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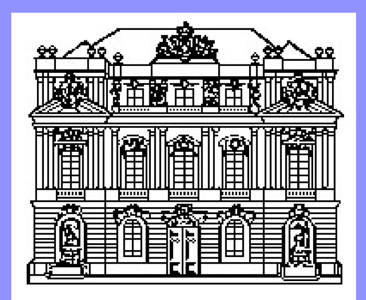

Interaural Time Differences in Fine Structure, Onset, and Offset in Bilateral Electrical Hearing: Effects of Stimulus Duration

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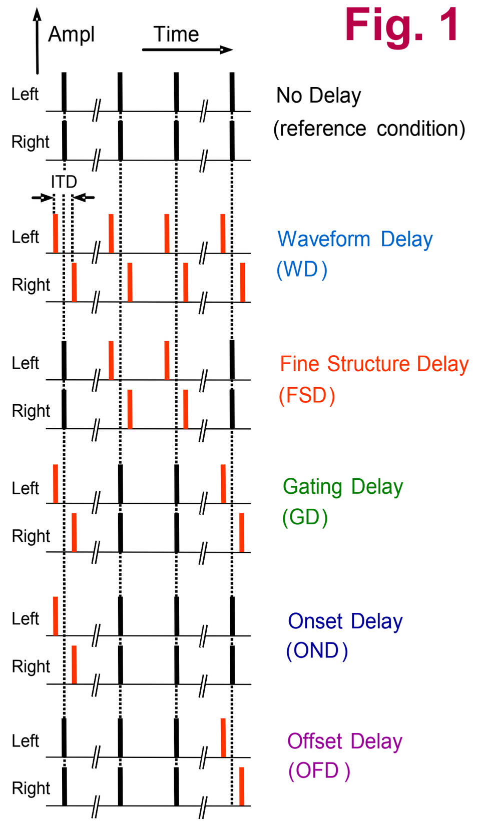
Fig. 1



INTRODUCTION

Current pulsatile clinical stimulation strategies for cochlear implants (CI) disregard temporal fine structure information, which has been shown to be important for lateralization of sound sources in normal hearing (Smith et al., 2002). The specific contribution of interaural time differences (ITD) in the ongoing temporal fine structure to lateralization has not yet been studied with bilateral CI listeners.

Both bilateral CI listeners and normal hearing (NH) subjects were tested to address the following questions:

- Are CI listeners sensitive to ITD in the ongoing fine structure only (without onset/offset ITD cues)? [Fig. 1, condition "FSD"]
- What is the relative contribution of ITD in the ongoing fine structure and in the gating portions (onset and offset)? [Fig. 1, conditions "GD", "OND", and "OFD"]
- How does this depend on the pulse rate?
- Does the advantage of higher pulse number at higher pulse rates (temporal integration) offset the disadvantage of lower amplitude (and SNR)? [Houtgast and Plomp, 1968]

APPROACH

Experiment I

- Four pulses with fixed pulse amplitude across pulse rates (Fig. 1)
- Advantage: At each pulse rate, equal information units carrying fine structure delay (FSD) and gating delay (GD) in terms of number of pulses and pulse amplitude
- Requires no loudness (energy) adjustment across pulse rates

Experiment II

- Verify that lateralization discrimination is not based on monaural cues such as periodicity pitch
- Pulse rates and ITD conditions (except for WD) tested in Experiment I

Experiment III

- Stimuli with constant duration (40 and 300 ms) across pulse rates (more realistic)
- Reduction of pulse amplitude at higher rates to achieve constant loudness according to the energy integration model

METHODS

1. Subjects and implant system

- Three postlingually deafened, bilaterally implanted CI listeners, supplied with C40+ systems. Bilateral deafness: 2 mo. (CI3), 5.5 mo. (CI1), and 12 y. (CI8). Binaural stimulation experience: 1 mo. (CI3), 2 mo. (CI8), and 6 y. (CI1)
- Five NH subjects listening to acoustic model of electrical stimulation

