Review of Sound Coding Strategies for Cochlear Implants

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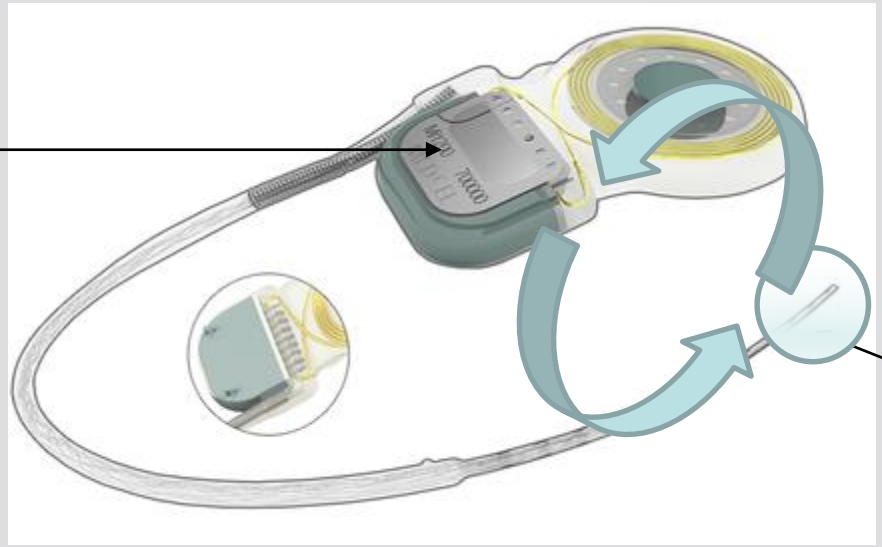
- Review of Sound Coding Strategies for Cochlear Implants
- Review of Evoked Compound Action Potential
- Practical Session on Fitting for Cochlear Implants (Sofia Bonfatti Sabbioni)
- Study on Bilateral CIs vs Bimodal CIs in realistic acoustic environments

Stimulation Mode

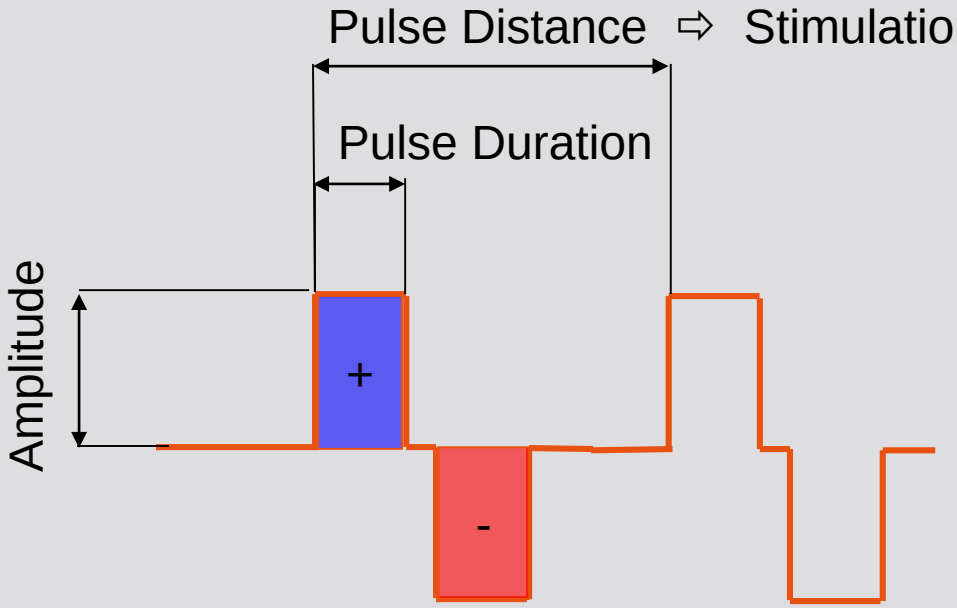
Monopolar Stimulation

- An intracochlear electrode is connected to an extracochlear reference electrode such that current flows between the two electrodes.

- Simultaneous stimulation of multiple electrodes is undesirable because it causes interaction between the channels.



Stimulation with Biphasic Pulses



- The amount of load defines the loudness (pulse duration and amplitude).

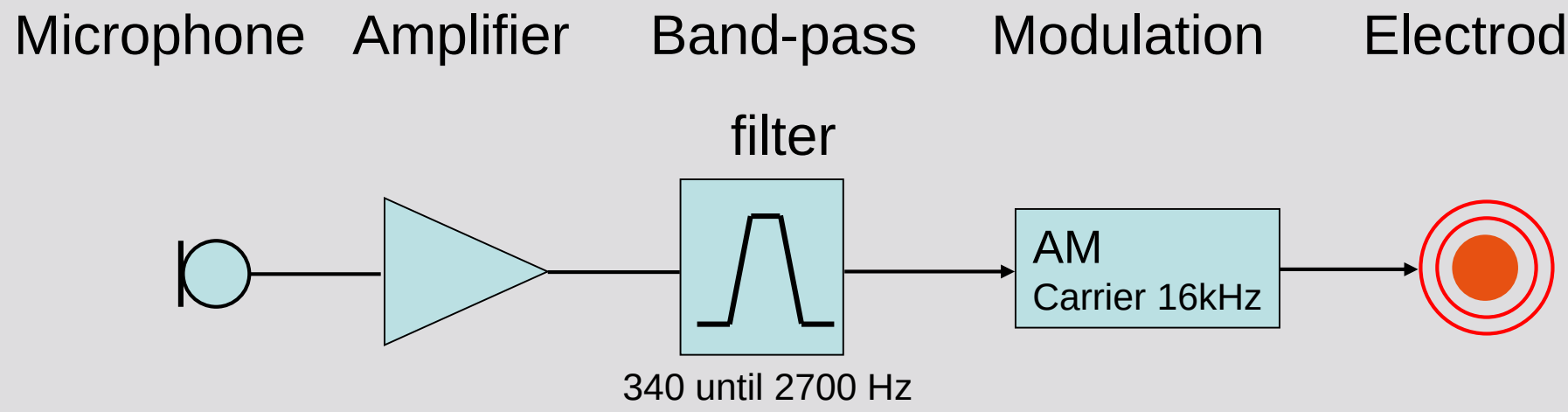
- Stimulation rate (Pulse rate)

- Charge balanced pulses

- The charge density must be limited (depends on the injected charge and the size of the electrodes).

This can cause an irreversible reaction around the electrodes, including changes in the pH level, detachment of parts of the electrode material and formation of protein-metal complexes.

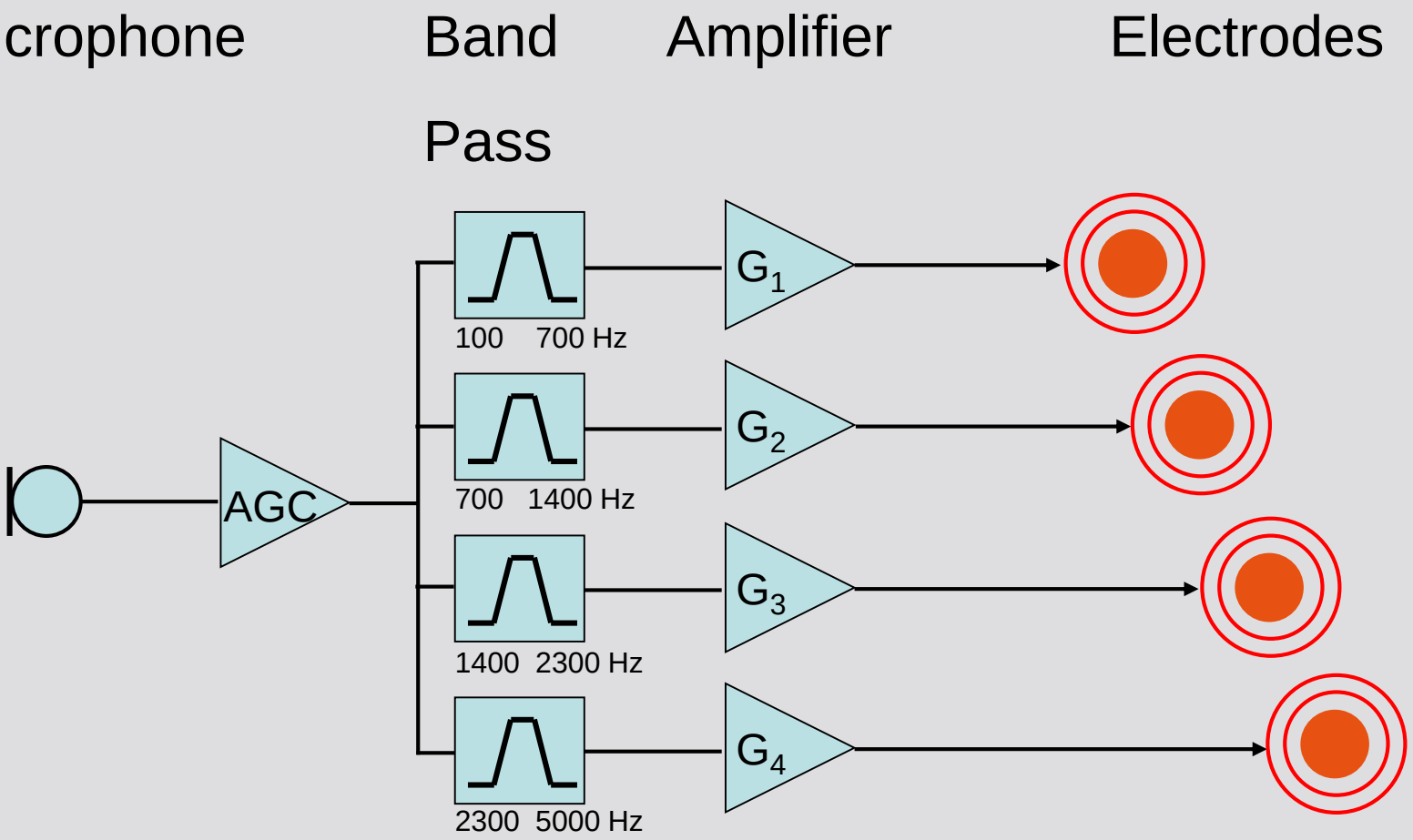
Cochlear implant with a single electrode



Speech Intelligibility

Zeng 2004

Compressed Analog (CA)

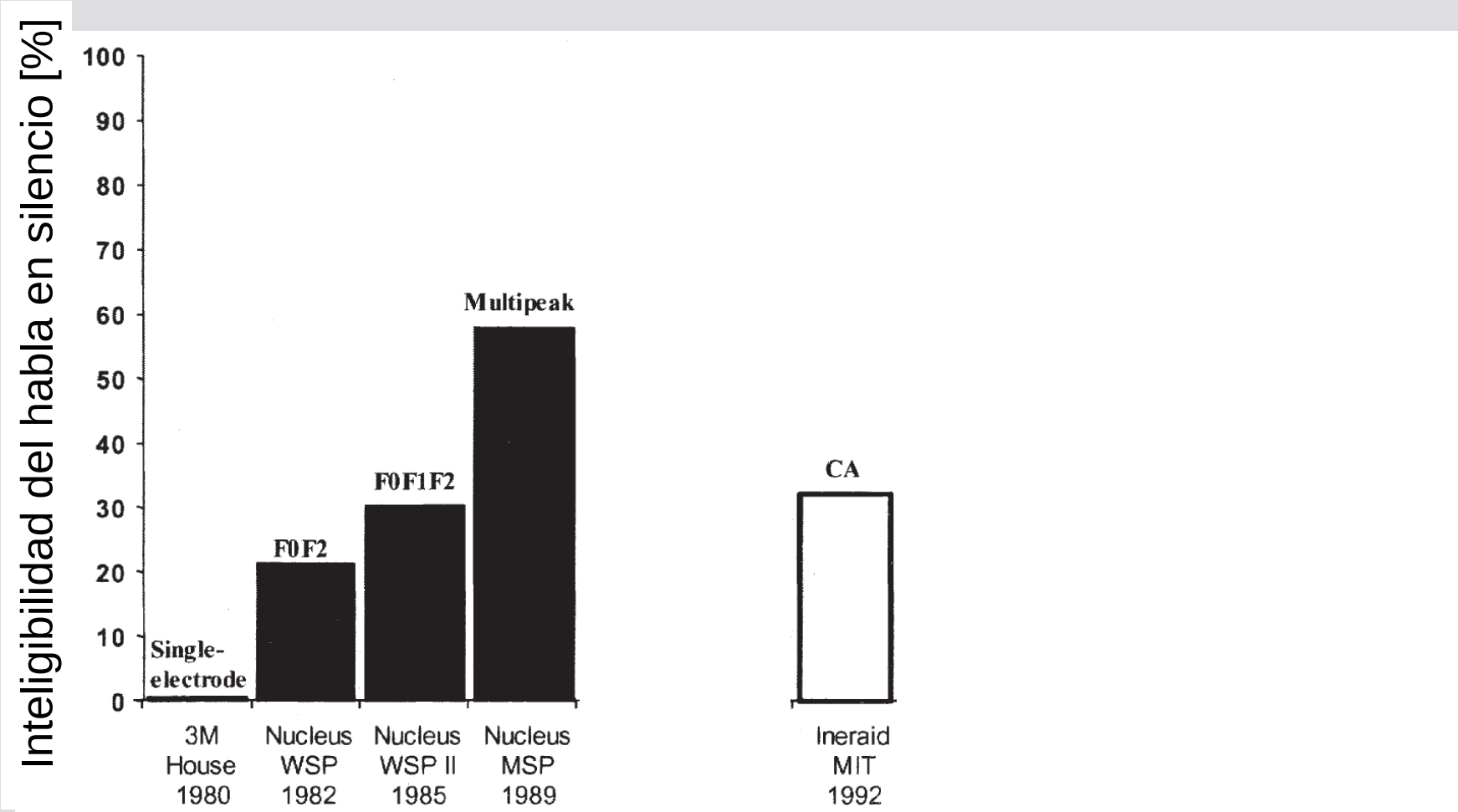


Compressed Analog (CA)

Characteristics of the CA-Strategy:

