Effects of Interaural Time Differences in Fine Structure and Envelope on Lateral Discrimination in Bilateral Electrical Hearing

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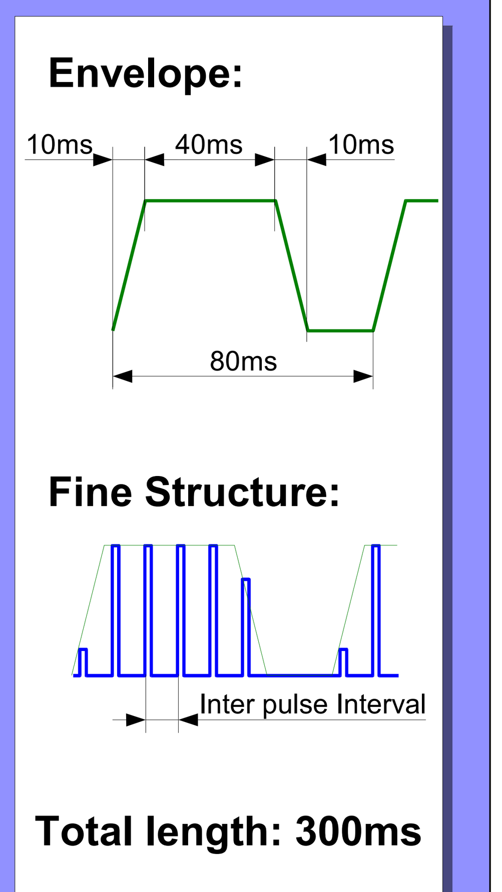


INTRODUCTION

Localization of sound sources is partly based on interaural time differences (ITDs). For lower frequencies, neural stimulation is synchronized to the phase of the carrier signal. Interaural difference of the phase, so called fine structure ITD (ITD FS), is important for determining the lateral position of the sound source. Bilateral cochlear implant (CI) listeners currently use stimulation strategies which encode ITD in the temporal envelope (ITD ENV) but which do not transmit ITD in the fine structure due to the constant phase in the electrical pulse train. The arbitrary interaural phase difference between the pulse trains causes uncontrolled fine structure ITD.

To determine the necessity for encoding ITD in the fine structure, ITD-based lateralization discrimination (LD) was investigated with CI listeners and normal hearing (NH) subjects. Lateralization discrimination was tested at different pulse rates for various combinations of independently controlled envelope ITD and fine structure ITD. Trapezoidally shaped stimuli were used whose basic parameters are based on speech signals.

SPECIFIC QUESTIONS

Current bilateral cochlear implant systems are implemented as two independently working systems, each consisting of an implant and a speech processor. The speech processor drives the implant controlling the signals and timing – most processors use coding strategies like CIS or SPEAK which are based on amplitude modulated electrical pulse trains. Due to the independence of the systems a phase difference occurs in the pulse trains, which can be regarded as a constant ITD FS. Furthermore, a small difference in the stimulation pulse rate leads to an uncontrolled, periodical change of ITD FS. If CI listeners are sensitive to the ITD FS cue, this could cause, depending on the beat frequency, a periodical movement of the auditory image.

This raises to two questions:

- Is it necessary, and if, under which conditions, to interaurally synchronize fine structure, ensuring ITD FS = 0? Since, in this case, the total ITD information only can be received by the ITD in the envelope, we call it the ENV condition;
- Can we obtain an improvement of the LD by synchronizing the ITD FS to the ITD information in the envelope? This way of synchronization corresponds to delaying the whole wave form – therefore we call it the WD condition.

