Electric-Acoustic Stimulation: Evaluation of speech intelligibility and its relationship with electrical-acoustic interaction

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12.10.2022

Milan

Medizinische Hochschule Hannover, Cluster of Excellence “Hearing4all”, Hannover, Germany

Cochlear Implant with EAS

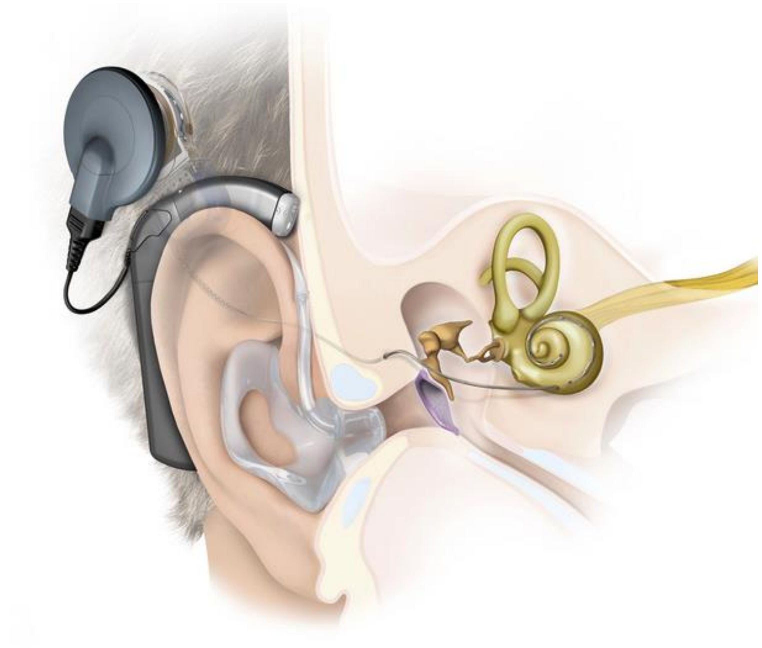
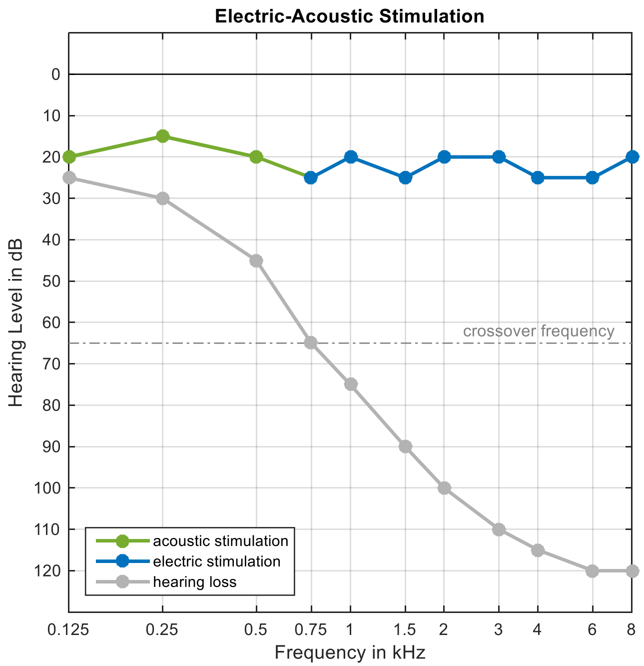


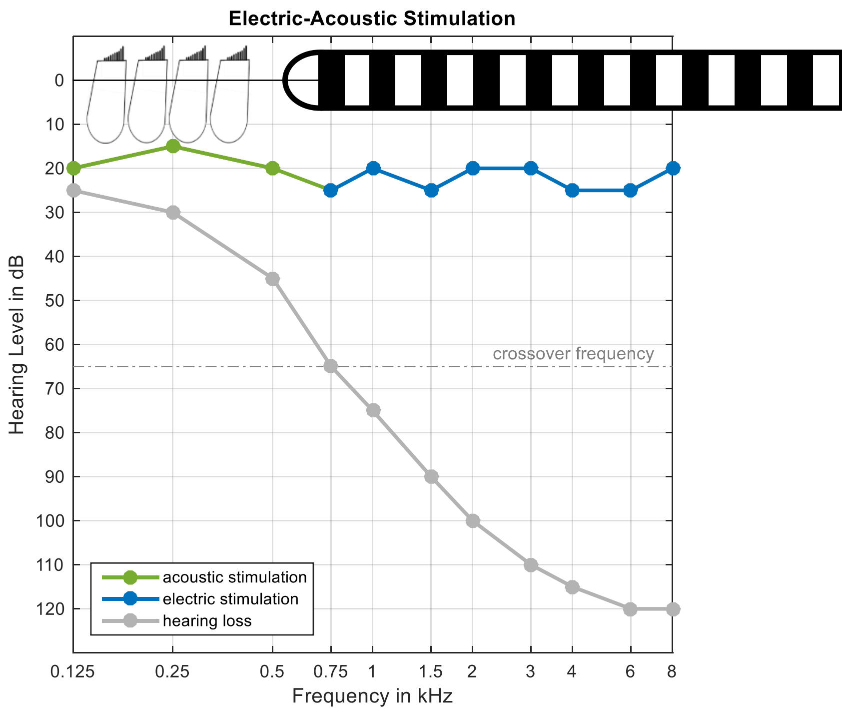
Figure from MED-EL



- Residual hearing preservation via flexible electrodes and atraumatic insertion
- Cochlear implant and hearing aid in a sound processor
- Residual hearing at low frequencies (green) complements stimulation through cochlear implant (blue)
  - Results in more natural hearing and improved speech perception

Cochlear Implante with EAS

Figure from MED-EL



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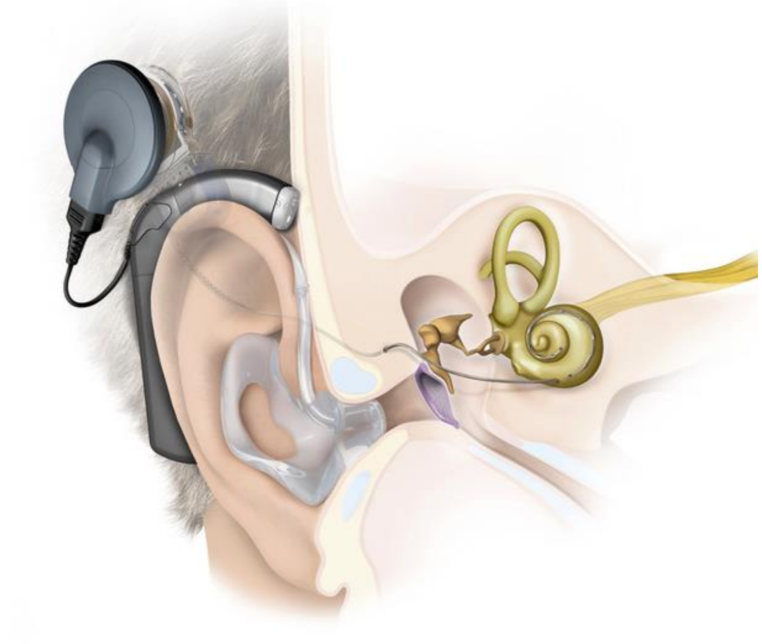
Cochlear Implant with EAS



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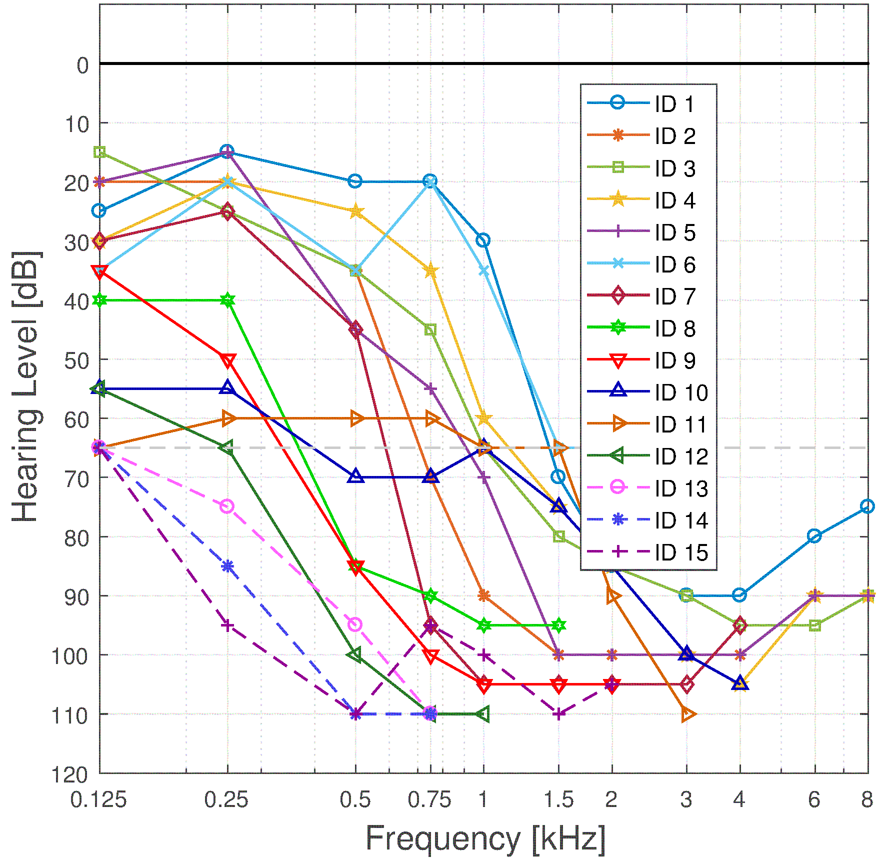
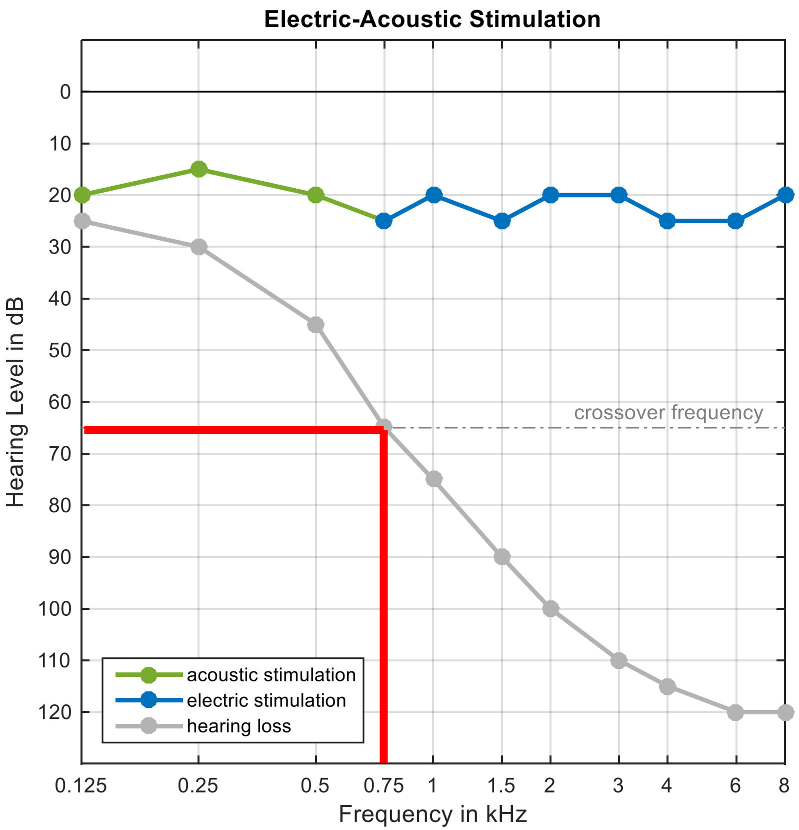


https://de.wikipedia.org/wiki/Elektrisch-akustische_Stimulation

- More and more patients with residual hearing in the low frequencies use a CI

Cochlear Implant with EAS

- Cross Over Frequency (CoF)



EAS Fitting

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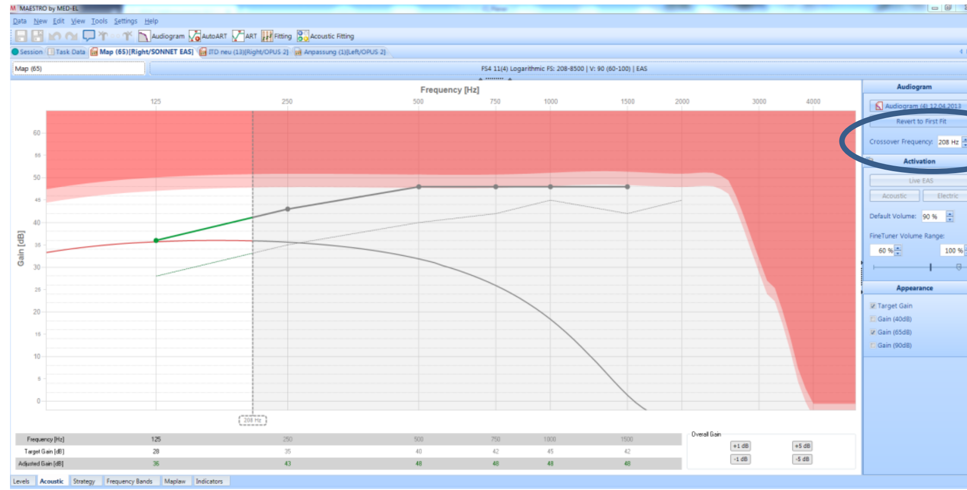
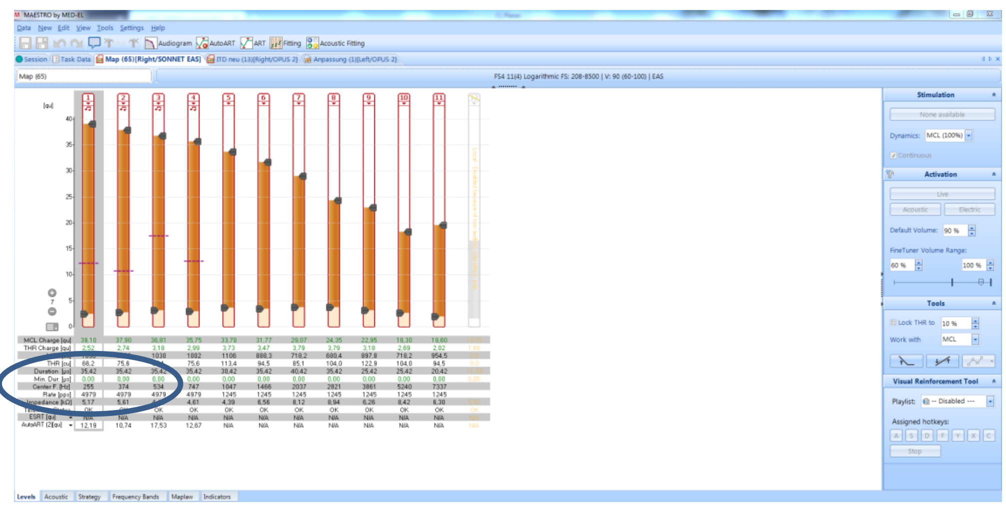
- Acoustic Component
  - CoF: Cross-Over-Frequency
  - Amplification



CoF

- Cochlear Implant
  - CoF: Cross-Over-Frequency
  - Current level



CoF

2. Motivation

- Motivation
  - It is not clear which fitting is optimal for EAS users. Which frequencies should be transmitted to the acoustic and electrical part?
    - What amplification should be configured in the acoustic part?
    - Is there an interaction between acoustic and electrical stimulation?
    - Does the interaction have to be taken into account in the fitting?
- Hypothesis
  - Performance with the EAS system may be limited by the interaction between electrical and acoustic stimulation.
    - Some EAS users do not use the acoustic component.
    - Some EAS users need more time to obtain maximum performance compared to cochlear implant users.

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Medizinische Hochschule Hannover

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→ Optimization of the EAS System is necessary!

2. Methods:
Optimization of the EAS system

Hearing4all

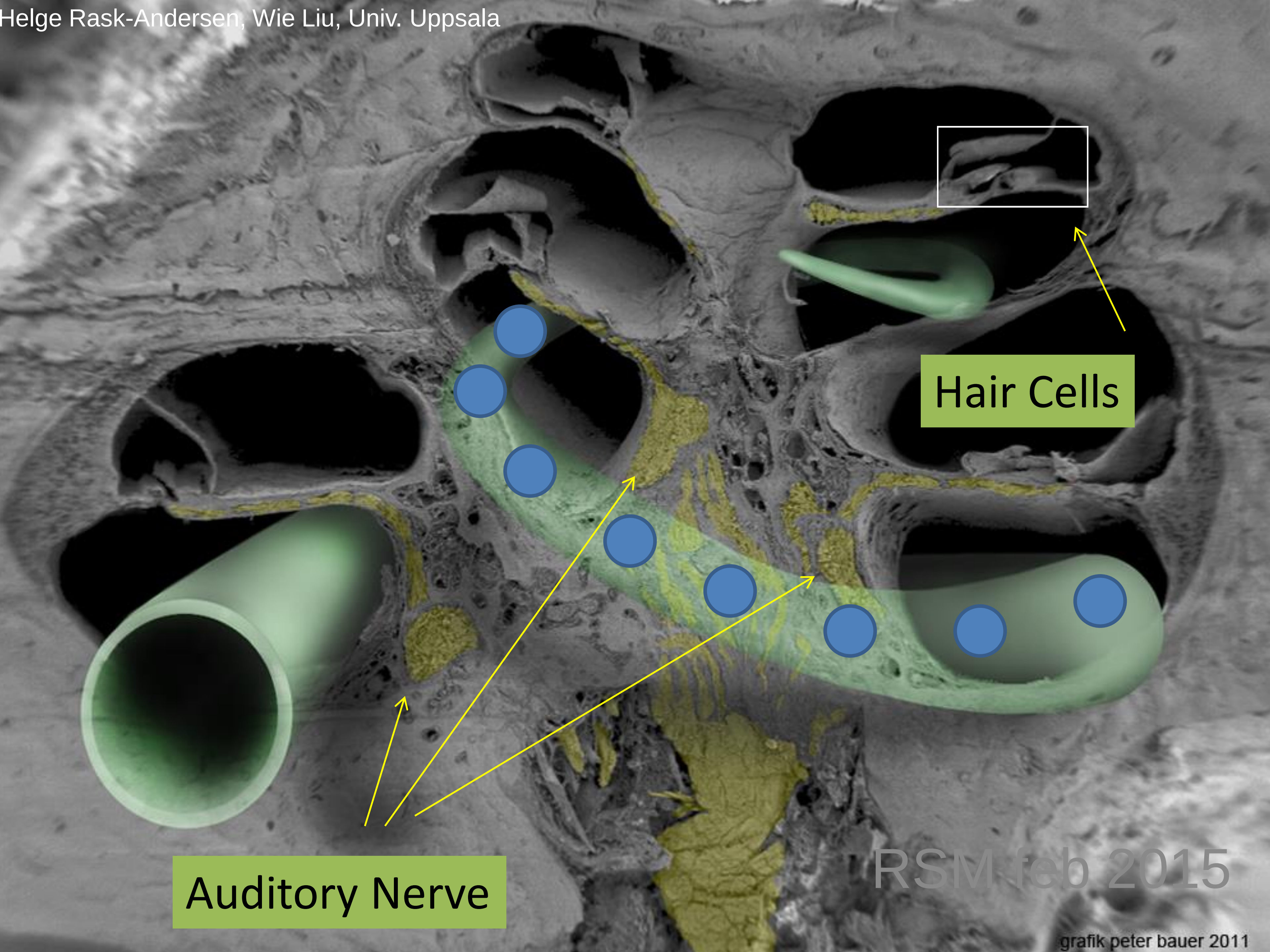
Medizinische Hochschule Hannover

- Characterization of EAS interaction
  - Electrode-nerve interface analysis
  - Psychoacoustic measurements
  - Electrophysiological measurements (ECochG)

- Development of adaptation strategy for EAS

2. Methods: Electrode-Nerve Interface Characterization

- 1. Where are the electrodes located in the cochlea?