1. Apparatus and stimuli

- Electrical stimulation:
  - ➢ Stimulus transmission via two synchronized Research Interface Boxes (RIB): Interaural timing accuracy ≤ 2.5 µs
  - ➢ Trains of equal-amplitude biphasic current pulses; phase duration: 26.7 µs
  - ➢ Presentation at interaurally pitch matched and loudness balanced electrode pair (pretests); the pairs selected (ascending numbering from apex to base) were: CI3: 4/3; CI1: 4/1; CI8: 7/5
- Acoustical stimulation: Model of electrical stimulation using filtered pulse trains (8^{th} order butterworth filter, center frequency: 4650Hz, bandwidth: 1500Hz)

2. Procedure for experiment I and III

- Lateralization discrimination task, method of constant stimuli
- Subjects indicate if the second stimulus moved to the left or right
- Visual response feedback
- Estimation of 80 % JND (unless otherwise noted)

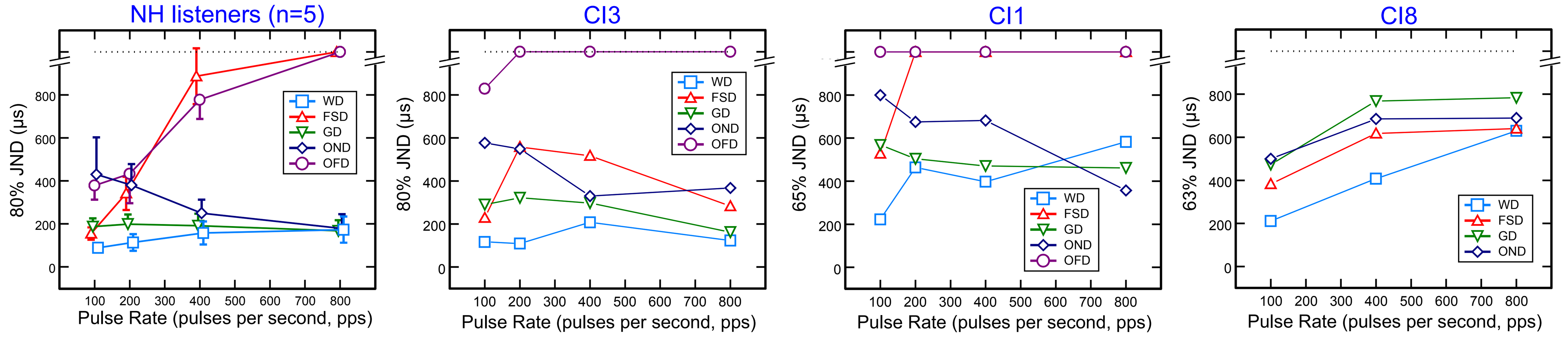
3. Procedure for experiment II: Monaural discrimination

- Monaural detection task (3AFC, "oddity task")
- Visual response feedback

4. Stimulus conditions

- Pulse rates: 100, 200, 400, and 800 pulses per second (pps)
- ITD types: see Fig. 1
- Experiment I and II
  - Sequence of four pulses
  - Constant pulse amplitude across pulse rates
    - NHs: RMS level of 66 dB SPL
    - CIs: comfortable level
- Experiment III
  - Constant duration across pulse rates: 40 ms and 300 ms
  - Constant long-time RMS level (NH) or loudness (CI) → lower amplitude at higher pulse rates

Fig. 2: Four-pulse stimuli



JNDs as a function of pulse rate for various ITD types (shown in Fig. 1).