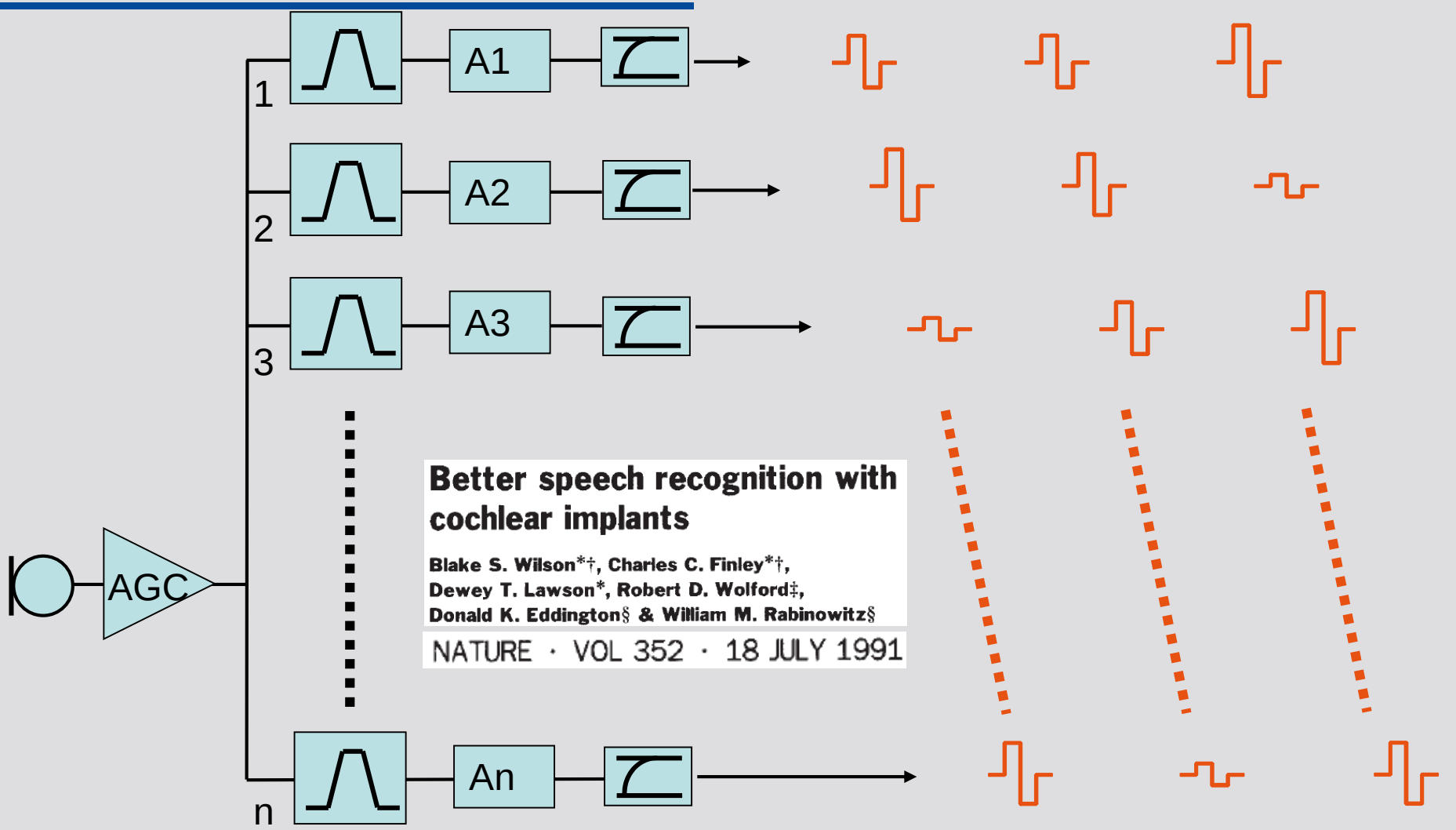
- Four bandpass filters between 300 and 5000 Hz
- Simultaneous stimulation of 4 intracochlear electrodes
- Monopolar stimulation (later upgraded to bipolar stimulation)
- Better performance than a single electrode system
- Better performance than F0F2 strategy
- Problem: Strong interaction between channels

Speech Intelligibility



Zeng 2004

CIS (Beginning of 1990‘s)



Better speech recognition with cochlear implants

Blake S. Wilson*†, Charles C. Finley*†, Dewey T. Lawson*, Robert D. Wolford‡, Donald K. Eddington§ & William M. Rabinowitz§

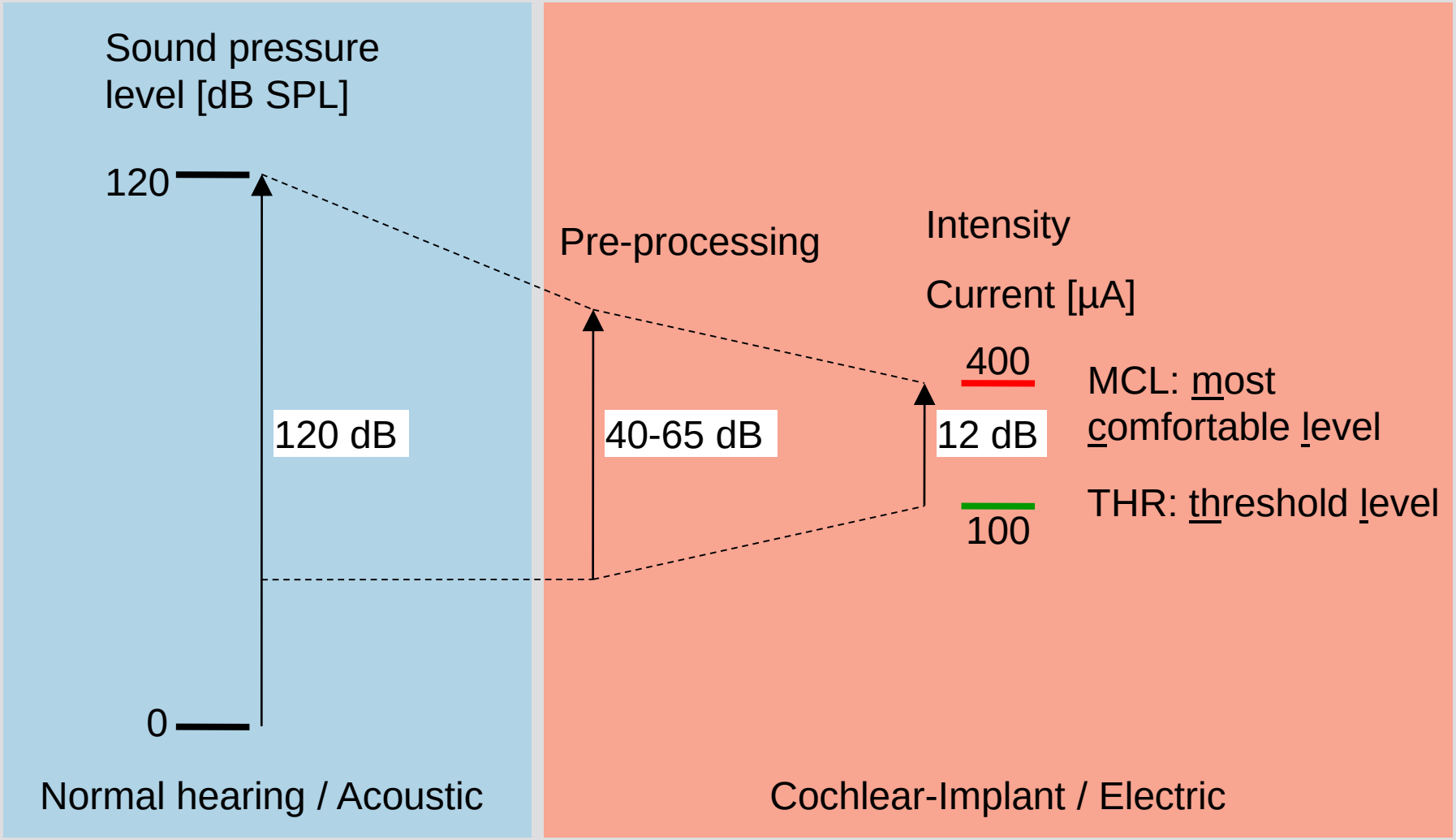
NATURE · VOL 352 · 18 JULY 1991

CIS (Begining of 1990‘s)

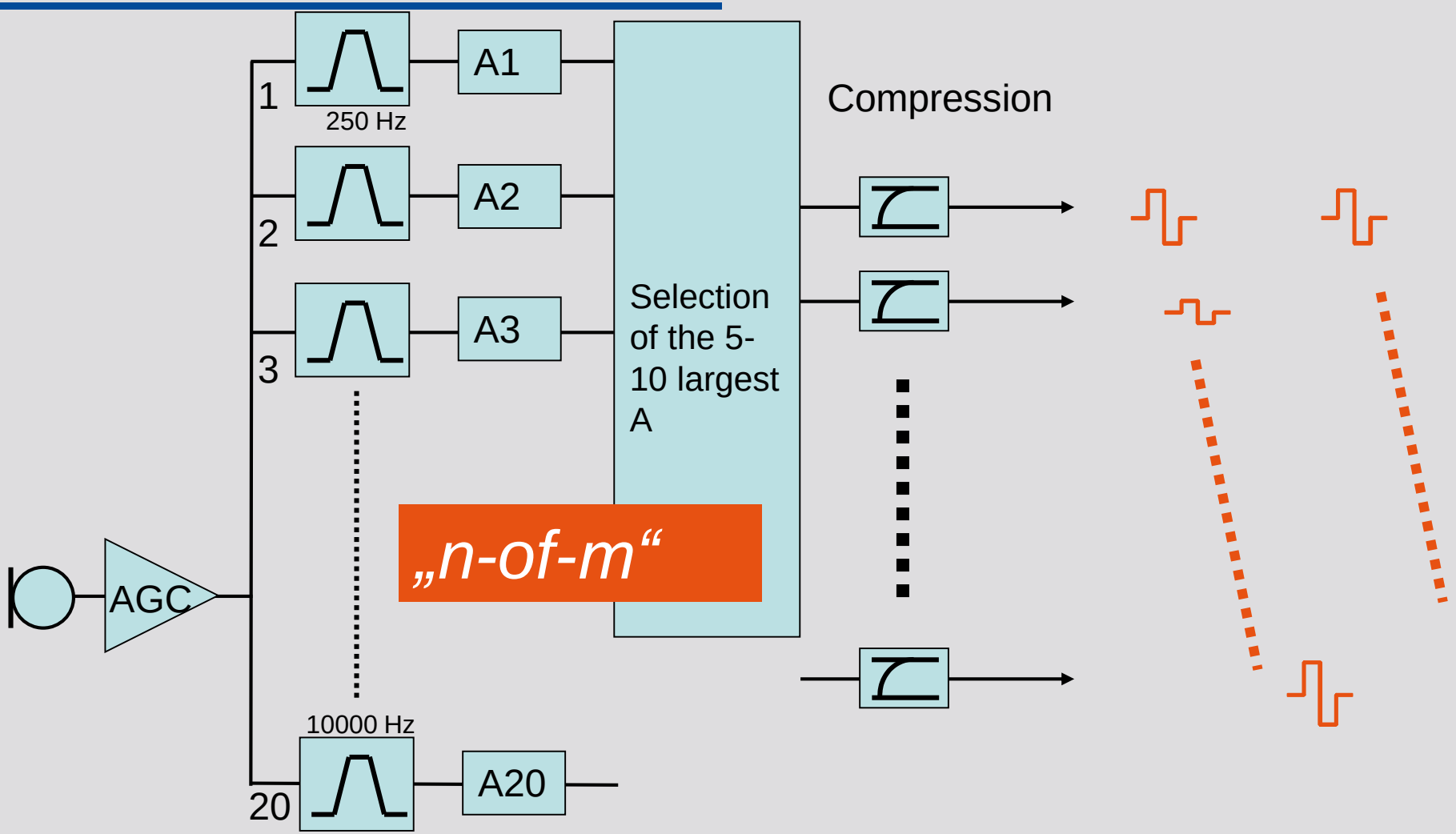
Characteristics of the CIS sound coding strategy:

- 8 bandpass filters from 250 to 5500 Hz
- 60 dB dynamic range => Compressed/mapped to patient-specific dynamic range
- Stimulation with square biphasic pulses with a 75 µs/phase duration
- Stimulation rate for each electrode is around 833 Hz
- It is based on a principle similar to the Dudley Vocoder (see next slide).

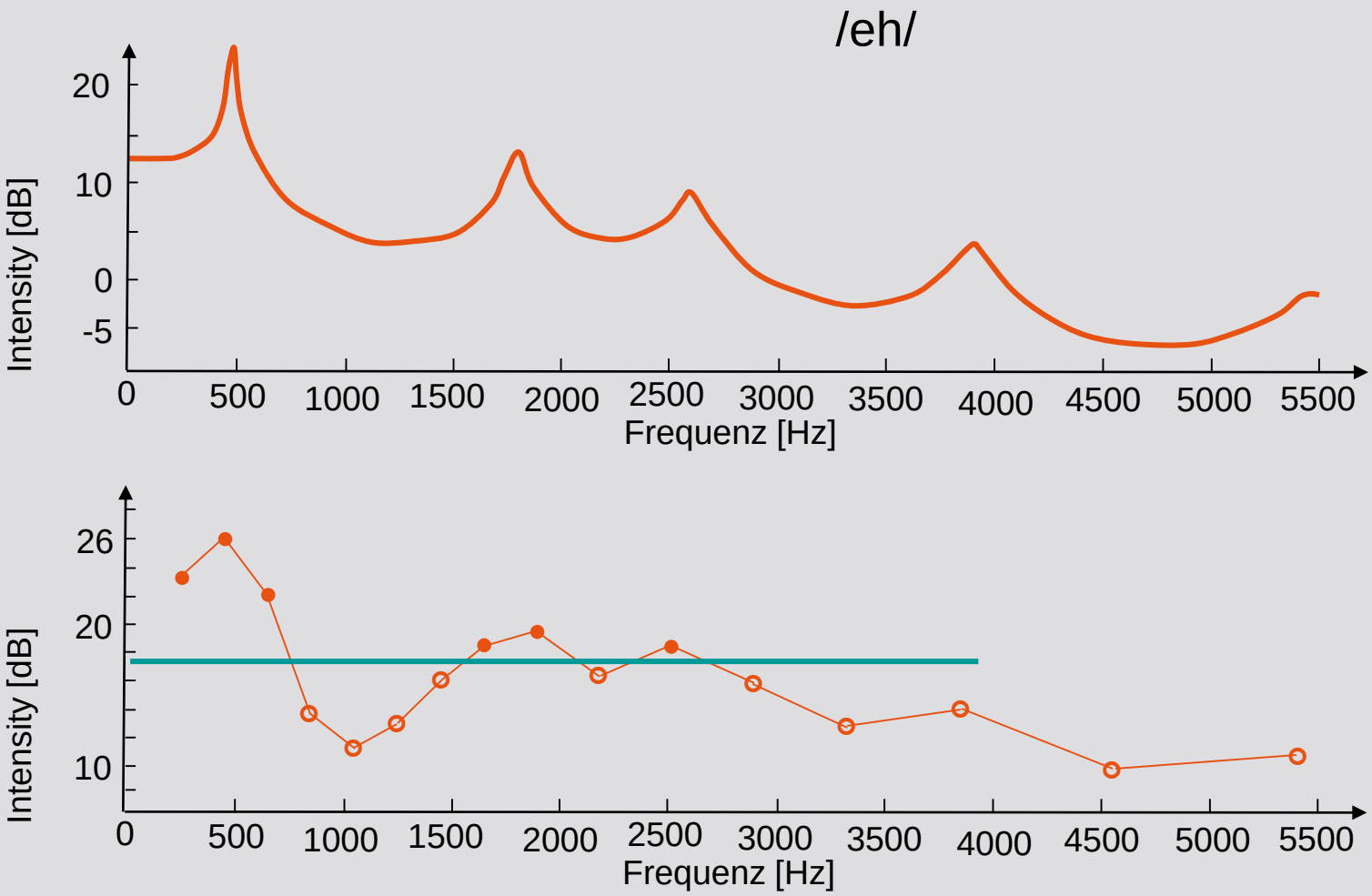
Input Signal Pre-Processing



SPEAK (Begining of 1990‘s)