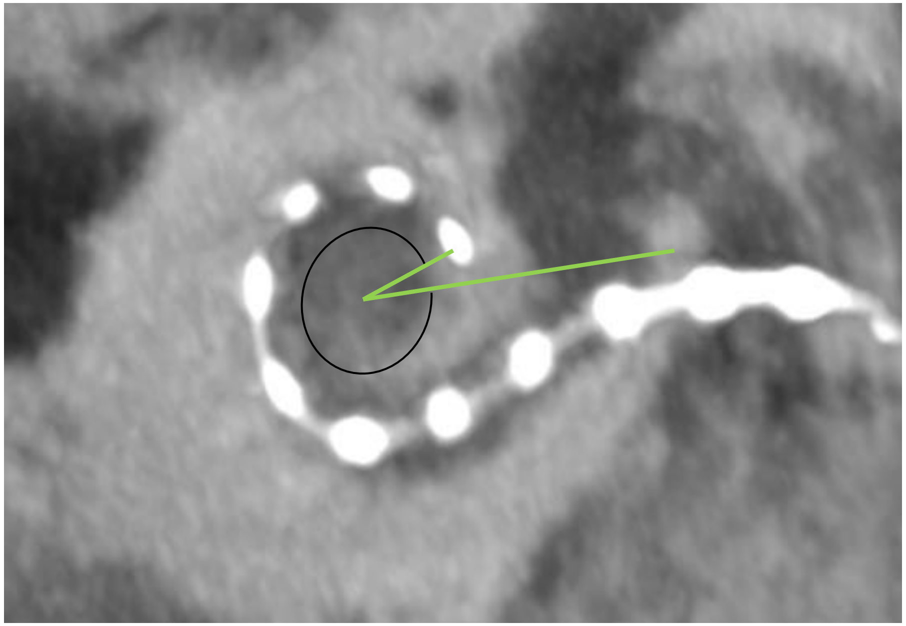


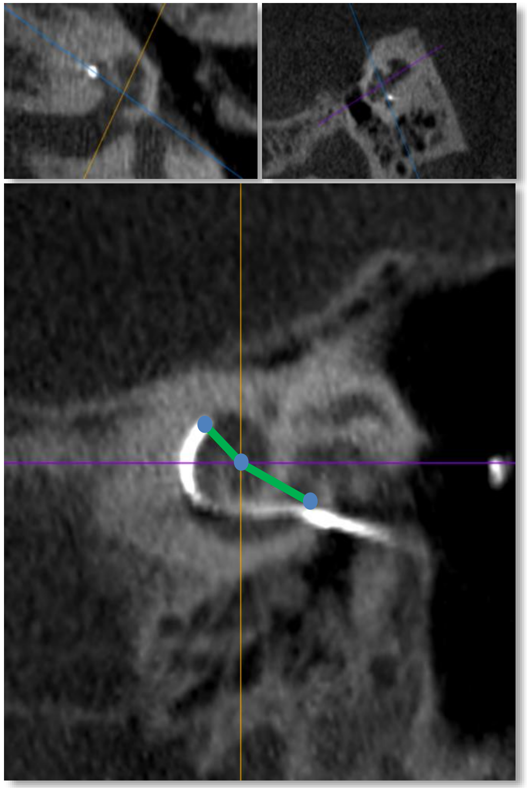
Helge Rask-Andersen, Wie Liu, Univ. Uppsala
Hair Cells
Auditory Nerve
RSM feb 2015
grafik peter bauer 2011

2. Methdos

- Where exactly are the electrodes located?

→ Computed tomography after cochlear implantation



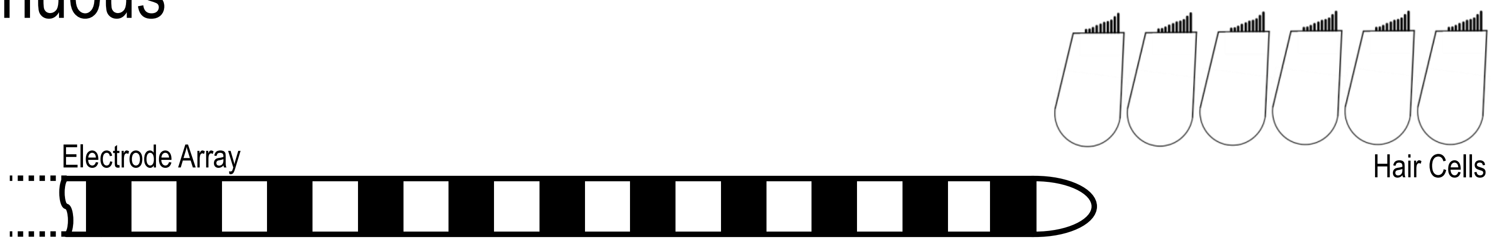


2. Methods: Characterization of the Electrode-Auditory Nerve Interface

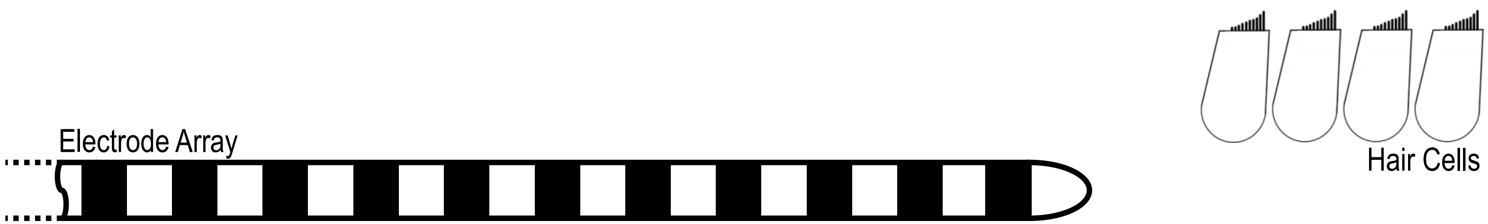
- 1. Where are the electrodes located in the cochlea?
- 2. What is the physical distance between the electrodes and the hair cells?

2. Methods: Which is the physical distance between the electrodes and the hair cells?

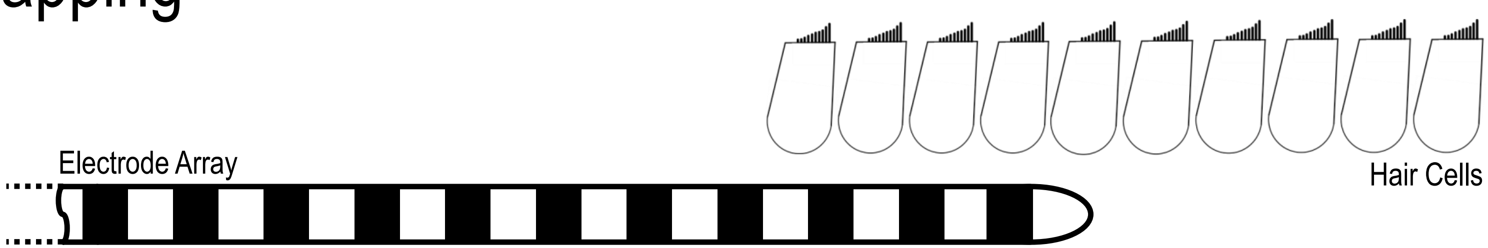
- Continuous



- Gap



- Overlapping



2. Methods:
Which is the physical distance between the electrodes and the hair cells?

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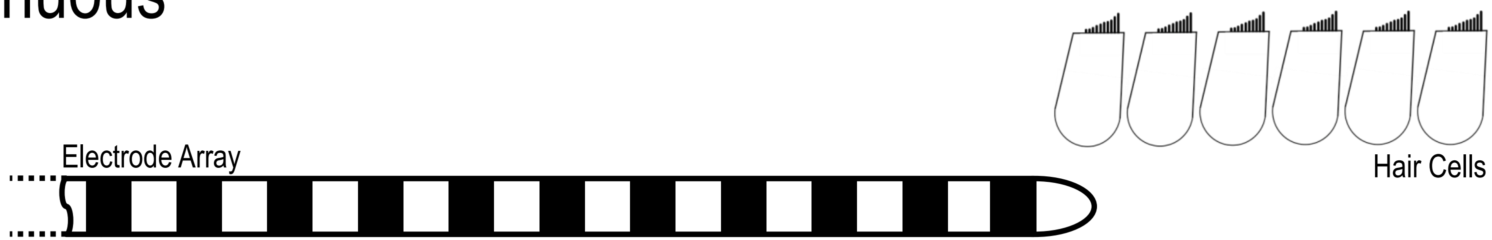

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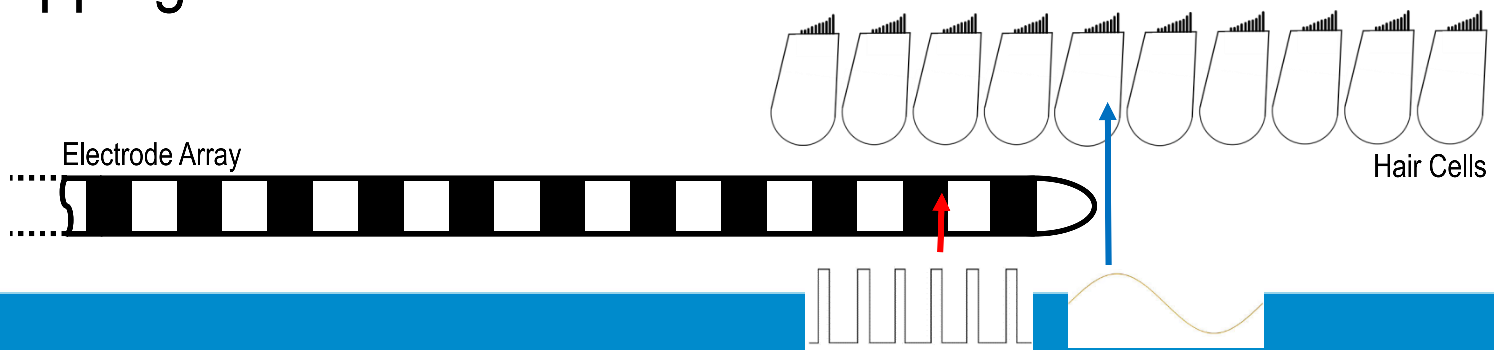

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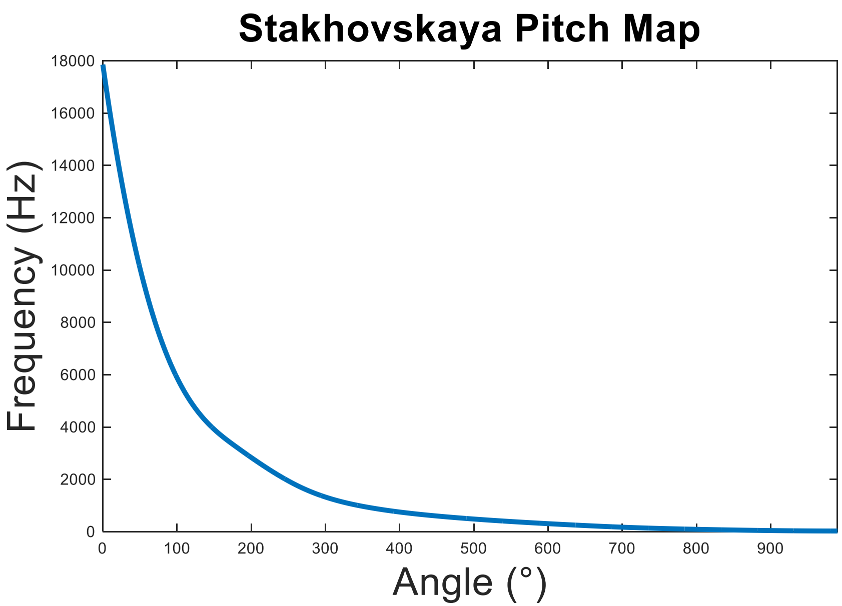

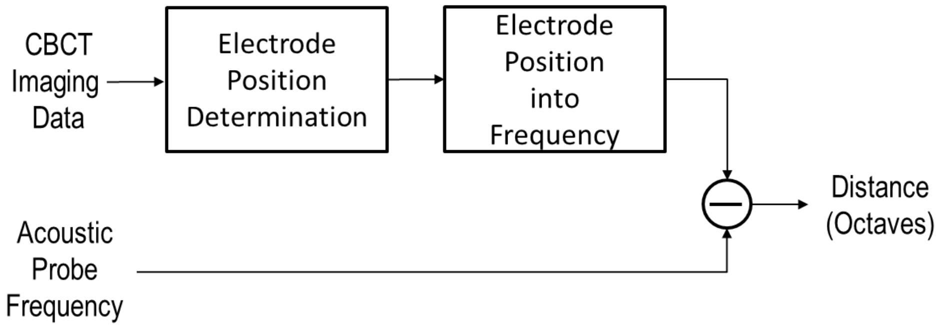

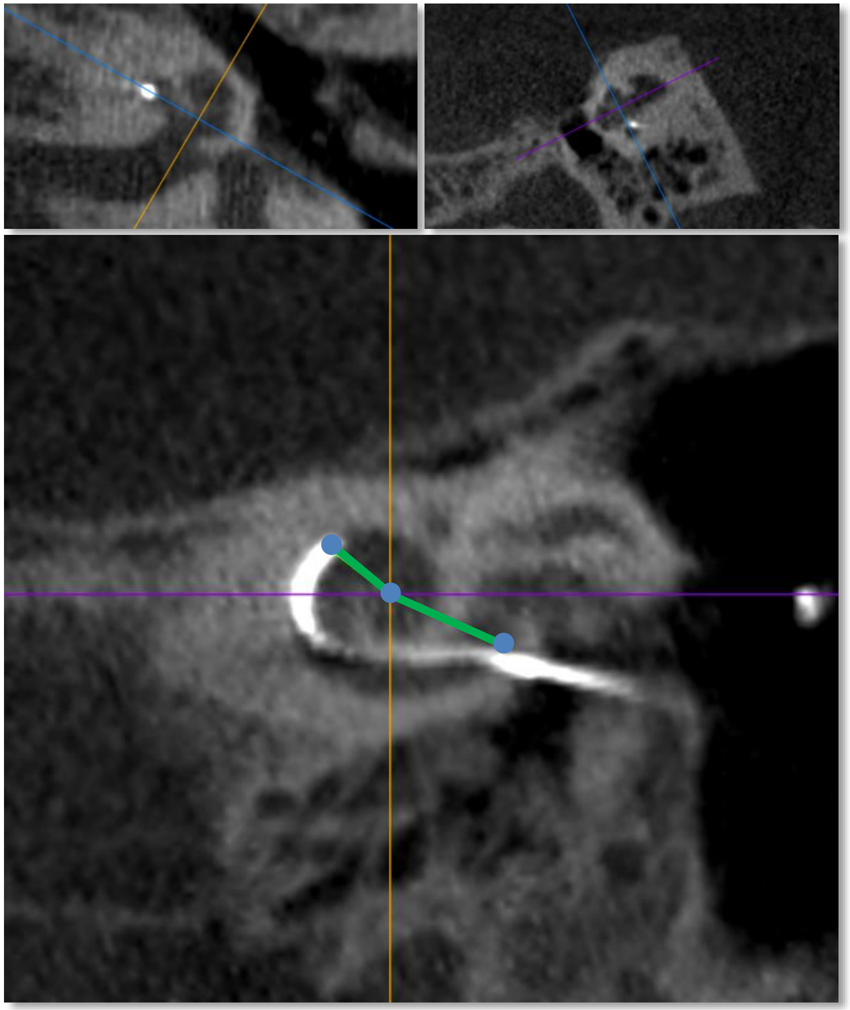

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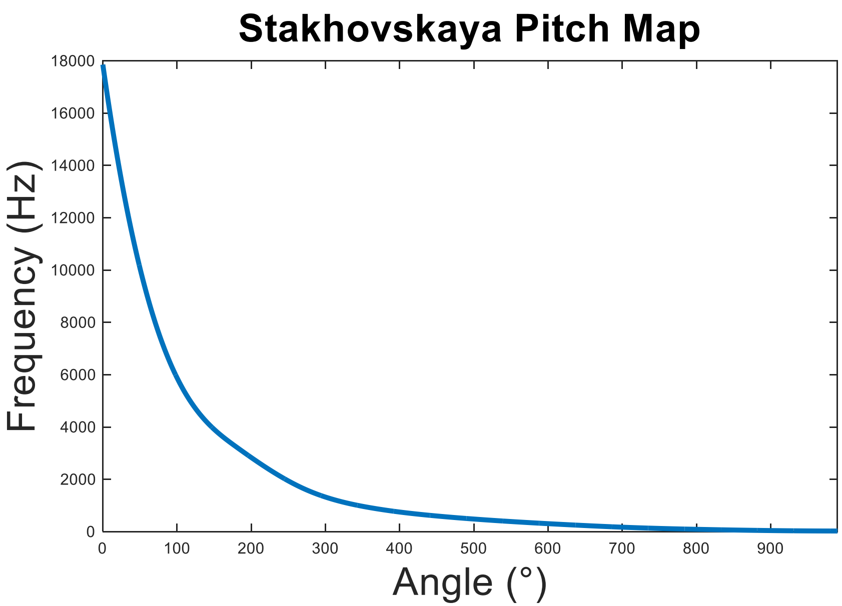
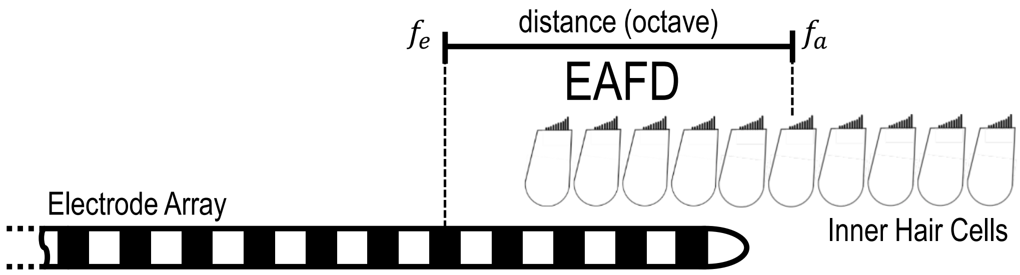
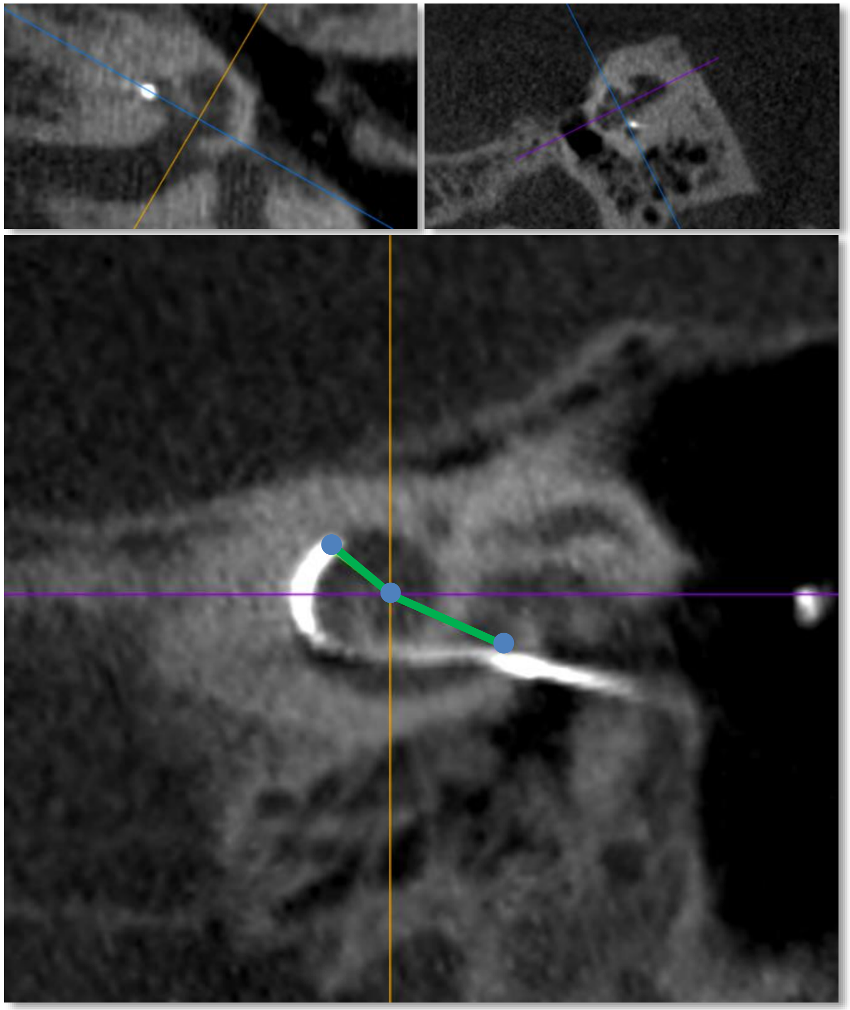


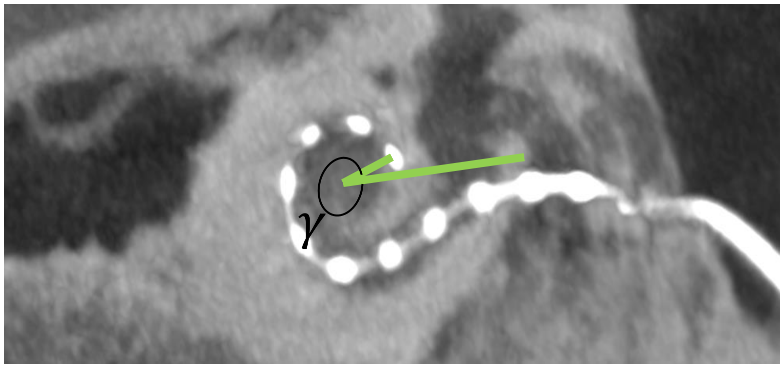


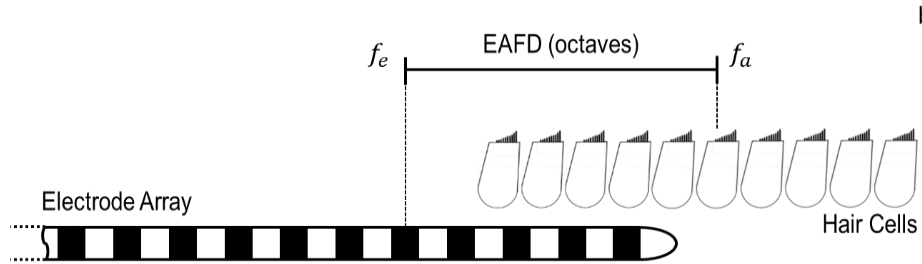


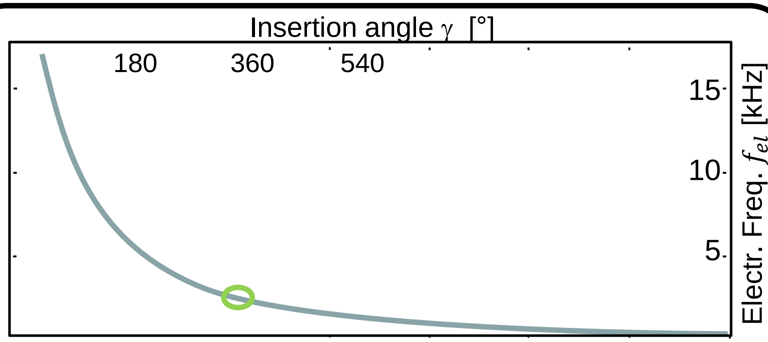
EAFD: Electric Acoustic Frequency Difference

Electric-Acoustic Frequency Difference (EAFD)

Measure of insertion angle







Place frequency

Spiral Ganglion Map

(Stakhovskaya et al., 2007)

f_{el}

$$EAFD = \log_2\left(\frac{f_{ac}}{f_{el}}\right)$$

Relation of frequencies

Acoustic Frequency f_{ac}

Methods: Characterization of the Electrode-Auditory Nerve Interface.

