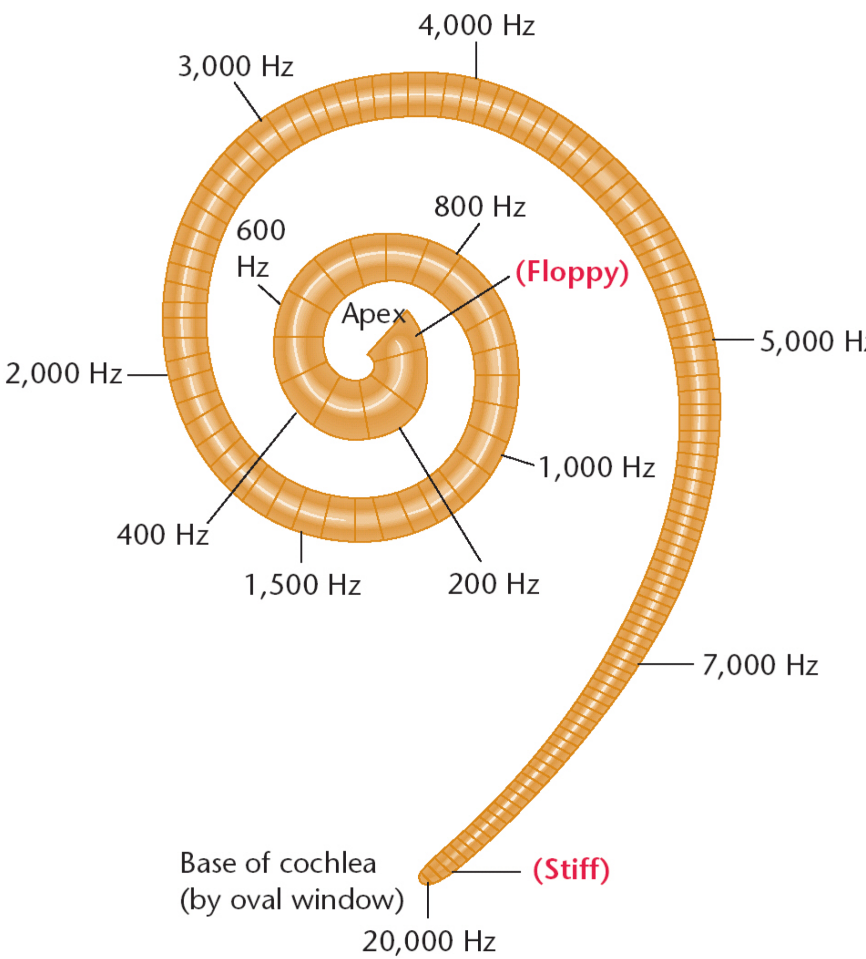
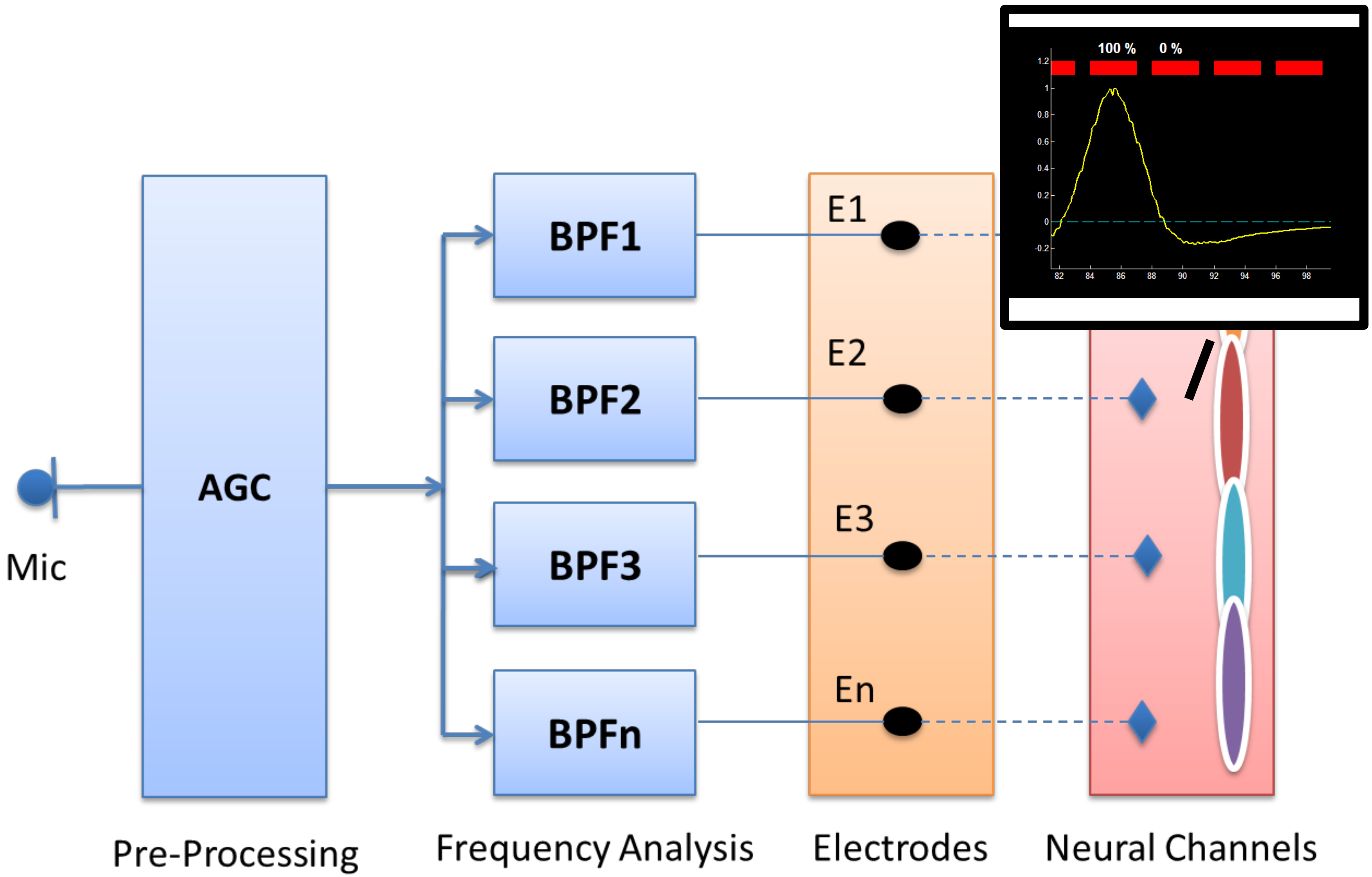
Low Frequency Stimulation in CIs: