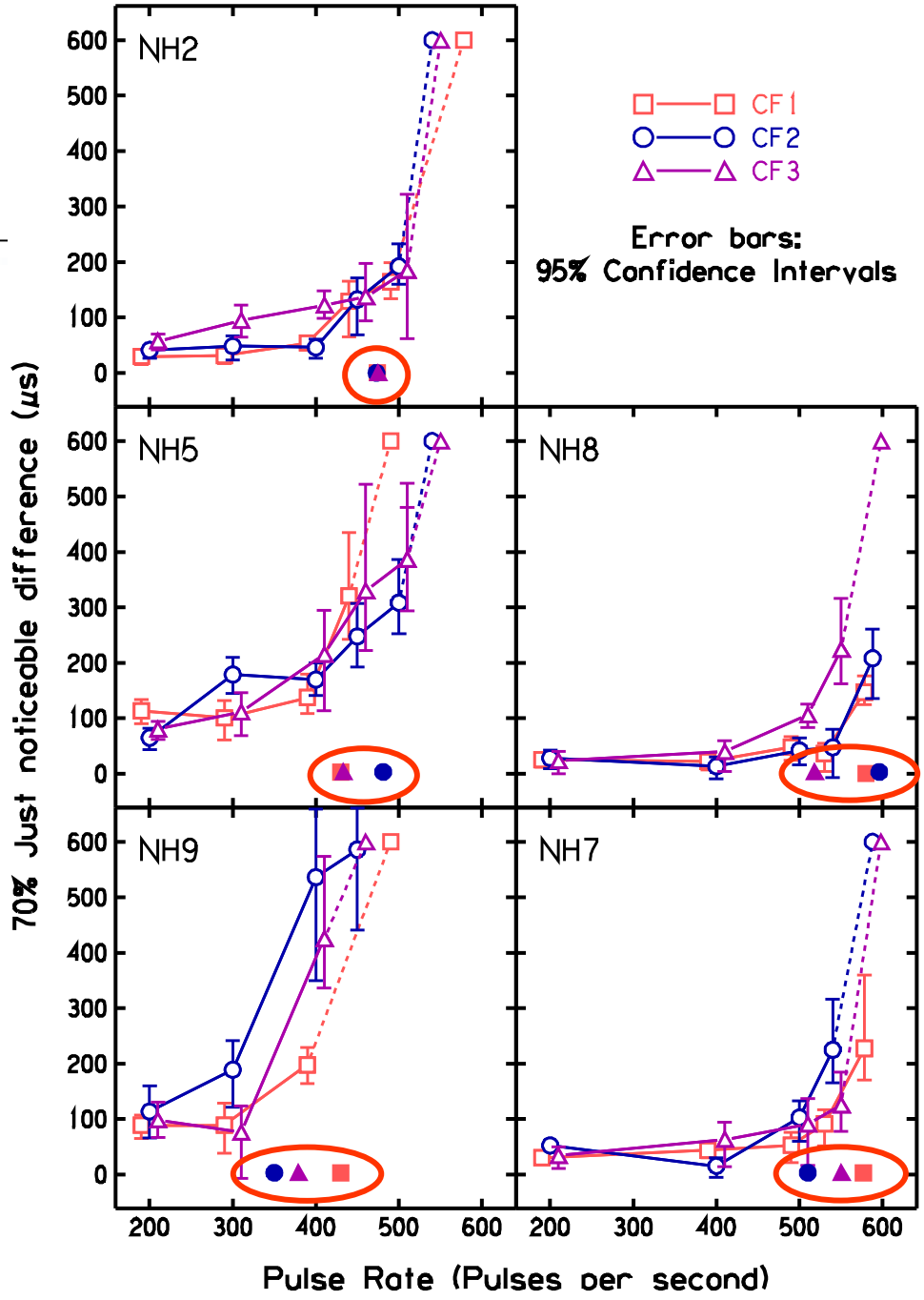
- 200 pps JNDs:
  - not affected by rate limitations
  - Reveal effect of CF on overall performance
- No effect of CF (p = 0.99)
- Aspects related to CF (audibility, number of stimulated neurons) have no effect on performance
- Average JND: 58 µs
- This is significantly lower than JND obtained for transposed tones (Bernstein and Trahiotis, 2002)