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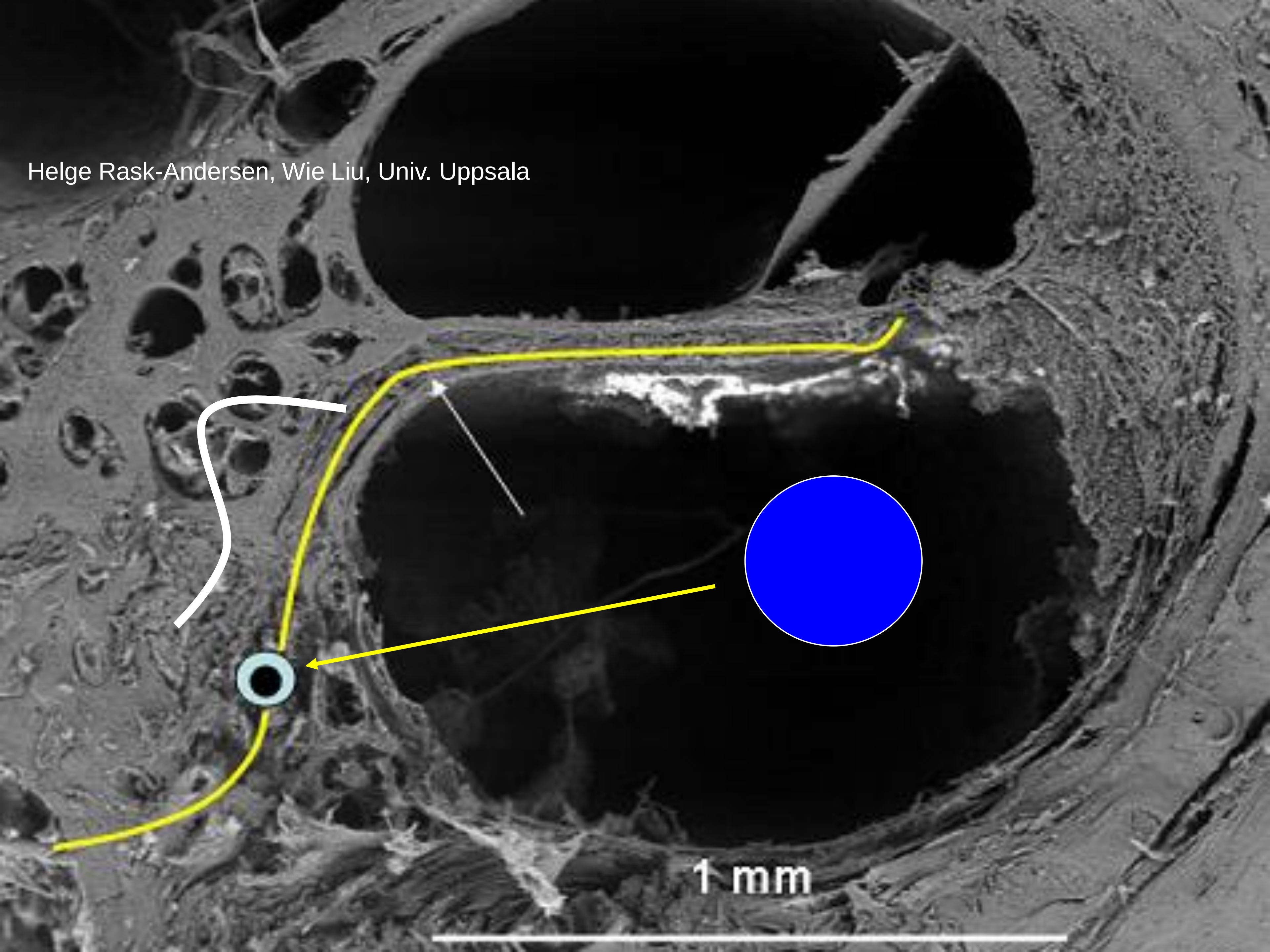
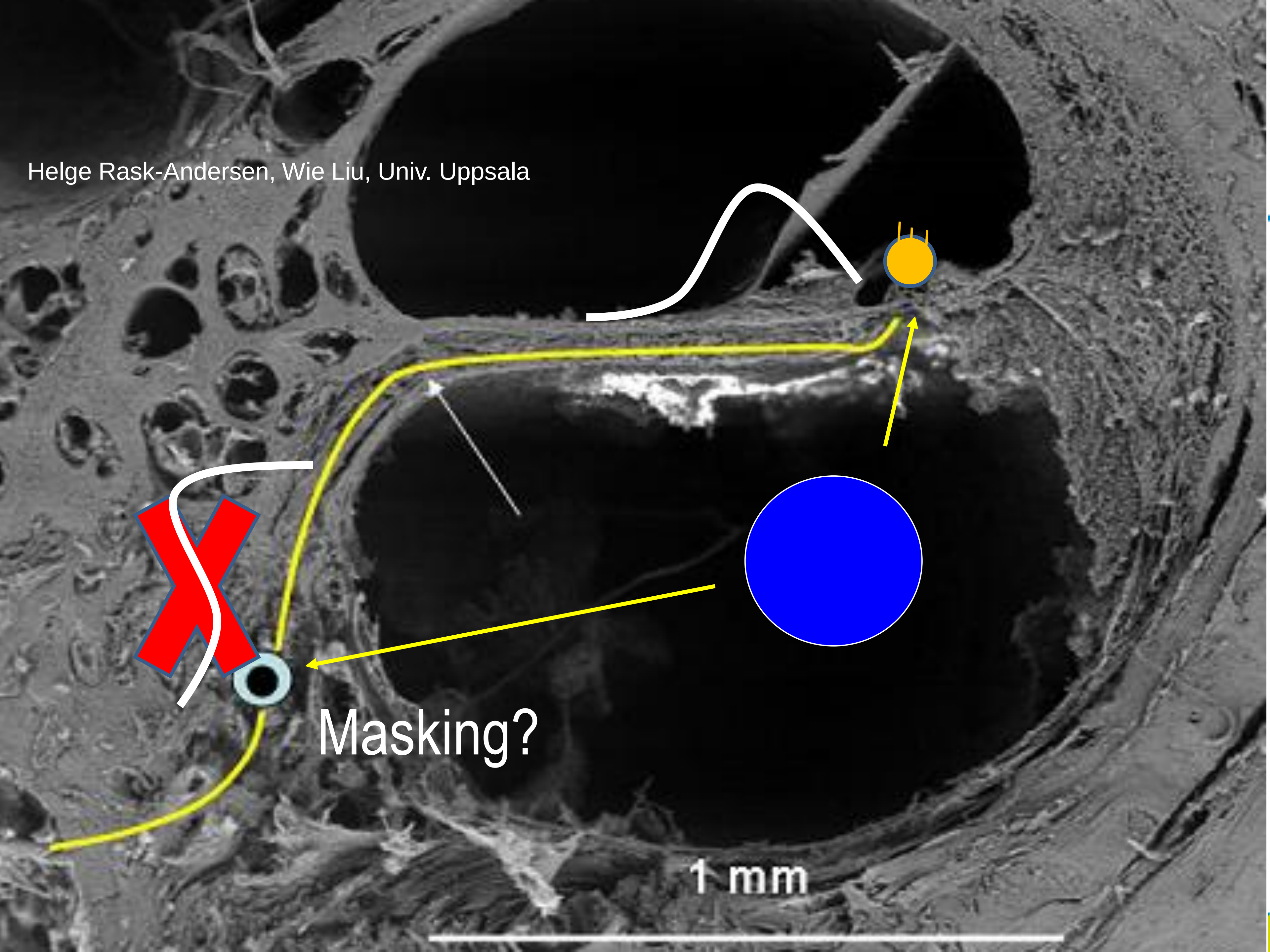

Helge Rask-Andersen, Wie Liu, Univ. Uppsala
1 mm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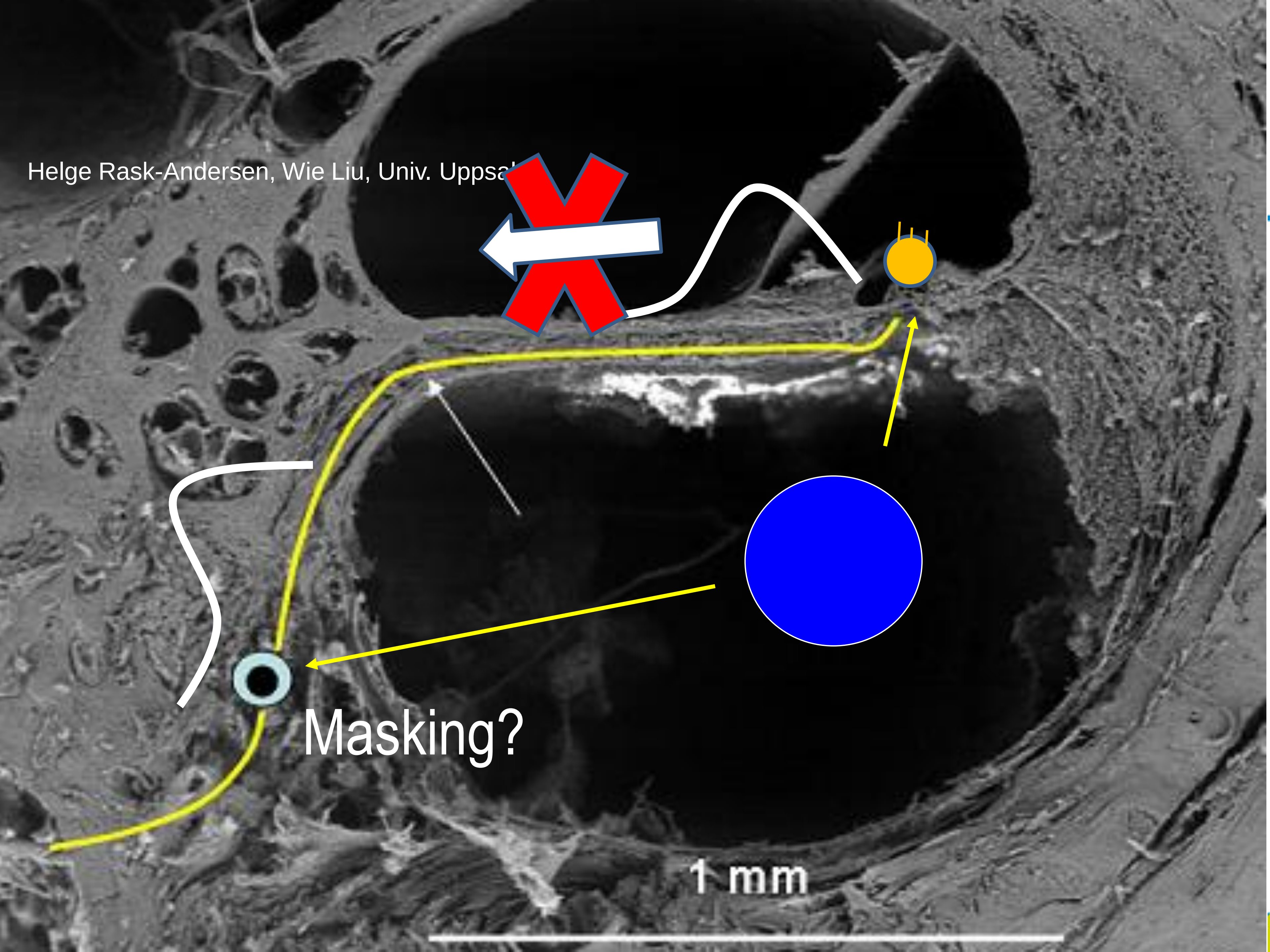
Masking?
1 mm


Helge Rask-Andersen, Wie Liu, Univ. Uppsa
Masking?
1 mm

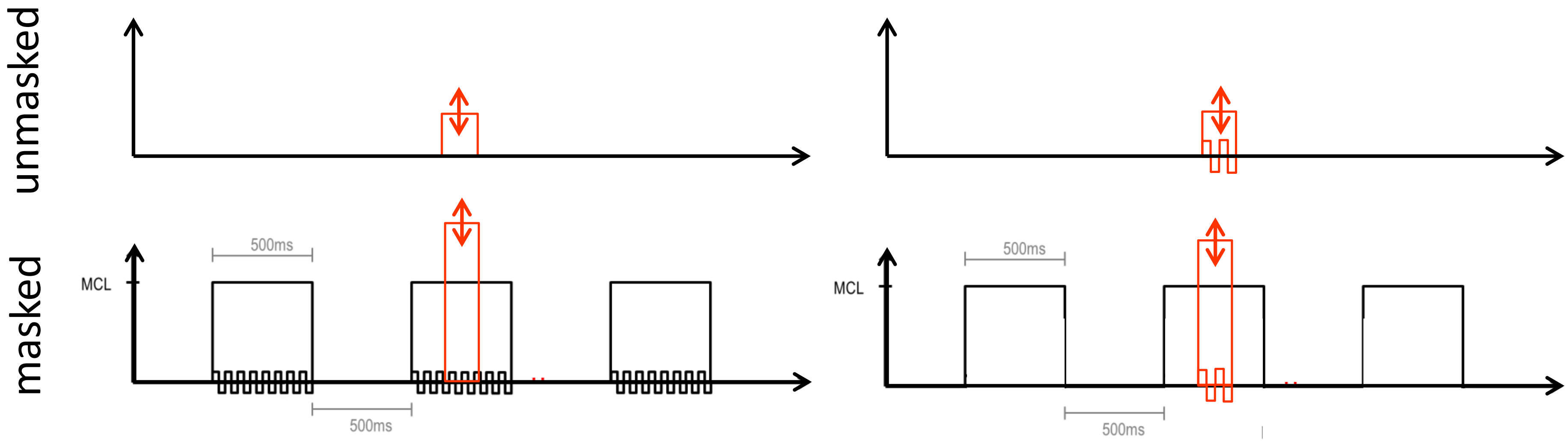
Methods:
Simultaneous Psychoacoustic Masking

Medizinische Hochschule Hannover

- Estimation of threshold elevation with an additional masker
- Different frequencies and electrodes are used
  - These combinations result in different EAFDs.
- Two conditions: electric-acoustics and acoustics-electrics
- Stimuli: pure tones (acoustics) and pulse trains (electrics)

Condition 1:
Electric masker – acoustic probe

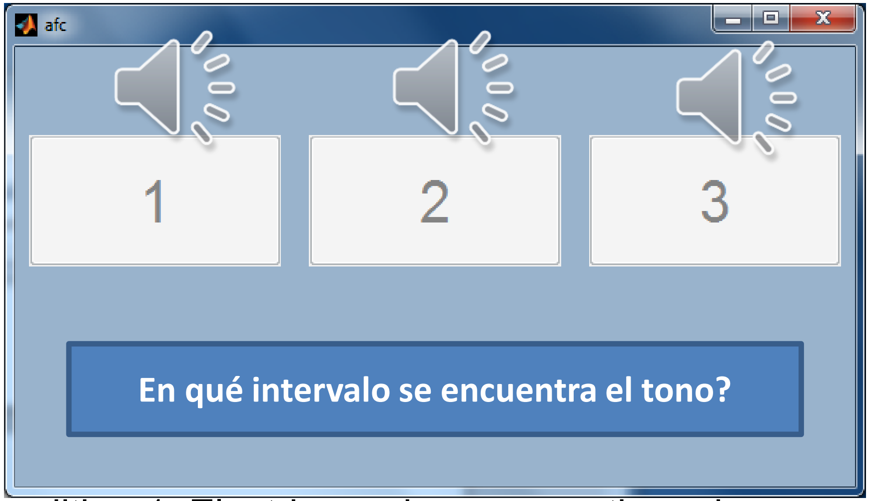
Condition 2:
Acoustic masker – electric probe



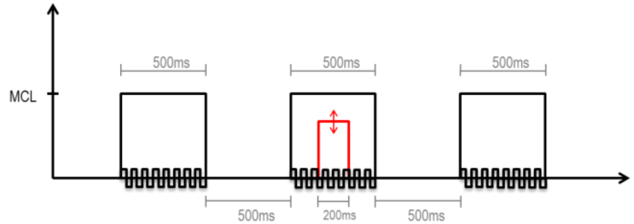
Methods
Experiment
Psychoacoustic Masking

- Electrode

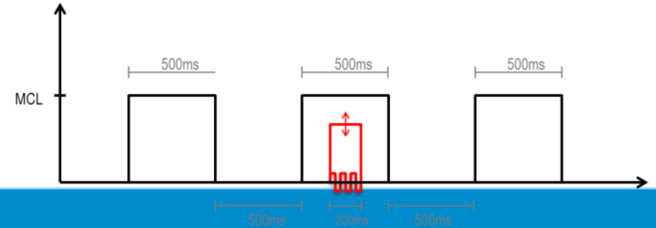
- Tone



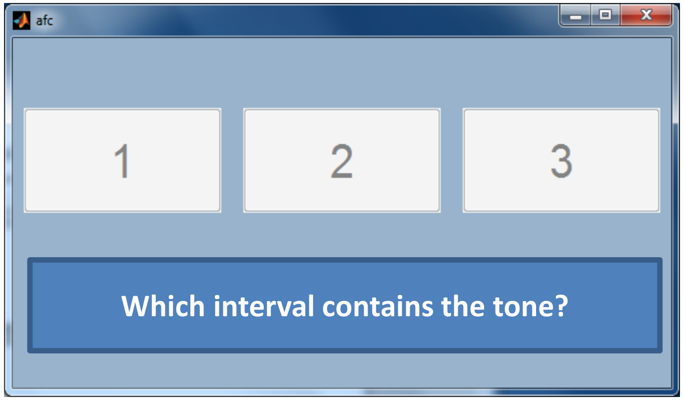
- Condition 1: Electric masker – acoustic probe