Maxima Selection

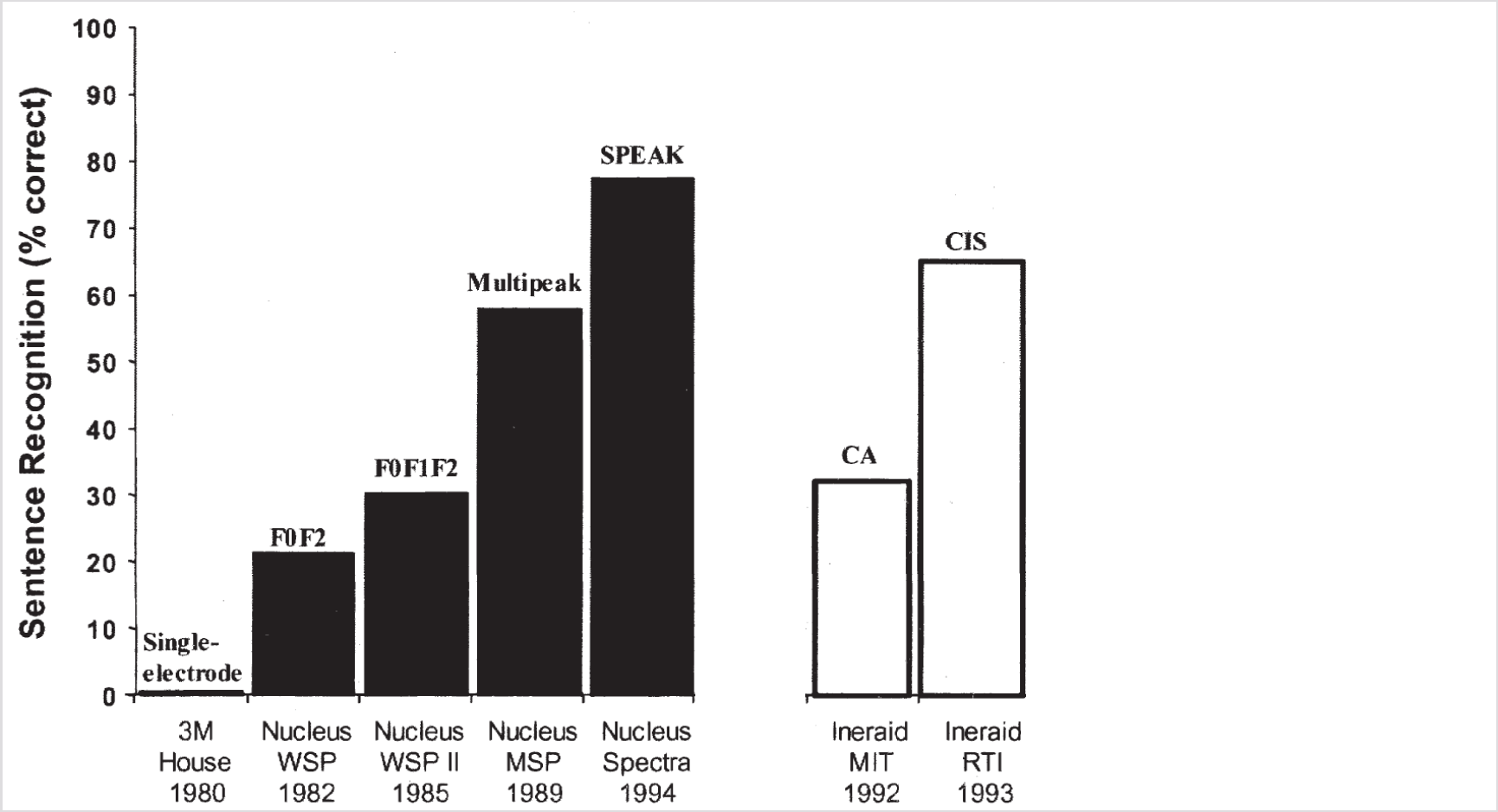


SPEAK (Begining of the 1990‘s)

Characteristics of the Speak sound coding strategy:

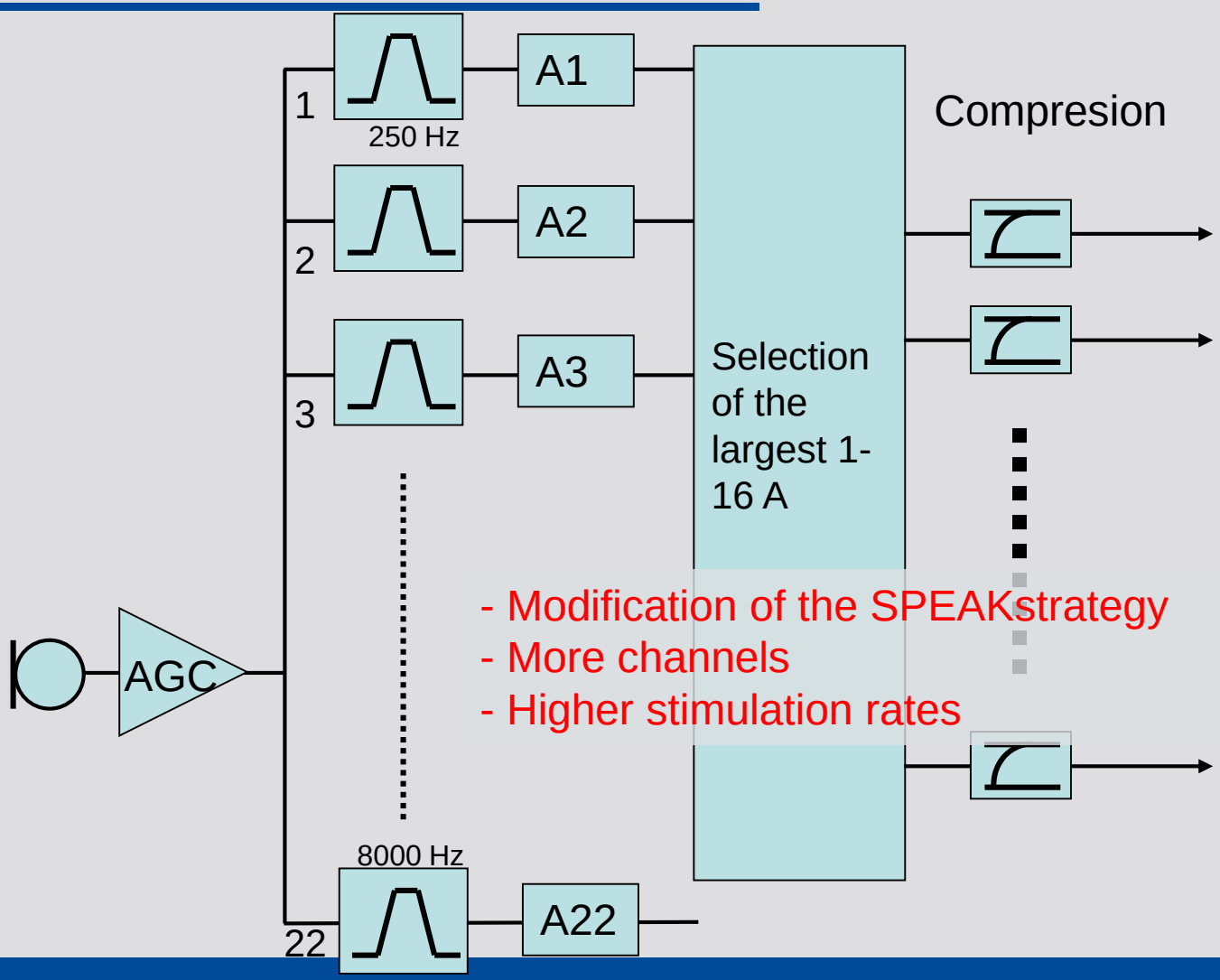
- Larger range of frequencies (250 until 10000 Hz)
- 20 channels
- Only 5-10 channels with largest energy (maxima) are selected for stimulation.
  - The amount of information requires time which causes a reduction in the stimulation rate.
- Stimulation rates up to 250 Hz (limited by Mini-22 implant technology)

Speech Intelligibility

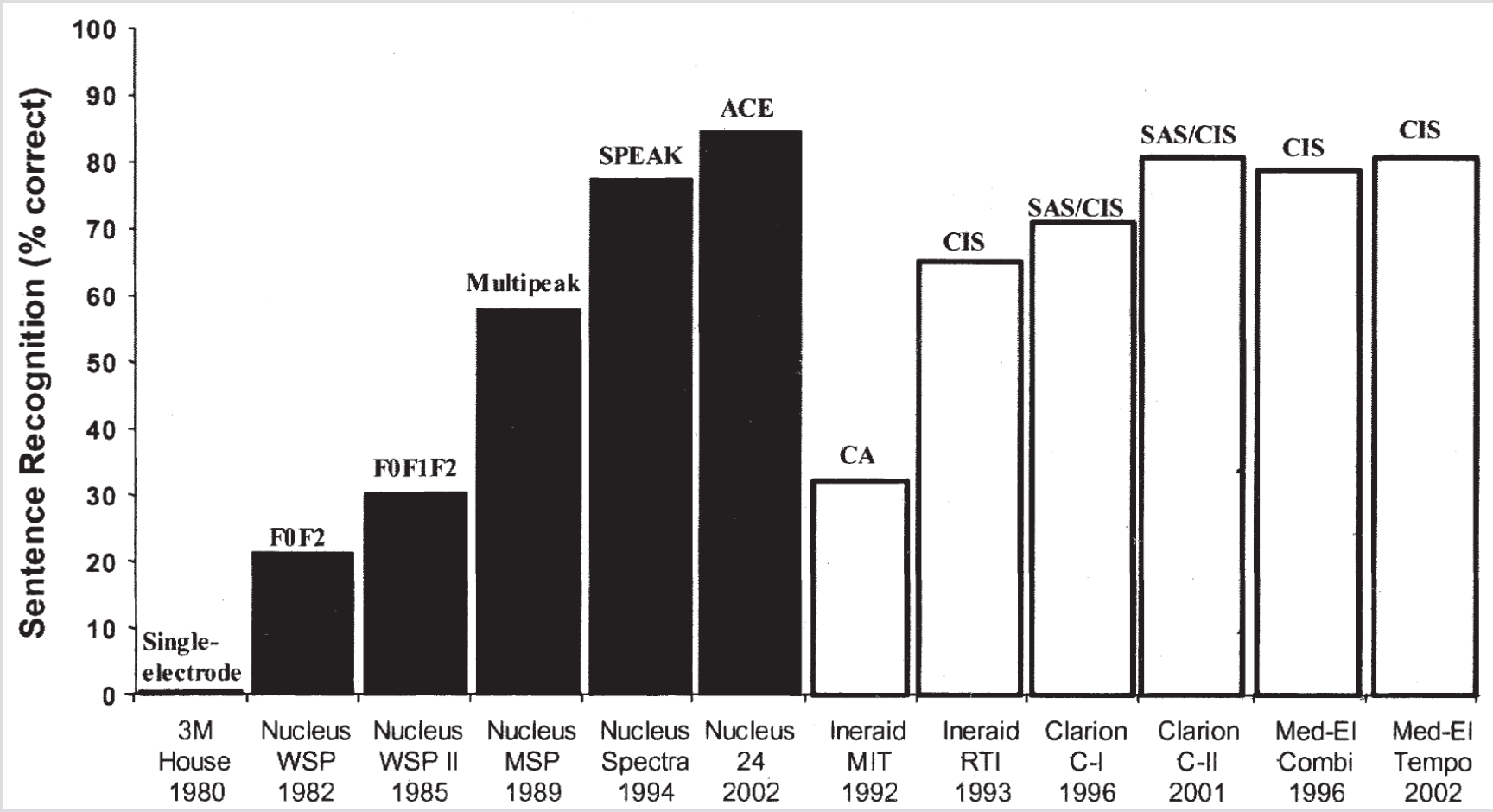


Zeng 2004

ACE (Middle of the 1990‘s)

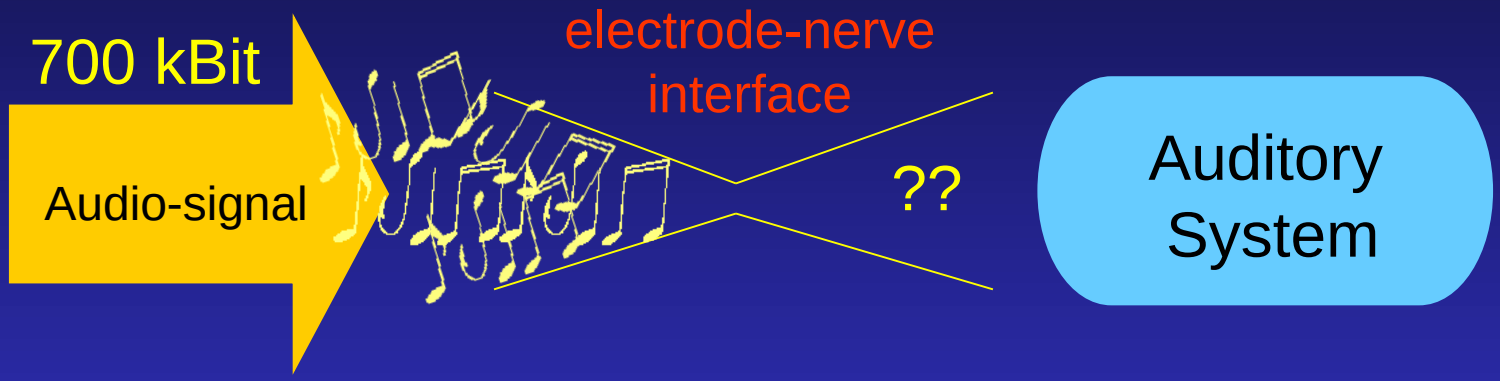


Speech Intelligibility



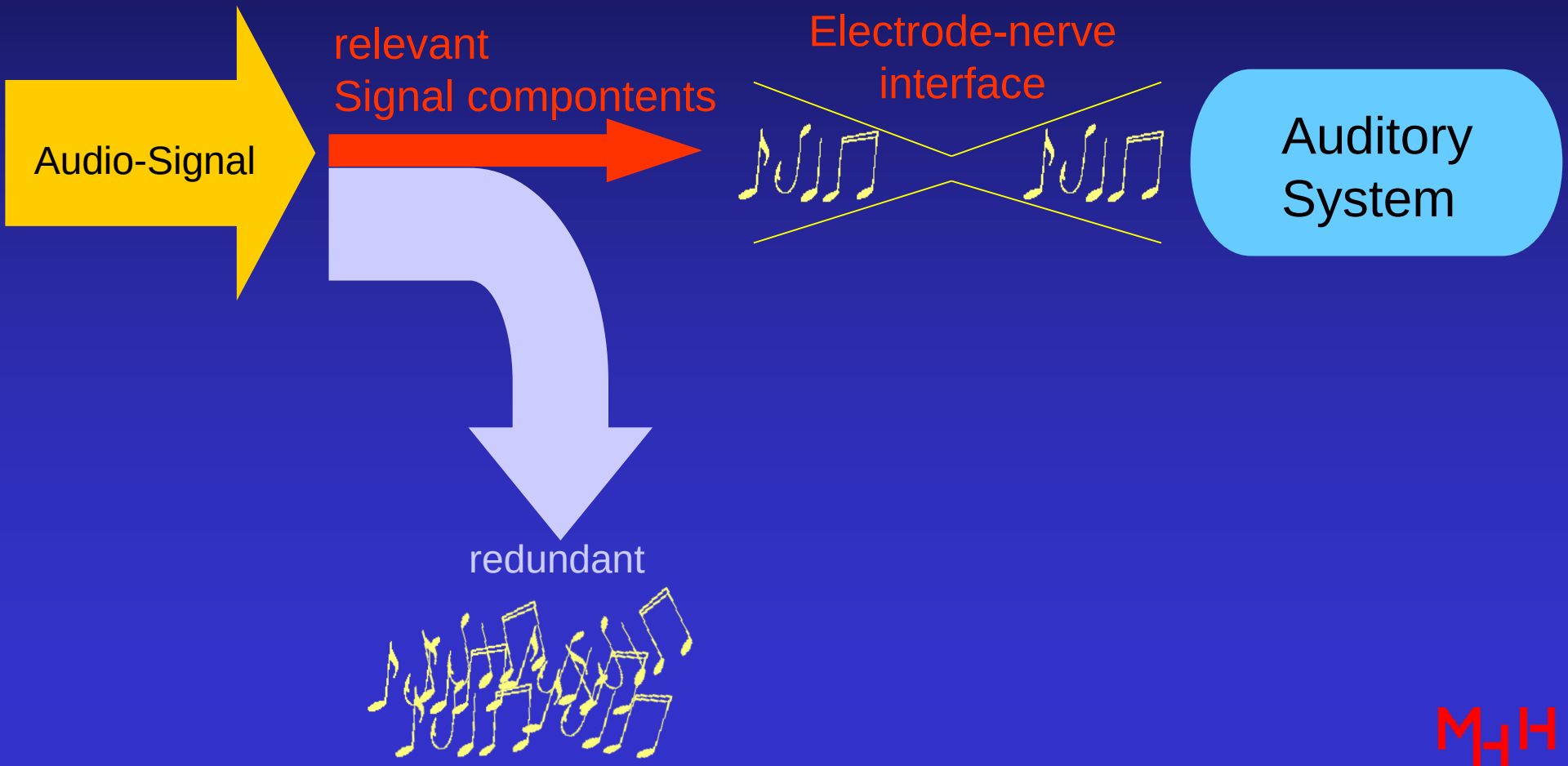
Zeng, Trends In Amplification 2004:8:1-34

The problem of low bandwidth in cochlear implants



Cochlear Implant System : 10 - 60 kbit/s

One possible solution: hearing related data reduction



Motivation for designing a psychoacoustic model-based speechcoding strategy

Psychoacoustic models have been successfully used in the HiFi domain without compromising sound quality.

