ARI
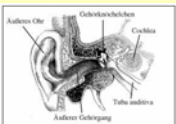
Acoustics Research Institute
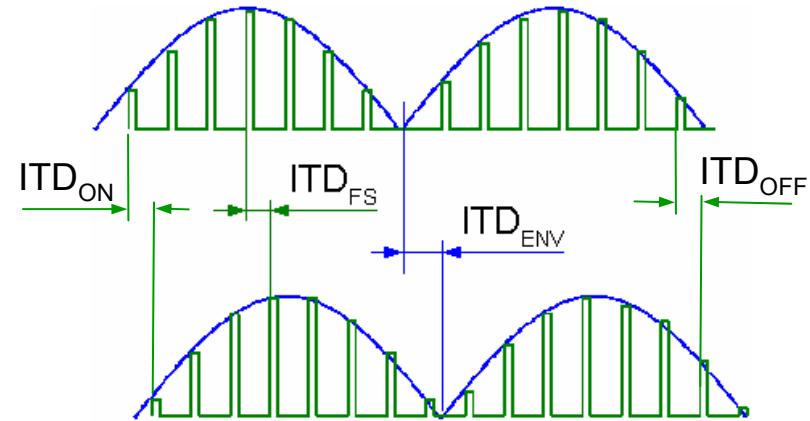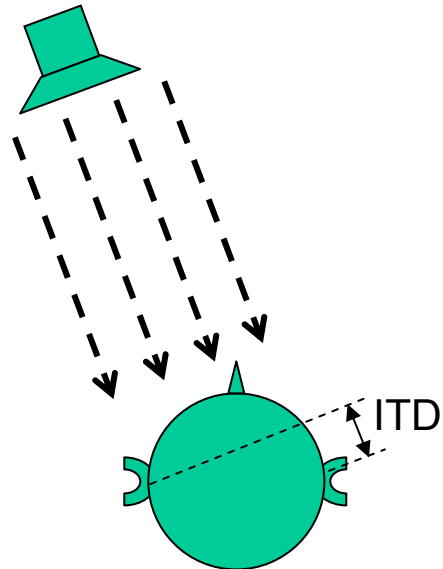**Austrian Academy of Sciences**

The role of fine structure in bilateral cochlear implantation

Laback, B., Majdak, P., Baumgartner, W. D.

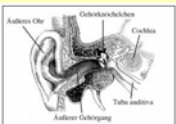# *Interaural Time Difference (ITD)*

Sound Source

Interaural Time Differences (ITDs) occur in

- Gating portions (ITD_{ON}/ITD_{OFF})

- Temporal fine structure (ITDFS)

- Ongoing envelope (ITD_{ENV})

Motivation for study

➤ Most clinical cochlear implant (CI) systems discard fine structure information

➤ In normal hearing (NH), fine structure information is important for lateralization of sound sources and for speech reception in noise (Wightman and Kistler, 1992; Smith et al., 2002)

➤ CI listeners show sensitivity to ITD in rectangularly gated pulse trains (e.g. van Hoesel and Tyler, 2003)

➤ Question: Are bilateral CI listeners sensitive to ITD in the fine structure?
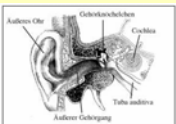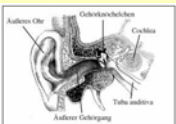
Study I

Lateralization Discrimination of ITD in Fine Structure, Onset, and Offset:
Four-Pulse Sequences
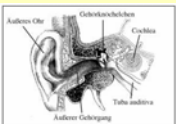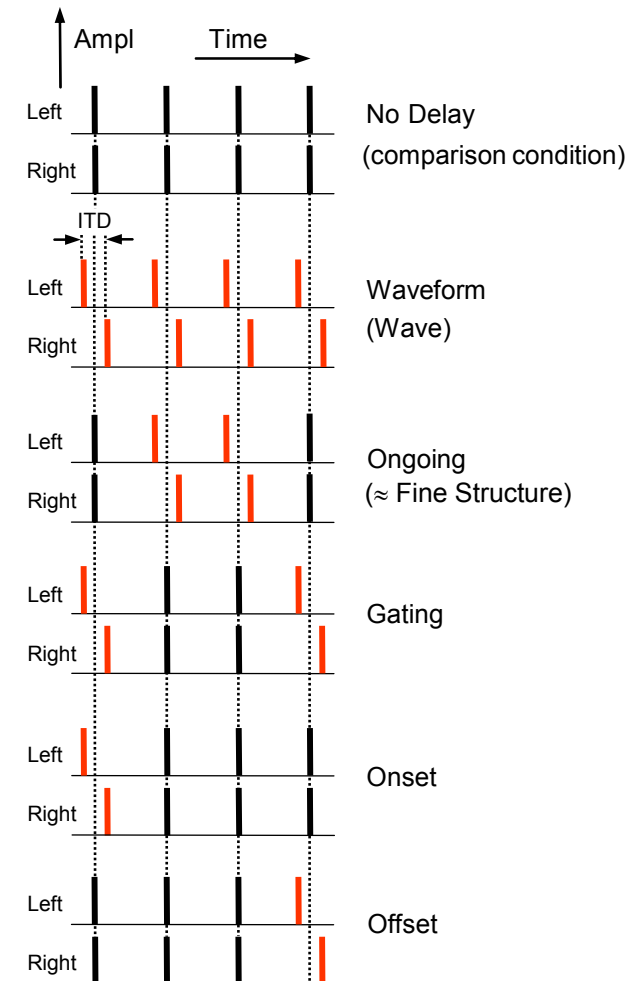
Methods I

➢ **Electric stimuli**

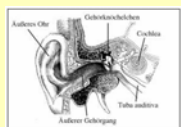– Biphasic pulse trains (4 pulses) presented

▪ at interaurally pitch-matched and loudness-balanced electrode pair (selected in pretests)