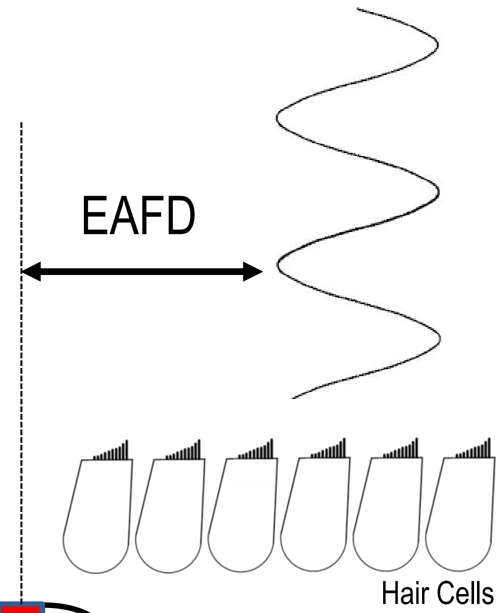


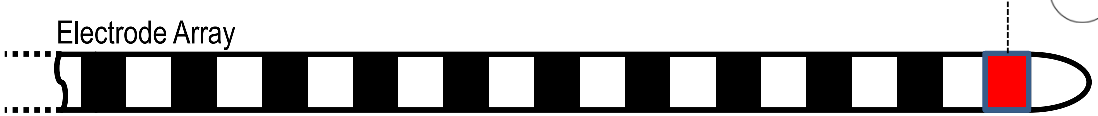
- Condition 2: Acoustic masker – electric probe



Methods
Experiment conducted at different frequencies and different electrodes







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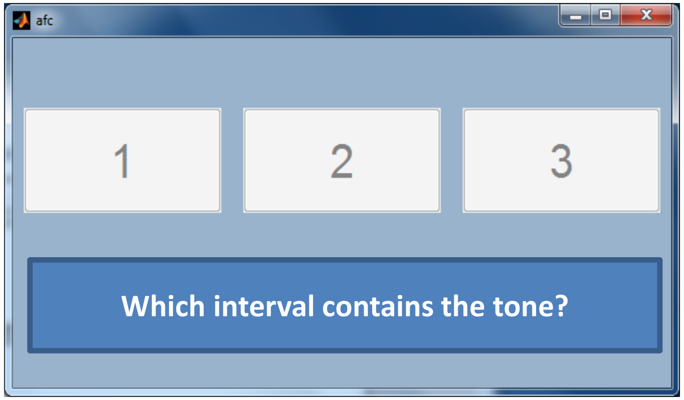

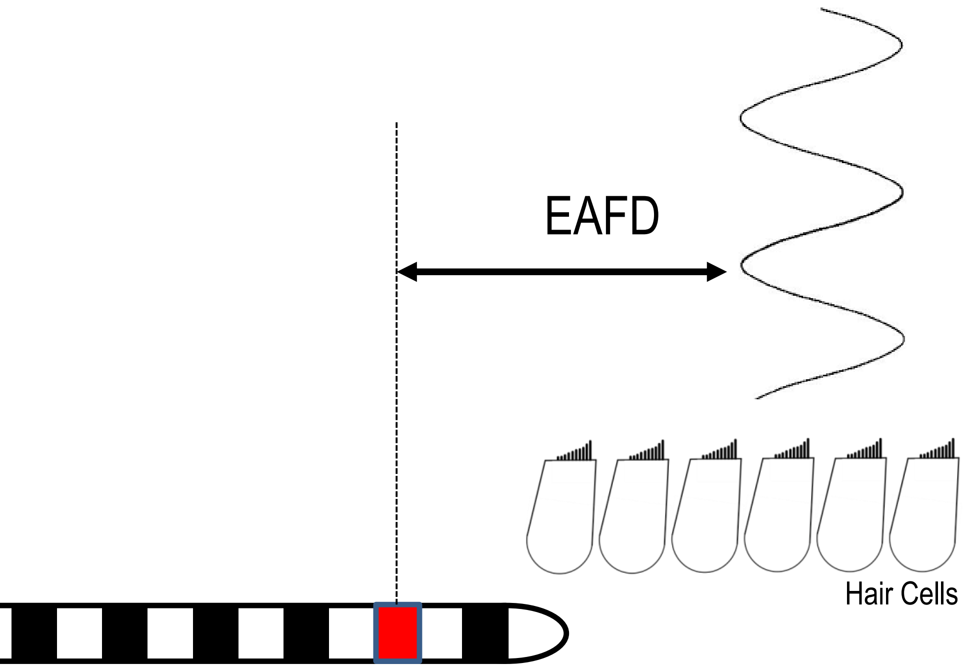

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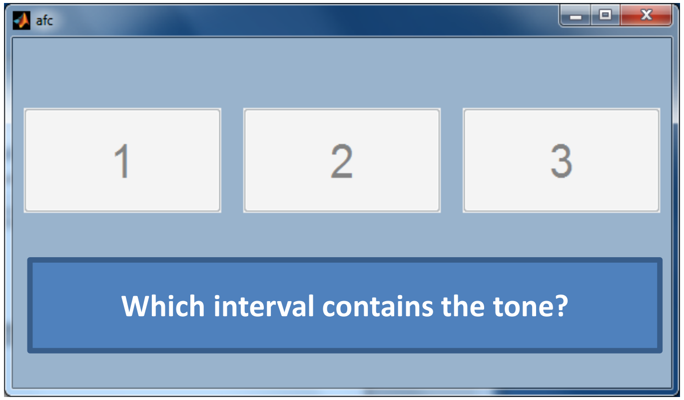

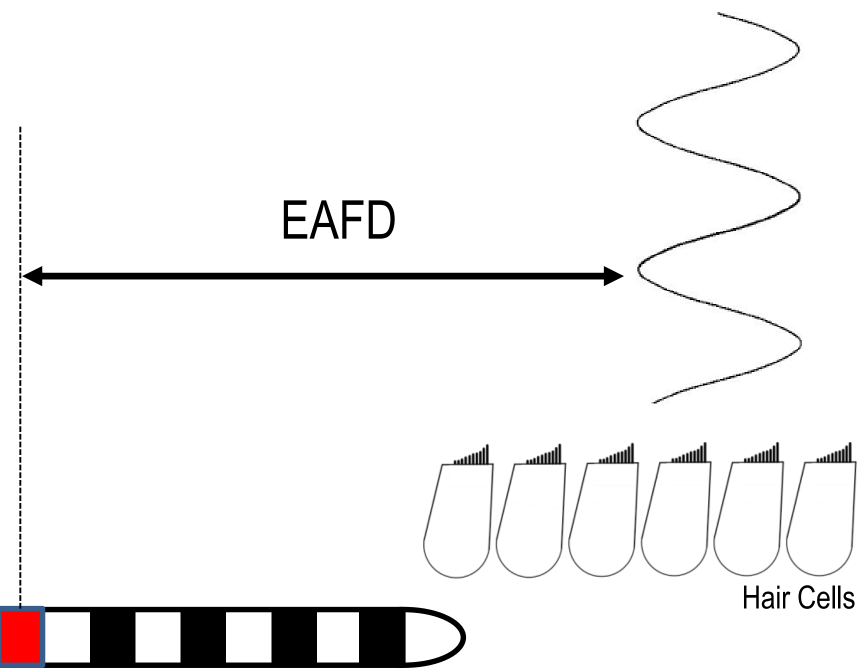


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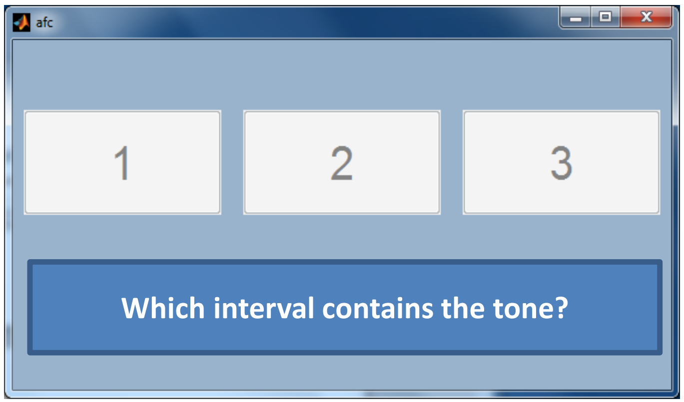
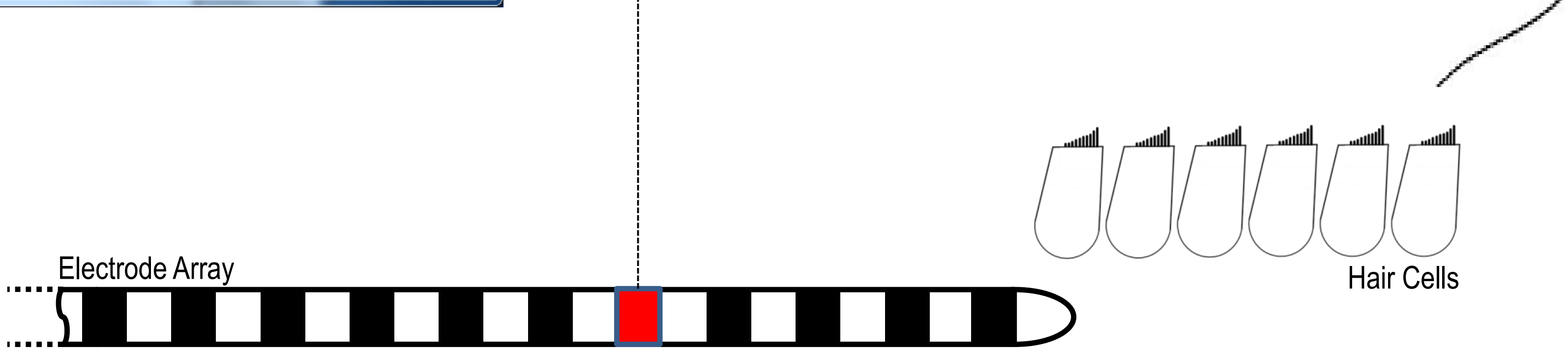
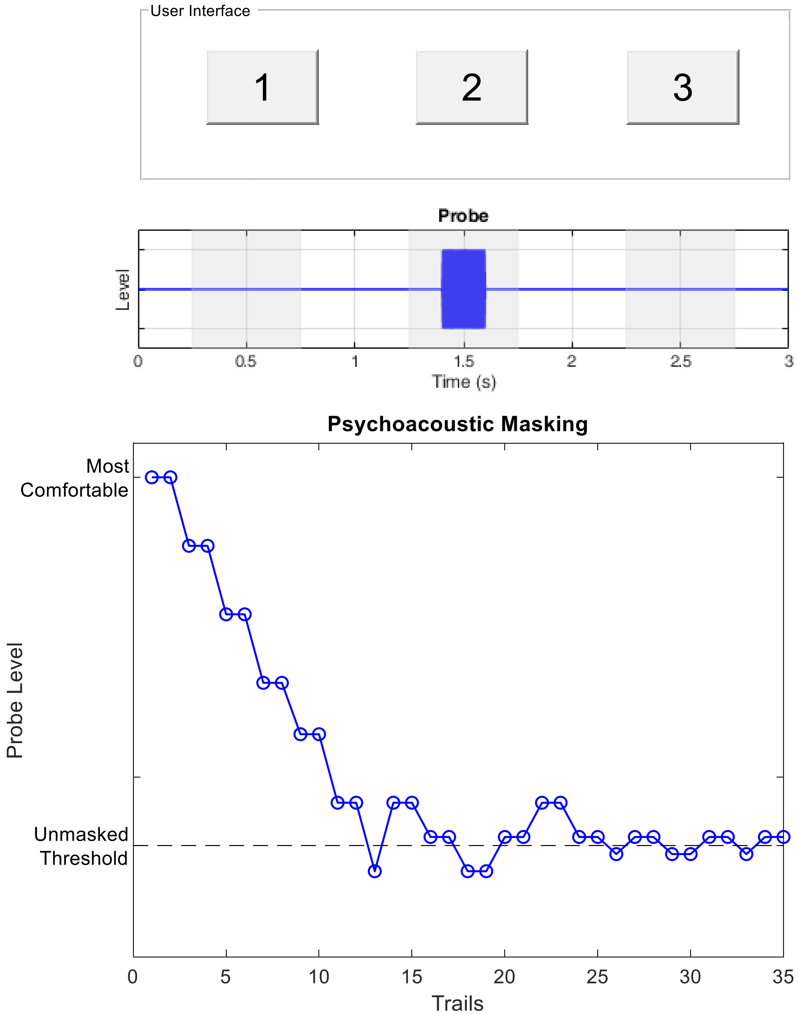
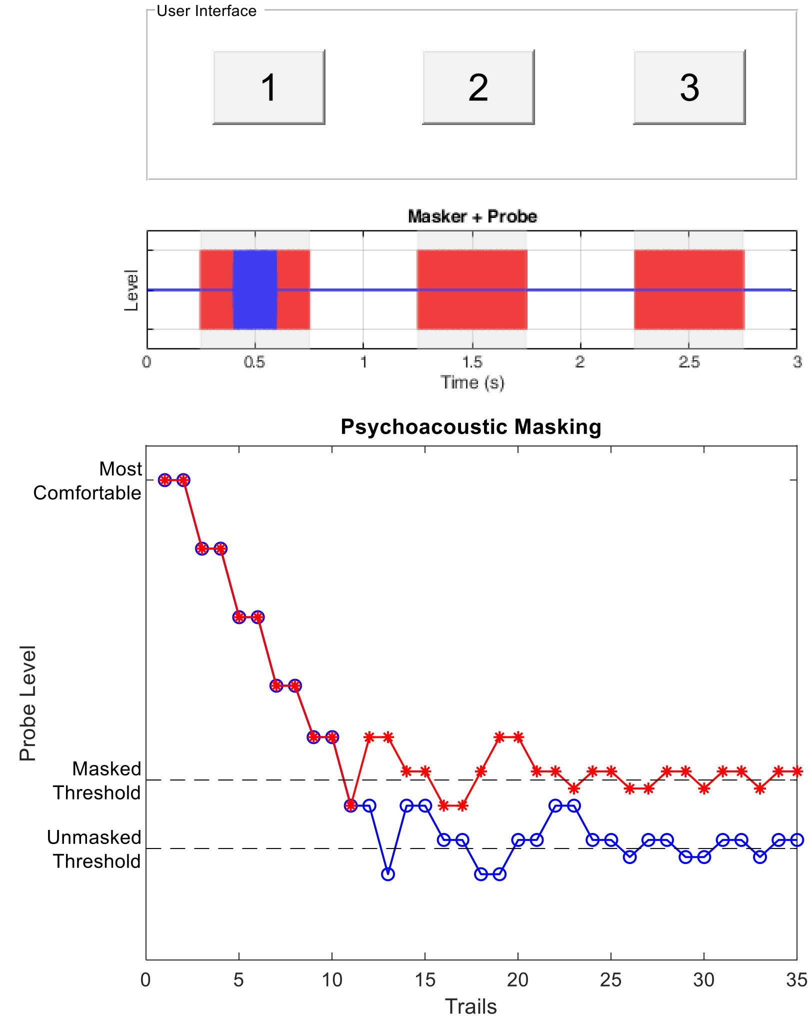