→ Reducing the data of audio-files to 1/10th !

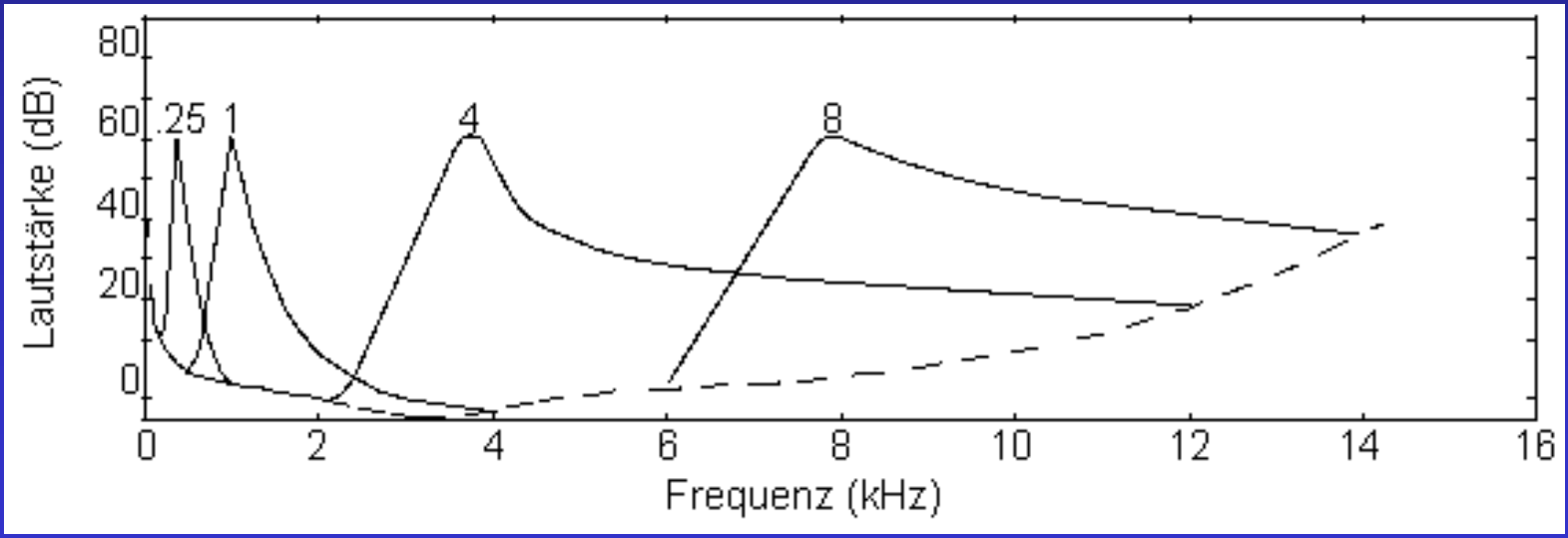
Apple‘s iPod

Psychoacoustics I

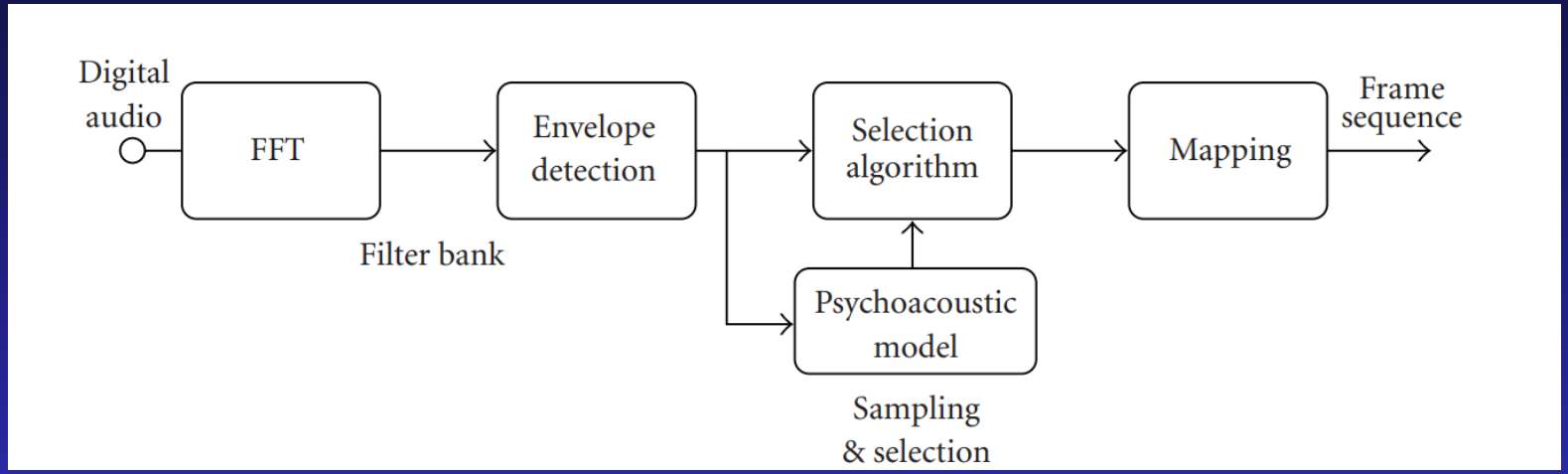
(simultaneous masking effect)

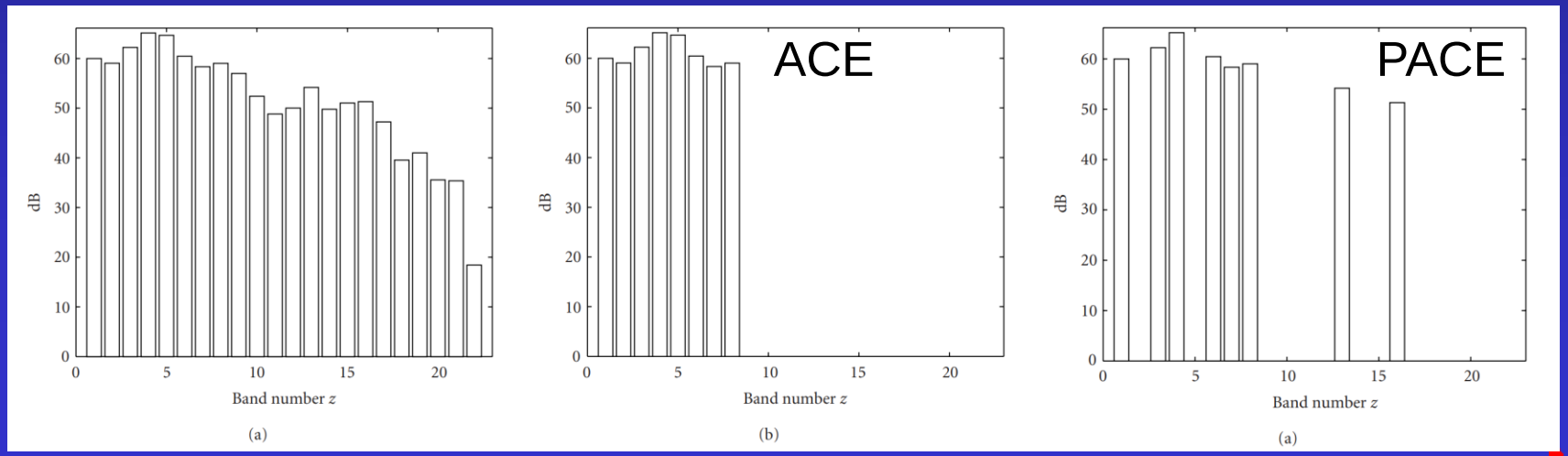
During an acoustic excitation the threshold of perception is lifted depending on the spectrum of the signal. All signal components below this threshold are imperceptible.

The simultaneous masking is the strongest masking effect.



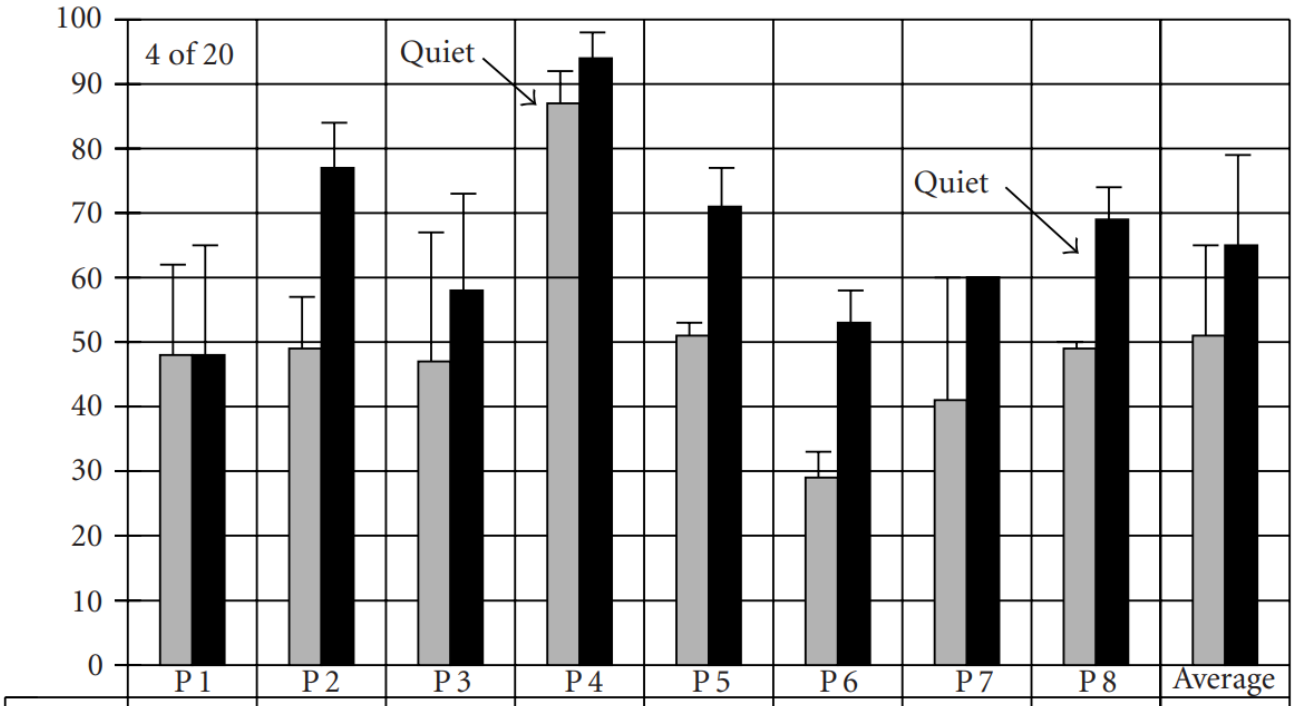
PACE-MP3000





Nogueira et al. 2005 (Eurasip)

ACE vs PACE 4of20



	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	Average
ACE	49	49	47	87	51	29	41	49	50
PACE	49	77	59	94	71	53	59	69	67

Nogueira et al. 2005 (Eurasip)

Next step:

Speechcoding based on psychoacoustic model

- achieve higher compression rates compared to ACE
  → further increase of stimulation rate

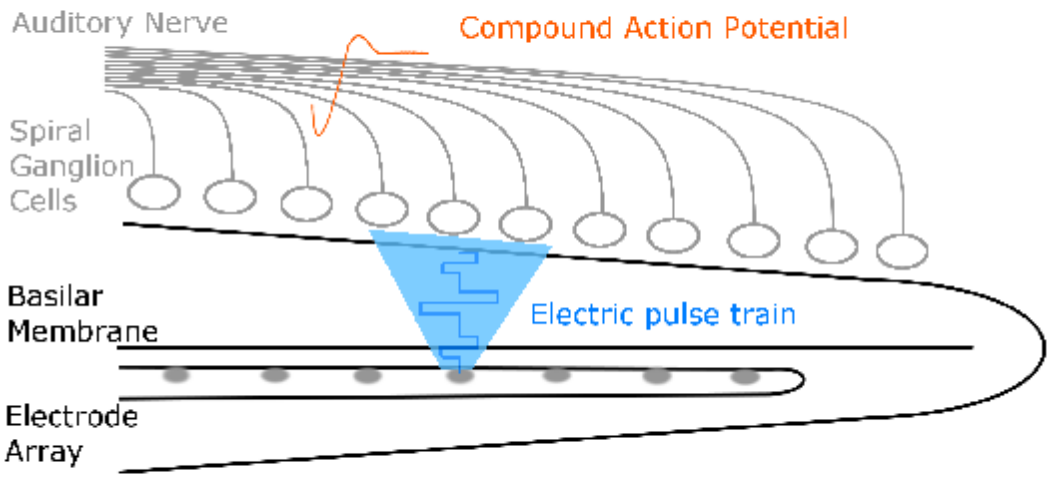
- more realistic selection of the electrodes
  due to more intelligent algorithms
  → should lead to better sound quality