▪ via Research Interface (*RIB*) with interaural accurracy of 2.5 *µs*

➢ **ITD conditions (see right side)**

Methods II

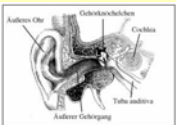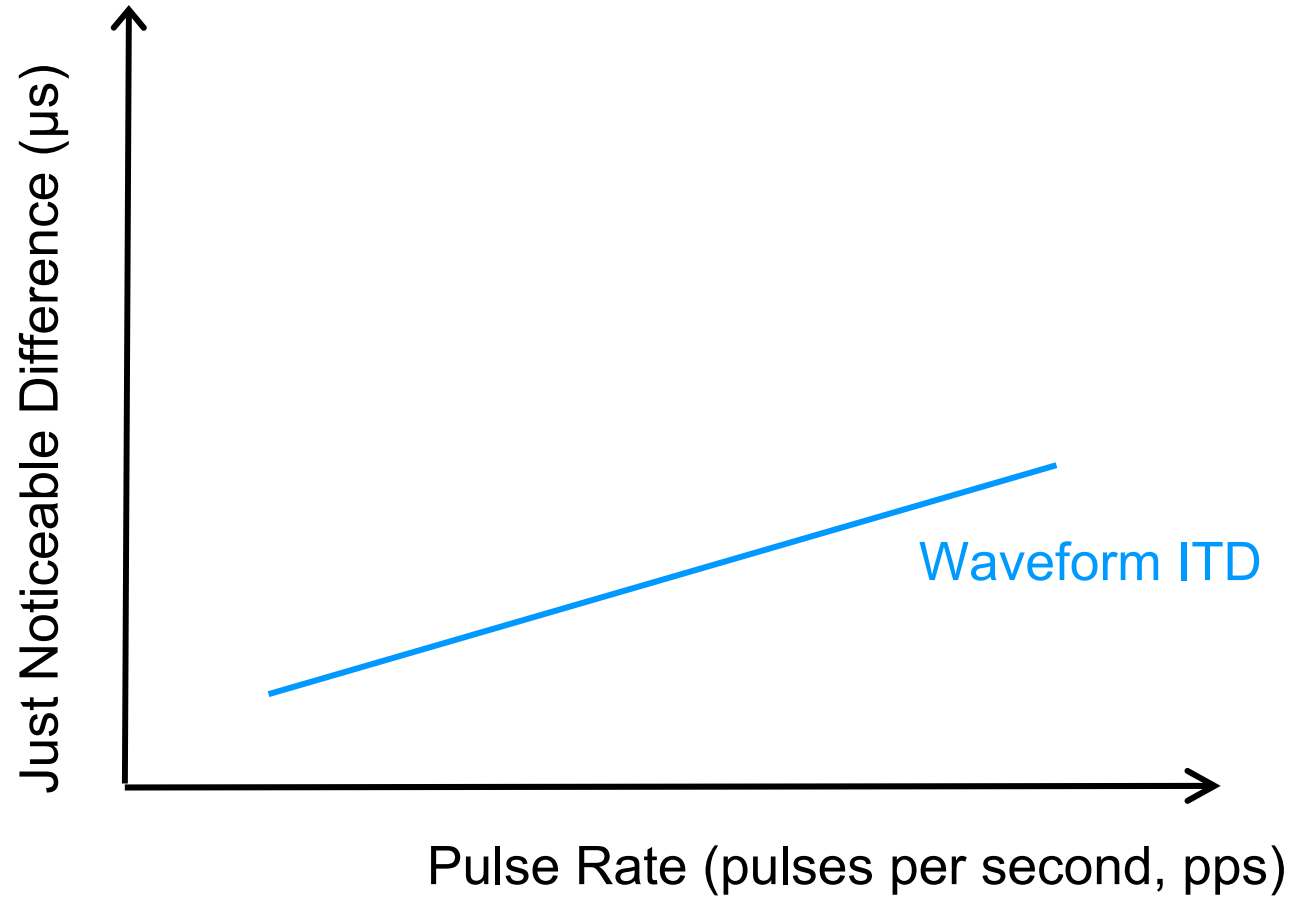> ➢ JNDs for Left/Right Discrimination

>> – 2-interval, 2-AFC

>> – Response feedback

> ➢ Subjects

>> – Four CI listeners (*C40+*, *MED-EL*), postlingually deafened, selected based upon minimum ITD sensitivity criterion