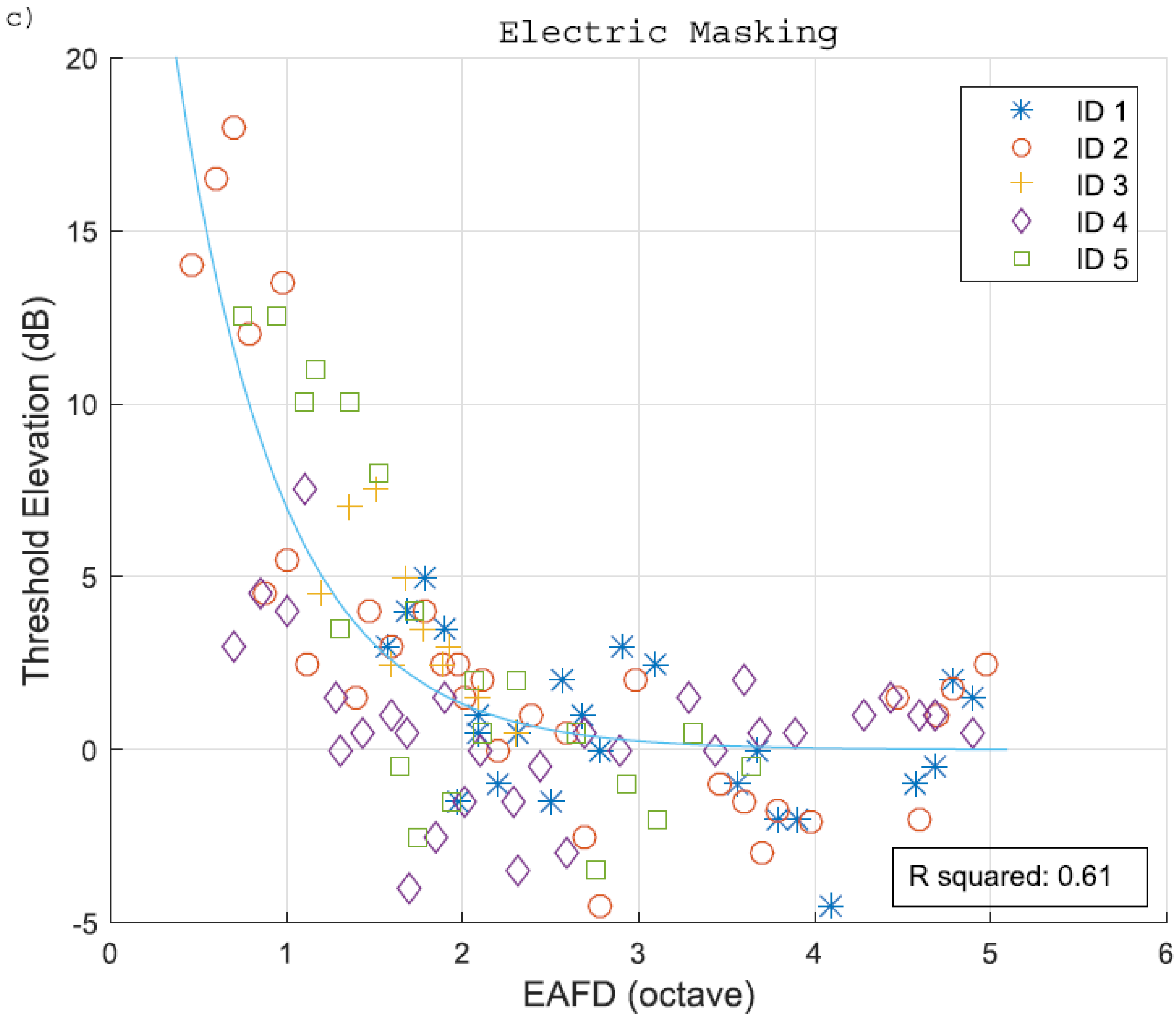
EAS masking

Psicoacustic Measure

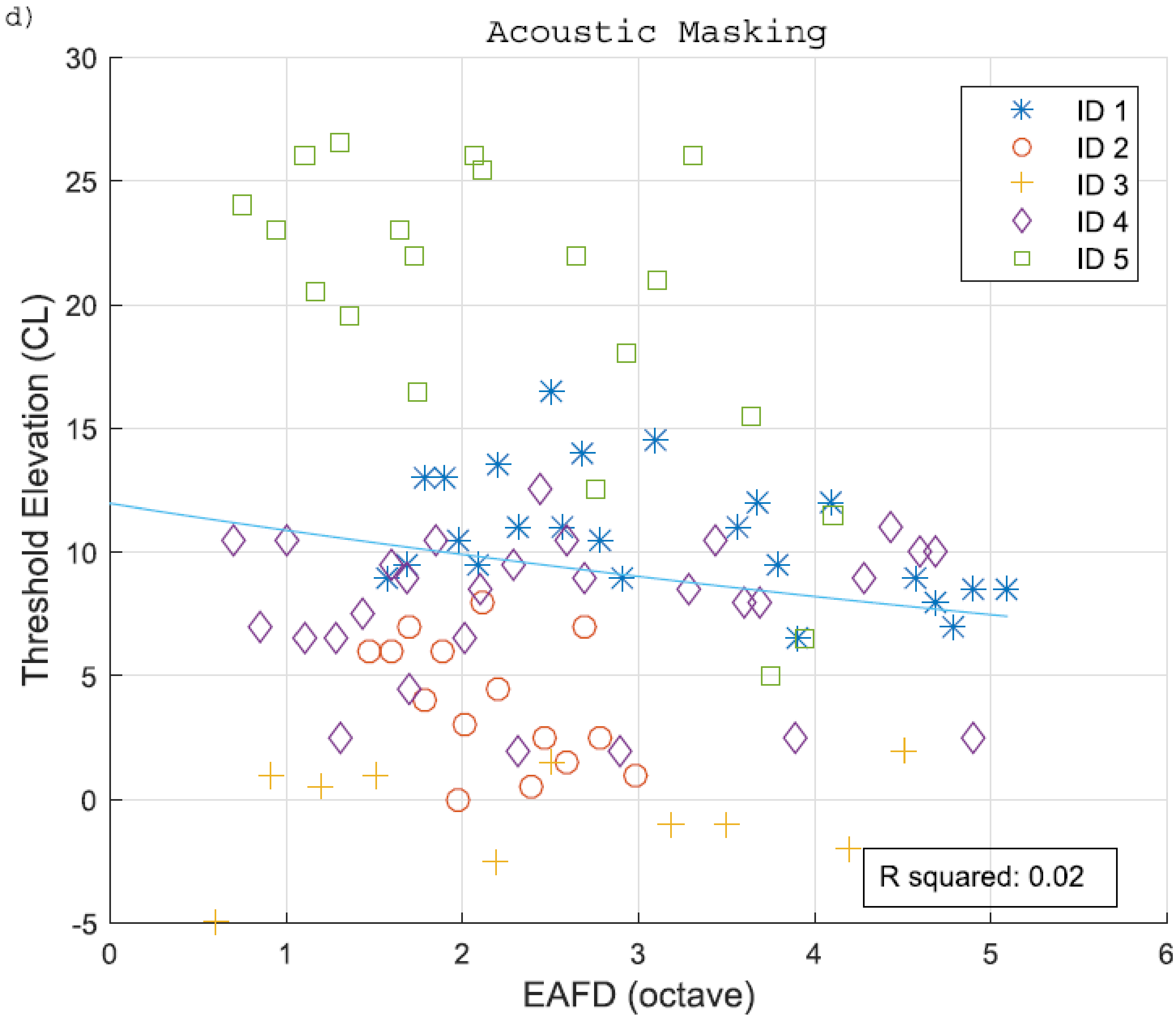




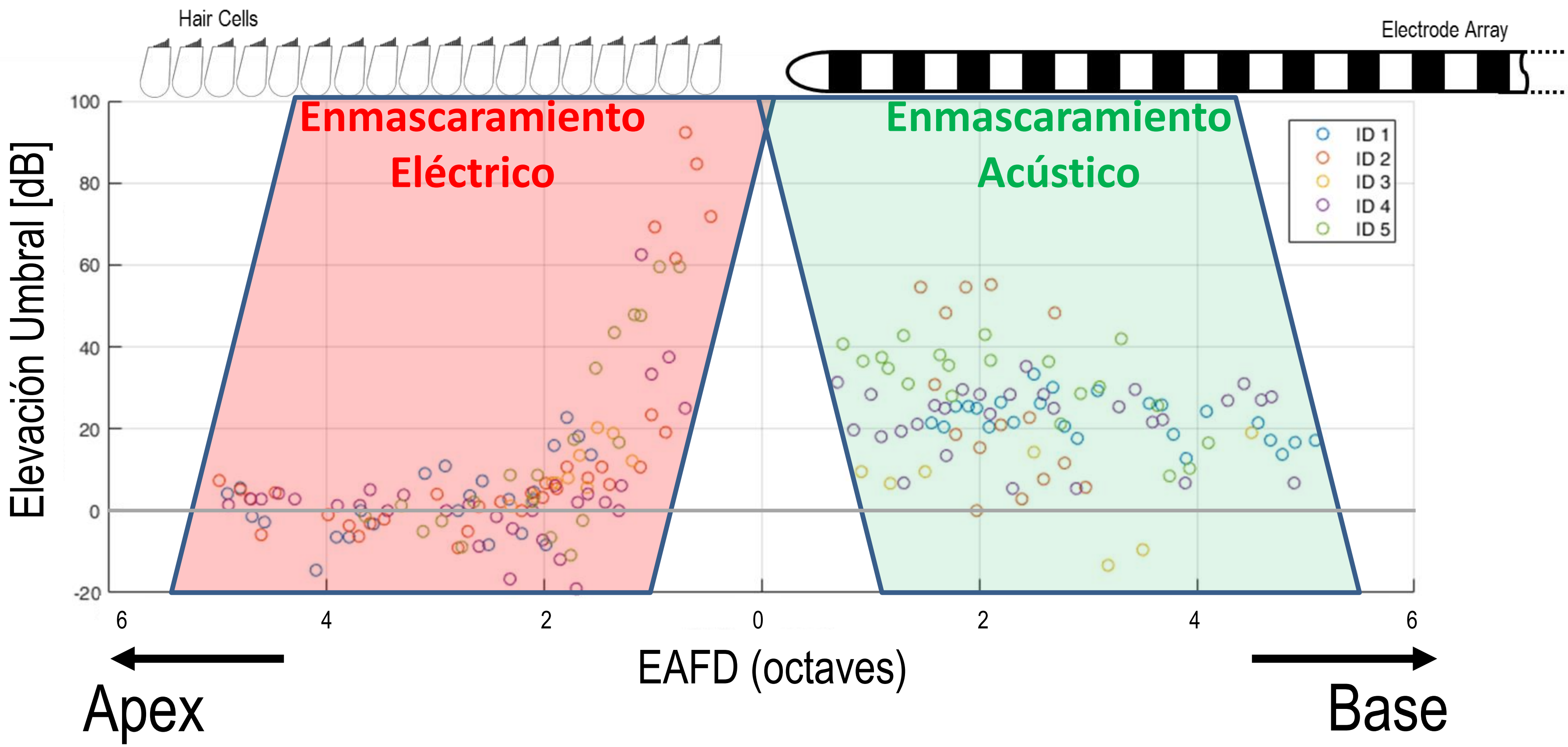
Electric Masking of Acoustic Tones



Acoustic Masking of Electric Tones



Results
Masking Assymetry



Krüger, Büchner, Nogueira, HearRes, 2017

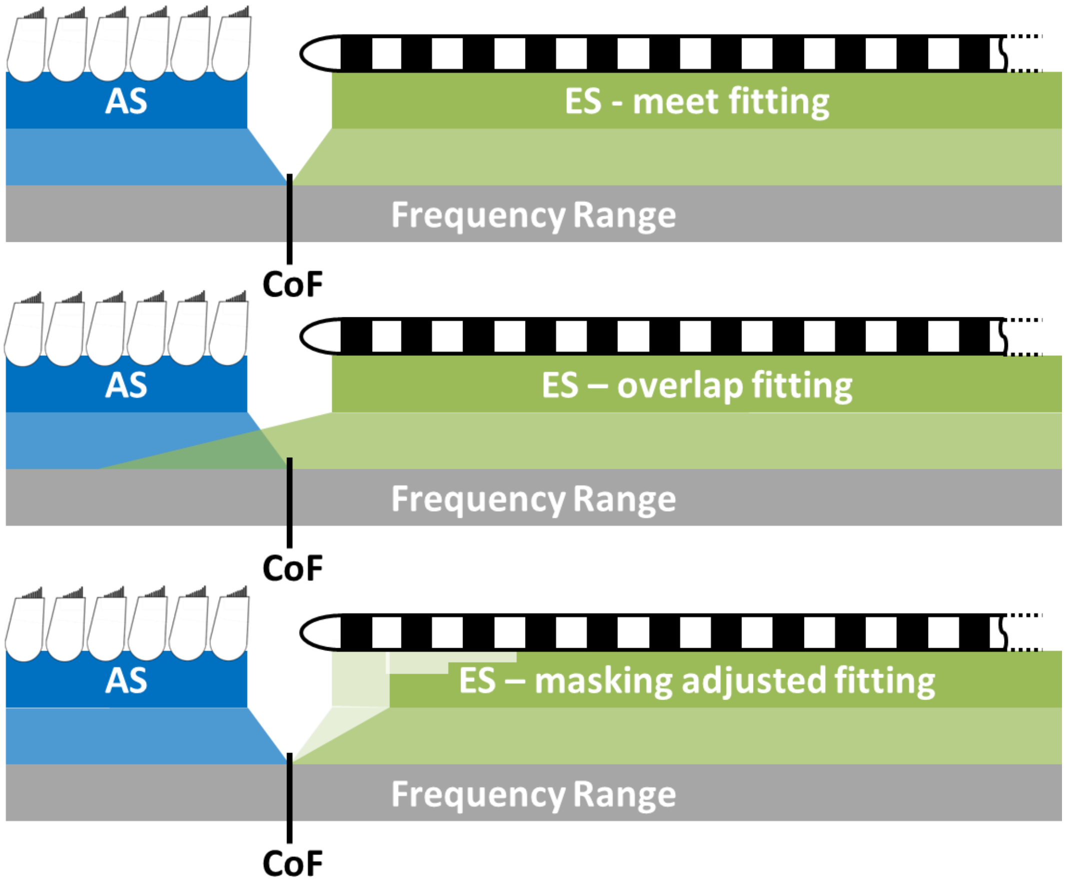
Imsiecke, Krüger, Büchner, Lenarz, Nogueira, HearRes, 2018

Methods: Characterization of the Electrode-Auditory Nerve Interface

- 1. Where are the electrodes located in the cochlea?
- 2. What is the distance between the electrodes and the hair cells?
- 3. What happens when the hair cells and the auditory nerve are simultaneously stimulated?
- 4. What impact does masking have on speech intelligibility?

Outline of EAS Fitting Strategies

- Constant Acoustic Amplification, CoF a 65 dB HL
- Meet:
  - Assignement based on CoF
- Overlap:
  - Increase in electric frequency content
- UNMASKfit:
  - M-level individually reduced based on masking



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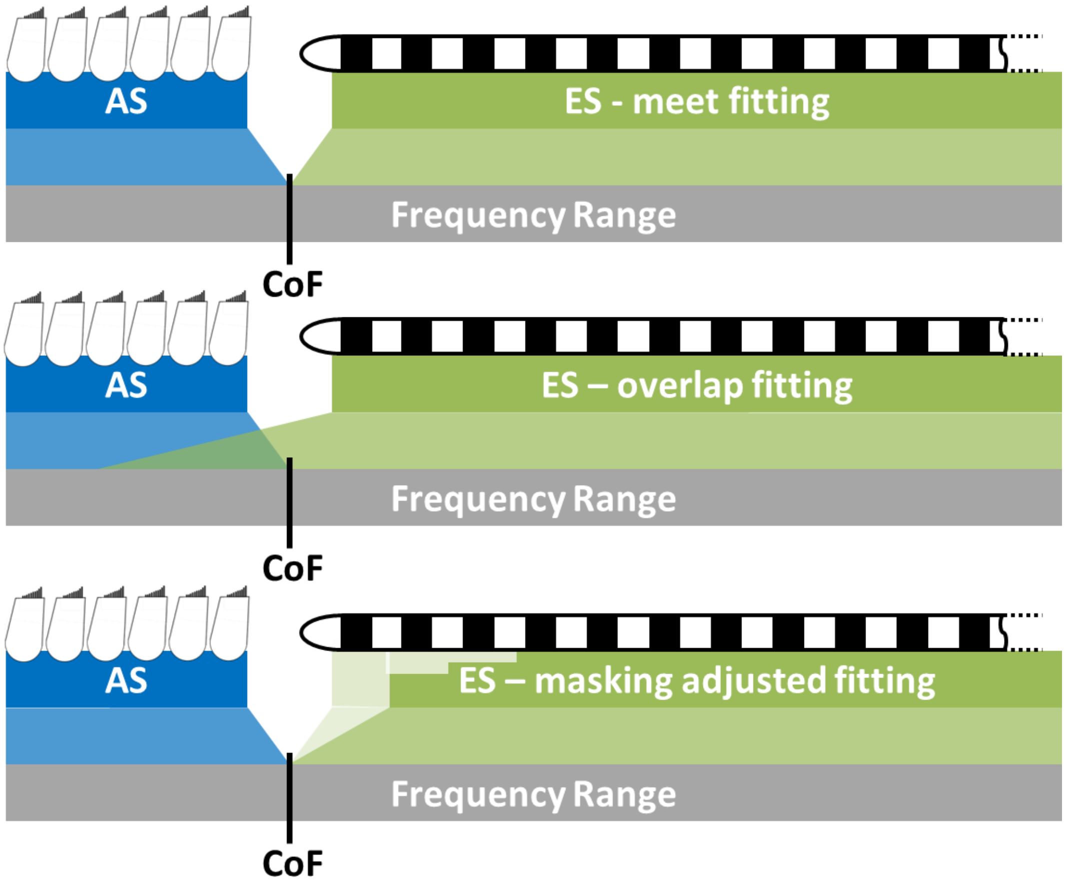
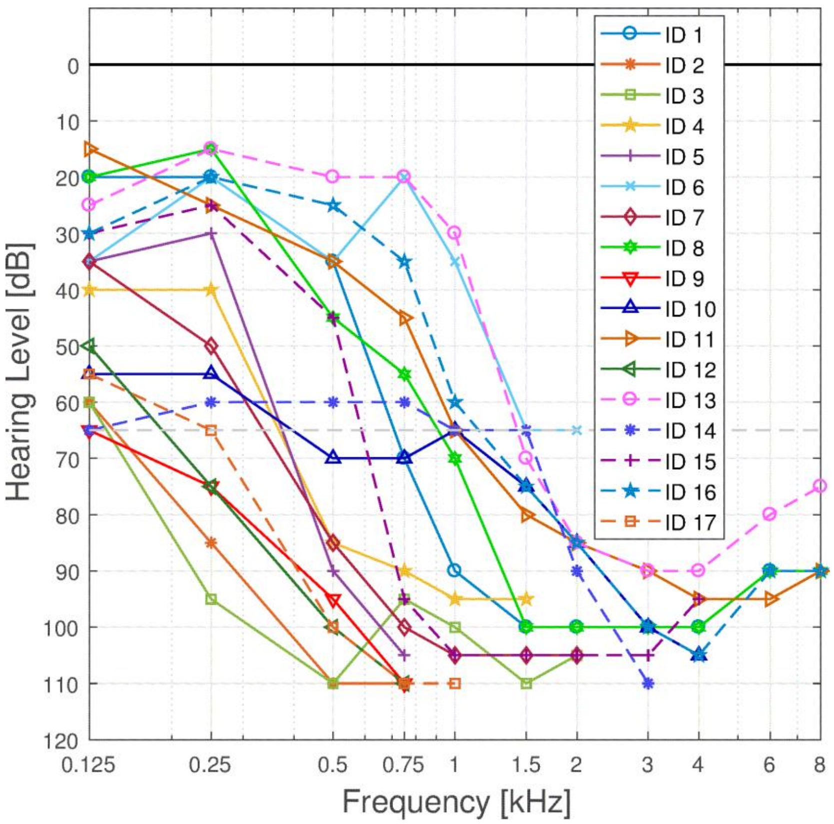


Each fitting was used during 1 month

Chronic Study: Patients

Subject ID		Electrode type	Insertion depth [°]	Stakhovskaya Frequency [Hz]
1		Flex 20	316	1044
2		Flex 20	348	840
3		Flex 28	532	352
4		Flex 28 PI	342	872
5+		Flex 24	450	550
6		Flex 16	237	2072
7		Flex 20	347	845
8		Flex 16	254	1781
9		Flex 24	346	850
10		Flex 16	220	2388
11		Flex 16	220	2388
12+		Flex 28	397	664
13		Flex 24 PI	242	2000
14		Flex 24 PI	192	2937
15		Flex 28 PI	324	984
16		Flex 16	217	2446
17		Flex 24	444	563

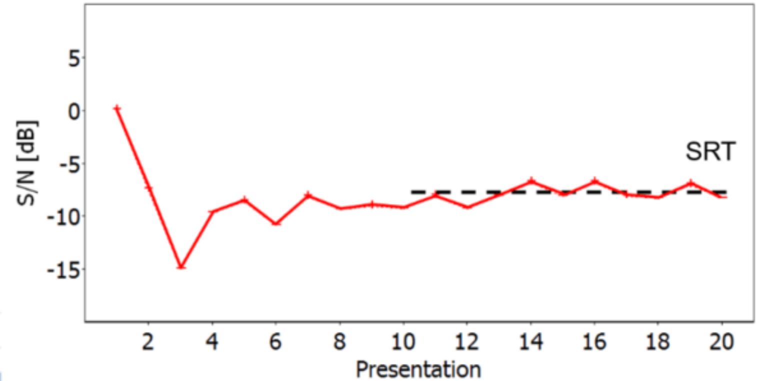
+ drop-out

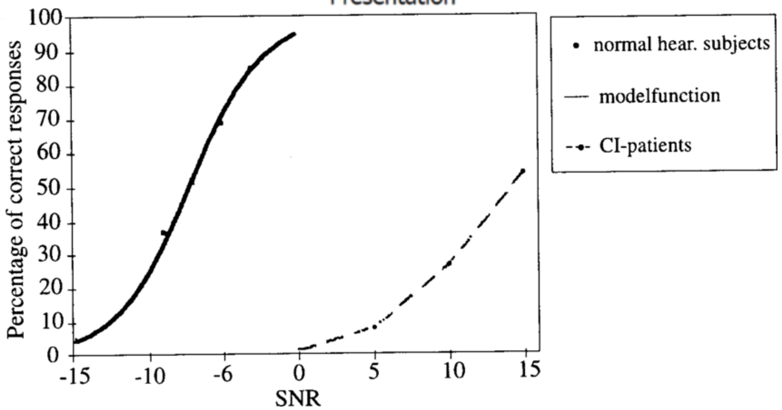


Speech Test

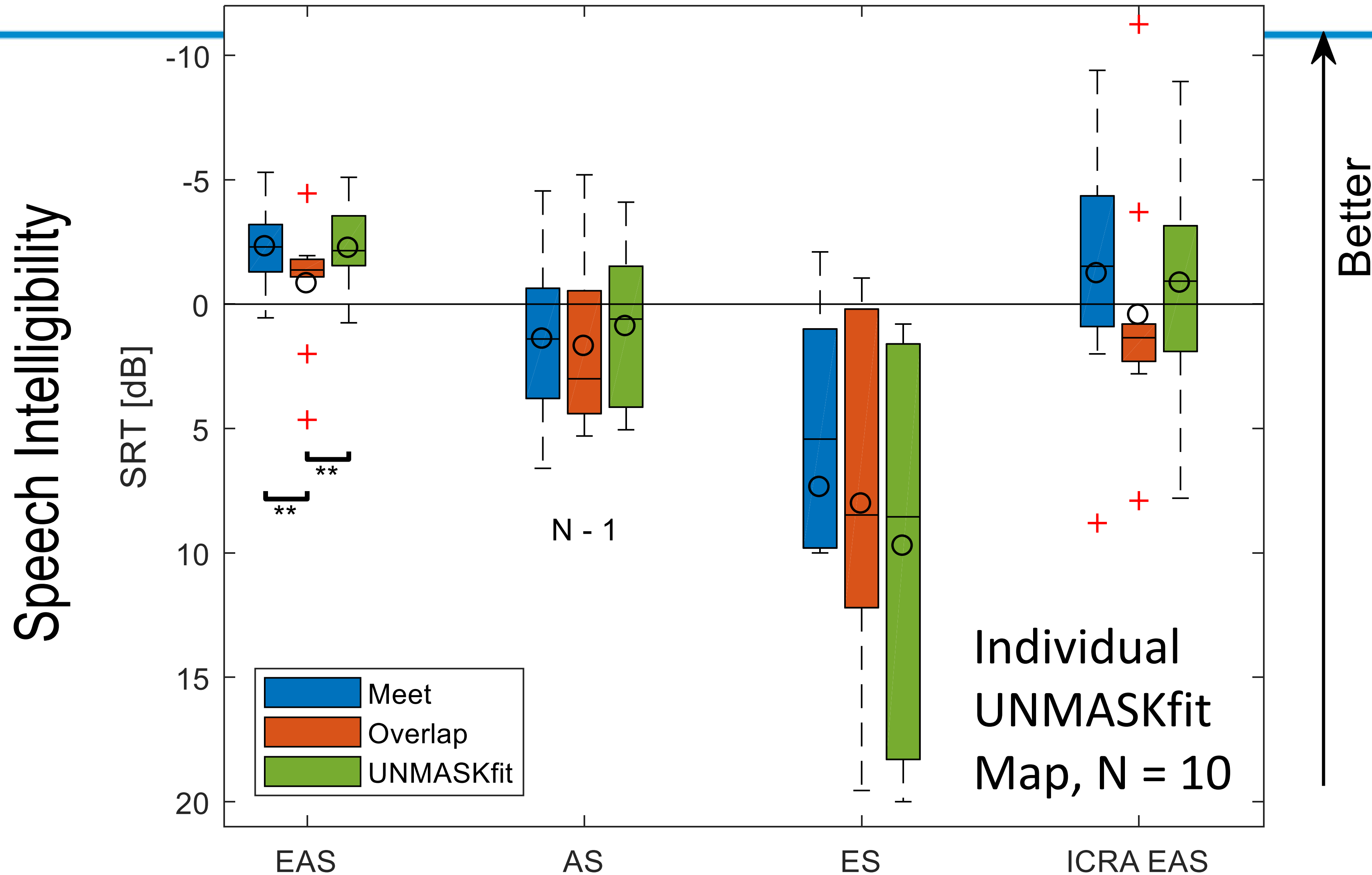
- OLSA: Adaptive Matrix Test
- Spech Reception Threshold (SRT)

Name	Verb	Numeral	Noun	Adjective
Claudia	tiene	dos	libros	grandes
Carmen	hace	tres	barcos	viejos
Elena	toma	doce	platos	nuevos
Teresa	busca	***siete***	regalos	pequeños
Josefa	quiere	seis	guantes	enormes
José	compra	diez	zapatos	azules
Antonio	***pinta***	cuatro	***juegos***	bellos
Carlos	mira	veinte	dados	lindos
Pedro	pierde	ocho	sillones	***baratos***
Manuel	vende	mil	anillos	negros





Speech perception results for each subject with masking.