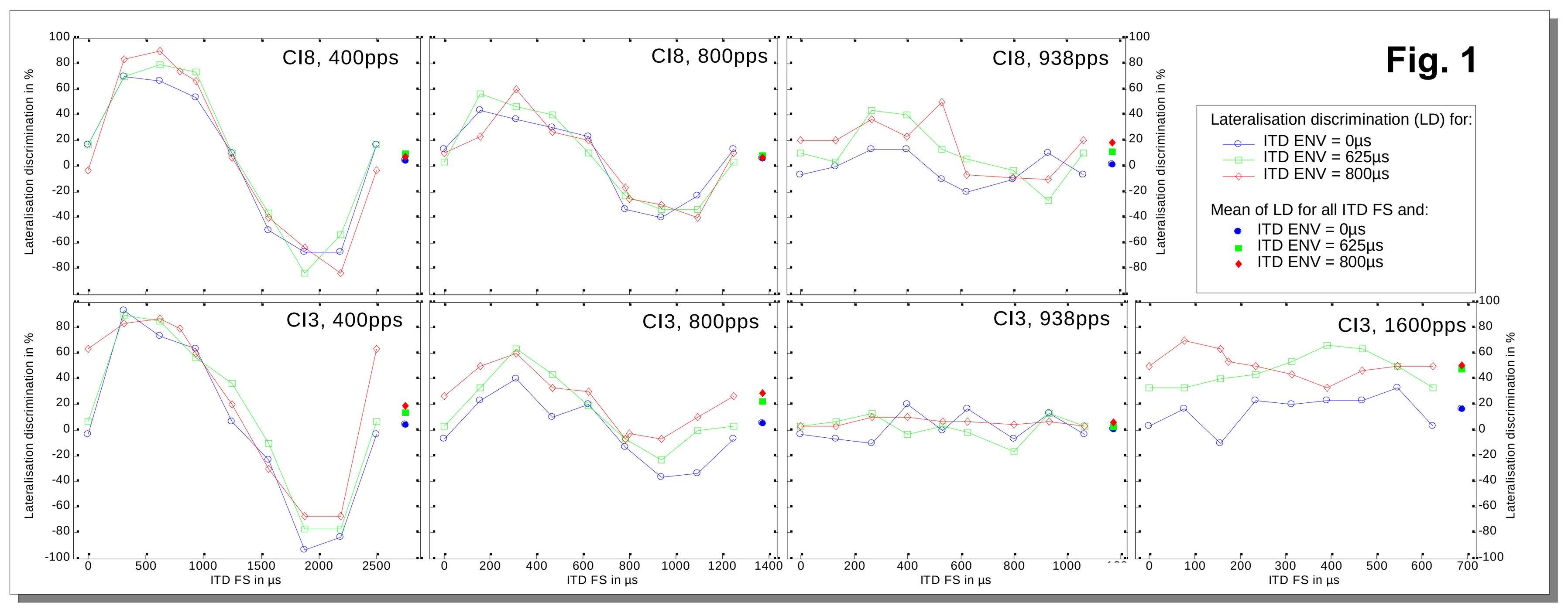


Fig. 1

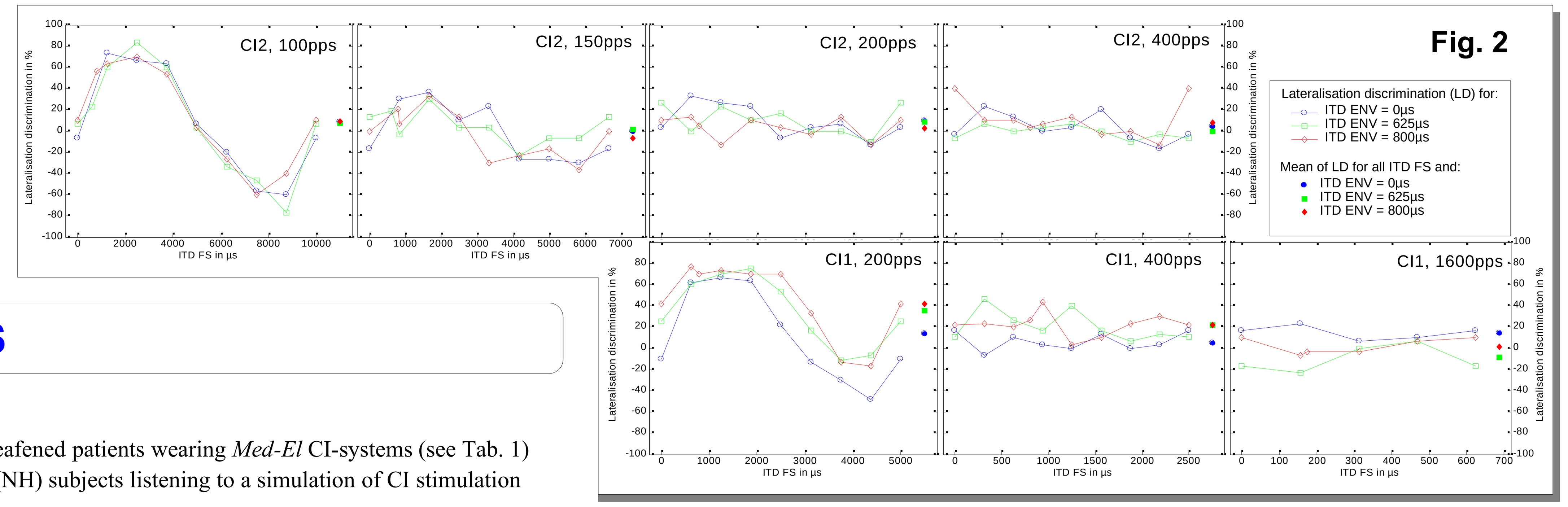


Fig. 2

METHODS

1. Subjects

- Four post-lingually deafened patients wearing *Med-El* CI-systems (see Tab. 1)
- Four normal hearing (NH) subjects listening to a simulation of CI stimulation

2. Experimental Conditions

- Definitions of ITD conditions:
  - ENV: ITD information in the envelope, ITD FS = 0µs
  - FS: ITD information in the fine structure, ITD ENV = 0µs
  - WD: waveform delay, ITD information in both envelope and fine structure
- Independent variables (conditions):
  - Pulse Rates: 100 to 1600pps, corresponding to the Inter Pulse Interval (IPI) of 10ms to 625µs; preselected for each subject according to his/her sensitivity
  - ITD ENV: 0, 625 and 800µs for CI listeners and 0, 400 and 625µs for NH
  - ITD FS: 0 to IPI in steps of 1/8 IPI

3. Procedures

- Lateralization discrimination (LD) task using a 2 interval, 2AFC paradigm:
  - Constant stimuli method: randomization of items in block of constant pulse rates
  - First interval: reference stimulus without ITD
  - Second interval: target stimulus with ITD
  - 60 repetitions for each condition (border of significance: ±20%)
- Binaurally balanced, pitch matched electrode pair as a result of following pretests:
  - Simple fitting procedure to estimate the comfortable level (CL)
