Binaural Masking Level Differences For Speech In Noise In Bilateral Cochlear Implant Listeners

Bernhard Laback[1], Stefan-Marcel Pok[1,Ψ], Piotr Majdak[1], Karin Schmid[1], W. D. Baumgartner[2]

1) Acoustics Research Institute, Austrian Academy of Sciences; 2) ENT-Department, Vienna University Hospital

Ψ) is currently affiliated at the Department of Otorhinolaryngology, University of Frankfurt, Frankfurt am Main, Germany

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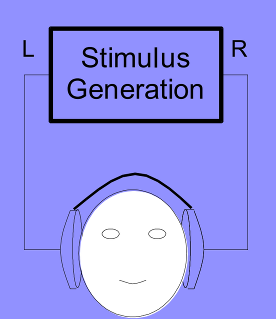
INTRODUCTION

Speech intelligibility is consistently improved when the speech signal is spatially segregated from the noise background for patients with bilateral cochlear implants (e. g. Tyler et al., 2002; Müller et al., 2002; van Hoesel and Tyler, 2003). According to Bronkhorst and Plomp (1988), normal hearing (NH) listeners gain a total binaural advantage of 9.8 dB in intelligibility under such conditions. Most of the gain is due to the monaural better-ear effect (7.2 dB), with the remaining gain (2.6 dB) the result of interaural time difference (ITD) cues. When the speech comes from the front and the noise background from the side, the binaural unmasking associated with interaural level differences (ILDs) is overshadowed by the better-ear effect.

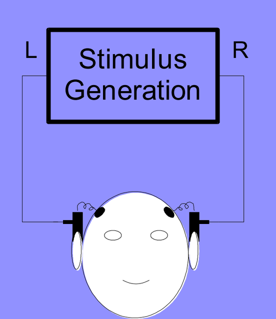
The current study examines speech intelligibility in noise for two bilateral cochlear implant (CI) patients under a variety of interaural conditions that result in large unmasking effects in normal hearing (NH) listeners (a.k.a. binaural masking level differences, or BMLDs). Such experimental conditions may shed light on the nature of the binaural cues that are used by bilateral CI patients to unmask speech in noise.

SPECIFIC QUESTIONS

- Do bilateral cochlear implant patients manifest a gain in speech reception thresholds (SRTs) with interaural phase inversion (=frequency-dependent phase delay) of either speech or noise compared with diotic presentation of speech and noise when the stimuli are processed through CIS-based clinical processors (transmitting only envelope information in each channel)?
- Do bilateral CI patients benefit from presentation of speech to a single ear and noise diotically compared with monotic presentation of both? Monotic presentation is regarded in this context as equivalent to an infinite ILD; thus comparison between these two conditions reflects binaural processing.



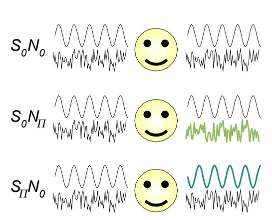
NH listener

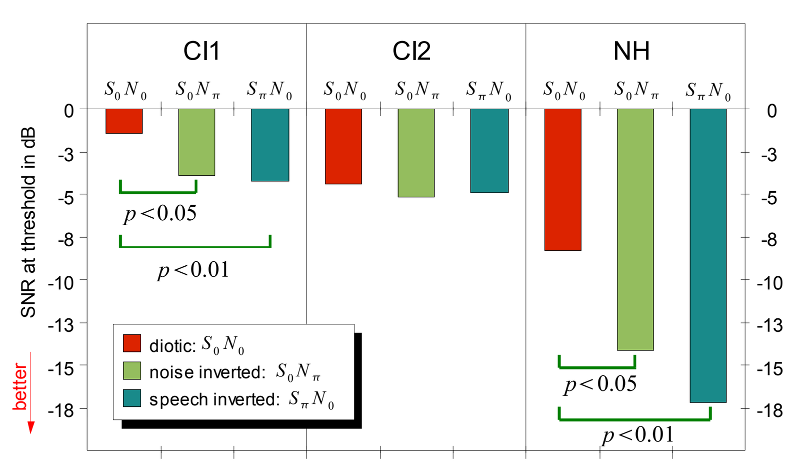


CI listener

BMLD For Phase

Fig. 1





SNRs at 50%-sentence recognition threshold.

p-values for significant BMLDs are denoted in the graphs.