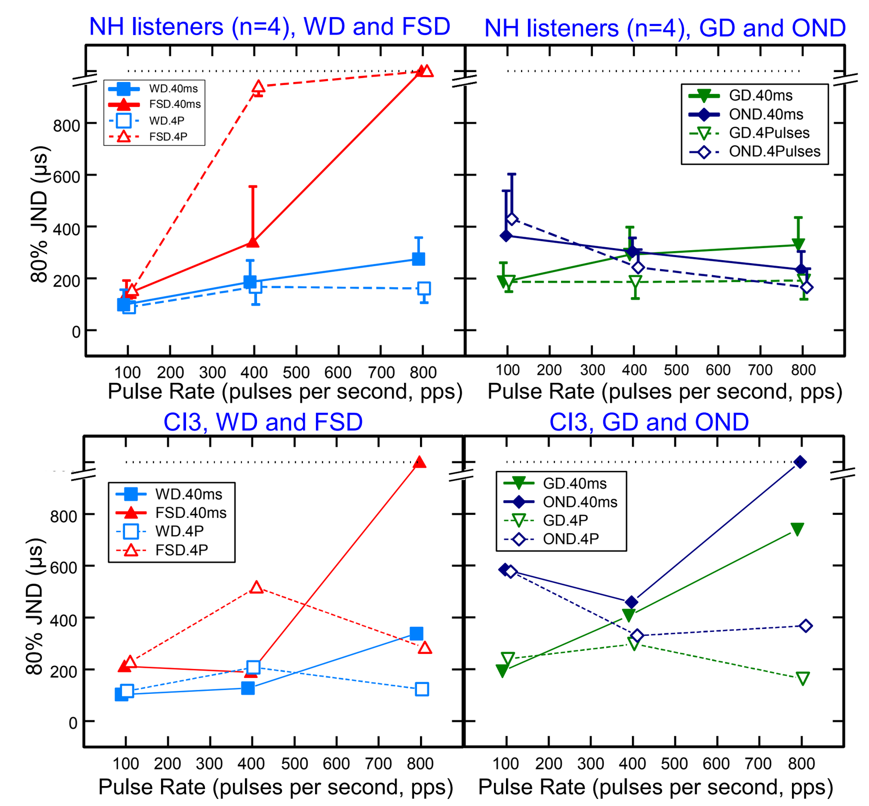
Left panel: Mean of five NH listeners (± 1 standard deviation)

Other panels: individual CI listeners.

Note that the JNDs were estimated at different percent correct points (as indicated on the y-axis label).

Undeterminable JNDs for are set to the arbitrary value of 1000 µs

Fig. 3: 40 ms vs. four-pulse stimuli



JNDs as a function of pulse rate for various ITD types (shown in Fig. 1).

Upper panels: Mean of four NH listeners (± 1 standard deviation)
Lower panels: CI listener CI3

Left panels: conditions WD and FSD
Right panels: conditions GD and OND

Undeterminable JNDs for are set to the arbitrary value of 1000 µs

RESULTS

Experiment I (Fig. 2)

- JNDs of the NH listeners (left panel; n=5; error bars: ± 1 standard deviation) and the individual CI listeners (other panels) as a function of pulse rate
- Sensitivity to fine structure ITD (FSD): up to 800 pps in CI3 and CI8, up to 100 pps in CI1, and up to 200-400 pps in the NH listeners
- Relative contribution of gating ITD (GD), in particular onset ITD (OND), increases with pulse rate
- Statistical Analysis (ANOVA):
  - Significant main effects ($p < 0.0001$) of factor ITD type, pulse rate, and subject group (NH/CI listener)
  - Significant interactions ($p < 0.002$) of ITD type x pulse rate and ITD type x subject group