  - Binaural balancing procedure to iterative determine binaurally loudness balanced levels for each electrode pair
  - Pitch ranking procedure implemented as a 2 AFC pitch discrimination paradigm

4. Stimuli (see illustration on the left border)

- Fine Structure: biphasic pulse trains with phase duration of 26.6µs/40µs (C40+/C40)
- Envelope: 4 Trapezoids with fast rising and falling edges and gaps inbetween
- Total length of the stimulus: 300ms

Tab. 1. Bibliographic data of CI listeners

Subject	Aetiology	Age at implantation		Deafness duration		binaural electr. stim. experience
		L	R	L	R	
CI1	Meningitis	14 yr	14 yr	5.5 mo	1.5 mo	6 yr
CI2	Skull trauma	54 yr	48 yr	21yr	25 yr	4 yr
CI3	Meningitis	21 yr	21 yr	1 mo	1 mo	1 mo
CI8	Osteogenesis imperfecta	41 yr	39 yr	3yr	12 yr	2 mo

5. Stimulus presentation

- CI listeners: Two interaurally synchronized interfaces "RIB":
  - Direct stimulation with electrical amplitude modulated pulse trains
  - Interaural synchronization accuracy better than 2.5µs
- NH listeners: Simulation of CI-stimulation presented via headphones (*Sennheiser HDA 200*) in double walled sound booth:
  - Monophasic pulse trains (pulse duration: 10µs) filtered with Butterworth filter (8th order, center frequency: 4650Hz, bandwidth: 1500Hz)
  - Stereo D/A-C with sampling rate of 96kHz and resolution of 24bit (ADDA 2402, Digital Audio Denmark)
  - Level of stimulation: 60.8dB SPL(A) RMS