- MP3000 was released as a commercial strategy

Nogueira et al. 2005

ECAP and Neural Health

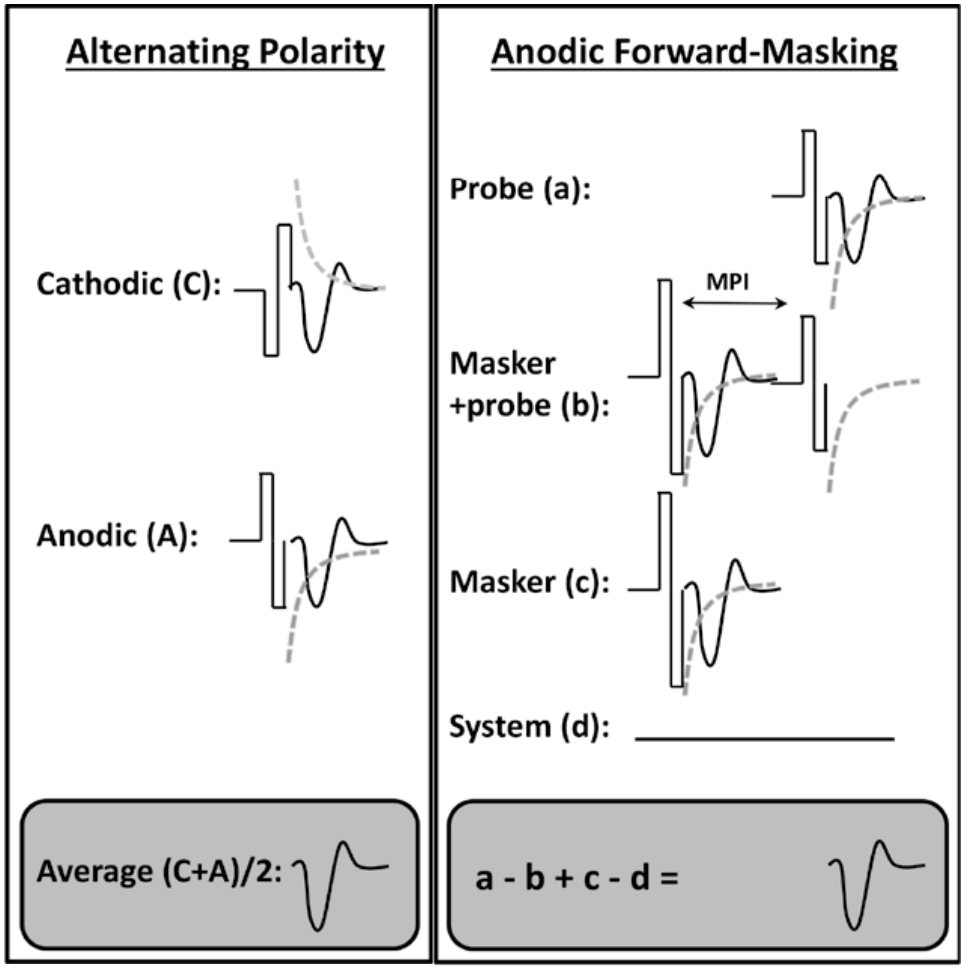
0: Electric Stimulation



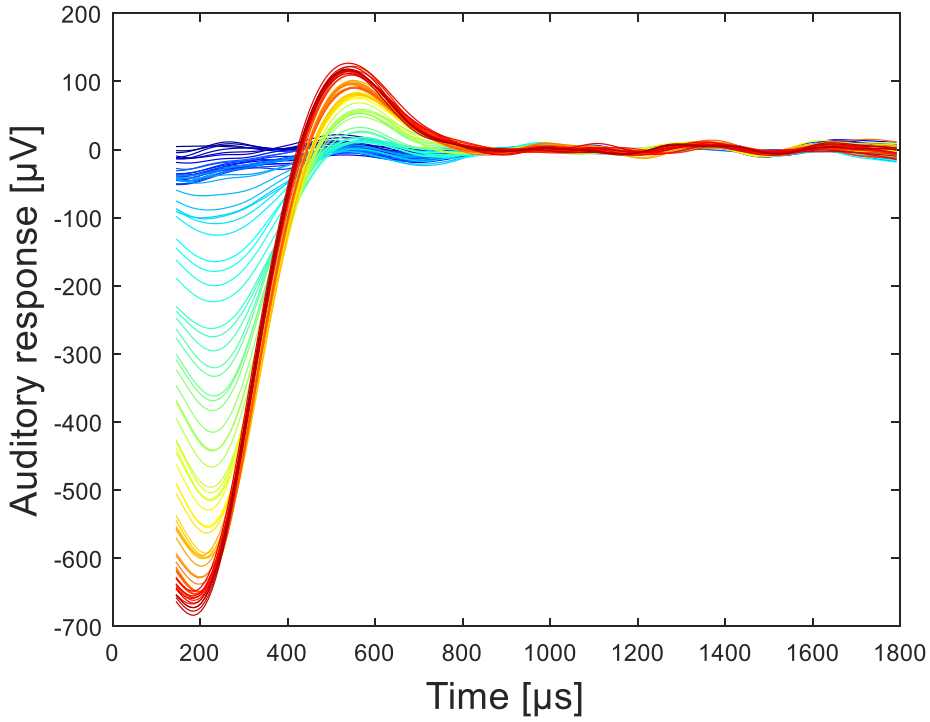
- Schematic of electric stimulation of spiral ganglion cells
- Electric pulse elicits compound action potential
- eCAP travels along auditory nerve

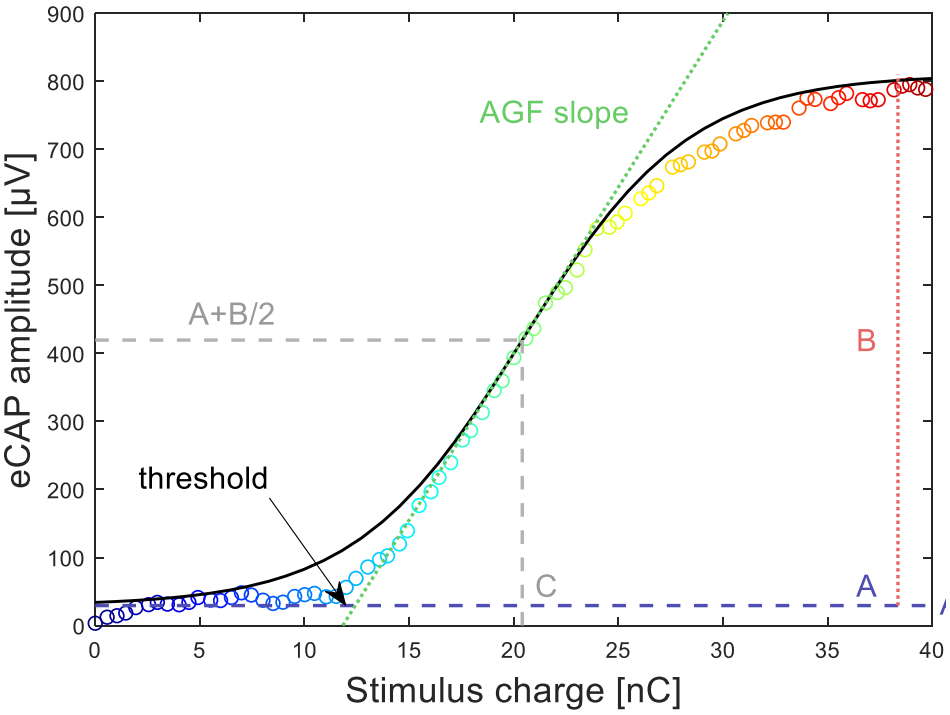
0: Artifact reduction algorithm

- Electric stimulation elicits artifact when measuring electric potential
- Artifact reduction by alternating polarity or forward masking paradigm
  - Forward masking: refractory period cancels out response
  - AP: Artifact cancels out



E: Background continuous eCAP





- Continuous increase of stimulation intensity
- Recording of evoked responses, estimation of eCAP amplitude by N_1 to P_2 difference
- Sigmoid fit of amplitude growth function (Strahl et al., 2018, DGA)

Implant

Electrode Array

Low frecuency

High frecuency

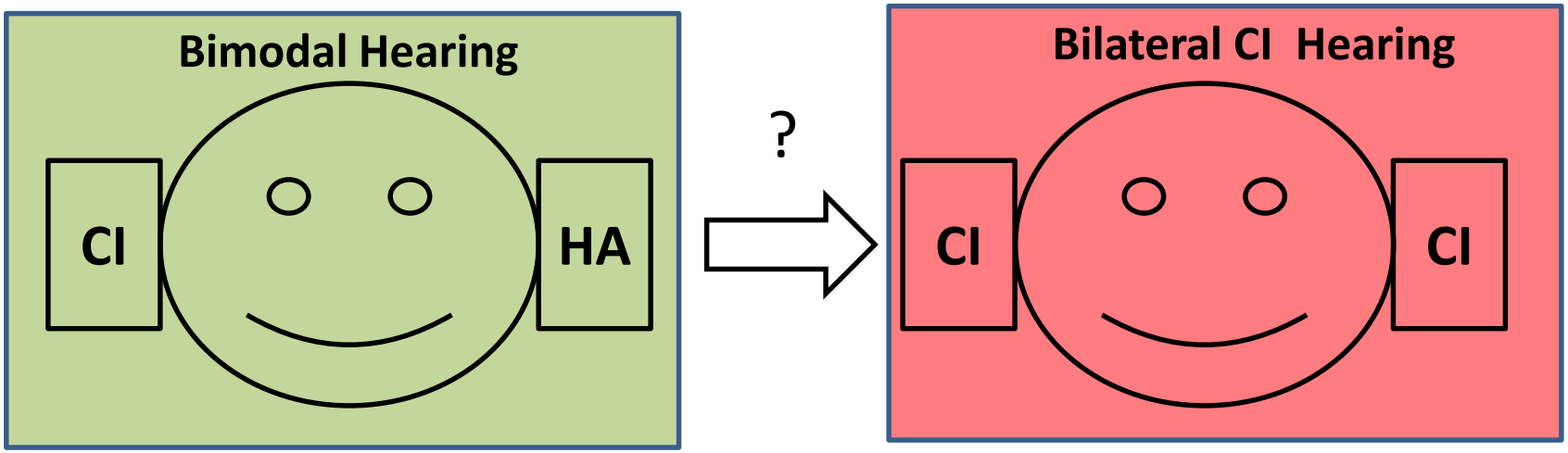
Deutsches HörZentrum Hannover

Medizinische Hochschule Hannover

Evaluation of bilateral and bimodal implantation in realistic sound environments and its consequences for indication criteria

Introduction

- Binaural hearing is essential to understand speech in noisy environments
- Bilateral cochlear implantation (BiCI) has the potential to rehabilitate binaural hearing
- Even with residual hearing in the contralateral ear of a CI binaural hearing is limited
  - It is crucial to investigate potential binaural benefits of a second implant



Introduction

- Laboratory settings play an important role in evaluation of binaural hearing
- Several studies have shown a gap in binaural speech performance measured in lab. conditions and in real conditions (e.g. Smeds et al., 2006)
  - No benefit of BiCIs in lab. conditions (Binaural Summation, Squelch, Spatial Release from Masking)
  - But subjective satisfaction of BiCIs in real acoustic environments

Goals

- The goal of this study is:
  - To assess potential binaural speech performance benefits of bimodal stimulation
  - To assess potential binaural speech performance benefits of bilateral implantation
  - To compare binaural speech performance between BiCIs and BiMOs

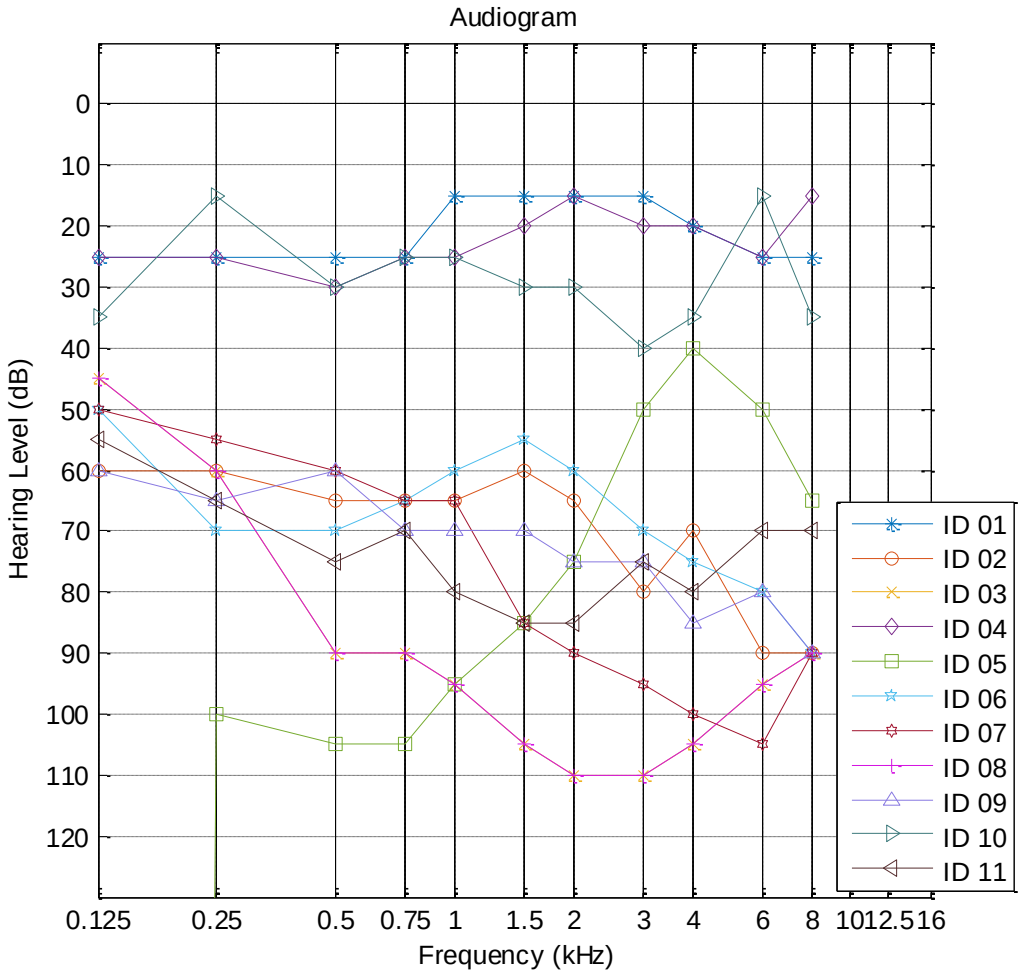
Methods

- Subjects
  - 10 Normal hearing (NH) subjects (Control group)
  - 12 BiCIs (Postlingual/Symmetric Performance/Experience >1 year)
  - 11 BiMOs (Experience with CI > 1 year)
- Materials and Methods
  - OLSA Sentence Test in Noise
    - Speech reception threshold (SRT = SNR@50% understanding)
    - Matrix Sentence test in noise (Sound field recording of a cafeteria)
  - SRT with different loudspeaker configurations
    - Classic laboratory conditions
      - Binaural Summation, Squelch, Spatial Release from Masking
    - Realistic acoustic virtual environment (TASCAR) [1]

[1] Toolbox for acoustic scene creation and rendering, Grimm et al 2015

Audiogram BiMOs

- 11 Bimodal CI users (BiMOs)
- Subjects that wear a CI and have sufficient residual hearing (to not be implanted)
- BiMOs were tested with their own HA