Challenges and Opportunities

Abhi Kulkarni, PhD
Advanced Bionics

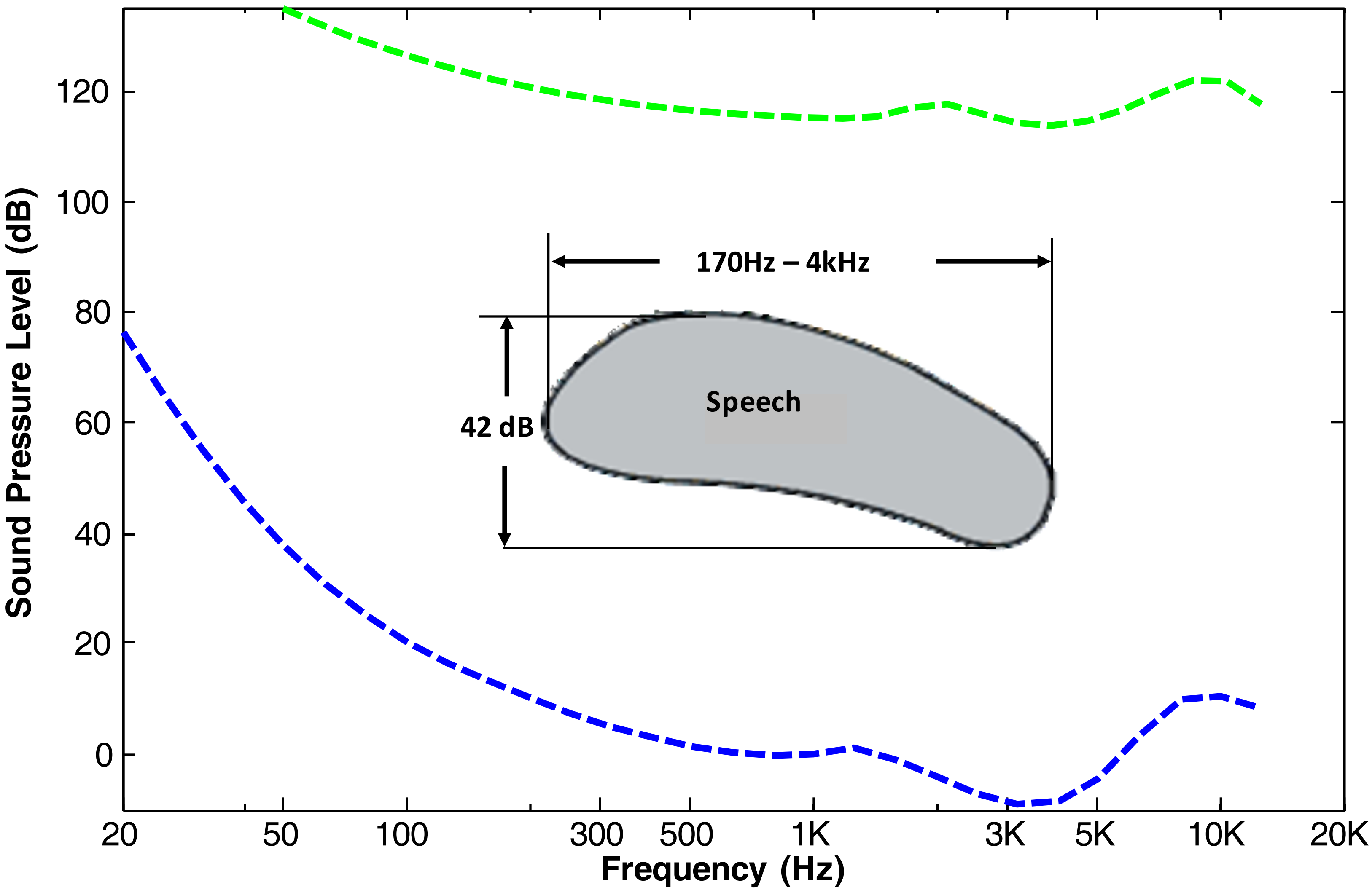
