# Sensitivity to Interaural Time Delay in Stimulus Fine Structure and Onset/Offset of a Bilateral Cochlear Implant Listener

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## Introduction

Published data on the sensitivity of bilateral CI listeners to interaural time delay (ITD) in electrical pulse sequences [e.g. 1] indicate generally higher just noticeable differences (JNDs) for lateralization discrimination than of normal hearing (NH) listeners. In addition, the JNDs appear to increase more rapidly with increasing stimulus (pulse) rate compared to NH listeners, although amplitude-modulation in higher-rate stimuli helps to preserve most of the sensitivity [1]. Up to now, it has not been directly proven that ITD in the temporal fine structure contributes to lateralization discrimination of CI listeners and how its contribution relates to that of ITD in the gating portions (onset and offset). This study directly measures the relative importance of ITD in the temporal fine structure and in the onset and offset of a four-pulse stimulus, attempting to exclude confounding effects of ILD in the onset/offset. Furthermore, conditions with delay only in the stimulus onset or offset are tested to examine if the particular importance of stimulus onset and offset, as known from normal hearing [2], can also be found in CI listeners. Since the relative contribution of fine structure and gating delay is expected to depend on the pulse rate, all types of ITD are tested as a function of pulse rate.

## Lateralization discrimination for different types of ITD as a function of pulse rate

### Subjects and Equipment

One bilateral CI listener (age: 20), referred to as CI3, implanted at both ears during one operation at the Vienna University Hospital with *Med-El Combi40+* implants, was tested. The time interval between the occurrence of deafness (Meningitis) and the implantation was 4 weeks and 6 weeks between the operation and the time of the experiments. CI3 had normal hearing before the occurrence of deafness. One NH listener (NH2) was tested as control subject. He listened to an acoustic simulation of CI perception.

Custom-made software routines controlled stimulus definition/generation and presentation for both electrical and acoustical stimulation. In case of electrical stimulation, a pair of interaurally synchronized Research Interface Boxes (RIBs), supplied by Med-El Corp, was used to deliver stimulation sequences. In case of acoustic stimulation, digitally generated stimuli were output via a D/A-converter and presented via a pair of headphones.

### Pretests

Based on the assumption that equal pitch and loudness at the two ears are important for achieving maximum sensitivity for ITD, pretests were performed to find one interaurally pitch matched and loudness balanced electrode pair. The methods largely followed those described in [3].

### Stimuli and Procedure

Psychometric functions for different types of interaural delay and different pulse rates were obtained by applying a lateralization discrimination task. The listeners had to indicate the perceived position of a variable stimulus (with ITD) relative to a reference stimulus (without ITD). Feedback on the correctness of each response was provided. The stimulus was a sequence of four pulses presented at both ears at a comfortable level. The electrical pulses had a phase duration of 27 µs (biphasic) and the acoustic pulses had a phase duration of 10.4 µs (monophasic, $8^{th}$ order butterworth bandpass filter, 3900-5400 Hz).

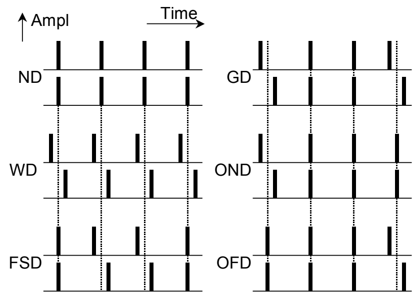


**Figure 1.** Different types of ITD applied to the sequence of four pulses. ND=no delay (reference stimulus), WD=waveform delay, FSD=fine structure delay, GD=gating delay, OND=onset delay and OFD=offset delay.

The types of interaural delay tested are depicted in Fig. 1. WD refers to waveform delay (all pulses delayed), FSD to fine-structure delay (middle two pulses delayed), GD to gating delay (first=onset and last=offset pulse delayed), OND to onset delay (first pulse delayed) and OFD to offset delay (last pulse delayed). Using such a stimulus configuration allows to determine the relative importance of fine-structure and onset/offset for ITD-JNDs independent of the specific shape of the onset/offset portion, which could involve unwanted ILD cues [1]. For the NH listener, a pink noise with a spectrum level of 10 dB at 4 kHz was presented to provide a constant detection cue and to avoid listening at frequencies remote from the filter passband. 4-5 ITD conditions were selected for each listener to estimate the 80% performance level of the psychometric function. Left/right discrimination scores with 60 repetitions were obtained at the pulse rates 100, 200, 400 and 800 pps, the latter being omitted for CI3. The entire set of conditions was presented in completely randomized order. To verify that the listeners did not make use of monaural cues (e.g., periodicity pitch), a monaural detection experiment was performed, in which the listener had to detect the odd stimulus out of three (3AFC). Again, response feedback was provided.