METHODS

1. Subjects

- Two post-lingually deafened patients wearing *Med-El* CI-systems (see Tab. 1). Both subjects achieved open-set speech understanding without lipreading prior to receiving the second cochlear implant
- Two normal hearing reference subjects

2. Experimental Conditions

- Electrical stimulation parameters:
  - Two interaurally unsynchronized *Tempo+* processors (*Med-El*)
  - Clinical processor fittings (CIS-strategy: logarithmic frequency distribution of bandpass-filters, numbers of channels as given in Tab. 1, extraction of envelope signal via the Hilbert-transform, 1515 pps/channel)
  - Deactivation of microphones and automatic gain controls (AGC)
- Speech material "*Oldenburg sentence test*" (Wagener et al., 1999):
  - consisting of 5-word, grammatically constrained sentences (name – verb – numeral - adjective – noun); e. g. "Thomas malt acht nasse Sessel" (english: "Thomas paints eight wet chairs")
  - sentences were created from an inventory of 10 words for each sentence position
  - each list consists of 30 sentences
- Masking signal: CCITT noise
- Interaural conditions:
  - $S_L N_L$, $S_R N_R$, $S_0 N_0$, $S_0 N_\pi$, $S_\pi N_0$, $S_L N_0$, $S_R N_0$

3. Stimulus presentation

- CI listeners: direct transmission into auxiliary inputs of clinical processors
- NH listeners: via Headphones (*Sennheiser HDA 200*) (see figures on the left side)

4. Procedures

A. Adaptive procedure
- Noise at constant (comfortable) level; identical for all conditions
- Adaptive variation of speech level according to the rules decribed in Wagener et al., 1999)
- One adaptive run consisting of 30 sentences
- Determination of speech reception threshold (SNR at 50 % word intelligibility computed over the last 20 sentences of a list)
- 2-4 repetitions for each condition

B. Psychometric function
- Aim: to obtain an estimate of the shape of the psychometric function, an additional measurement was performed with one of the CI listeners (S2)
- Condition: $S_0 N_0$
- Measurement of % correct recognition performance at SNRs in 2 dB steps between -2 and -14 dB
- 30 sentences for each SNR

Tab. 1. Bibliographic data of CI listeners

	Duration of Deafness (left/right)	Binaural experience	Implant (left/right)	Electrod number (left/right)
S1	5.5m / 1.5m	3y 5m	C40+/C40+	12 / 12
S2	21y /25y	1y 7m	C40+/C40	11 / 8

RESULTS

NH Listeners

- BMLDs for NH listeners are consistent with the literature:
  - BMLD for phase: ~7.4 dB for phase inversion of either noise or signal (Fig. 1)
  - BMLD for amplitude: ~6.5 dB for contralateral presentation of correlated noise (Fig. 3)
- No binaural summation effect (Fig. 4)

CI Listeners

- BMLD for phase (Fig. 1):
  - significant effect of phase inversion for S1:
    $S_0 N_\pi$ vs. $S_0 N_0$: 2.4 dB ($p < 0.018$)
    $S_\pi N_0$ vs. $S_0 N_0$: 2.8 dB ($p < 0.008$)
  - but only small (not significant) effect of about 0.7 dB in S2
- BMLD for amplitude (Fig. 3):
  - ~1.4 dB difference ($p < 0.003$) in S2 at one ear
  - but non-significant effect for S2 (~1.2 dB)
- No significant binaural summation effect, although there is a trend (Fig. 4)

Psychometric functions

- Slope of psychometric function at 50-% point similar for CI listener (S2) and NH listeners: ~12 % correct per dB-SNR (Fig. 2)
- 3.3 dB higher SNR at 50-% point of psychometric function for the CI listener than for NH listeners.

Psychometric functions for speech recognition as a function of SNR for the CI listener (S2) in diotic condition (S_0N_0) and 20 NH listeners replicated from Wagener et al. (1999) in monaural condition.

Note that NH listeners perform equally for the diotic condition.

The curves are least squares fits to the measured data points using a sigmoidal function.

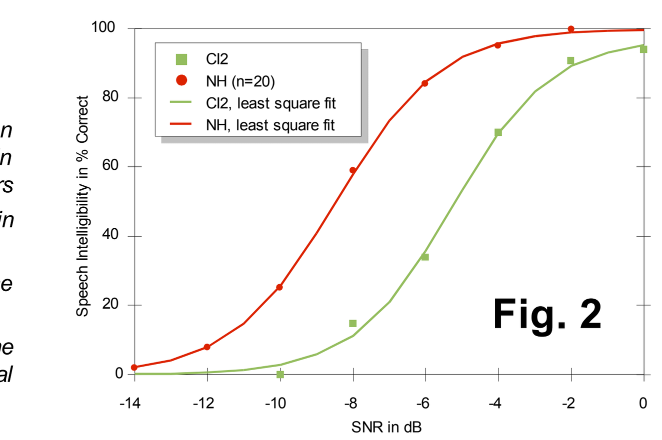
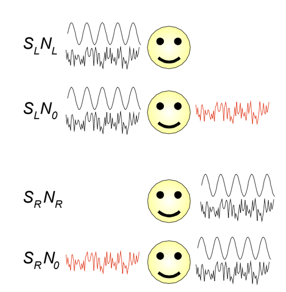
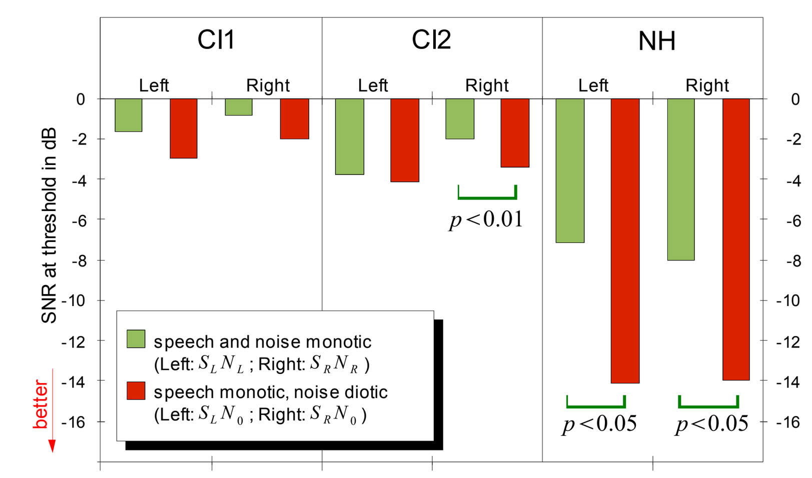