Methods:

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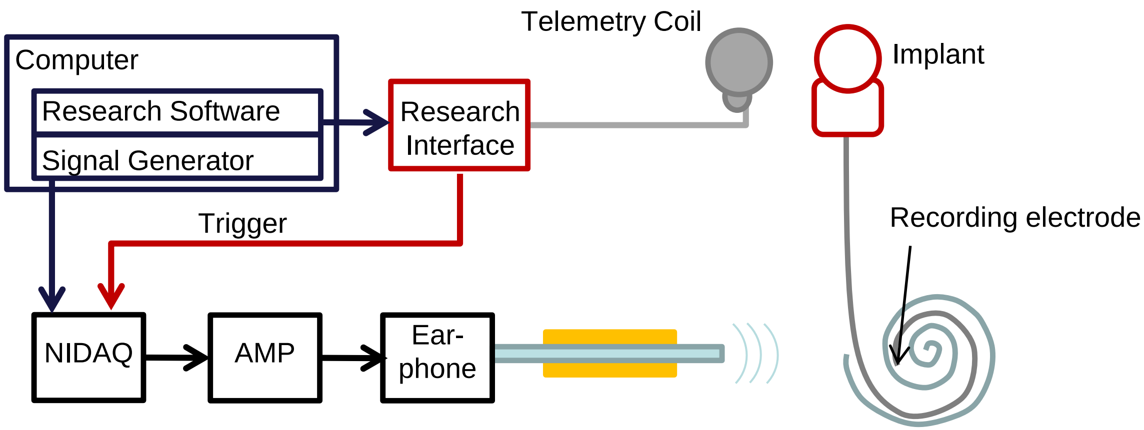
- 2. What is the distance between the electrodes and the hair cells?
- 3. What happens when the hair cells and the auditory nerve are simultaneously stimulated?
- 4. What impact does masking have on speech intelligibility?
- 5. Can the interaction be measured objectively?

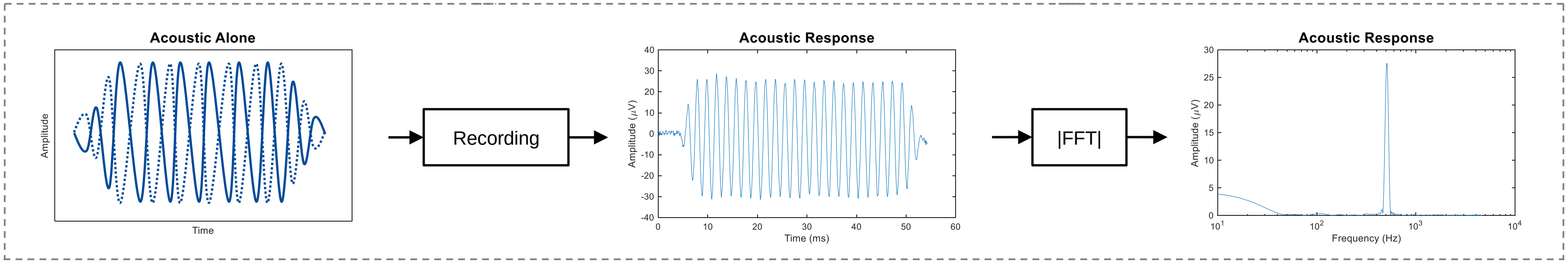
Electrophysiogical Masking

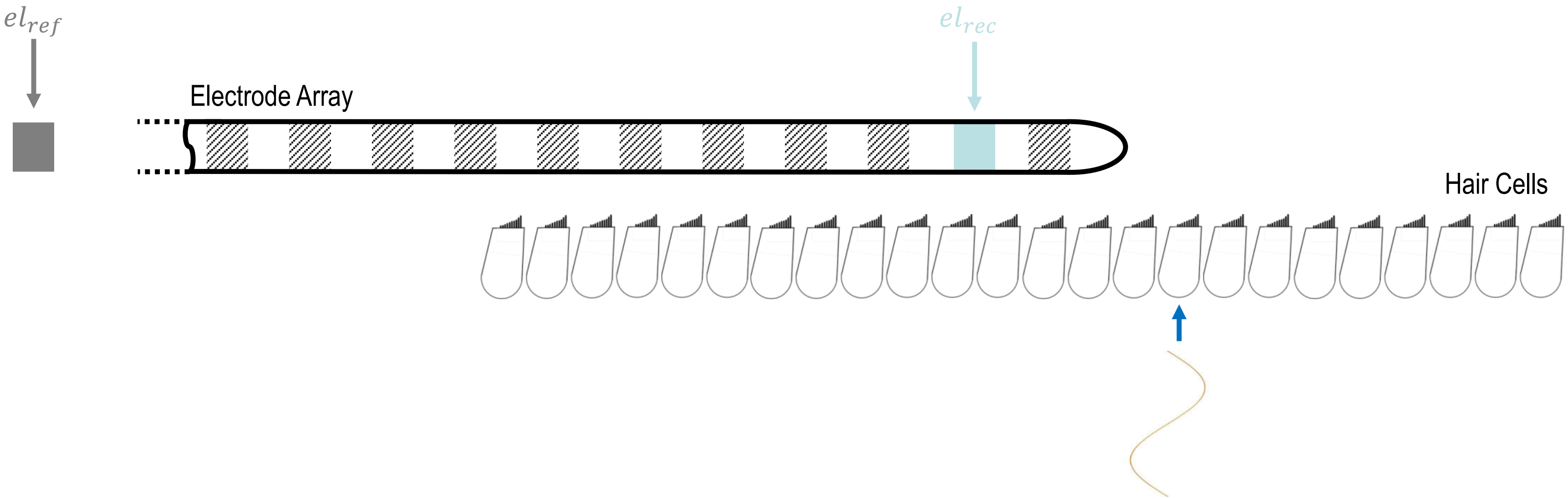
- Goals:
  - Investigate possible effects of masking in the peripheral system, where does masking occur?
  - To objectively measure EAS masking
  - Accelerate interaction measurements based on psychoacoustics
- Methods:
  - Electrophysiological measurements based on the implant telemetry system.



EAS Interaction

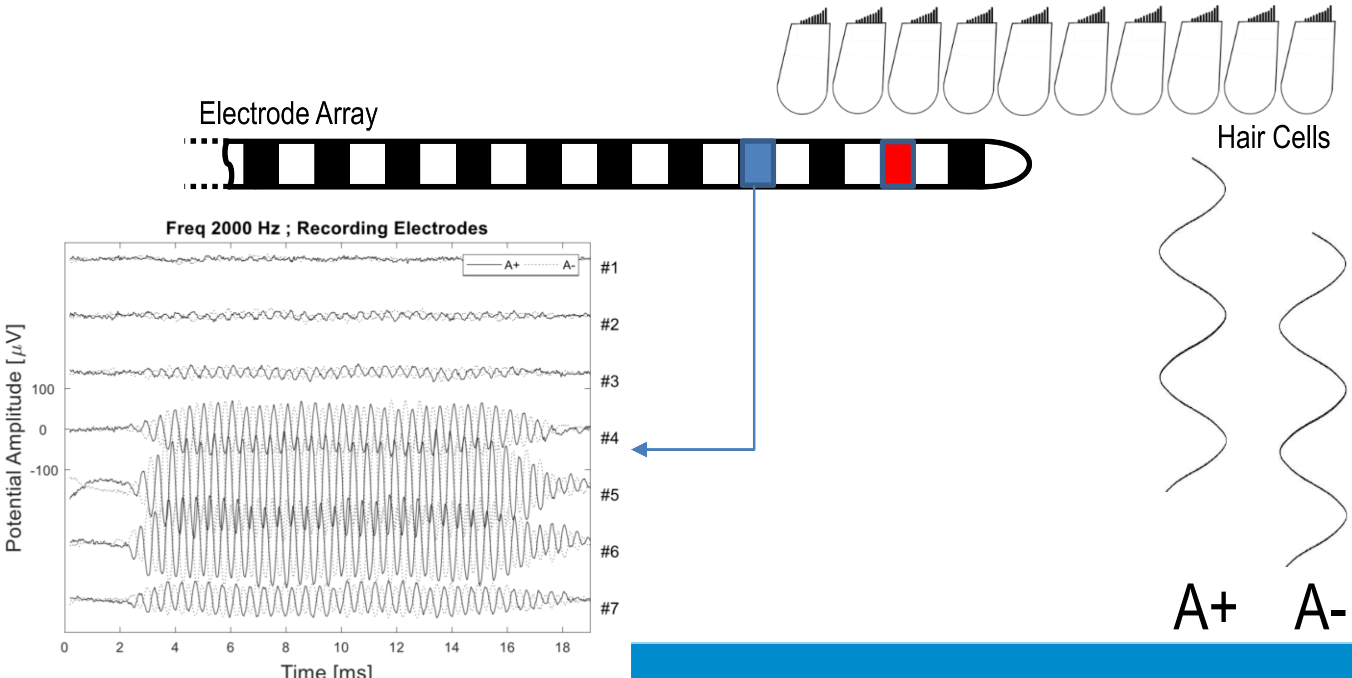
ECochG / Cochlear Microphonics



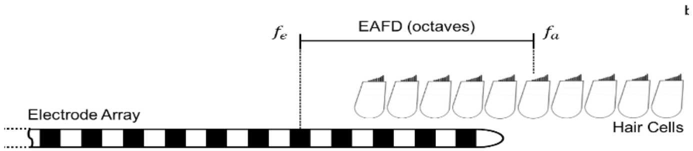


Intracochlear Electrococleography

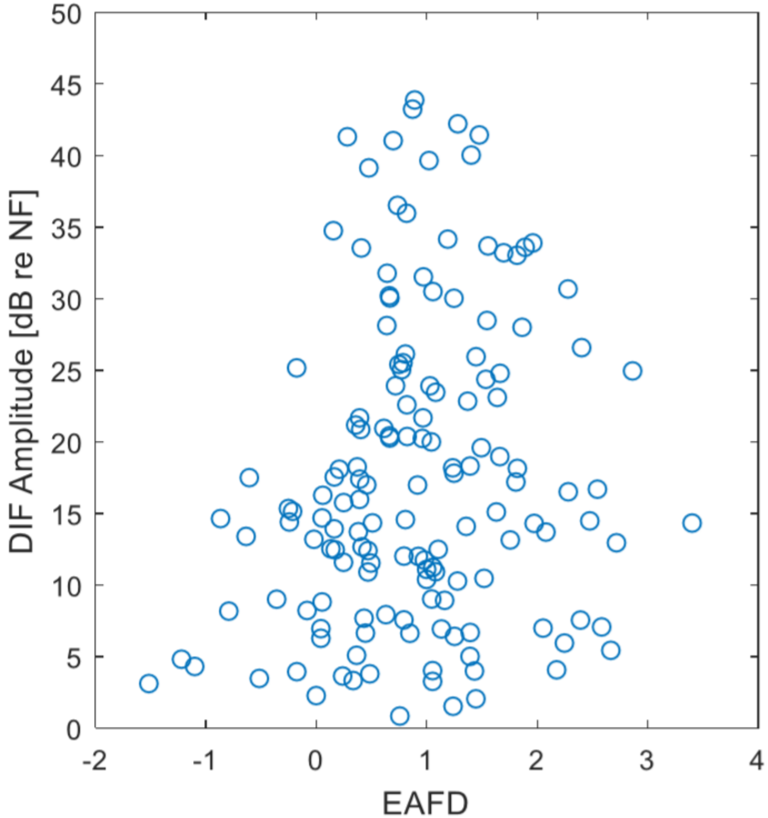
- Response of the hair cells and auditory nerve when an acoustic tone is presented
- An acoustic tone with two phases (A+ and A-) is presented.
- By subtracting (DIF) the response or summing (SUM) the hair cell or auditory nerve response can be estimated.



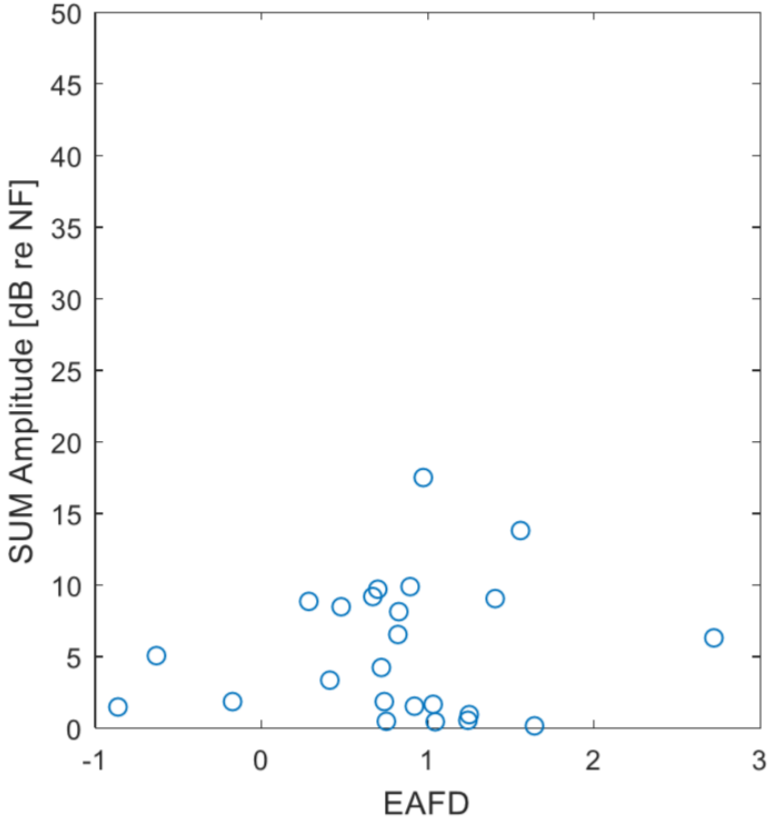
Intracochlear Electrococleography



DIF/CM



ANN/SUM



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Summary and Conclusions

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- Characterization of the Electrode-Nerve Interface in EAS
  - CT-based medical imaging: Where are the electrodes located in the cochlea and how far from the hair cells?
  - Psychoacoustic Experiments
    →EAS interaction exists
  - Use of electrocochleography to investigate the interaction

- There is an interaction between electrical and acoustic stimulation.
  - An acoustic tone has a greater masking effect than an electric tone.
- Clinical Application: Fitting of EAS devices
  - High overlap between acoustic and electrical stimulation
    → Worse speech understanding

Contralateral Efferent Suppression of Human Hearing Sensitivity in Single-sided Deaf Cochlear Implant Users)

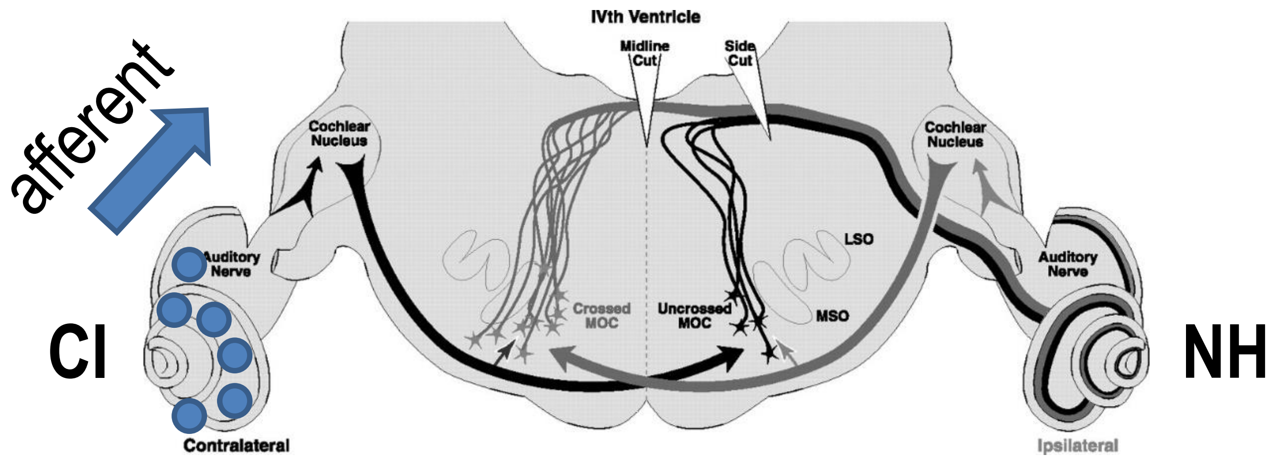
<u>Waldo Nogueira</u>, Enrique Lopez-Poveda, Andreas Büchner, Benjamin Krüger

Milan

12/10/2022

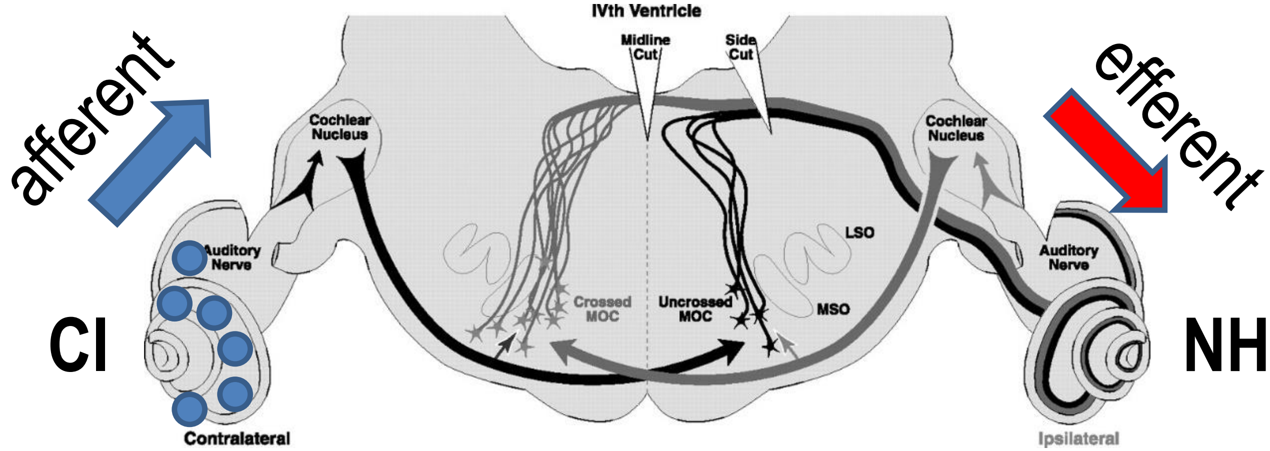
Introduction

- Cochlear implants (CIs) implanted in people with unilateral hearing loss
  - Speech intelligibility
  - Sound source localization
- CIs are designed to restore the afferent auditory system



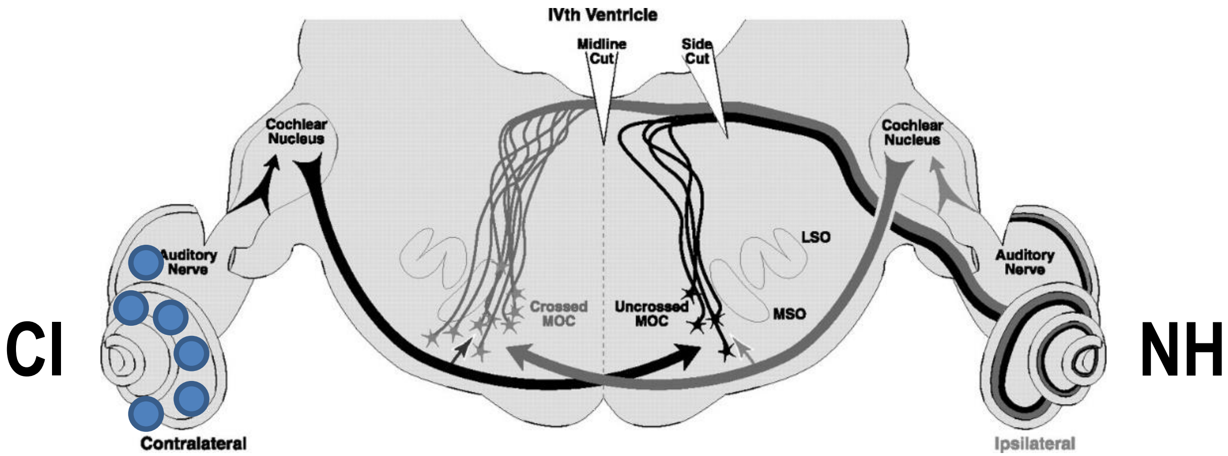
Introduction

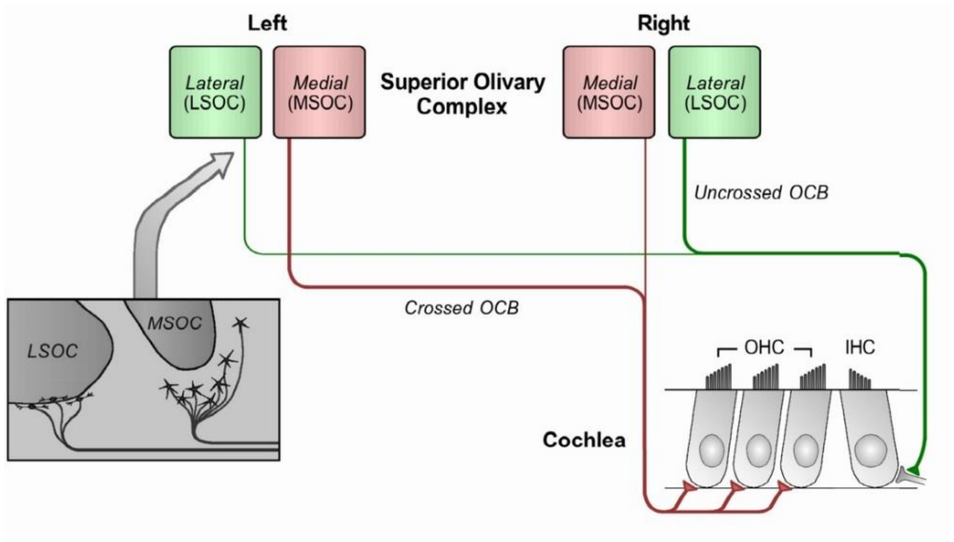
- The present study aimed at investigating whether a CI can also restore some efferent effects