RESULTS and CONCLUSIONS

LD results for the CI-listeners are shown in Fig. 1 and 2. The average results for the NH subjects are shown in Fig. 3. Mean LD accros ITD FS conditions is drawn on the right side of each plot, to depict the overall effect of ITD ENV regardless of ITD FS. To answer the question of interaural synchronization (ITD FS=0), the dependence of LD on ITD FS had to be investigated. Therefore, results were grouped in half-periods of the IPI. The first group contains all LDs for 0 < ITD FS < ½ IPI. The second group resembles all LDs for ½ IPI < ITD FS < IPI. LDs for ITD FS = 0 and ½ IPI were discarded. We postulated, that, if there is a significant difference between the LD for these groups, LD depends on ITD FS (see Fig. 4). This comparison was done for each pulse rate and ITD ENV = 0.

To investigate the improvement in LD by synchronizing fine structure to the envelope, conditions WD and ENV were compared to each other. This was performed for all pulse rates and ITD ENVs. A significantly higher LD for WD than for ENV indicates improvement of LD by synchronizing ITD FS to ITD ENV (see Fig. 5)

Fig. 3

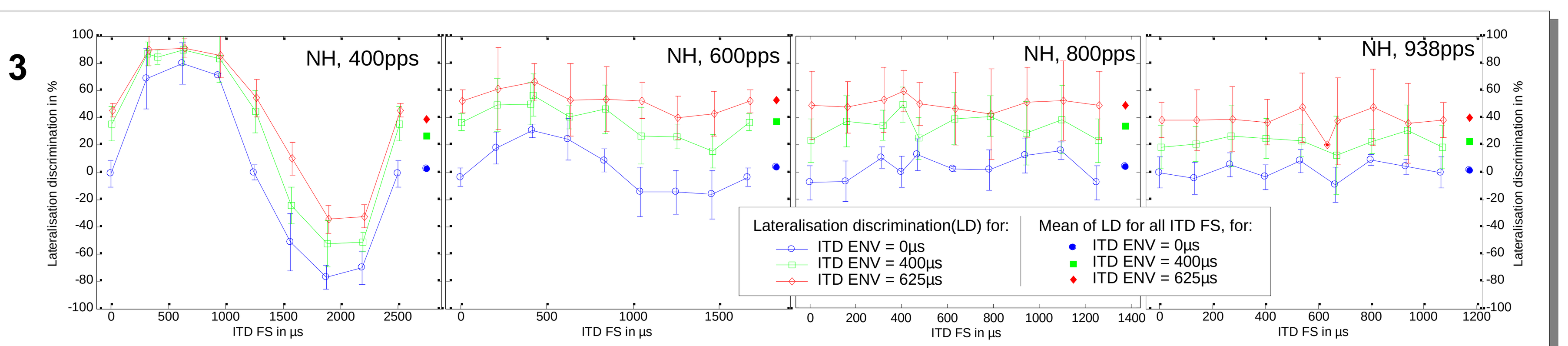
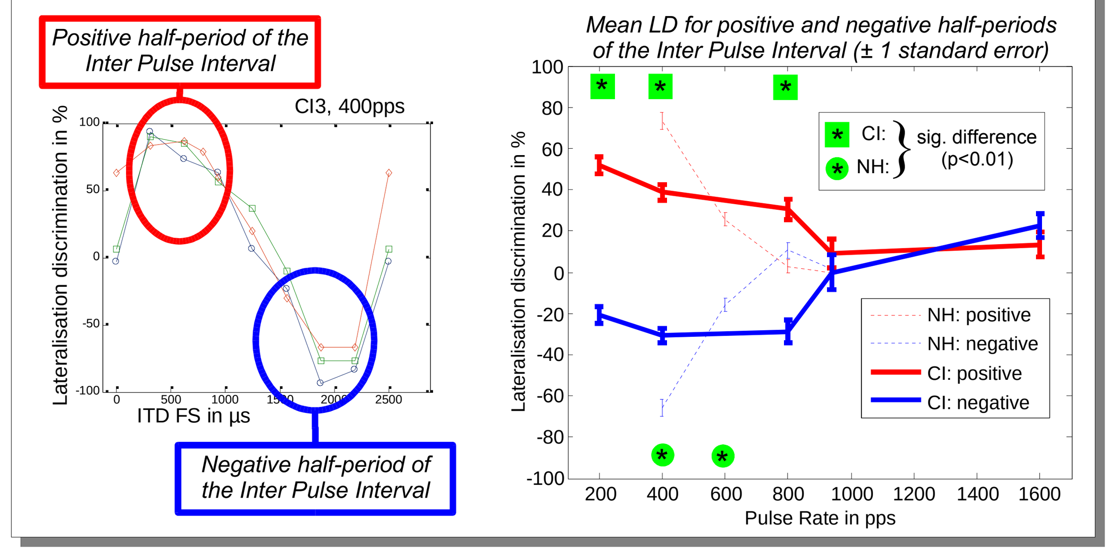