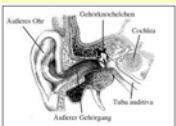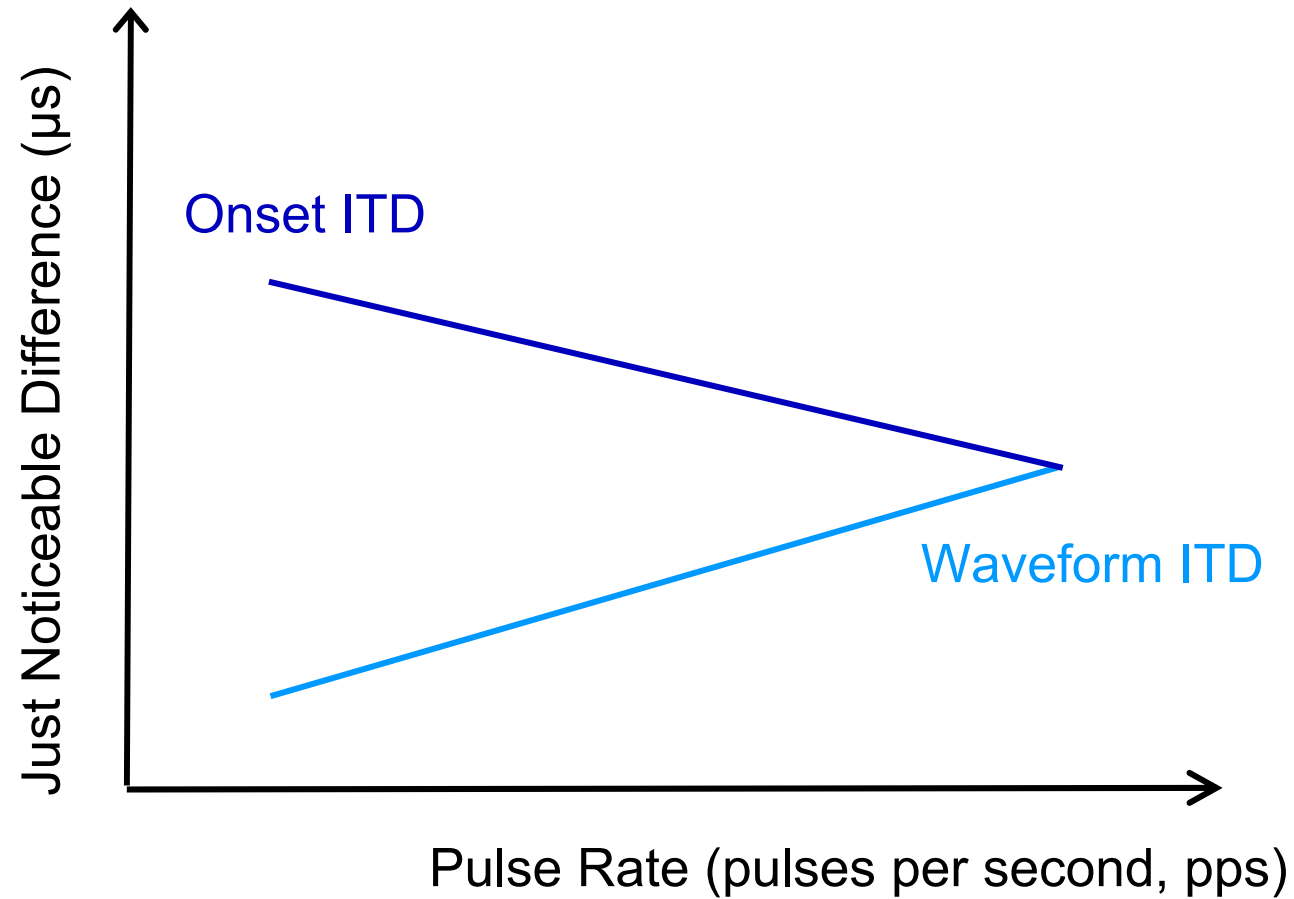>> – Five NH listeners (listening to CI simulation)

> ➢ Independent Variables
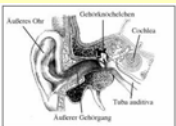
>> – ITD condition

>> – Pulse Rate

Expectations

Expectations

Expectations

Results for CI listeners: CI1

CI1

- Wave ITD sensitivity decreases with rate (p < 0.003)
- Ongoing ITD contributes at 100 pps only
- Onset ITD contribution increases with rate (p < 0.0001)

Results for CI listeners: CI12

CI12

- Wave ITD sensitivity independent of rate
- Ongoing ITD contributes up to 400 pps
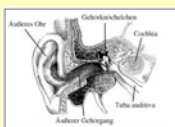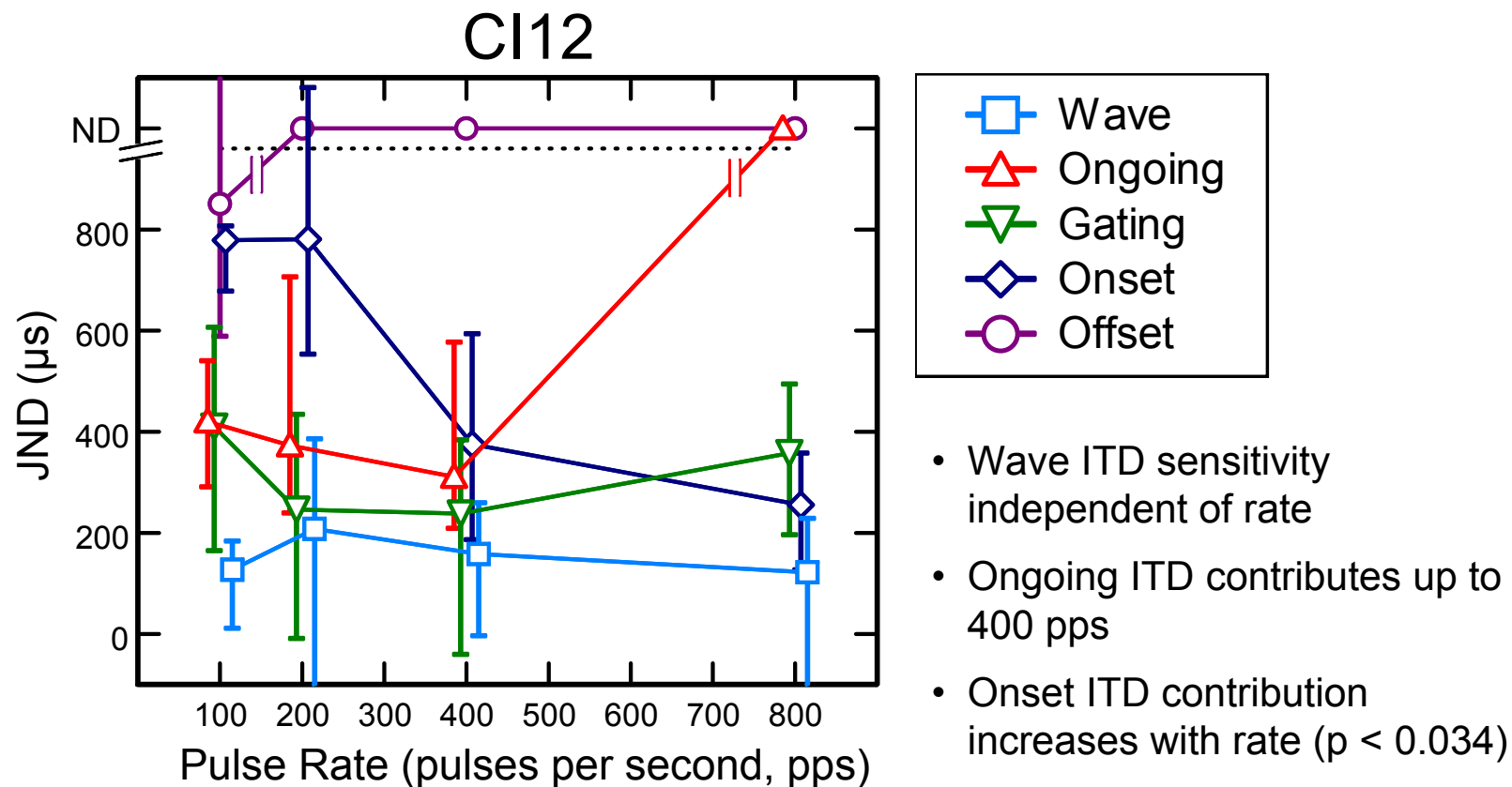- Onset ITD contribution increases with rate ($p < 0.034$)