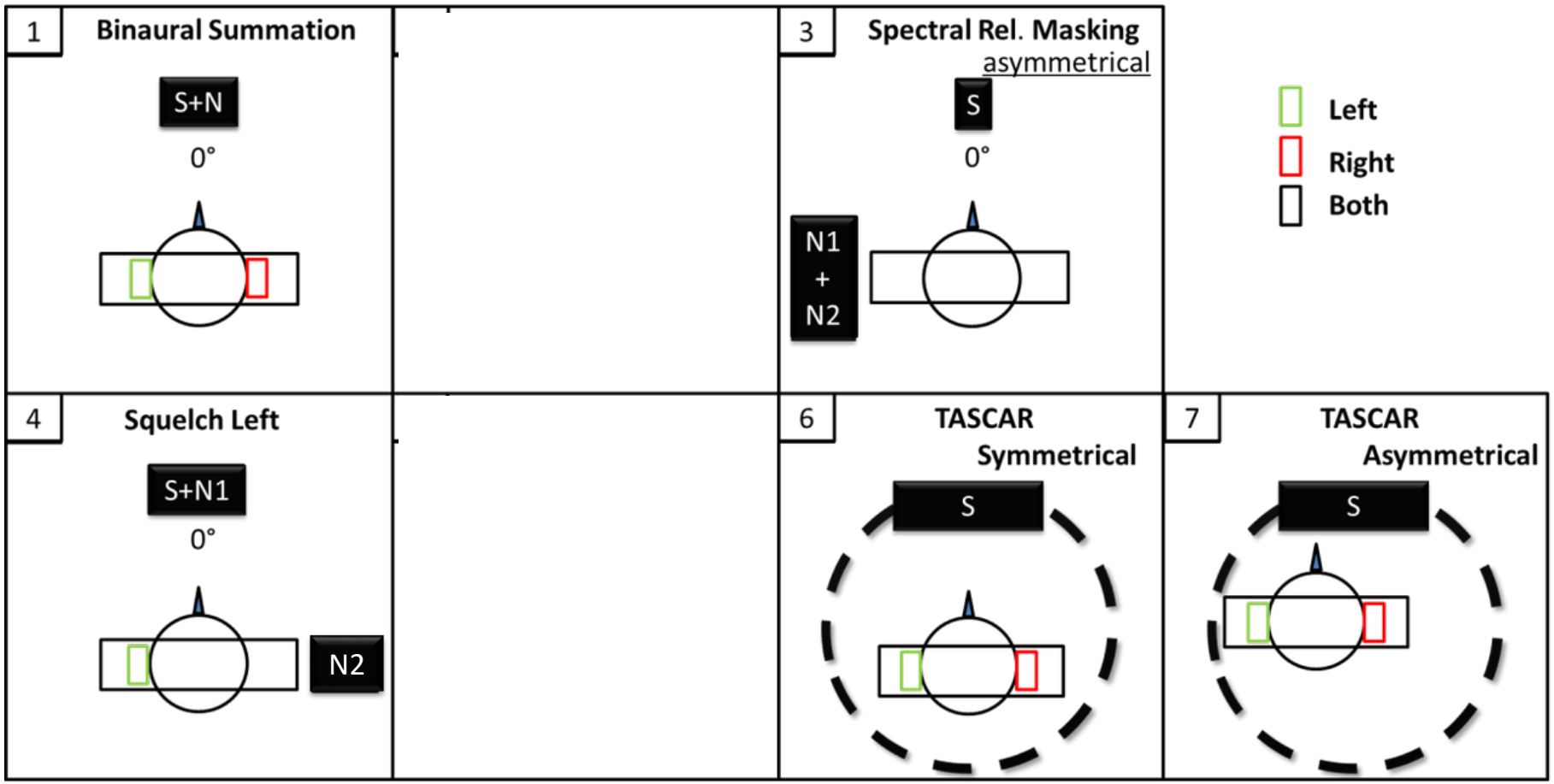


Evaluation Binaural Performance

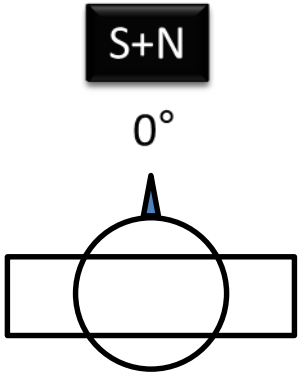
- TASCAR system [1]
- 16 Loudpspeakers (r = 4.40 m)
- Ambisonics Order 7
- Soundfield recording of Cafeteria Noise
- Image Model
  - Reflectivity, Damping

[1] Realistic Environment Simulation G. Grimm, V. Hohmann (Uni. Oldenburg, H4all)

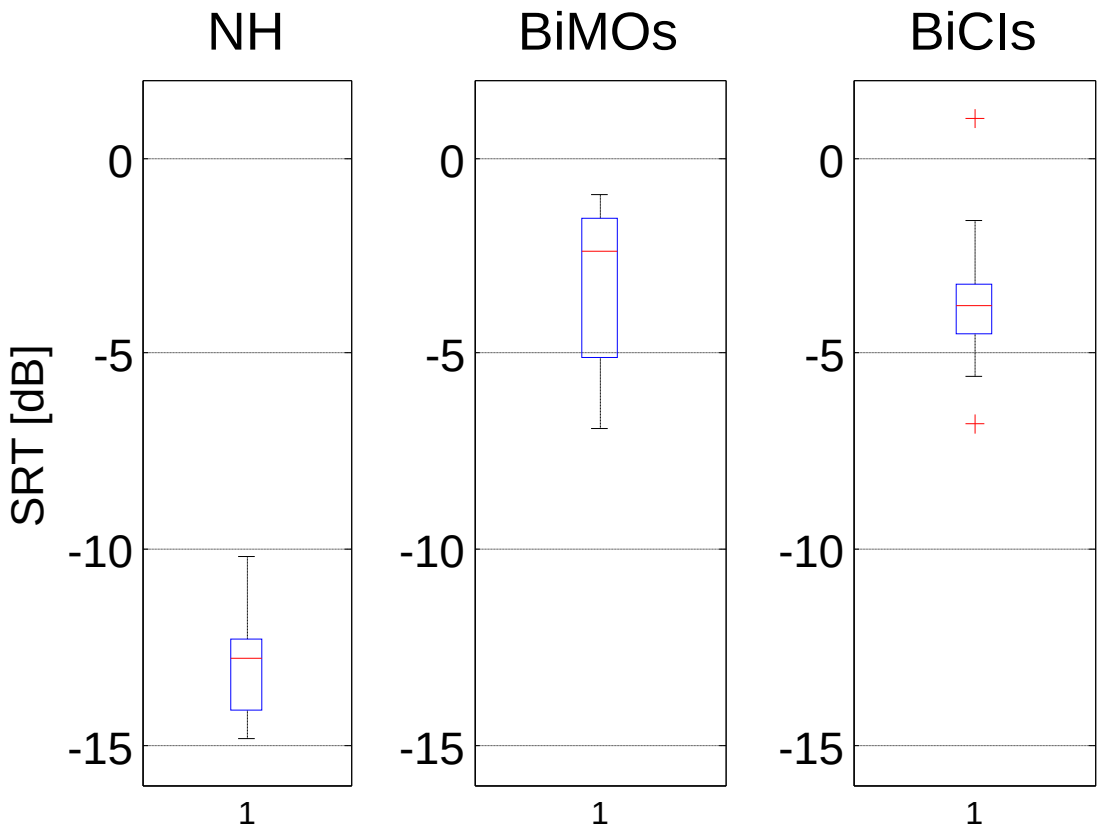
Methods
Test Setups



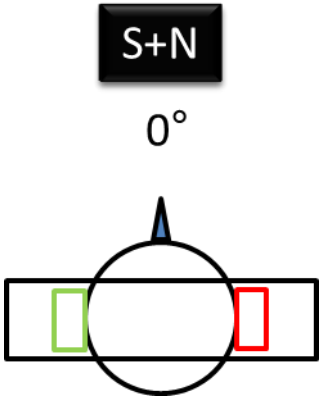
Results
Performance using both ears



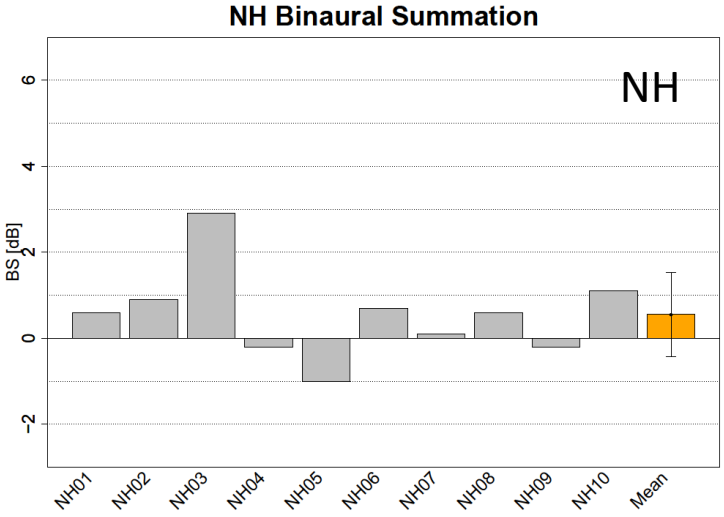
$BS(dB)=SRT_{best\_side}-SRT_{both}$

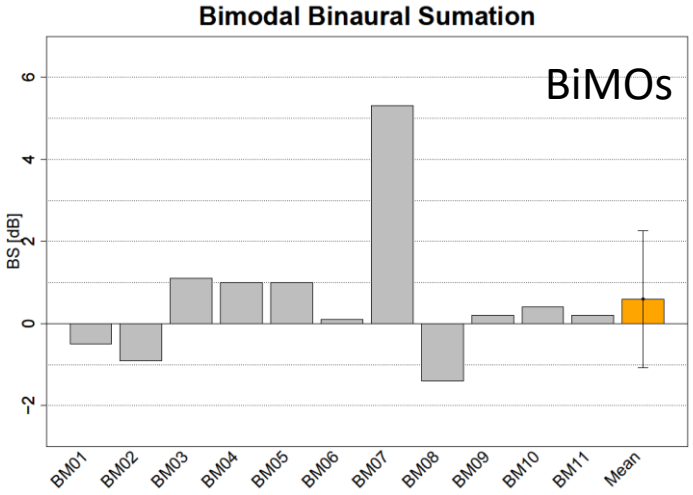


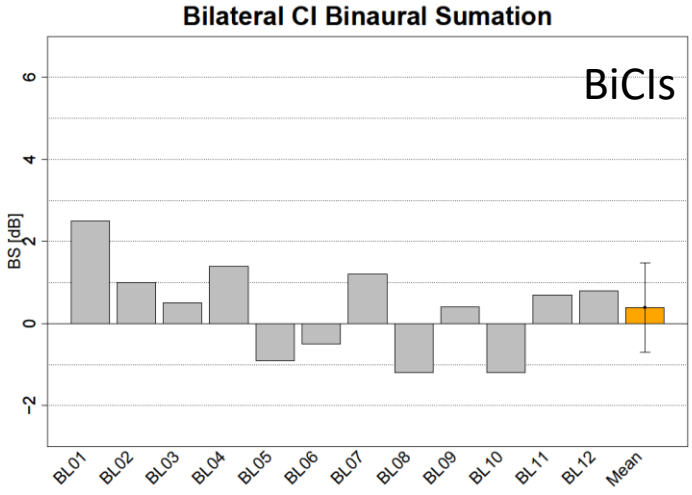
Results
Binaural Summation



$BS(dB) = SRT_{best\_side} - SRT_{both}$

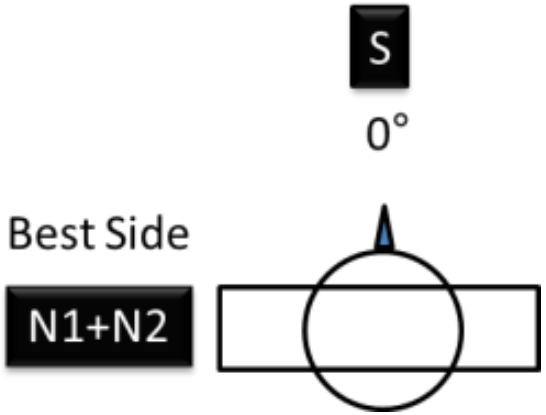


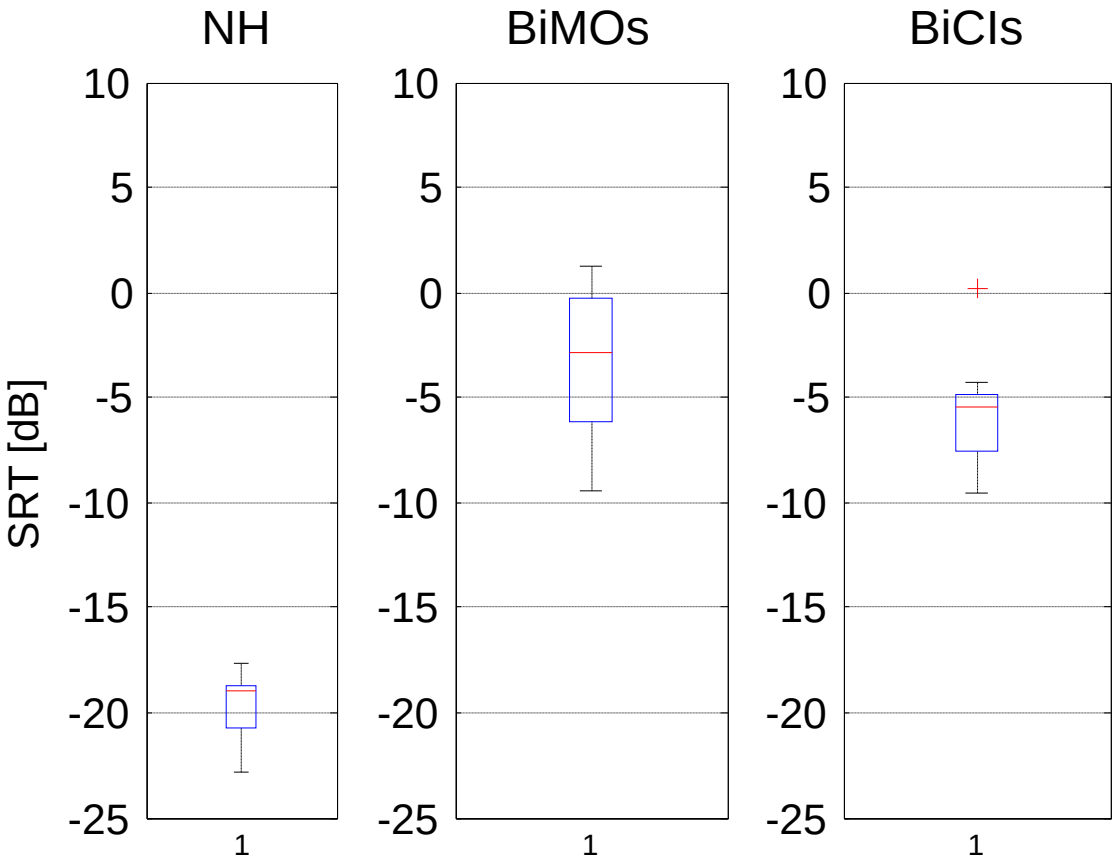




Results
Performance with both ears

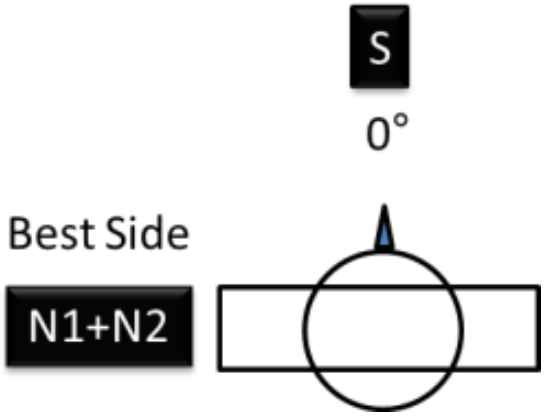
$SRM_{ASYM}(both) = SRT_0(Both) - SRT_{90,90}(Both)$

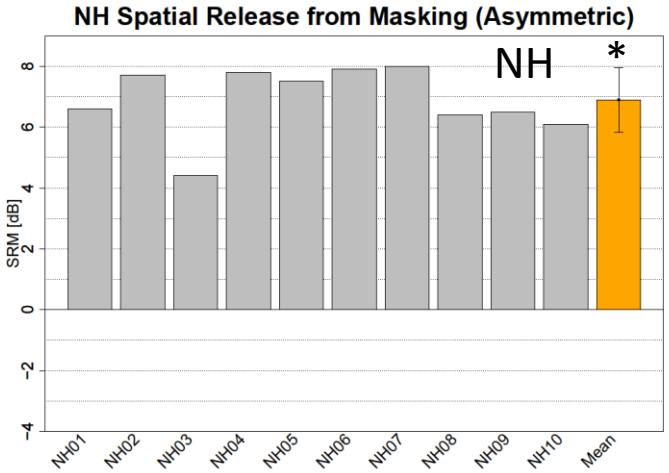


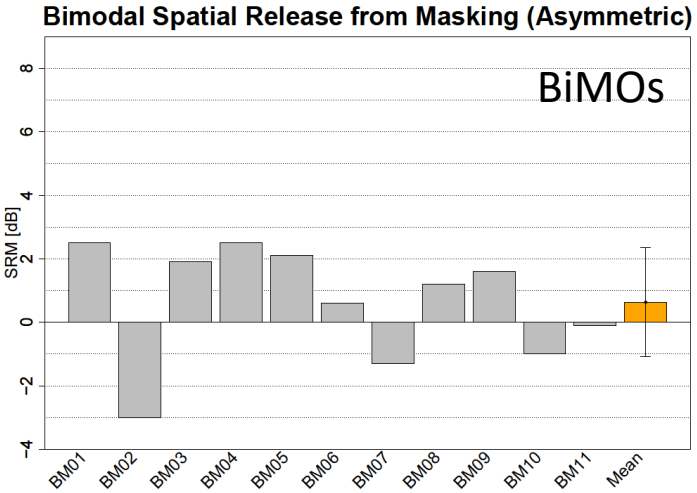


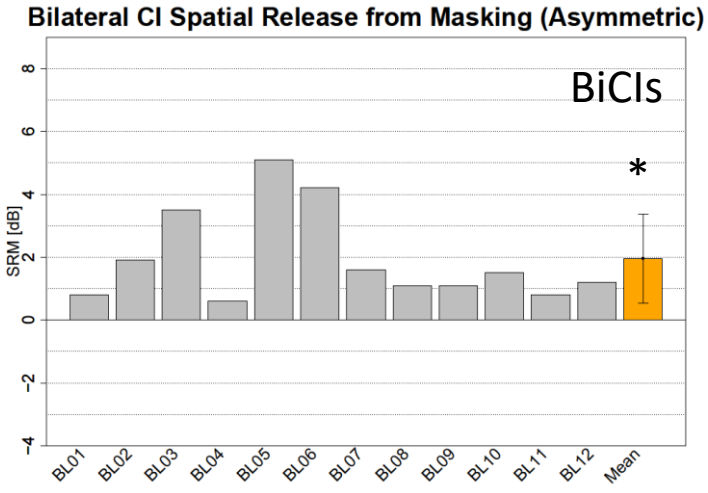
Results
Spatial Release Masking Asymmetric