- Specifically, we investigated the potential **<u>suppressing effect</u>** of CI electrical stimulation on the normal hearing ear via activation of the contralateral medial olivocochlear (MOC) efferents

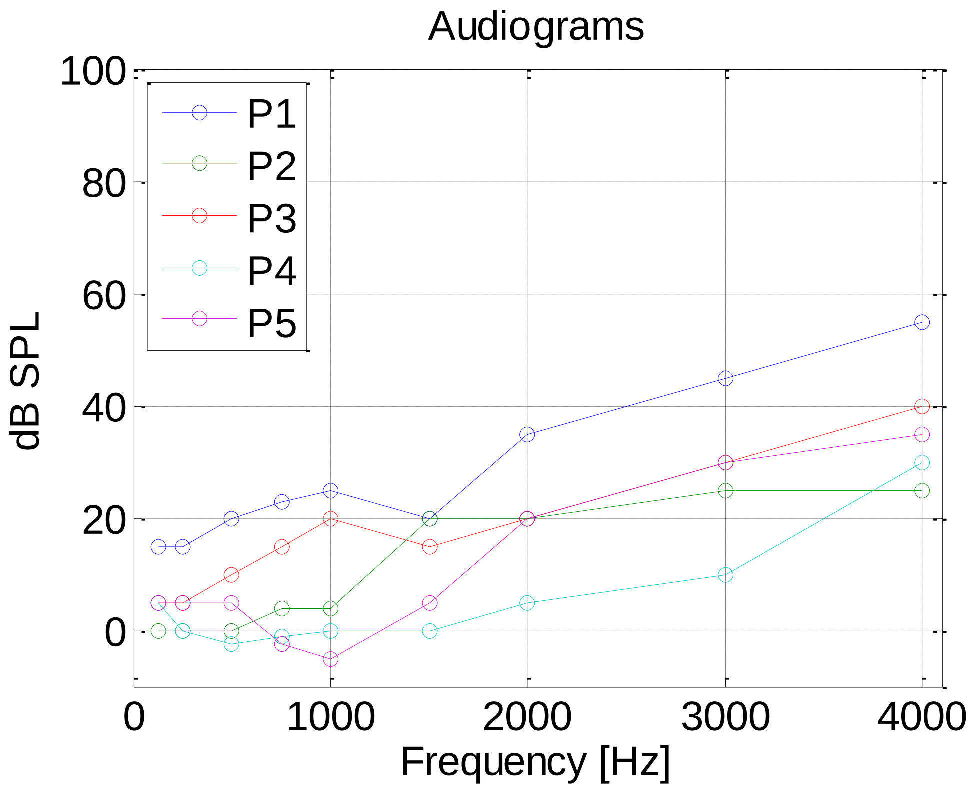
The mammalian olivocochlear bundle





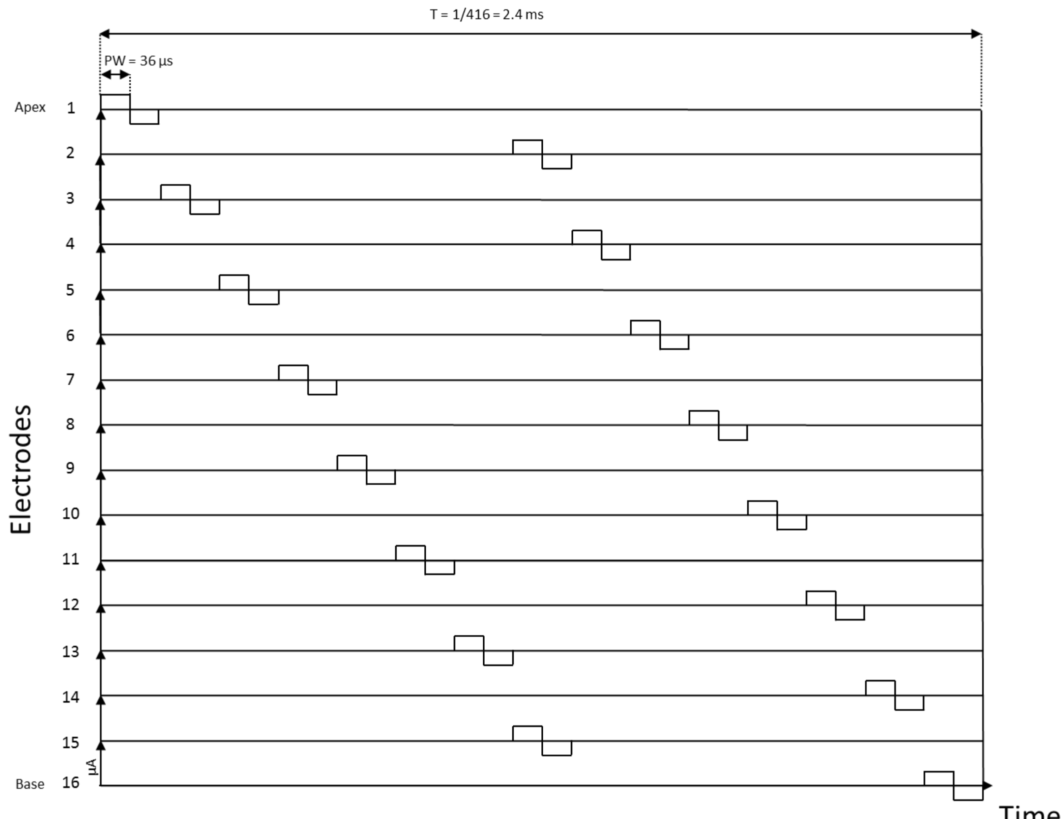
Materials and Methoids
Subjects

- 5 AB unilateral CI users with an average hearing loss of less than 15 dB HL up to 4000 Hz in the acoustic ear participated in the study



Materials and Methods
Experimental set-up

- Contralateral Broadband Electrical Stimulus (CBES):
  - Wideband → Increase probability of activating the MOC reflex



Material and Methods
Hardware Setup

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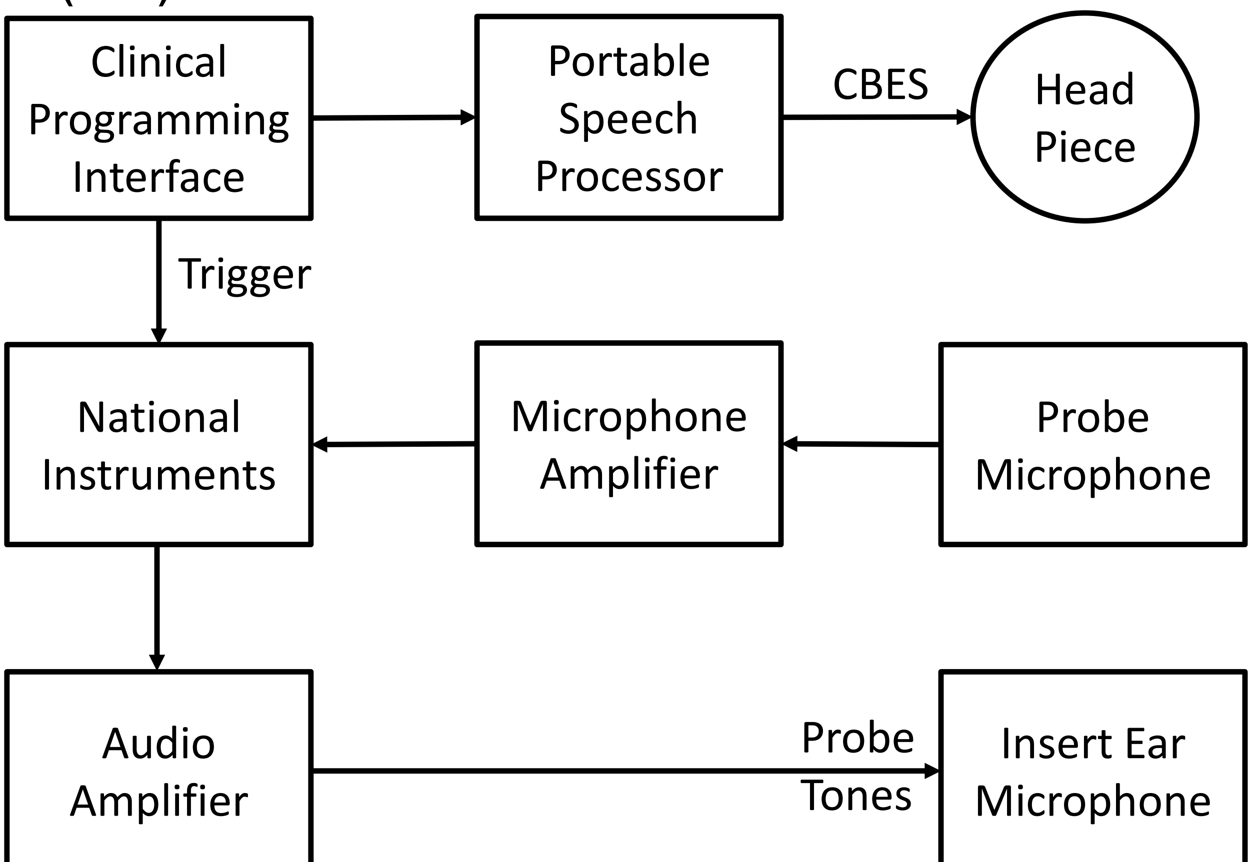
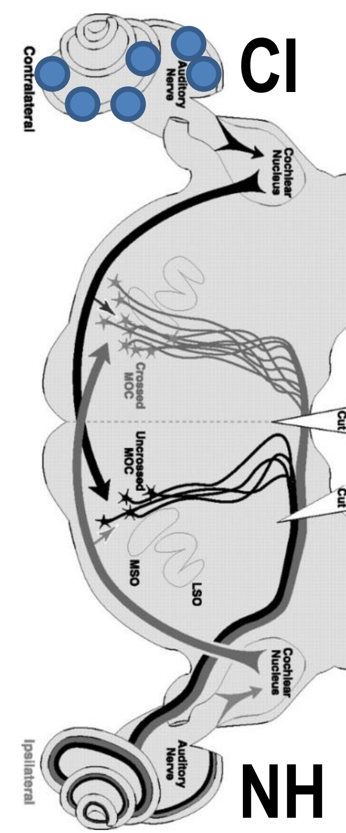
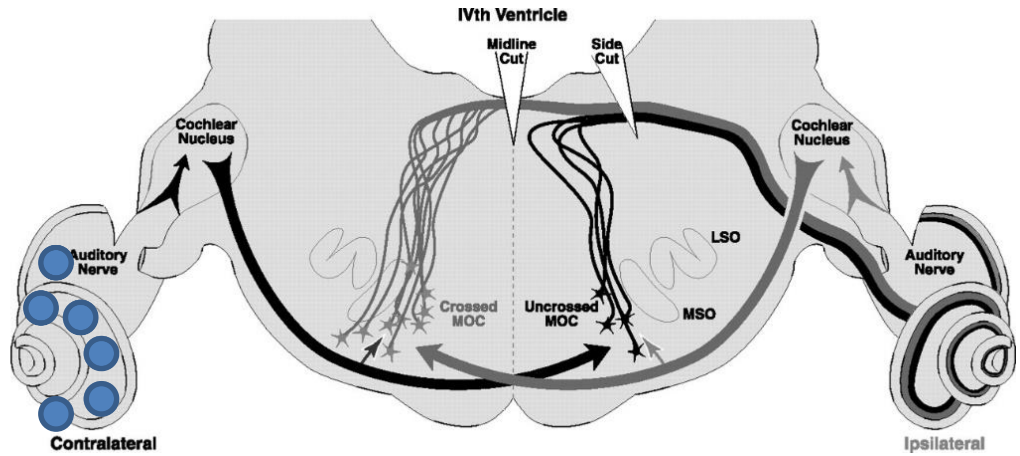
- Full synchronization between electric and acoustic stimulation
- BEDCS (AB) + Hardware Interface



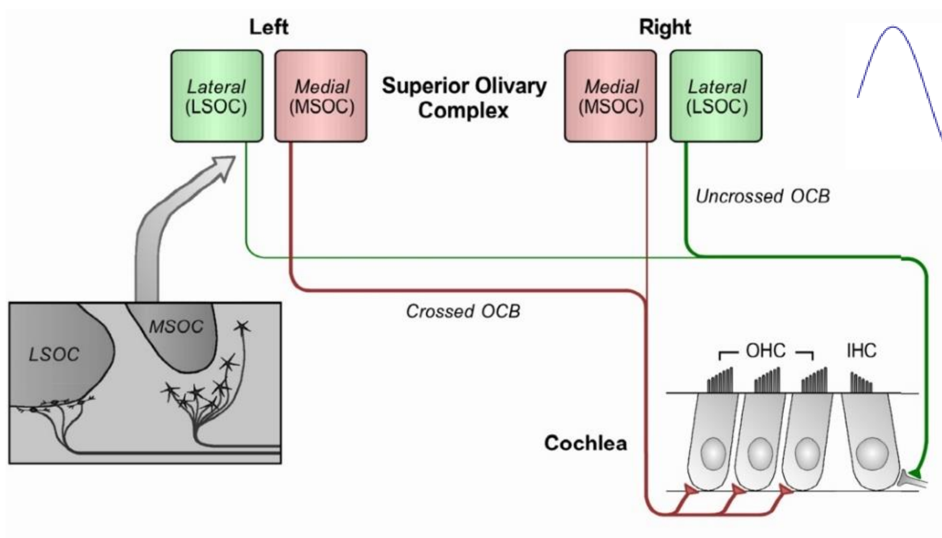


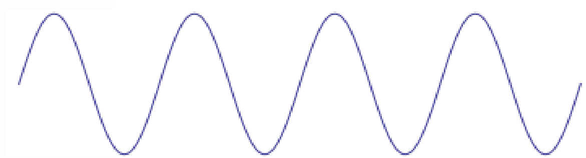
Material and Methods
Probe Threshold Detection Acoustic Ear

CI



NH





Frequencies: 500 Hz and 4000 Hz
Durations: 10 ms and and 200 ms

Material and Methods
Probe Threshold Detection Acoustic Ear in the Presence of a CBES

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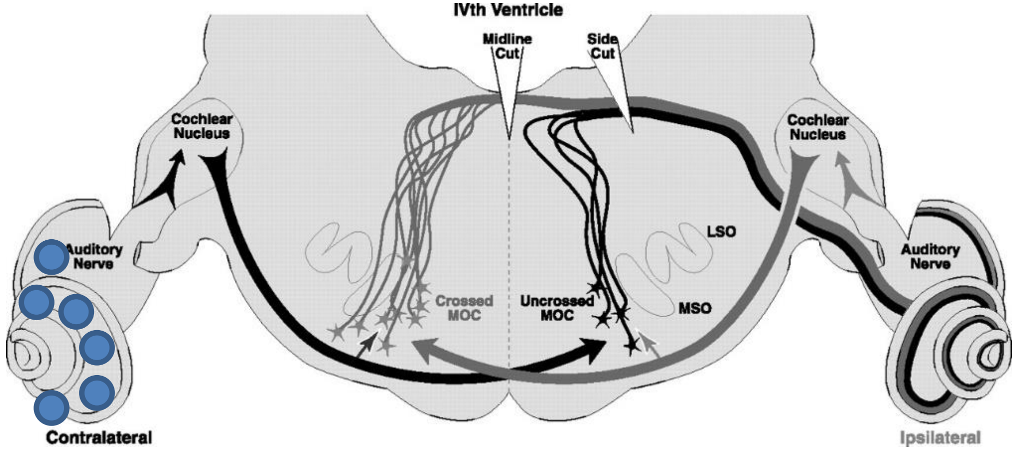
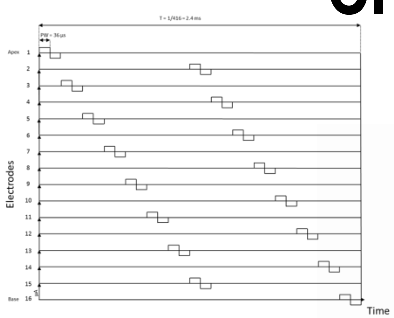
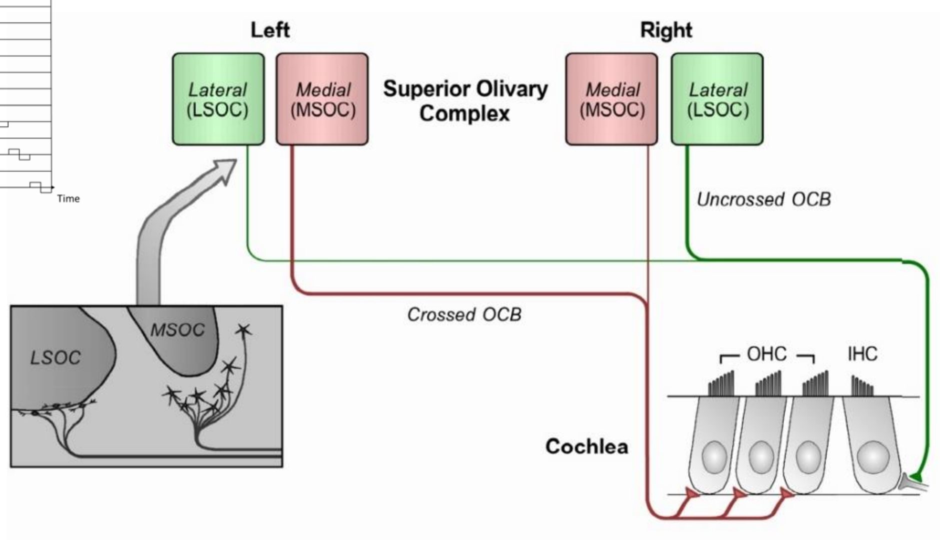
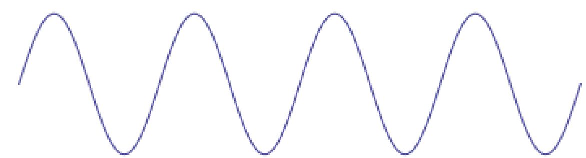


CI

NH







Frequencies: 500 Hz and 4000 Hz
Durations: 10 ms and and 200 ms

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Materials and Methods
Procedure