- Only a few significant differences between the CFs at higher rates
- In summary, no consistent effect of CF across the subjects

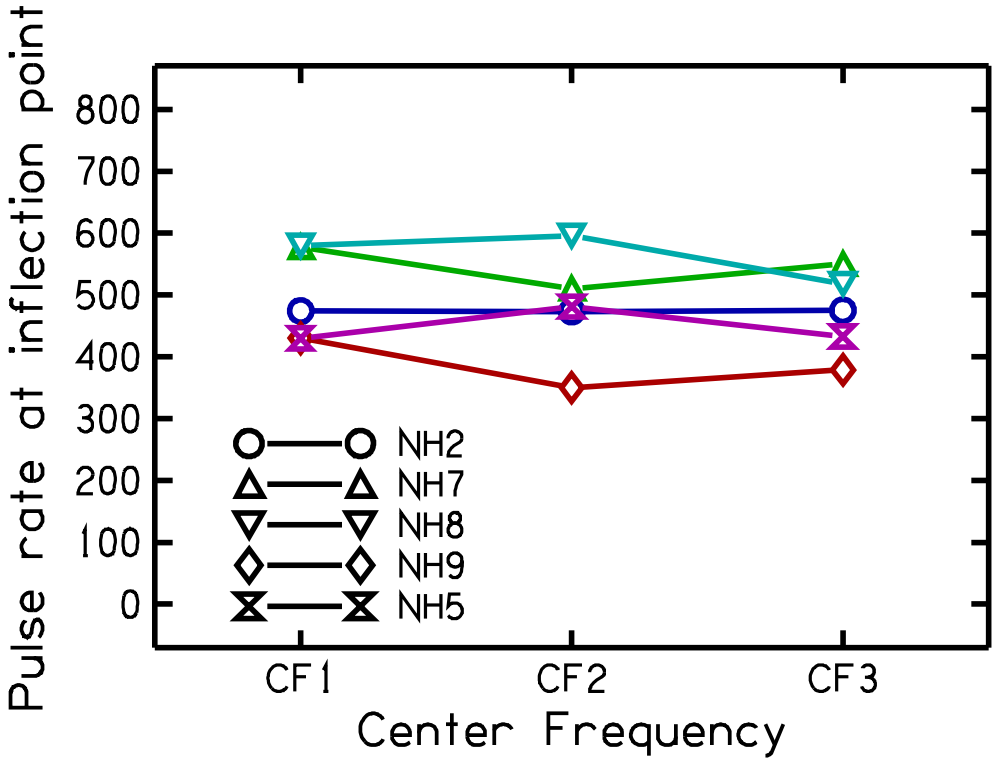
ANOVA

- Pulse rate: $p = 0.0001$
- CF: $p = 0.11$
- Pulse rate x CF $p = 0.73$



- Because of the larger amount of modulation at higher CFs, the inflection points of functions "JND vs. rate" may shift towards higher rates
- Inflection points based on derivative of exponential least-squares fit