Results for CI listeners: CI8

CI8

- Wave ITD sensitivity up to 400 pps only

- Ongoing ITD contributes up to 400 pps

- Onset ITD does not contribute

Results for CI listeners: CI3

CI3

- Wave ITD sensitivity independent of rate

- Ongoing ITD contributes at all rates tested (up to 800 pps)

- Onset ITD contribution increases with rate ($p < 0.04$)

Summary of Study I

➤ Bilateral CI listeners are sensitive to "pure" fine structure ITD in a lateralization discrimination task

➤ High inter-subject variability both …

– in absolute sensitivity

– in the highest rate showing fine structure ITD sensitivity (100 pps in one listener, 400 pps in two listeners, and 800 pps in one listener)

➤ Increasing contribution of onset ITD with increasing pulse rate (in agreement with onset dominance effect in normal hearing listeners)
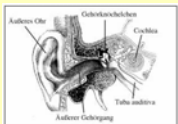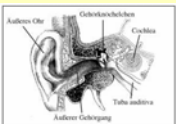
ARI

Study II

Lateralization Discrimination of ITD in Fine Structure and Ongoing Envelope: Modulated pulse trains

Motivation

➢ Envelope-based bilateral CI systems consist of two independently running devices

→ Interaurally unsynchronized pulsatile stimulation at fixed pulse rate

→ Uncontrolled fine structure ITD

➢ Requirement of bilateral control …

– of fine structure ($ITD_{FS} = 0$)?

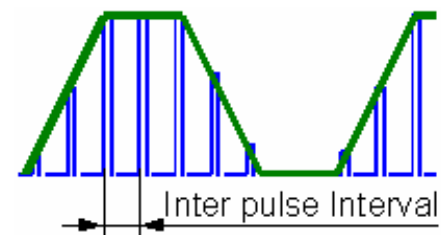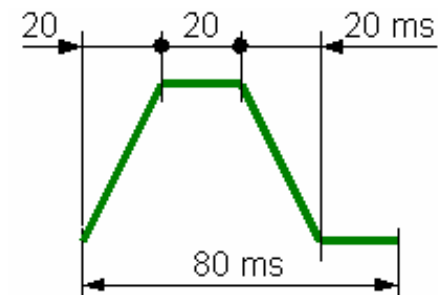– of fine structure ITD to envelope ITD ($ITD_{FS} = ITD_{ENV}$)?
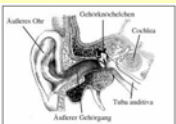
Methods
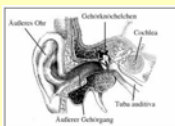
➢ **Stimuli**

   – Amplitude modulated pulse trains

➢ **Independent variables**

   – ITD_{FS}: 0…IPI (inter-pulse interval)

