Interaural Time Differences in Temporal Fine Structure, Onset, and Offset in Bilateral Electrical Hearing

Bernhard Laback[1], Piotr Majdak[1], W. D. Baumgartner[2]

[1)] Acoustics Research Institute, Austrian Academy of Sciences, Austria

[2)] ENT-Department, Vienna University Hospital, Austria

ARO 2005

28th Annual Midwinter Research Meeting of the

Association for Research in Otolaryngology

New Orleans, U.S.A.

INTRODUCTION

Current 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). While a number of studies investigated the sensitivity of bilateral CI listeners to interaural time differences (ITDs) in unmodulated and modulated pulse trains (e.g. van Hoesel and Tyler, 2003), the specific contribution of ITD in the temporal fine structure has not yet been studied. In particular, the influence of onset and offset ITD cues has not been considered. Determination of the relative effects of fine structure and onset/offset ITD cues helps to estimate the benefit to be expected from encoding fine structure ITD cues in CI systems.

The relative contributions of fine structure, onset, and offset ITD for lateralization discrimination were studied at four pulse rates, using trains of four equal amplitude pulses. These stimuli have the advantage that the effects of fine structure and onset/offset ITD can be compared across pulse rates without confounding variation of pulse number and pulse amplitude. An additional experiment verified that lateralization performance in experiment I was indeed mediated via binaural processing and not influenced by monaural cues. Both bilateral CI listeners and normal hearing (NH) subjects were tested.

SPECIFIC QUESTIONS

- Are CI listeners sensitive to ITD in the fine structure only? (without onset/offset ITD cues) [Fig. 1]
- What is the relative contribution of ITD in the fine structure and in the gating portions (onset and offset)?

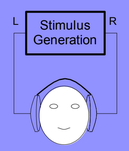


Fig. 1

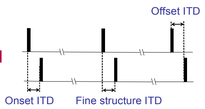
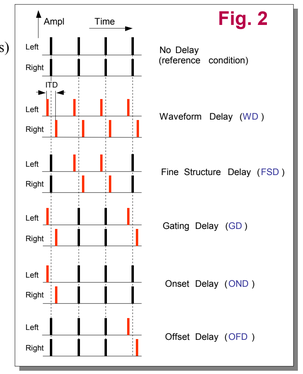


Fig. 2



APPROACH

- Determination of sensitivitiy to ITD carried in specific signal portions (fine structure, onset or offset) [experiment I]
- Train of four pulses with constant amplitude across pulse rates
  - Information units carrying fine structure delay (FSD) and gating delay (GD) are identical (in terms of pulse number and pulse amplitude) at each pulse rate
  - Requires no amplitude adjustment across pulse rates
  - Stimuli with constant duration would require reduction of pulse amplitude to compensate for the increasing number of pulses at growing pulse rate, to provide constant energy (or loudness) across pulse rates
    → confounding effects of pulse amplitude (SNR) and pulse number on performance
- Verification that stimuli used in experiment I (lateralization discrimination) are not discriminated based on monaural cues such as periodicity pitch [experiment II]

METHODS

1. Subjects and implant system

- Three postlingually deafened, bilaterally implanted CI listeners, supplied with C40+ systems by *Med-El*. Bibliographic data are provided in **Table I**.
- Five normal hearing listening to acoustic simulations of electrical stimulation

2. Apparatus and stimuli

- Electrical stimulation:
  - Stimulus transmission via two synchronized Research Interface Boxes (*RIB*, University of Innsbruck); Interaural timing accuracy ≤ 2.5µs
  - 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 were (ascending numbering from apex to base): CI3: 4/3; CI1: 4/1; CI8: 7/5
- Acoustical stimulation:
  - Digital stimulus generation
  - Presentation via headphones in double walled sound booth
  - Monophasic pulses (duration: 10µs), filtered with a bandpass filter (-3dB cutoff frequencies: 3900 and 5400 Hz)
  - Filter bandwidth broad enough to preserve modulation and narrow enough to approximate the range of tonotopic activity in single electrode stimulation
  - Continuous, interaurally uncorrelated pink noise (50 - 10050 Hz) at spectrum level of 15.2 dB SPL (at 4.6 kHz): to avoid sensation of combination tones