$SRM_{ASYM}(both) = SRT_0(Both) - SRT_{90,90}(Both)$



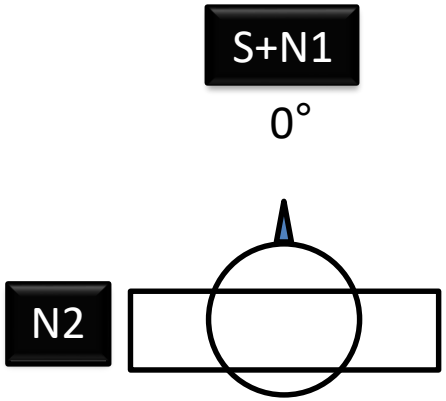




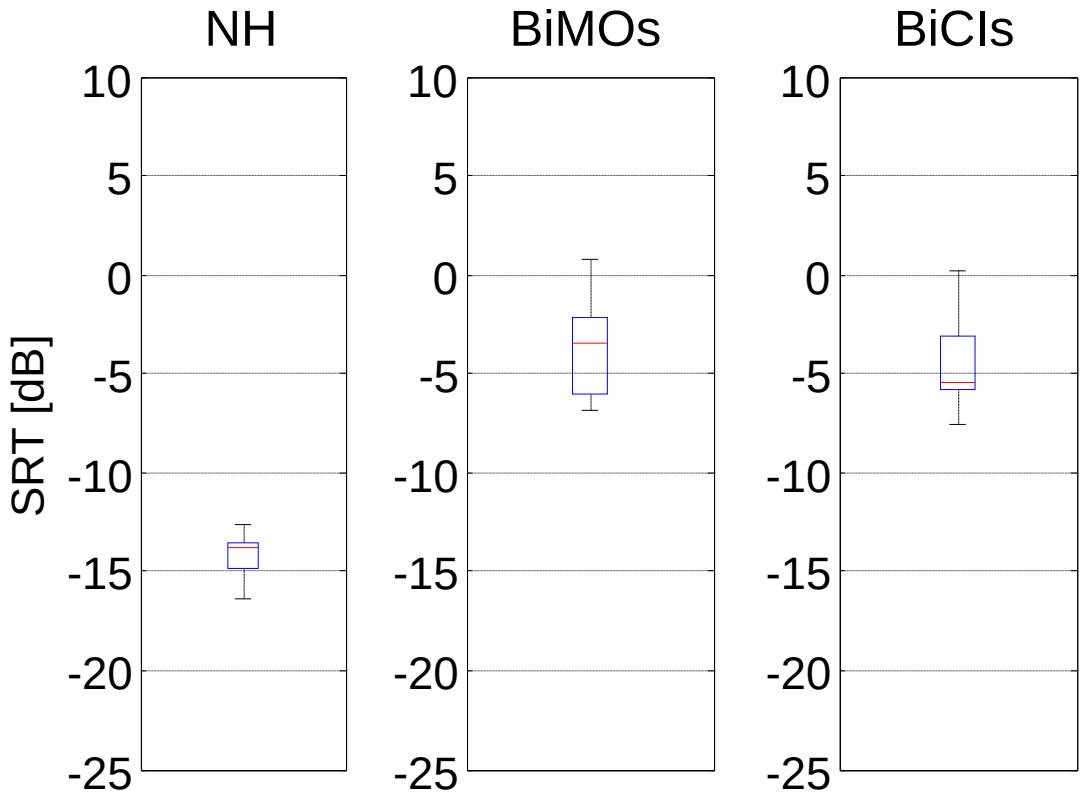


Results
Performance with both ears

$SQ_{right} = SRT_{-90,0}(right) - SRT_{90,0}\ (Both)$

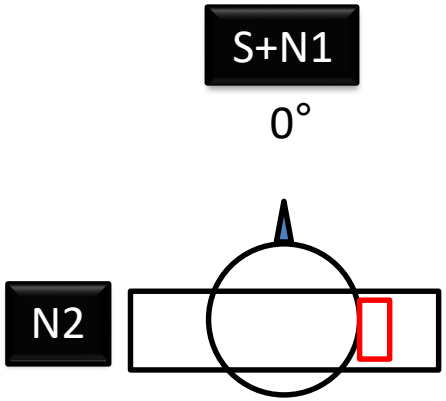


Best score

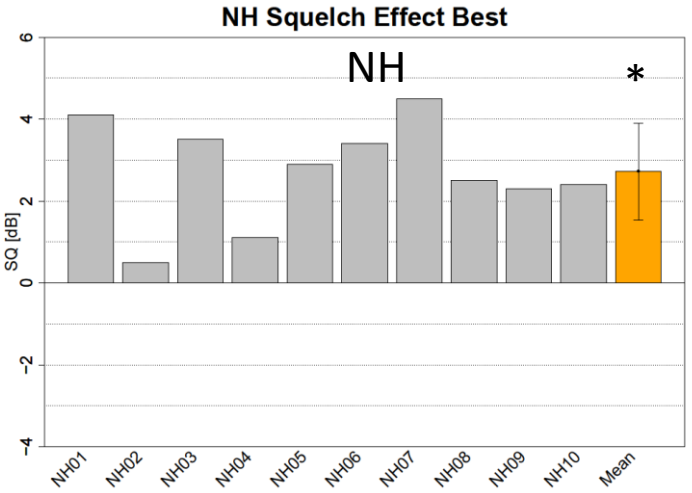


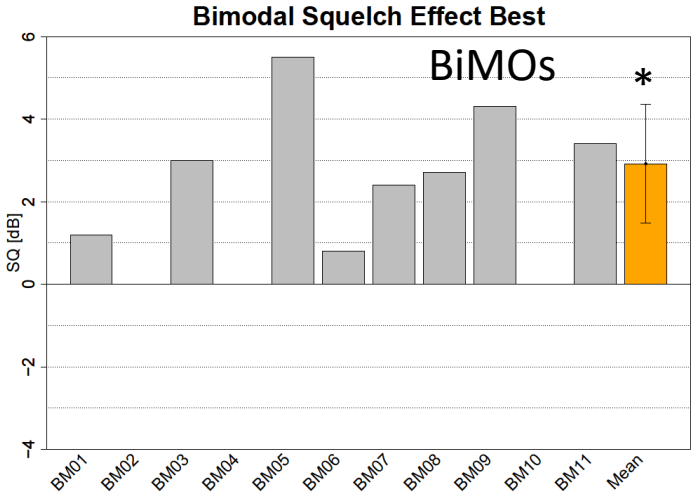
Results
SQUELCH Effect

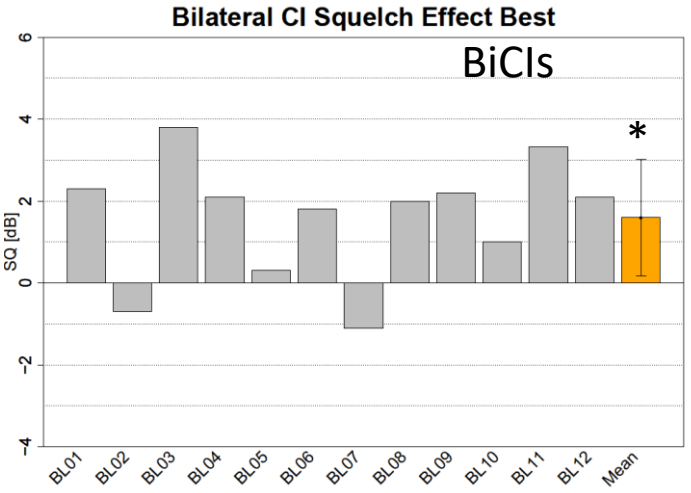
$SQ_{right} = SRT_{-90,0}(right) - SRT_{90,0}(Both)$