Experiment II

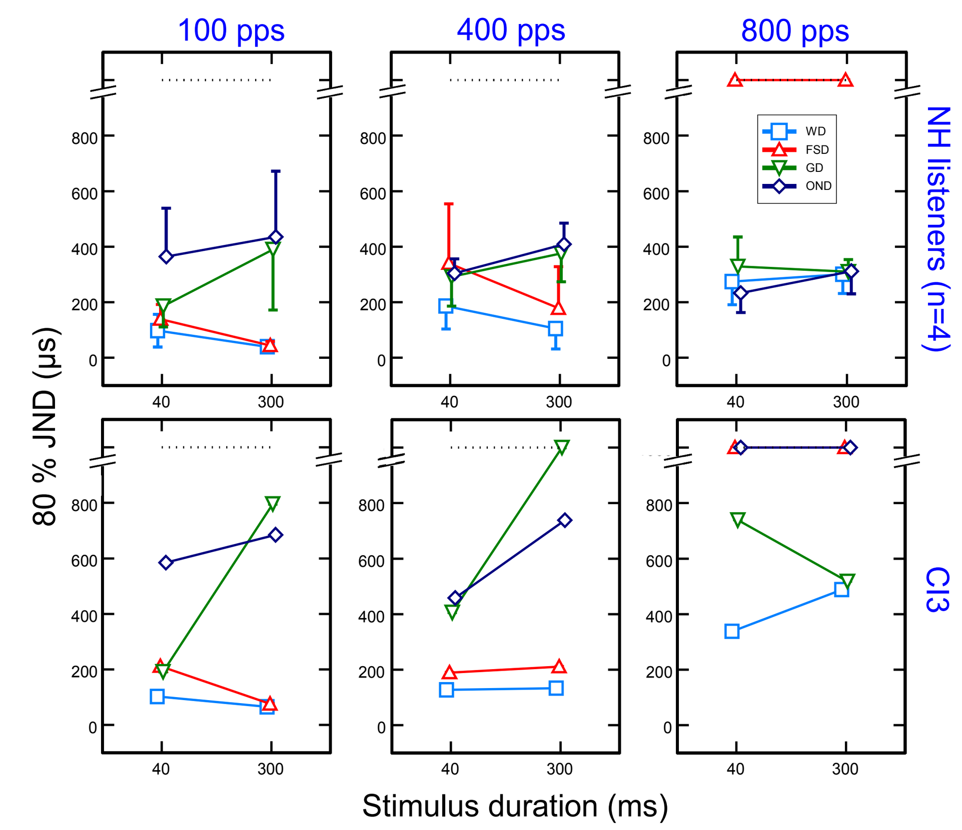
All subjects performed at chance level for all stimulus conditions

Experiment III (four NH listeners and CI3)

Performance for 40 ms stimuli relative to four-pulse stimuli (Fig. 3):

- 400 pps: Lower JNDs (=higher performance) in case of FSD ($p = 0.01$), no effect in case of waveform ITD (WD), higher JNDs in case of GD ($p = 0.035$), no significant effect in case of OND (although all individuals show higher JNDs)
- 800 pps: Higher JNDs (=lower performance) for all ITD conditions

Fig. 4: 300 ms vs. 40 ms stimuli



JNDs as a function of stimulus duration (40 and 300 ms). The parameter is the type of ITD.

Upper panels: Mean of four NH listeners (± 1 standard deviation)
Lower panels: CI listener CI3
Left panels: 100 pps
Middle panels: 400 pps
Right panels: 800 pps

Undeterminable JNDs for are set to the arbitrary value of 1000 µs

Performance for 300 ms stimuli relative to 40 ms stimuli (Fig. 4)

- 100 pps: Lower JNDs in case of FSD and WD ($p = 0.007$), higher JNDs in case of GD (0.022), no effect in case of OND
- 400 pps:
  - ➢ WD and GD: different outcome for NH listeners and CI3
    - ➢ NH listeners: Lower JNDs in case of WD ($p = 0.05$), no significant effect in case of FSD (although three out of four listeners show lower JNDs)
    - ➢ CI listener CI3: no effect in case of FSD and WD
  - ➢ Higher JNDs in case of GD ($p = 0.06$) and OND ($p = 0.025$) for NH and CI listeners
- 800 pps: JNDs not determinable in case of FSD and OND, no systematic effect in case of WD and GD

CONCLUSIONS

- CI listeners are sensitive to ongoing fine structure ITD with respect to lateralization discrimination. The upper rate limit varies strongly between the individual CI listeners (from 100 to 800 pps)
- NH listeners are sensitive to fine structure ITD up to 200-400 pps only. The performance of the NH listeners appears to be limited by cochlear filtering
- The onset contributes relatively more at high pulse rates than at low rates in both electrical and acoustical hearing, consistent with the onset dominance effect reported in the NH literature (e.g. Hafter and Dye, 1983)
- The monaural experiment verified that lateralization performance was mediated via binaural processing and not influenced by monaural cues
- Up to 400 pps, the sensitivity to fine structure ITD increased and to gating ITD decreased with increasing stimulus duration, indicating temporal integration of ongoing fine structure ITD.
- At 800 pps, the performance generally decreased with increasing duration, which can be attributed to the lower signal amplitude, a consequence of the requirement to preserve constant energy and loudness.
- New stimulation strategies (first approach by van Hoesel and Tyler, 2003) should encode fine structure information to provide important ITD cues to bilateral CI listeners

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