3. Procedure for experiment I: Lateralization discrimination

- Lateralization discrimination task: two alternative forced choice (2AFC)
- 1st interval: reference stimulus (without ITD); 2nd interval: target stimulus (with ITD)
- Subjects indicate if the second stimulus was to the left or right of the first one
- Visual response feedback
- Method of constant stimuli
- Estimation of 80 % JND (unless otherwise noted)

4. Procedure for experiment II: Monaural discrimination

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

5. Stimulus conditions

- Pulse rates: 100, 200, 400, and 800 pulses per second (pps)
- Sequence of four pulses
- Constant pulse amplitude for all pulse rates
  - NHs: rms level: 66 dB SPL (measured with continuous pulse train at 100 pps)
  - CIs: comfortable level
- ITD types: Waveform delay (WD), Fine structure delay (FSD), Gating delay (GD), Onset delay (OND), and Offset delay (OFD) [**Fig. 2**]
- Experiment II:
  - Monaural presentation of signals and conditions of experiment I (exception: WD)
  - One ITD value per ITD type and pulse rate, corresponding to the binaural JND

Table 1

Bibliographic data of the CI listeners

Subject	Aetiology	Age	Age at implantation		Duration of deafness		Binaural electrical stimulation experience
			L	R	L	R	
CI1	Meningitis	20	14 yr	14 yr	5.5 mo	1.5 mo	6 yr
CI3	Meningitis	21	21 yr	21 yr	2 mo	2 mo	1 mo
CI8	Osteogenesis imperfekta	41	41	39	3yr	12 yr	2 mo

RESULTS

EXPERIMENT I

- **Fig. 3** shows mean JNDs of NH listeners (n=5) as a function of pulse rate for the different ITD types (error bars: ±1 standard deviation)
- **Fig. 4 a-c** show individual JNDs of three CI listeners
- ANOVA [pooled data]:
  - significant main effects of ITD type ($p<0.0001$), pulse rate ($p<0.04$), and subject group ($p<0.0001$)
  - Significant two-way interactions: ITD type vs. pulse rate ($p<0.0001$), ITD type vs. subject group ($p<0.002$)

→ separate ANOVAs +Tukey's post hoc tests for each subject group:

NH listeners

- All main effects and interactions significant ($p<0.0001$)
- Separate ANOVAs for different pulse rates:
  - Significant contribution of FSD for pulse rates up to 200 pps (difference WD vs. GD at 200 pps: $p<0.026$)
  - Significant contribution of OFD up to 200 pps (difference GD vs. OND at 200 pps: $p<0.012$) and onset dominance for pulse rates ≥ 400 pps (difference GD vs. OFD: $p<0.0001$)

CI listeners

- Significant main effects of ITD type ($p<0.001$)
- Separate ANOVAs for different pulse rates:
  - Significant contribution of FSD at 100 pps (difference WD vs. GD: $p<0.02$) but not at higher rates ...
  - ... however, higher significance for cumulative grouping of pulse rates up to 400 pps ($p<0.009$) → FSD may contribute up to 400 pps
  - Onset dominance for pulse rates ≥ 200 pps (OFD not determinable)

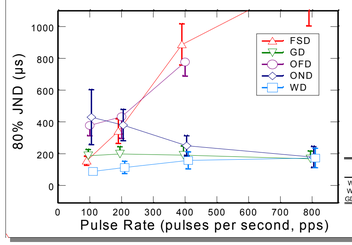
CI listeners (trends for individuals)

- CI3 (Fig. 4 a):
  - High sensitivity to WD and FSD up to 800 pps
- CI1 (Fig. 4 b):
  - No sensitivity to FSD at pulse rates ≥ 200 pps
- CI8 (Fig. 4 c):
  - High contribution of FSD up to 800 pps despite a highly decreasing performance of WD with growing pulse rate

EXPERIMENT II

All subjects (NH listeners as well as CI listeners) performed at chance level for all stimulus conditions (ITD type, pulse rate)
→ Lateralization discrimination JNDs were NOT influenced by monaural cues