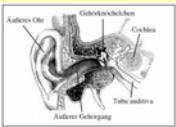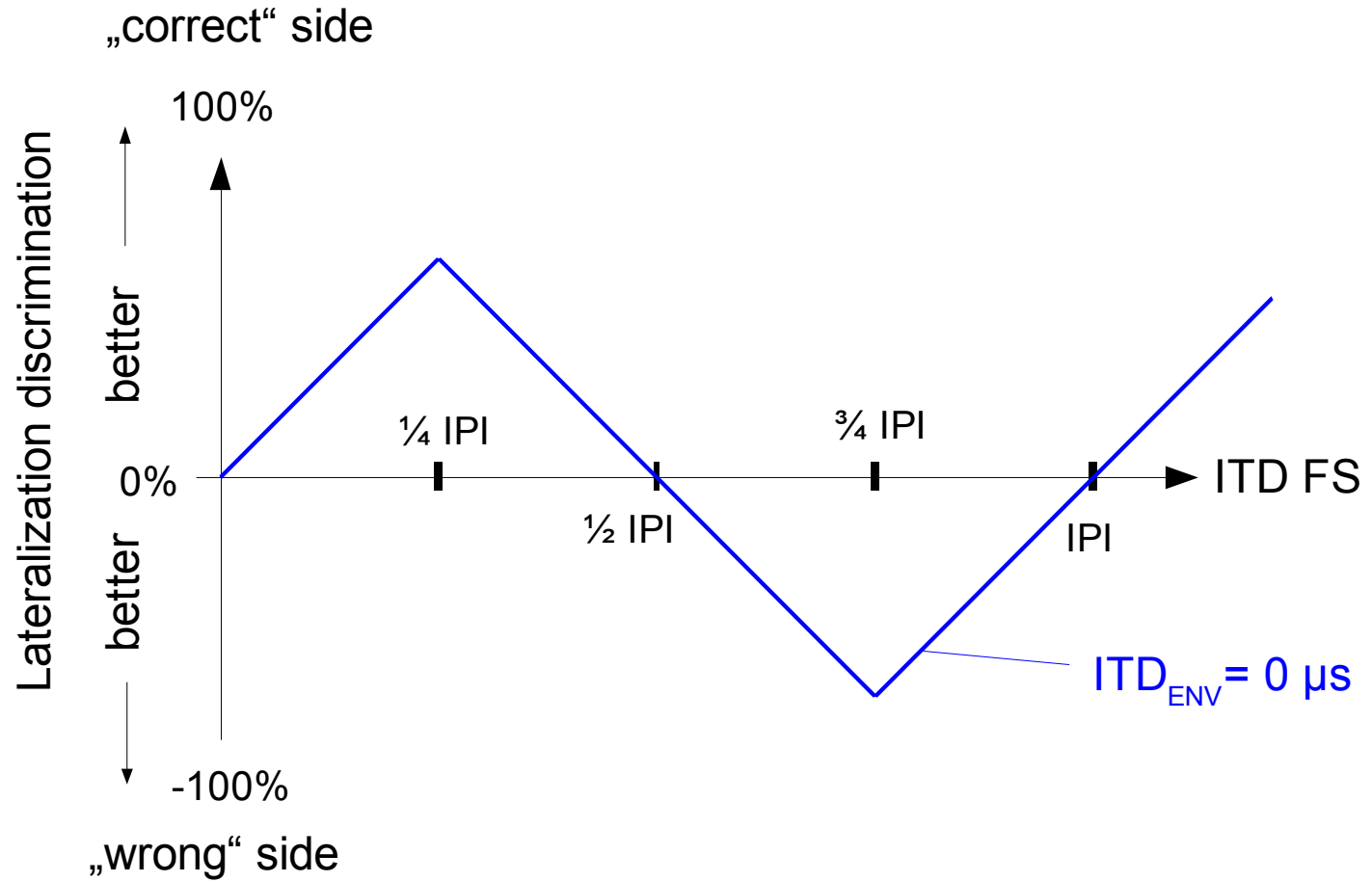   – ITD_{ENV}: 0…800µs
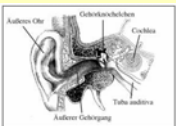
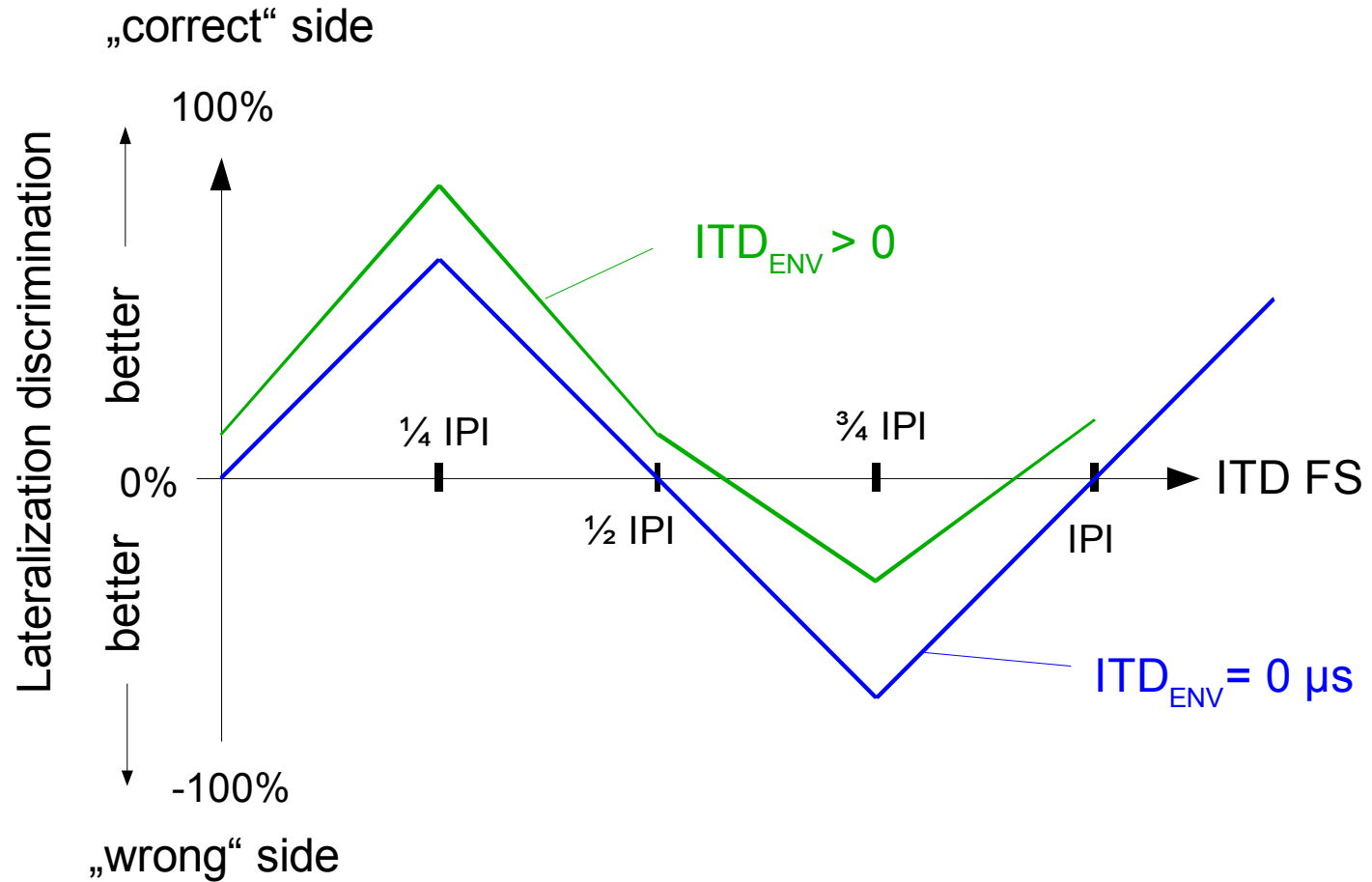   – Pulse rate: 100 … 1600 pps

➢ **Subjects**

   – 4 CI listeners (postlingually deafened)

   – 4 NH listeners (listening to CI simulation)