Pulse rate at Inflection Point vs. CF



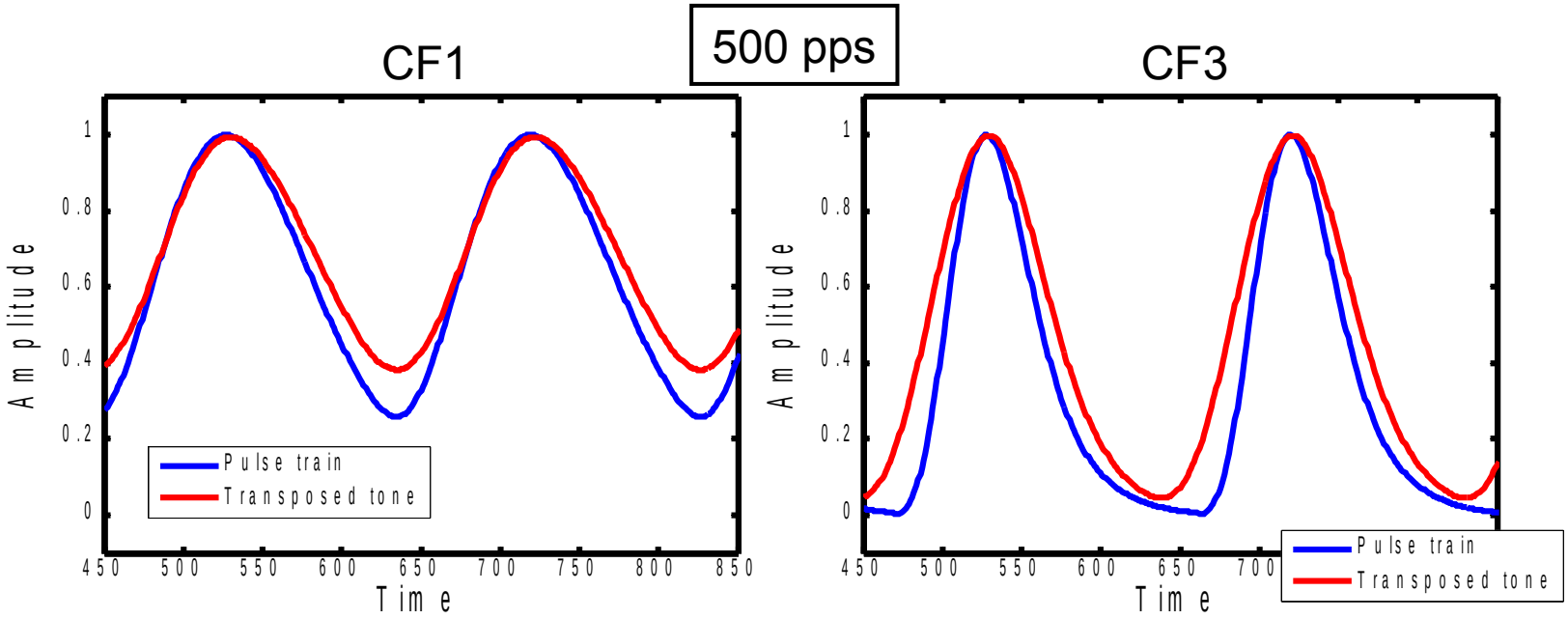
- No systematic effect of CF (ANOVA: $p = 0.86$)

Interpretation I

- Results do not support the hypothesis that ringing of auditory filters limits ITD sensitivity at higher rates
- If this were the case, then the rate limit would be higher for higher CFs
- However, the finding of constant ITD sensitivity across CFs differs from the study by Bernstein and Trahiotis (2002)
  - They found decreasing ITD sensitivity with increasing CF
  - They used transposed tones with a constant bandwidth in Hz

Interpretation II

- Two possible reasons for lack of decrement at higher CFs in our study:
  - Broader bandwidth at higher CFs (exceeding critical bandwidth) stimulates more neurons
  - Better representation of modulation for broader bandwidth



Summary & Conclusions

- ITD sensitivity is constant across CFs (4589 – 9178 Hz) for pulse trains with a constant bandwidth in ERB
  - Both in terms of overall ITD sensitivity and in terms of pulse rate limit
- Compared to transposed tones, pulse trains yield higher ITD sensitivity and higher rate limit, particularly at higher CFs
- In relation to acoustic simulations of ITD perception of cochlear implant listeners (Laback et al., 2007; Majdak et al., 2006):
  - The NH listener's performance in those studies was not limited by cochlear filtering at the CF of the stimuli (4589 Hz)