JNDs for NH hearing listeners — Fig. 3

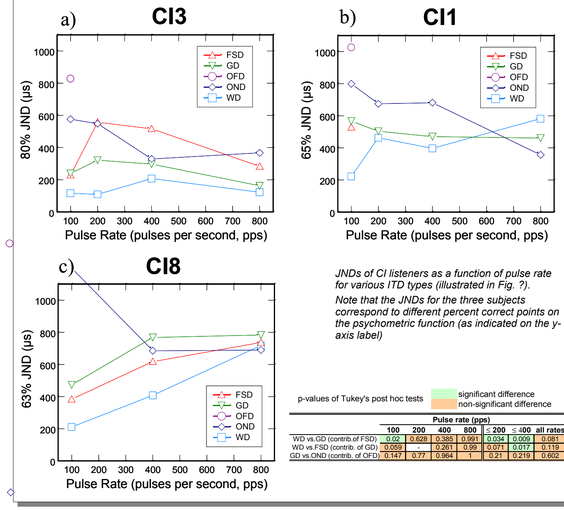


JNDs of NH listeners as a function of pulse rate for various ITD types (illustrated in Fig. 2). Error bars indicate ± 1 standard deviation.

p-values of Tukey's post hoc tests: significant difference / non-significant difference

Pulse rate (pps)	100	200	400	800	≤ 200	≤ 400	all rates
WD vs.GD (contrib.of FSD)	0.005	0.026	0.792	1	0.000	0.000	0.002
WD vs.FSD (contrib. of GD)	0.067	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
GD vs.OND (contrib. of OFD)	0.007	0.012	0.545	0.998	0.0001	0.0001	0.0001

JNDs for CI listeners — Fig. 4



JNDs of CI listeners as a function of pulse rate for various ITD types (illustrated in Fig. 2). Note that the JNDs for the three subjects correspond to different percent correct points on the psychometric function (as indicated on the y-axis label)

p-values of Tukey's post hoc tests: significant difference / non-significant difference

Pulse rate (pps)	100	200	400	800	≤ 200	≤ 400	all rates
WD vs.GD (contrib.of FSD)	0.02	0.628	0.385	0.991	0.034	0.009	0.081
WD vs.FSD (contrib. of GD)	0.058	-	0.261	0.99	0.071	0.017	0.119
GD vs.OND (contrib. of OFD)	0.147	0.77	0.964	1	0.21	0.219	0.602

CONCLUSIONS

- CI listeners are sensitive to fine structure ITD (without onset and offset ITD cues)
- Sensitivity for CI3 exceeds even that of NH listeners [binaural deafness: 8 weeks; testing time: 4 weeks after activation of CIs]
- Large inter-individual variability in upper pulse rate limit of sensitivity to fine structure ITD (100 pps – 800 pps)
- Sensitivity to gating ITD (onset+offset ITD) independent of pulse rate
- Onset dominance at high pulse rates
- Normal hearing listeners show upper rate limit of sensitivity to fine structure ITD between 200 and 400 pps (limiting factor: auditory filters)
- Effects of signal duration (Laback, Majdak, and Baumgartner, 2005): improved performance for FSD and WD at rates up to 400 pps (temporal integration of ITD information)
- Results are consistent with a study by Majdak, Laback, and Baumgartner (2005), showing strong lateralization effects of fine structure ITD for amplitude modulated pulse trains
- New stimulation strategies should encode fine structure information to provide important ITD cues to CI listeners (e.g. PULSAR system by Med-El)

Laback, B., Majdak, P., and Baumgartner, W. D. (2005). "Sensitivity to interaural time differences in temporal fine structure, onset, and offset in electrical and acoustical hearing," to be submitted to J. Acoust. Soc. Am.

Majdak, P., Laback, B., Baumgartner, W. D. (2005). "Effects of interaural time differences in fine structure and envelope on lateral discrimination in bilateral electrical hearing," poster presented at 28th midwinter meeting of the Association for Research in Otolaryngology, New Orleans.

Smith, Z. M., Delgutte, B., Oxenham, A. J. (2002). "Chimaeric sounds reveal dichotomies in auditory perception," Nature 416, 87-90.

van Hoesel, R. J., & Tyler, R. S. (2003). "Speech perception, localization, and lateralization with bilateral cochlear implants," J. Acoust. Soc. Am., 113, 1617-1630.

Corresp. Author: Bernhard Laback, Acoustics Research Institute, Austrian Academy of Sciences, Reichsratsstr. 17, A-1010-Wien, Austria

E-Mail: Bernhard.Laback@oeaw.ac.at

http://www.kfs.oeaw.ac.at

We thank the CI listeners for their enthusiastic participation in this study
This research was supported by the Austrian Academy of Sciences