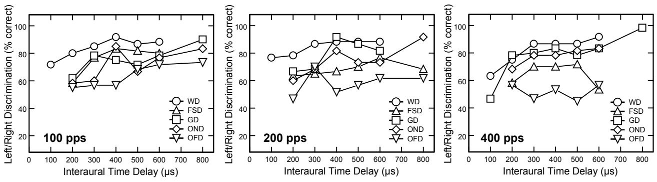


**Figure 2.** Percent-correct scores of the lateralization discrimination experiment for CI listener CI3 at the different pulse rates indicated at the bottom left. The ITD conditions correspond to Fig. 1.

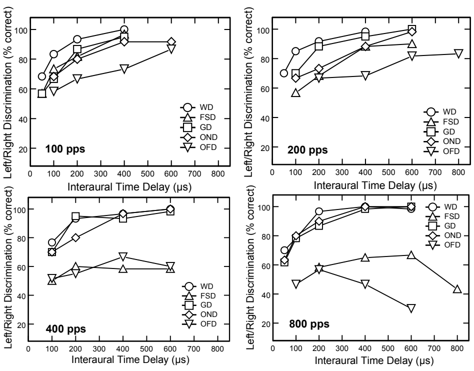


**Figure 3.** As for Fig. 2, but data from NH listener NH2.

Fig. 2 and 3 show the %correct scores of the lateralization discrimination experiment for CI3 and NH2, respectively, at the different pulse rates tested. The finding that all scores for the monaural detection task (3AFC) are within the range of chance rating and much lower than the lateralization scores indicates that monaural cues had no influence. In contrast, the scores of most conditions of the lateralization experiment were above the bounds of chance rating (2AFC; 57.6%, $p < 0.05$; 65%, $p < 0.01$).

Cumulative Gaussian psychometric functions were fitted to the percent correct data points and thresholds (JNDs) at a performance level of 80% were determined [4]. For a few conditions the 80% points could not be determined from the data points measured. The decrease in performance for FSDs at large ITDs relative to the interpulse interval (IPI) might be explained by the ambiguity with respect to the leading signal. Lateralization ambiguity appears to occur already at ITDs > IPI/4 for the CI listener and at ITDs > IPI/2 for the NH listener.

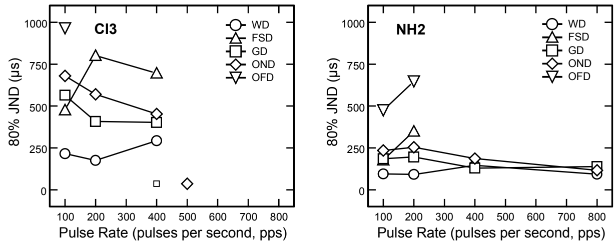


**Figure 4.** 80% JNDs estimated from the psychometric functions for CI3 (left panel) and NH2 (right panel) as a function of pulse rate.

The JNDs for the NH listener are generally lower than for the CI listener, but both listeners show a similar relative weighting of ITD conditions as a function of pulse rate (Fig. 4); the JNDs for condition WD increase slightly from 100 to 400 pps for CI3 and appear to be independent of stimulus rate for NH2; At each rate, JNDs for WD are always lower than or at least as low as any other ITD condition. At 100 pps, the JNDs are similar for FSD and GD and increase with growing pulse rate for FSD and decrease with growing pulse rate for GD. Condition OND performs slightly worse than GD for rates up to 400 pps and nearly identical as GD at 800 pps. OFD shows generally higher JNDs.

## Conclusions

Most interestingly, both CH3 and NH2 lateralized upon ITD in the stimulus fine-structure only. While the sensitivity to fine-structure delay decreases with pulse rates > 100 pps, the sensitivity to gating delay tends to improve with increasing rate. In accordance with the onset dominance effect found in NH listeners [2], the first (onset) pulse appears to be of particular importance, carrying nearly as much perceptually relevant ITD-information as all four pulses (waveform delay). However, the last (offset) pulse is much less important. These data could contribute to the design of new stimulation strategies, attempting to improve the transmission of ITD cues for bilateral CI listeners. Fine-structure ITD cues appear to be best transmittable at lower pulse rates. The similar trends in the results for the CI and NH listener suggest that acoustic simulations of CI perception presented to NH listeners might be valuable to study ITD phenomena in CI stimulation.


## Acknowledgements

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