Fig. 4: Dependency of LD on ITD FS (ITD ENV=0)



General

Significant differences were found in LD for ITD ENV. For the NH group, all ITD ENV values (0, 400 and 625µs) showed different LDs. For the CI listener group, a difference was found between ITD ENV = 0µs and higher values. This suggests that increasing the ITD ENV from 625 to 800µs doesn't change the lateralization discrimination and leads to ceiling effects in the performance for CI listener.

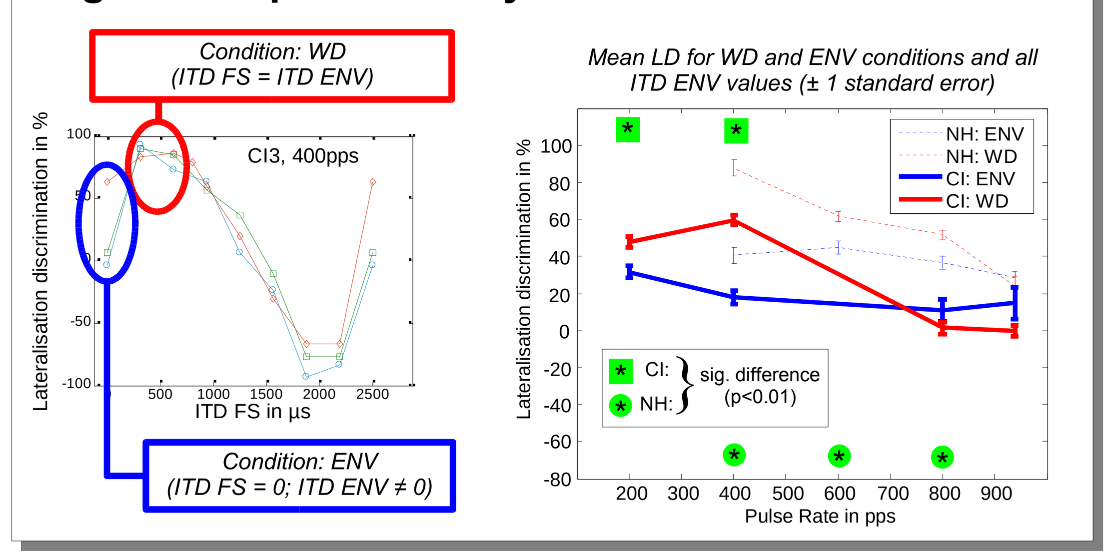
Interaural synchronization of pulse trains (ITD FS = 0):

Significant differences were found between both half-period groups for pulse rates up to 800pps (CI) and up to 600pps (NH). This suggests that for these pulse rates the synchronization of the speech processors is necessary to avoid a movement of the auditory image. The difference in performance between both subject groups can be explained by analyzing effects of the auditory filters, which are included in the signal path for NH subjects: smearing of the fine structure increases with the pulse rate, reducing the performance of LD.

Synchronization of the fine structure to the envelope (ITD FS = ITD ENV)

Significant improvements were found between conditions WD relative to ENV for pulse rates up to 400pps (CI) and up to 800pps (NH). This suggests that synchronization of the fine structure to the ITD ENV improves the LD for these pulse rates. The difference in the performance between NH and CI-listener can be reduced to a better discrimination of ITD ENV and a worse discrimination of ITD FS by NH subjects.

Fig. 5: Comparison of synchronization conditions



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