Expectations

Expectations
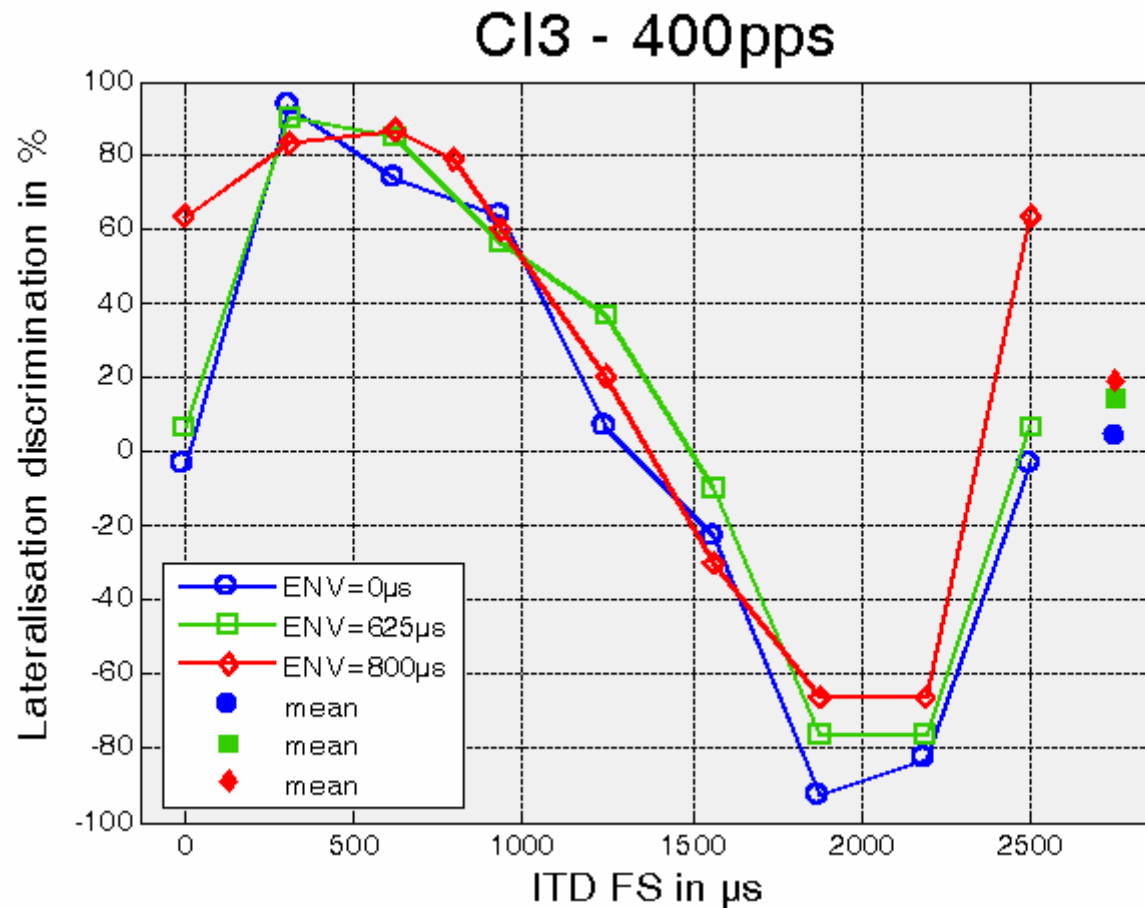
"correct" side

Lateralization discrimination

100%

better

0%

better

-100%

"wrong" side

¼ IPI   ½ IPI   ¾ IPI   IPI

$ITD_{ENV} > 0$

$ITD_{ENV} = 0\ \mu s$

ITD FS

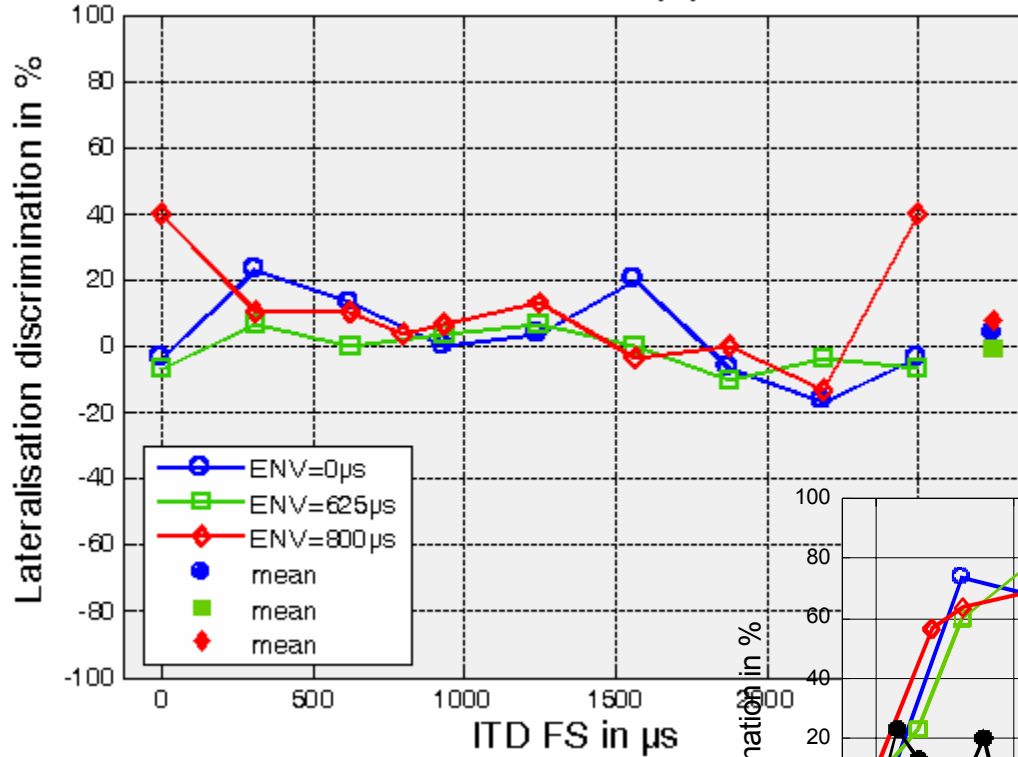# Results for Lower Pulse Rates