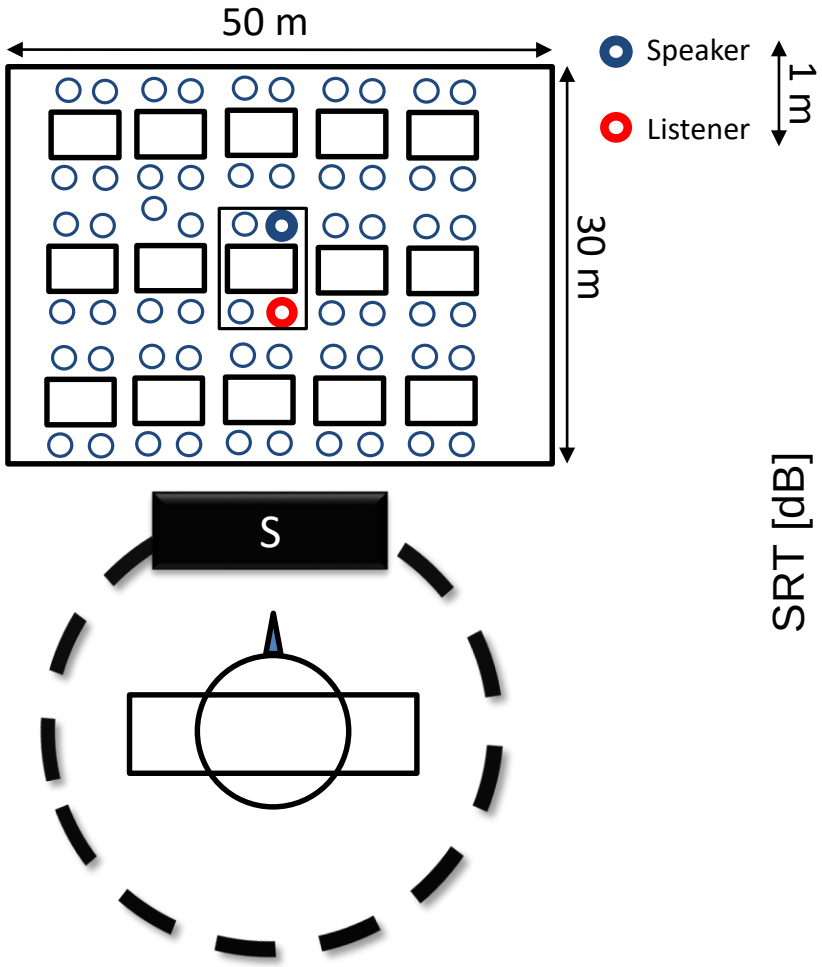
Best score

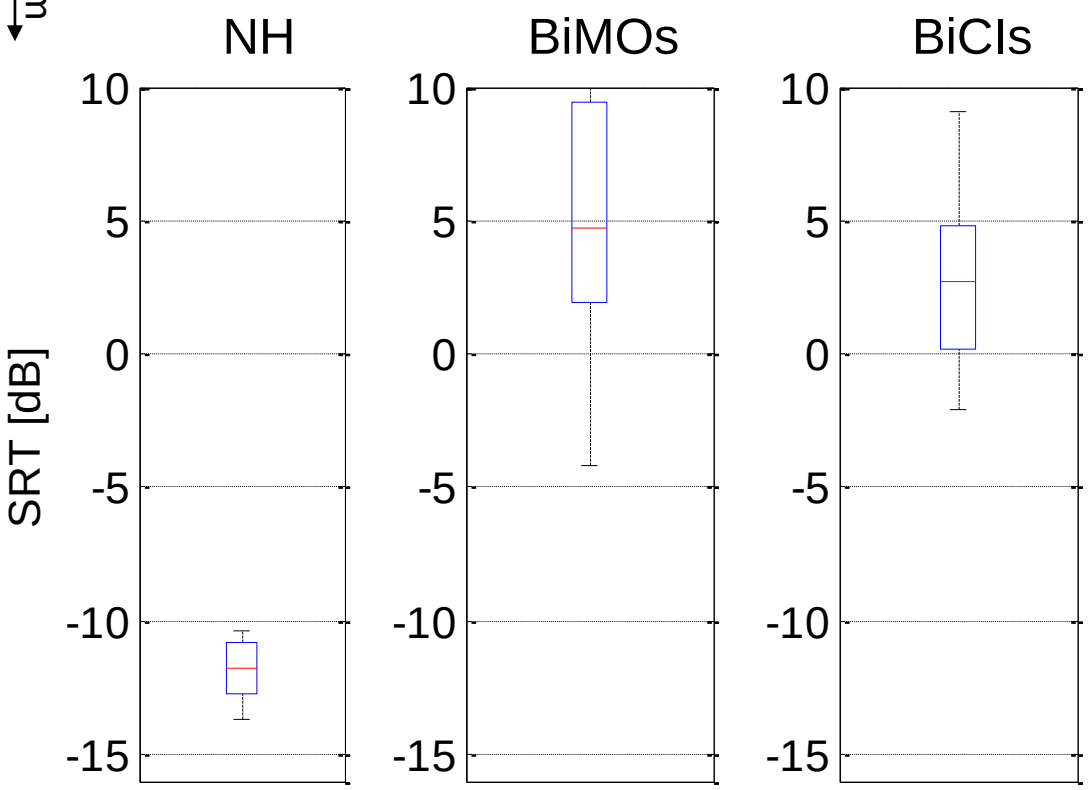






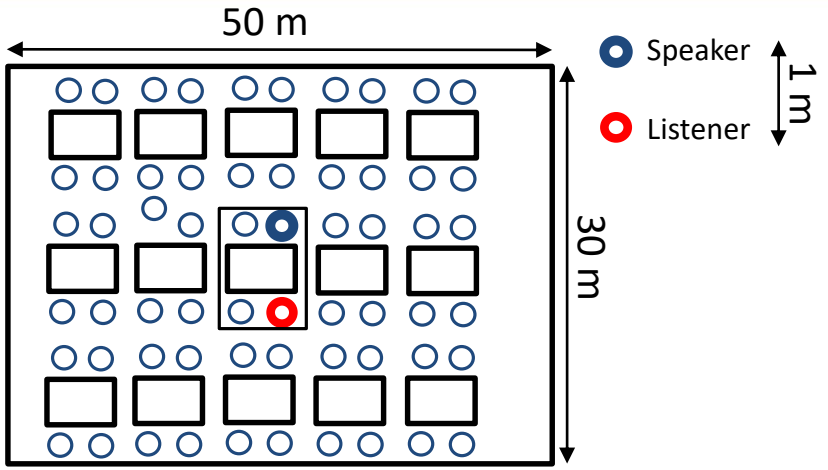
TASCAR Symmetric Results with both ears

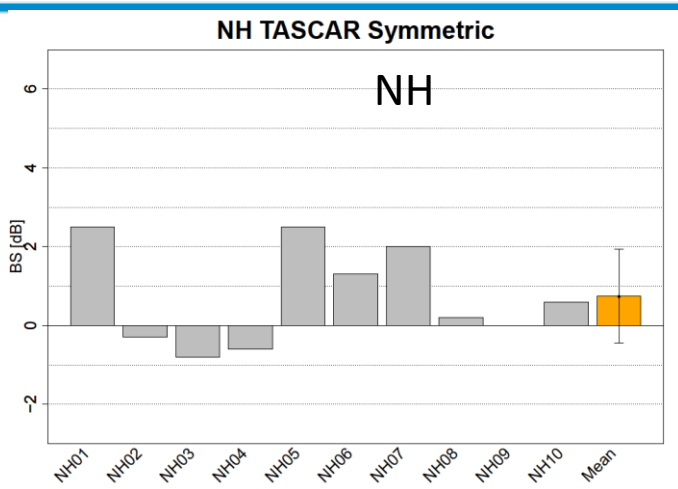


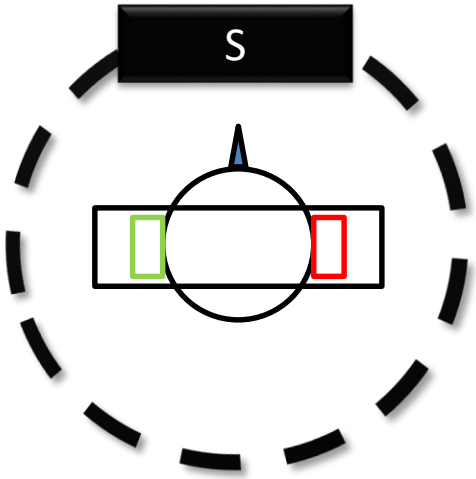


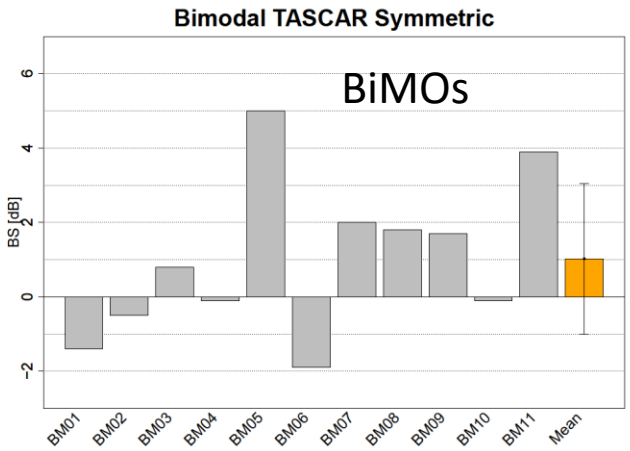
$BS_{TASCARsym,\ asym} = SRT_{\Omega}(lc) - SRT_{\Omega}\ (Both)$

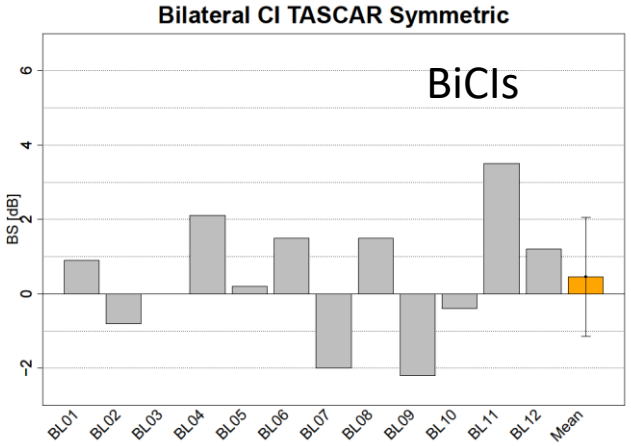
TASCAR Symmetric Binaural Summation





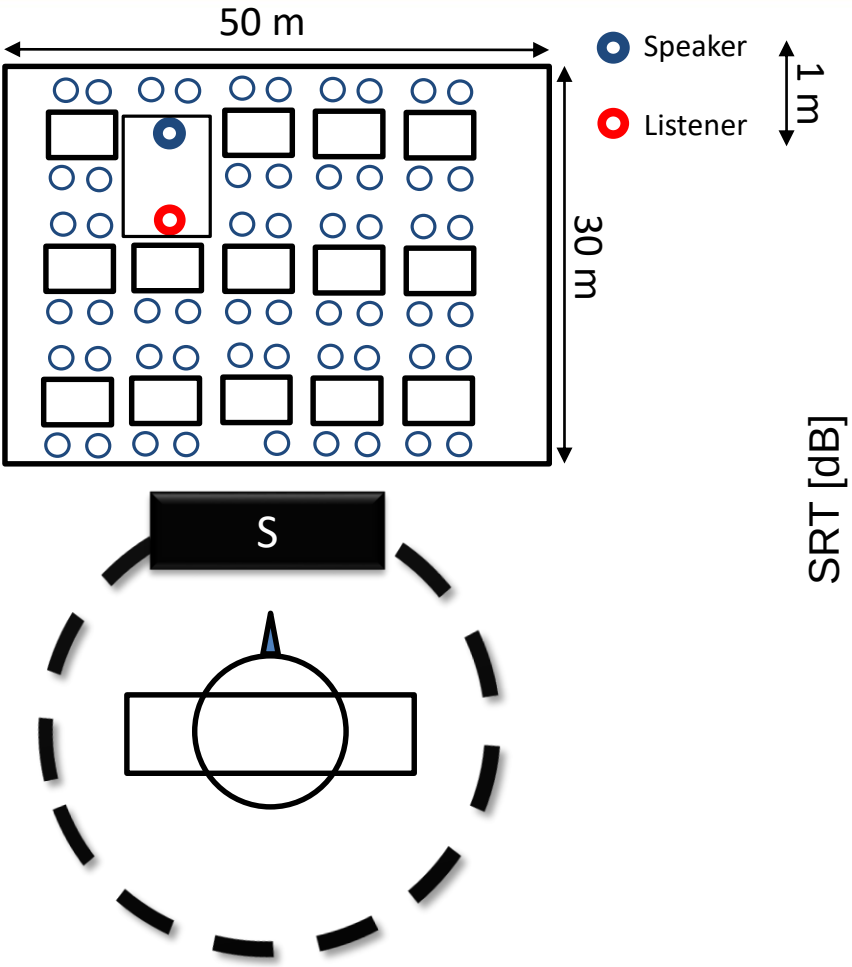


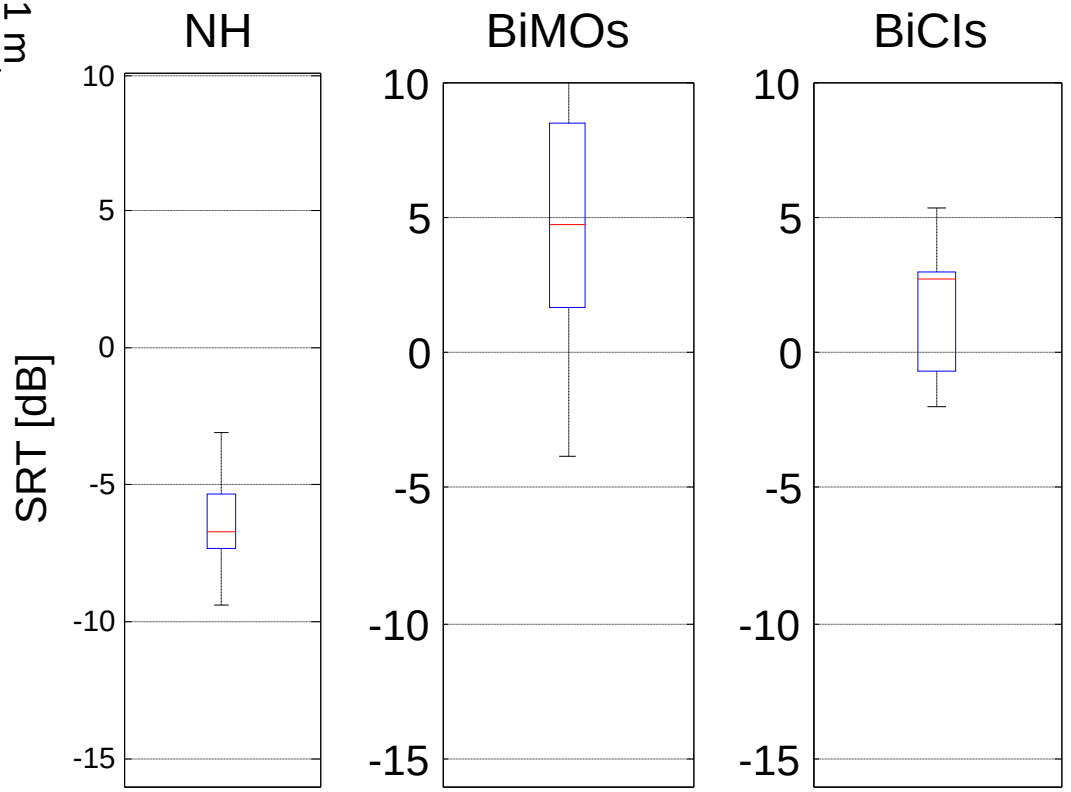




$$BS_{TASCARsym,\ asym} = SRT_{\Omega}(lc) - SRT_{\Omega}\ (Both)$$

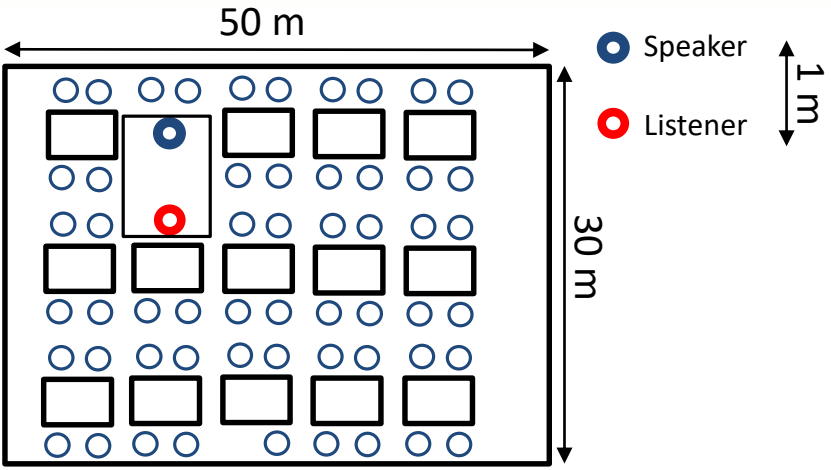
TASCAR Asymmetric Binaural Summation

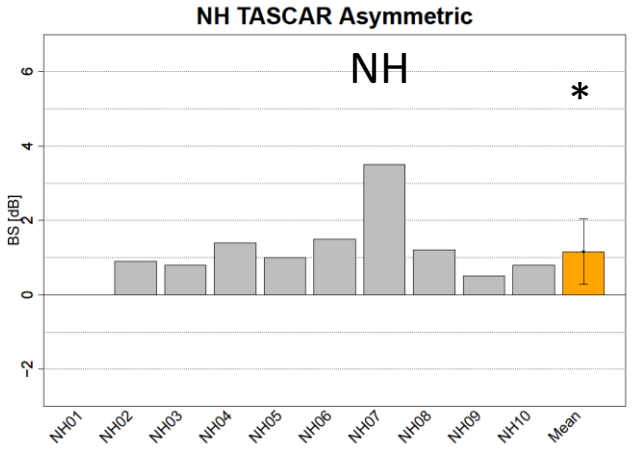


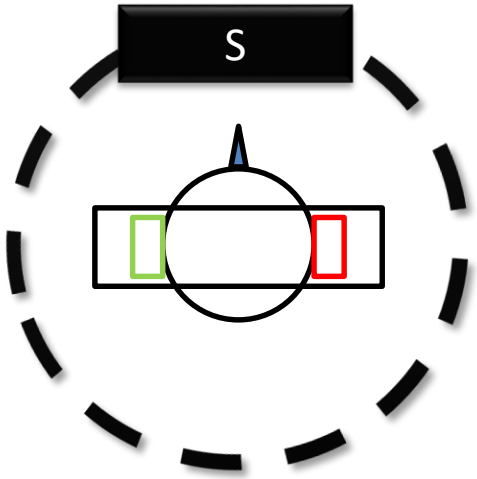


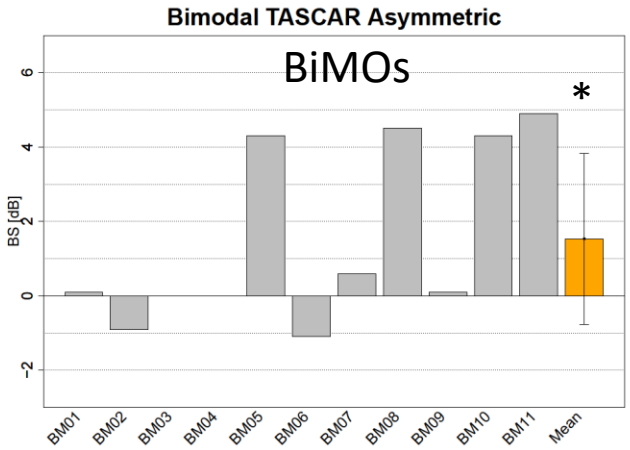
$$BS_{TASCARsym,\ asym} = SRT_{\Omega}(lc) - SRT_{\Omega}\ (Both)$$

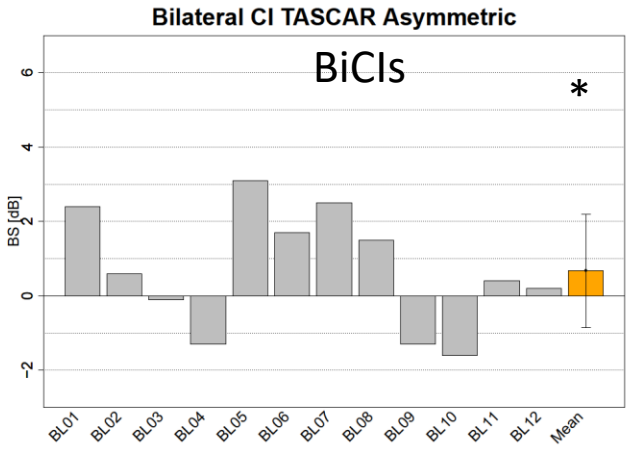
TASCAR Asymmetric Binaural Summation











$$BS_{TASCARsym,\ asym} = SRT_{\Omega}(lc) - SRT_{\Omega}\ (Both)$$

Summary

- Performance in BiCIs is simlar to BiMOs with good residual hearing
- BiCIs show increased spatial release from masking than BiMOs
  - SRM is not a „true“ binaural effect
  - Having symmetric ears as in BiCIs may explain this result
- Squelch effect in BiMOs is significant and larger than in BiCIs
  - Increased spectral resolution and coding of temporal fine structure on the acoustic side may explain this result
- BiMOs obtain larger binaural benefits in realistic acoustic environments.

Consequences for implantation criteria

- In Germany a second CI is implated if residual hearing is larger than 65 dB HL at around 500 Hz and monosylable speech scores in quiet are below 60%
- It seems that BiCIs cannot recover binaural hearing altough BiCIs provide bilateral benefits (Spatial Release from Masking-Head Shadow)
- Advantages of BiCIs in comparison to BiMOs with good residual hearing cannot be demonstrated and monaural implantation criteria seems reasonable if good residula hearing on the acoustic side exists

Hearing 4all

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Thank you

DFG Deutsche Forschungsgemeinschaft