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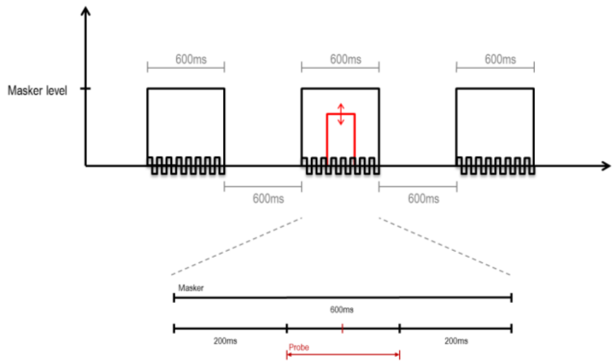
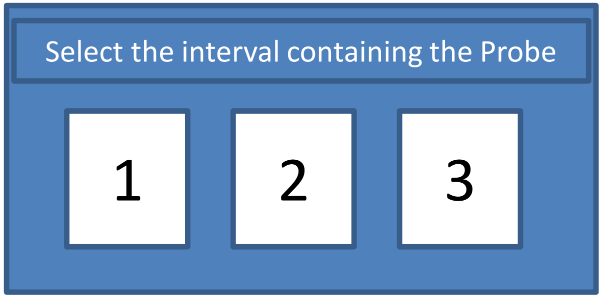
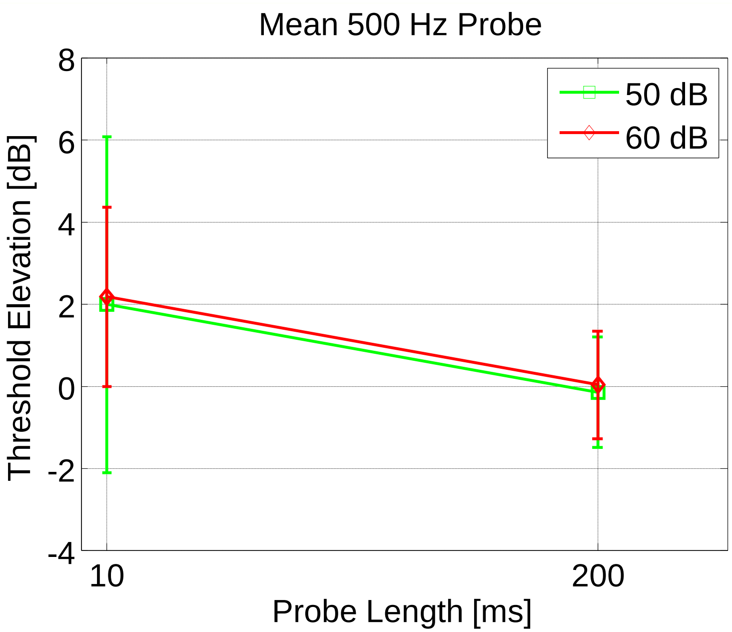
- Absolute thresholds on acoustic ears measured for pure tones:
  - Frequencies: 500 Hz and 4000 Hz
  - Durations: 10 ms and and 200 ms
- In the presence and absence of a CBES (3-AFC) (at 50 and 60 dB SPL)

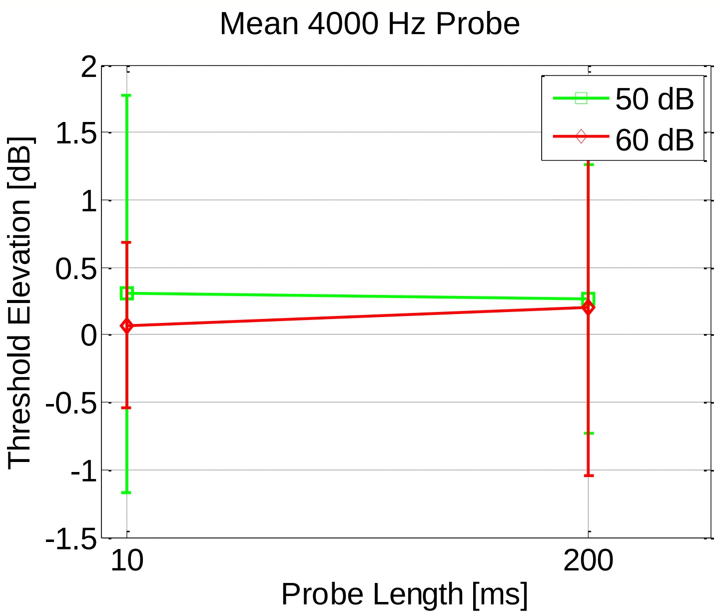




- Each threshold measured 2 times
- The difference in thresholds between the conditions with and without CBES was regarded as estimation of inhibitory effect of contralateral MOC reflex evoked by the CI → Threshold Elevation in dB

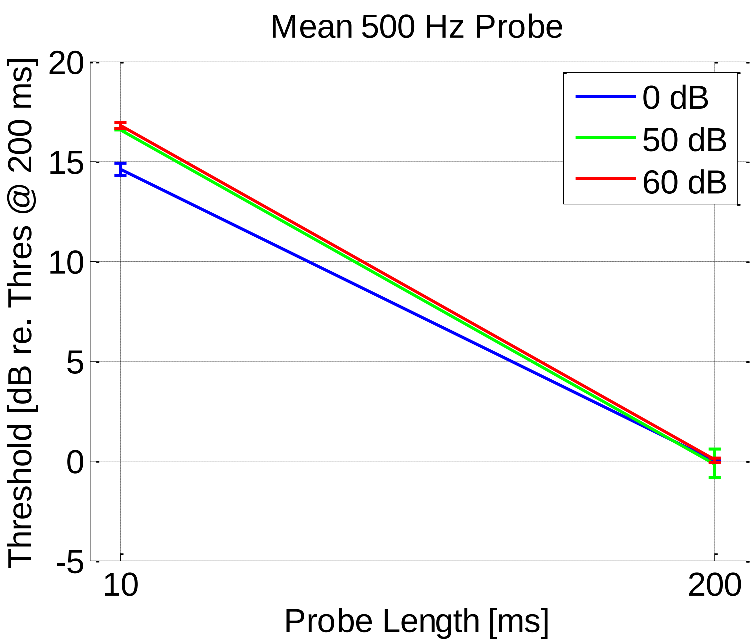
Results:
Mean Threshold Elevation

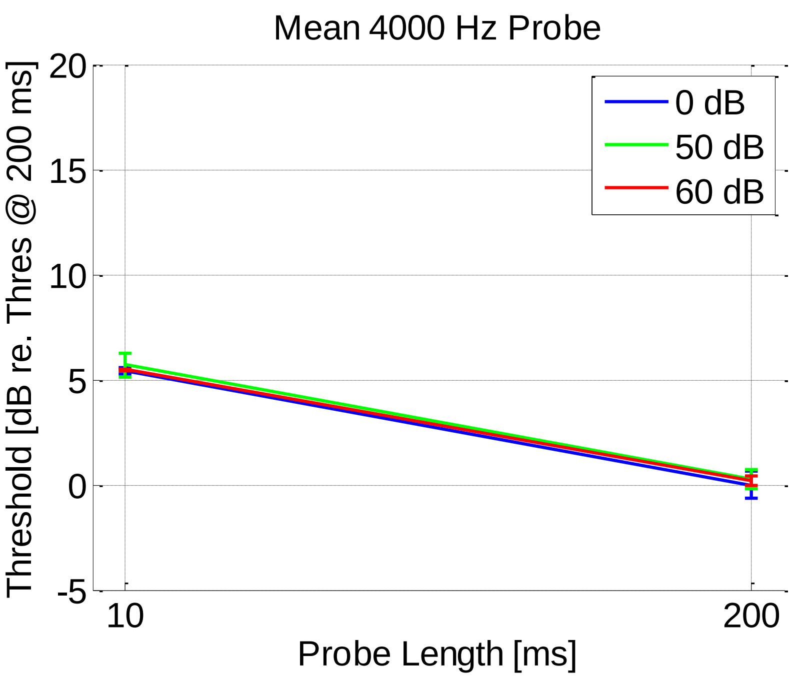




- Results revealed a statistical significant interaction between duration and frequency ($F(1,4) = 16.041$, $p = 0.016$).
- All other possible interactions between pairs of factors or between the three factors were not statistically significant.
- The analysis also revealed a significant effect of duration ($F(1,4)=21.094, p=0.010$) on threshold elevation.

Results:
Mean Threshold Elevation





- Decay slope of threshold elevation was more prominent at 500 Hz than at 4000 Hz

Results
Individual Threshold Elevation

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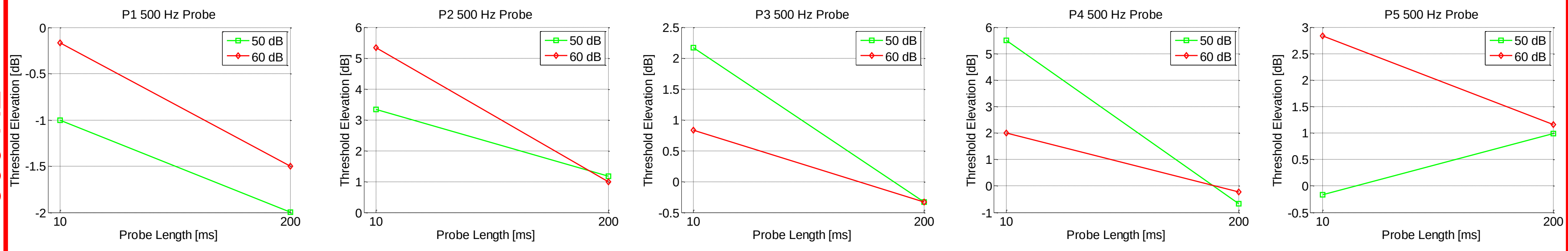
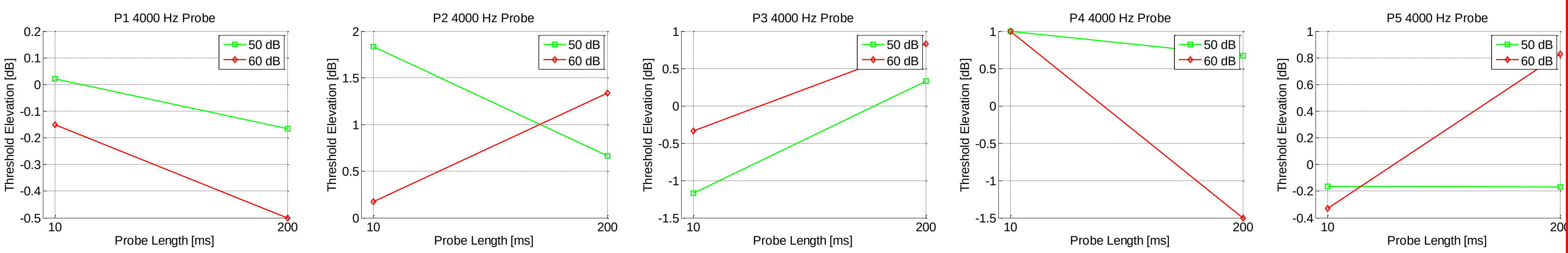
500 Hz



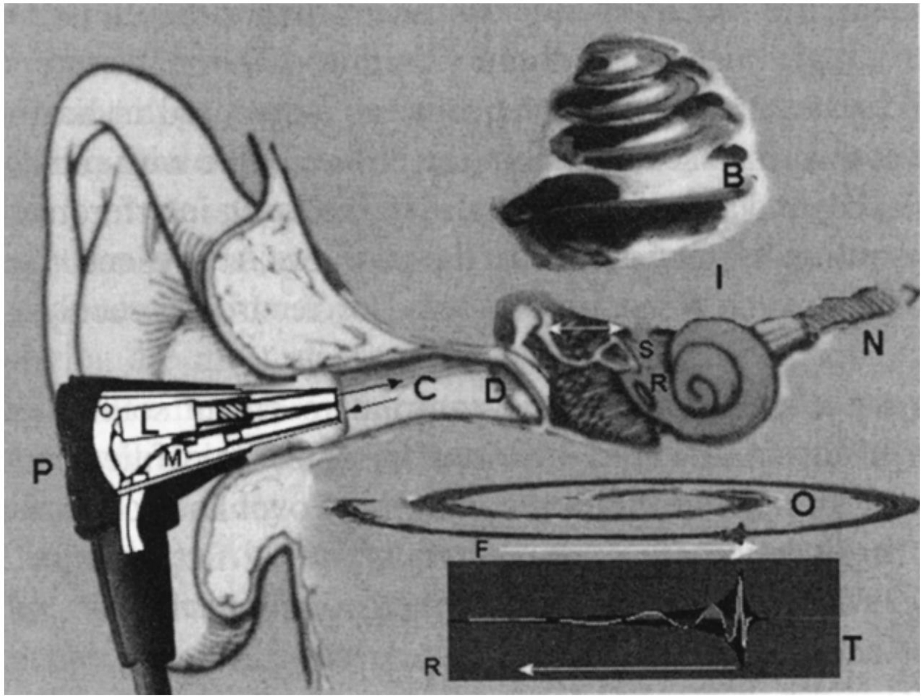
4000 Hz



- Wilcoxon signed rank test demonstrates an almost significant threshold elevation of 0.63 dB ($p=0.06$).

Otoacoustic Emissions

- Discovered by David Kemp in 1978

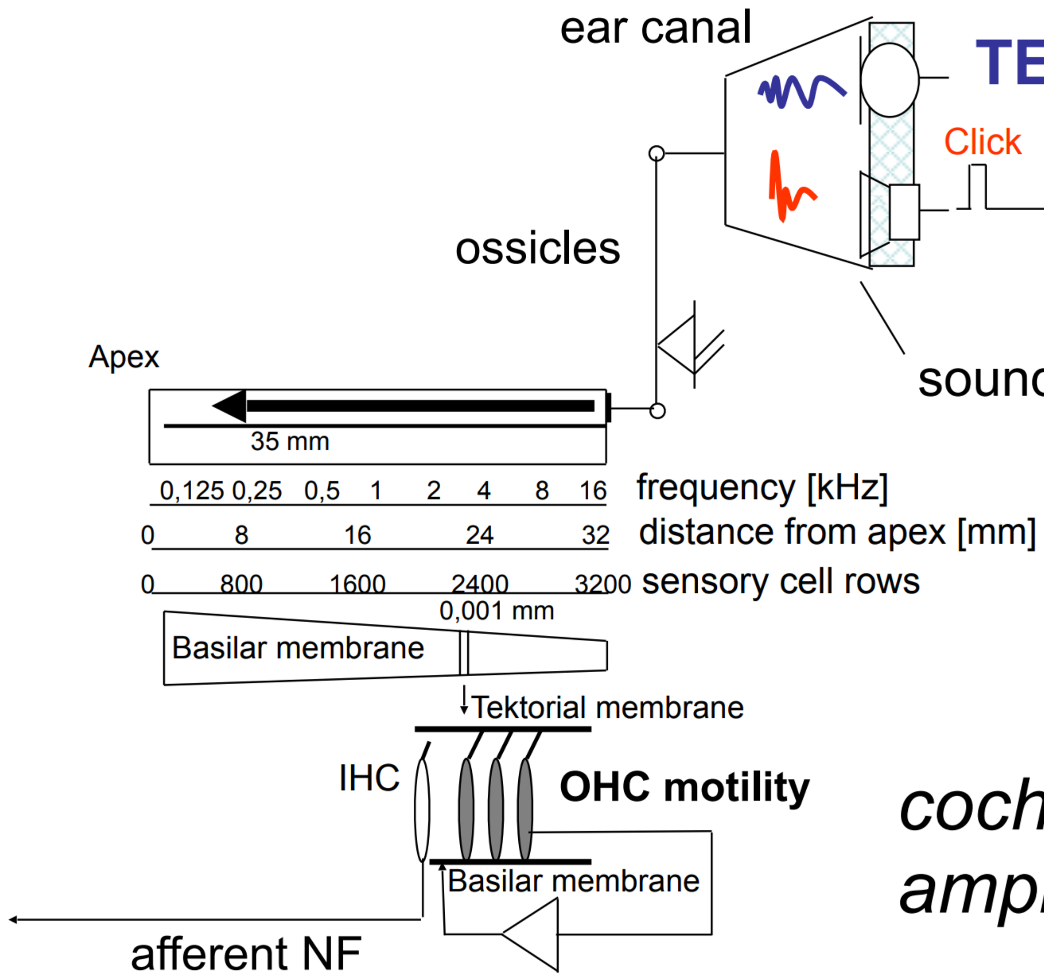


D. T. Kemp: Stimulated acoustic emissions from the human auditory system. J Acoust Soc Am 1978. Figures from „Otoacoustic Emissions in Perspective.“ In: Otoacoustic Emissions (Eds.: M.S. Robinette, T. J. Glattke) Thieme 1997.

Oto-Acoustic Emission (OAE)

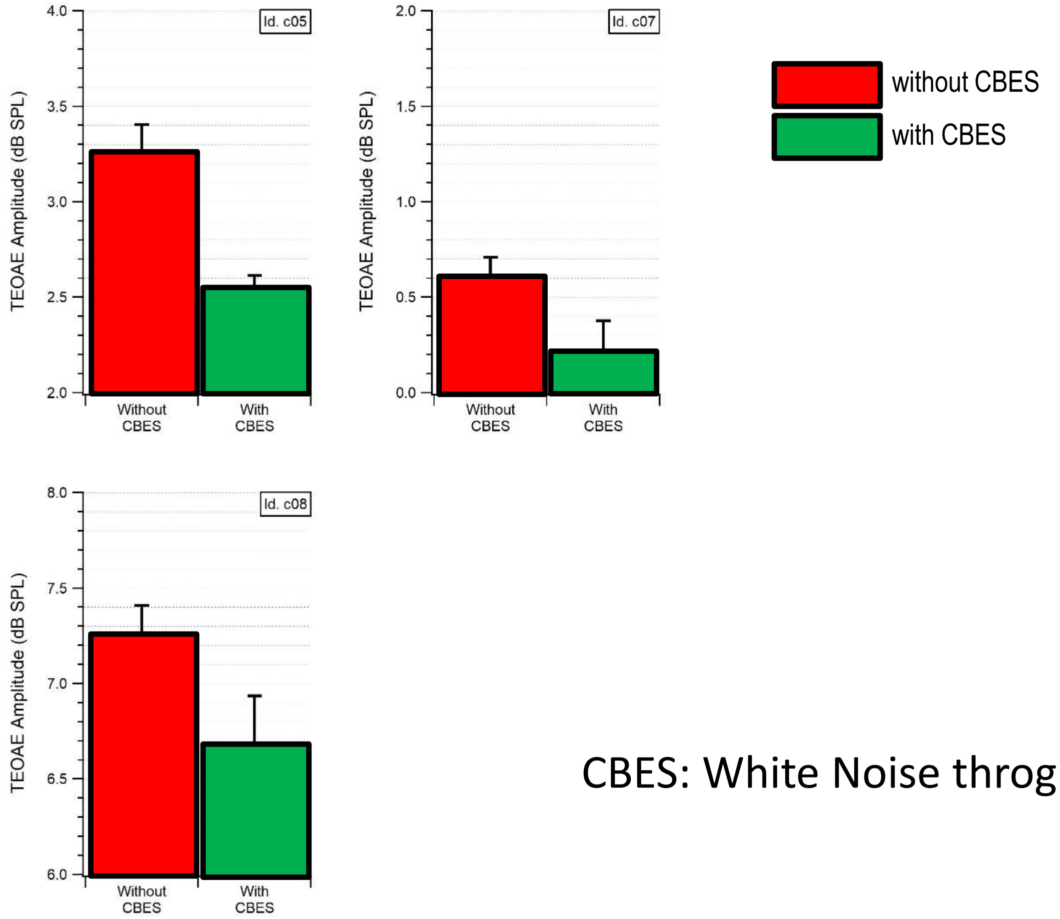
- The discovery of oto-acoustic emissions (OAEs) by David Kemp in 1978 has produced a fast, powerful, and versatile tool for diagnosing cochlear integrity.
- OAE measurements are today a standard part of the audiometric test battery. OAEs are elicited and measured by means of electro-acoustic transducers (loudspeaker and microphone) within an ear probe placed in the outer ear canal.
- There are spontaneous (SOAEs) and evoked OAEs (EOAEs).
  - EOAEs are the byproduct of the non-linear sound amplification process in the cochlea.
  - OAEs are low-level sound emissions generated by the outer hair cells (OHCs) within the cochlea.
  - OAE levels depend on the number of functioning outer hair cells given a normal middle-ear function. OAE levels depend on the ear canal volume.
  - Because of the smaller ear canal volume, OAE amplitude in newborns and infants is higher compared to that in adults.
  - Thus, OAEs are easier to measure and thus provide a suited tool for newborn-hearing screening and follow-up diagnostics.

Transient Evoked Oto-Acoustic Emission (TEOAE)



cochlear amplifier

Results:
Control Group (3 Normal Hearing Listeners TEOAE)



CBES: White Noise throguh the CI

DISCUSSION

- Small but almost significant effect of CBES on threshold elevation in the acoustic ear.
- This increase appears smaller than previously reported for normal hearing listeners.
- These preliminary results support the notion that for single-sided deaf CI users, the CI may modulate hearing in the normal, acoustic ear via activation of the contralateral MOCR.
- Further research is required to fully characterize such modulations.

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EXZELLENZCLUSTER IM AUDITORY VALLEY ZUKUNFT HÖREN

APG Auditory Prosthetic Group

Medizinische Hochschule Hannover

Andreas Büchner

Thomas Lenarz

We gratefully thank for funding of this project:

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Thank you! – Questions?

Nächste Schritte

- Entwicklung von EAS Anpassungsmethode
- Entwicklung von EAS Soundverarbeitungsstrategien

Auditory Prosthetic Group

Benjamin Krüger
Dr.-Ing (cand)

Marina Imsiecke
Dr. rer. Nat (cand)

Vielen Dank!

- Mehr Info unter: http://auditoryprostheticgroup.weebly.com/