Results for Lower Pulse Rates
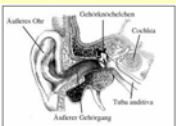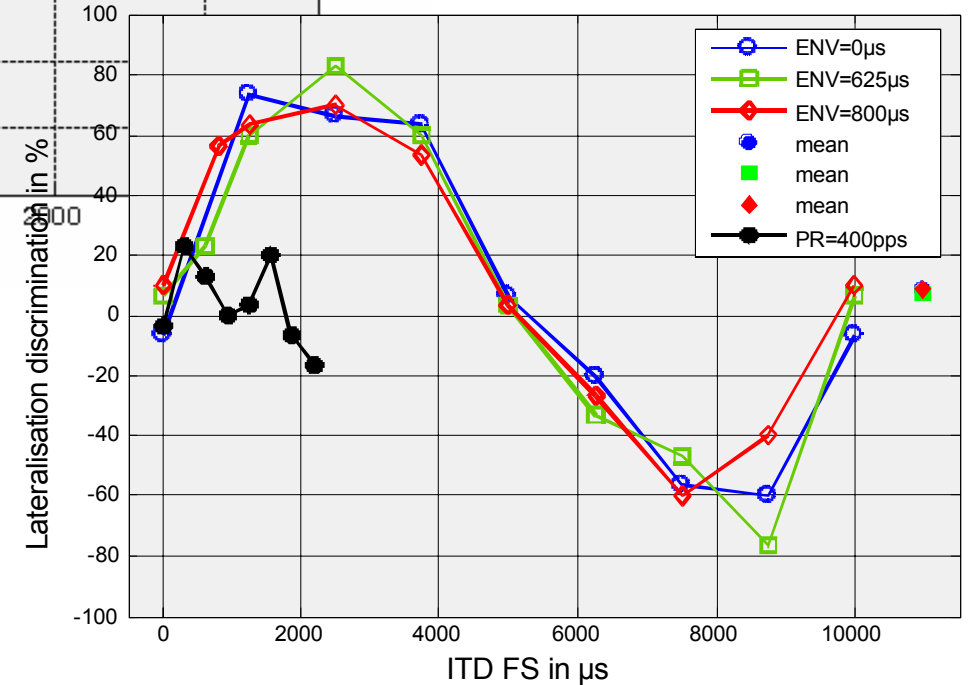
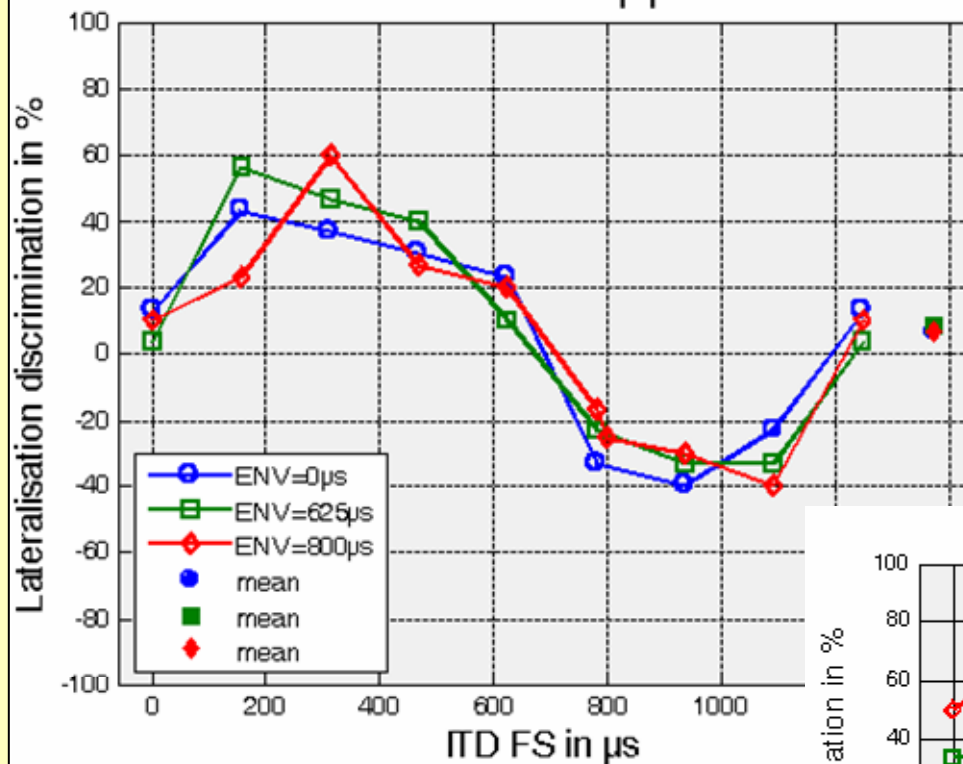# Results for Higher Pulse Rates
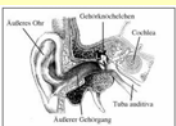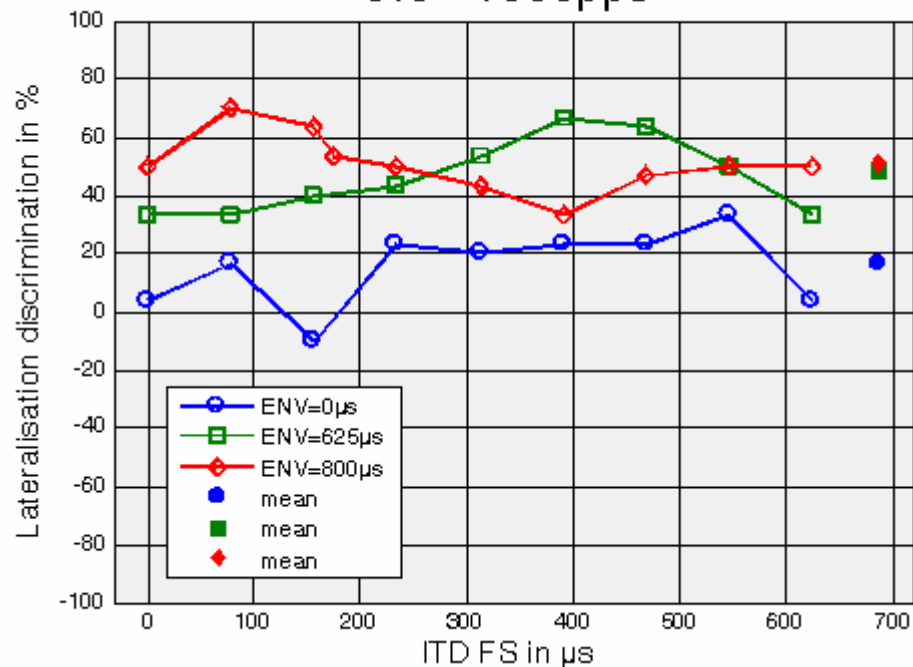
Control of Fine Structure