Fig. 2

BMLD For Amplitude

Fig. 3



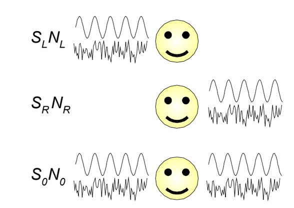


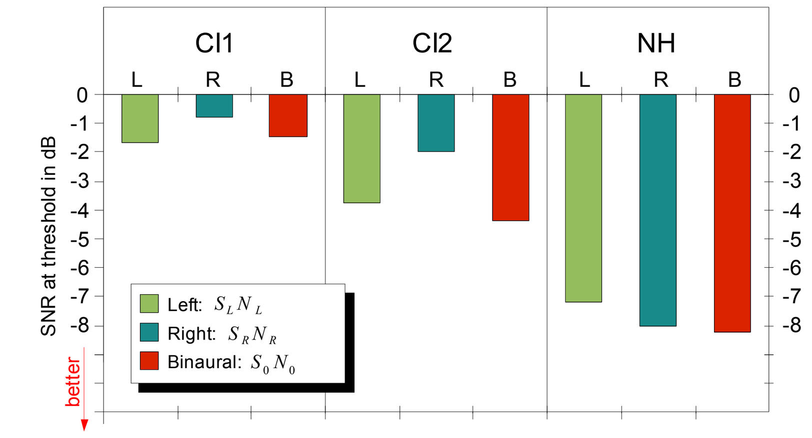
SNRs at 50%-sentence recognition threshold.

p-values of significant BMLDs are denoted in the graphs.

Binaural Summation

Fig. 4





SNRs at 50%-sentence recognition threshold.

CONCLUSIONS

- BMLDs of ~2.6 dB were obtained for one of the CI patients (S1) when either speech or noise was inverted in phase, suggesting that:
  - interaural phase inversion is coded by unsynchronized processors (extracting the Hilbert-envelope in each channel)
  - CI listener, S1, can take advantage of this cue for speech recognition in noise.

  The nature of the cue present in the electrical signals has to be studied in detail.
- The gain associated with phase inversion (for S1) is comparable to binaural unmasking found in free-field studies (e. g. Tyler et al., 2002; Müller et al., 2002; van Hoesel and Tyler, 2003).
- Adding correlated noise to the contralateral ear (BMLD for amplitude) yields a small, but significant, improvement in the speech reception threshold for one of the CI patients (S2), and there is a small trend in this direction for the other CI patient. This result is surprising in view of the high sensitivity of CI patients to ILDs (e. g. Lawson et al., 2001).
- There is a small (but, non-significant) trend for a binaural summation effect in the conditions explored. However, no attempt was made to compensate for binaural loudness summation in the current study, so this result should be treated with caution.
- Further conditions should be tested, e. g. including non-infinite ILD in the speech signal. These relate to situations where the speech signal is not in the front.

These results offer the opportunity for further improvements of future cochlear implant systems with respect to speech intelligibility in noise.

Bronkhorst, A. W., and Plomp, R. (1988). "The effect of head-induced interaural time and level differences on speech intelligibility in noise," J. Acoust. Soc. Am., 83,1508-1516.
Lawson, D. T., Wolford, R., Brill, S., Schatzer, R., and Wilson, B. S. (2001). 12th quarterly progress report: Speech processors for auditory prostheses, Center of Auditory Prosthesis Research, RTI, NIH project N01-DC-8-2105. Bethesda.
Müller, J. M, Schön, F., and Helms, J. (2002). "Speech Understanding in Quiet and Noise in Bilateral Users of the MED-EL COMBI 40/40+ Cochlear Implant System," Ear and Hearing 23, 198-206.
Tyler, R. S., Gantz, B. J., Rubinstein, J. T., Wilson, B. S., Parkinson, A. J., Wolaver, A., Preece, J. P., Witt, S., & Lowder, M. W. (2002). "Three-month results with bilateral cochlear implants," Ear and Hearing, Suppl., 23, 80S-89S.
Wagener, K., Brand, T., Kollmeier, B. (1999). "Entwicklung und Evaluation eines Satztests in deutscher Sprache III: Evaluation des Oldenburger Satztests," Zeitschrift für Audiologie. 38, 86-95.
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

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