Relevant if

LD depends on ITD$_{FS}$
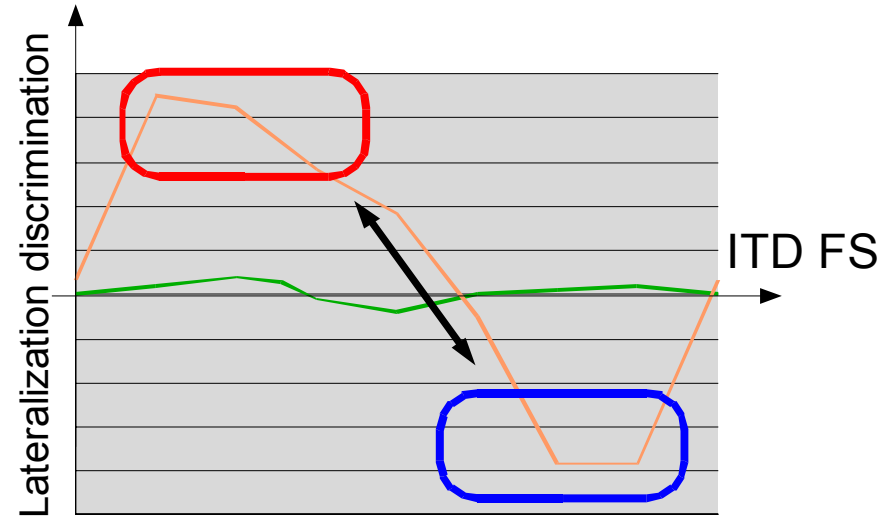
Pulse rate	CI1	CI2	CI3	CI8	NHs
100		< 0.001	-	-	-
150		< 0.001	-	-	-
200	< 0.001	0.01	-	-	-
400	0.75	0.21	< 0.001	< 0.001	< 0.001
600	-	-	-	-	< 0.001
800	-	-	<0.001	<0.001	< 0.139
938	-	-	-	0.45	< 0.712
1600	0.46	-	0.11	-	-
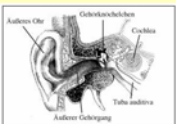
Synchronization of ITD_{FS} to ITD_{ENV}: Waveform Delay (WD)

Required if:

$LD(ITD_{FS} = ITD_{ENV})$

$> LD(ITD_{FS} = 0)$

WD: $ITD_{FS} = ITD_{ENV}$
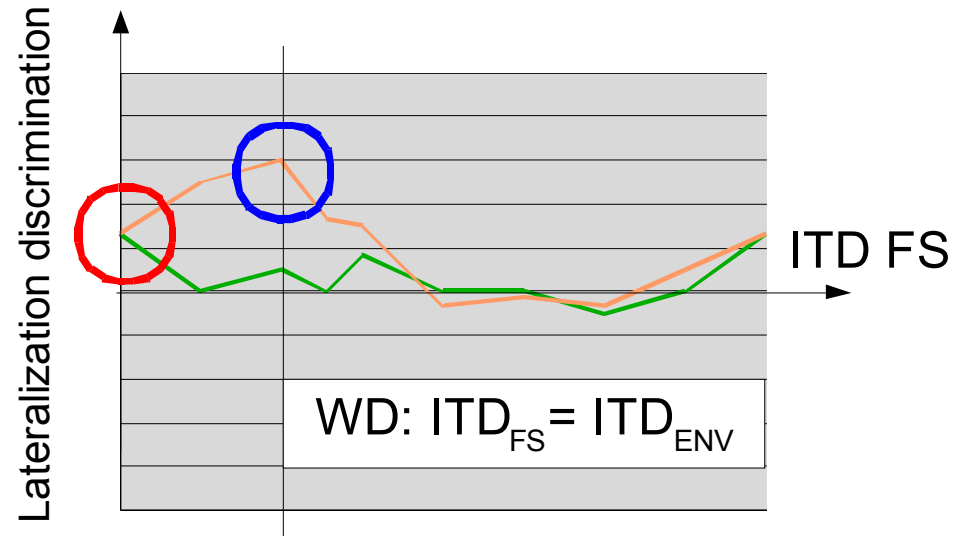
Pulse rate	CI1	CI2	CI3	CI8	NHs
100		0.36	-	-	-
150		0.68	-	-	-
200	< 0.001	0.14	-	-	-
400	-	-	< 0.001	< 0.001	< 0.001
600	-	-	-	-	< 0.696
800	-	-	0.27	0.17	-
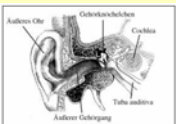
Summary of Study II

➢ High sensitivity to ITD_{FS} - low to ITD_{ENV}

➢ High inter-subject variability of performance

➢ Control of ITD in fine structure

    – required up to $\approx$ 800 pps

➢ Synchronization of ITD_{FS} to ITD_{ENV}

    – improves performance up to $\approx$ 400 pps
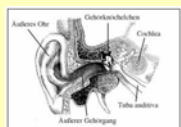
Overall Conclusions

➢ Strong effects of fine structure ITD; in "better performing" CI listeners up to 800 pps

    $\rightarrow$ CI listeners are likely to benefit from encoding fine structure ITD at lower rates in CI systems

➢ In electric hearing, the highest rate providing fine structure ITD cues (800 pps) is somewhat higher than in acoustic hearing with high-frequency filtered clicks (400-600 pps)

➢ However, the rate limit in electric hearing is lower than in acoustic hearing with sinusoids (up to 1500 Hz)