Spectral Coverage with CIs



Contemporary Sound Coding Framework



Spectral Content in Acoustical Signals



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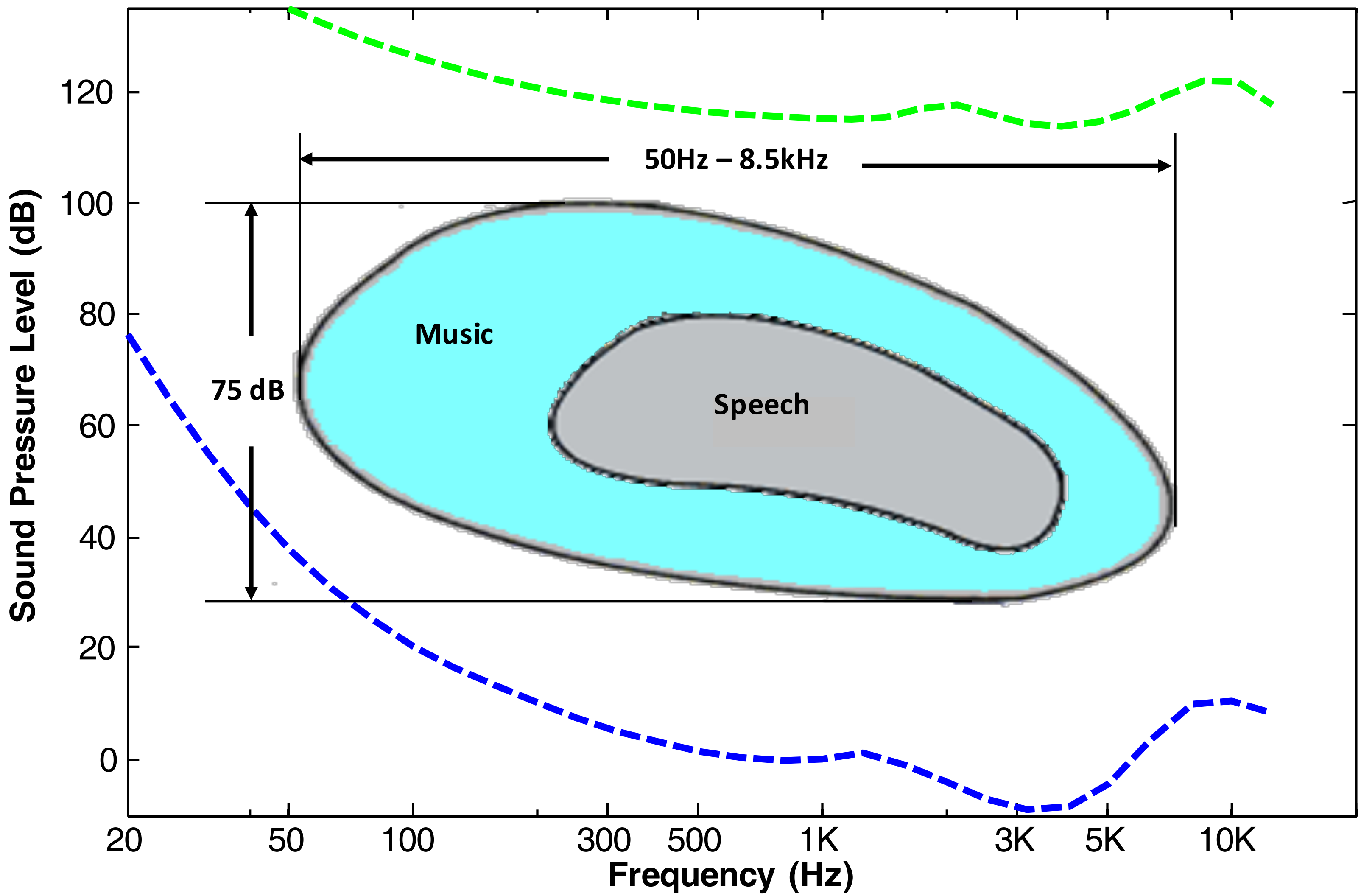
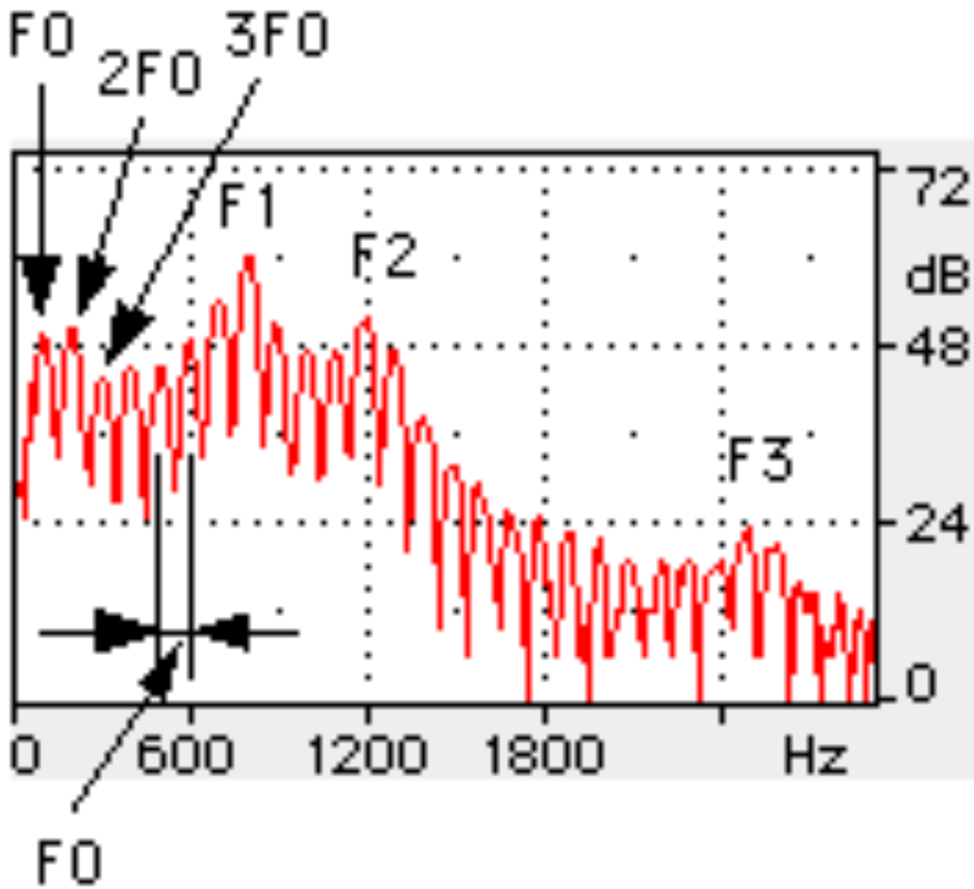
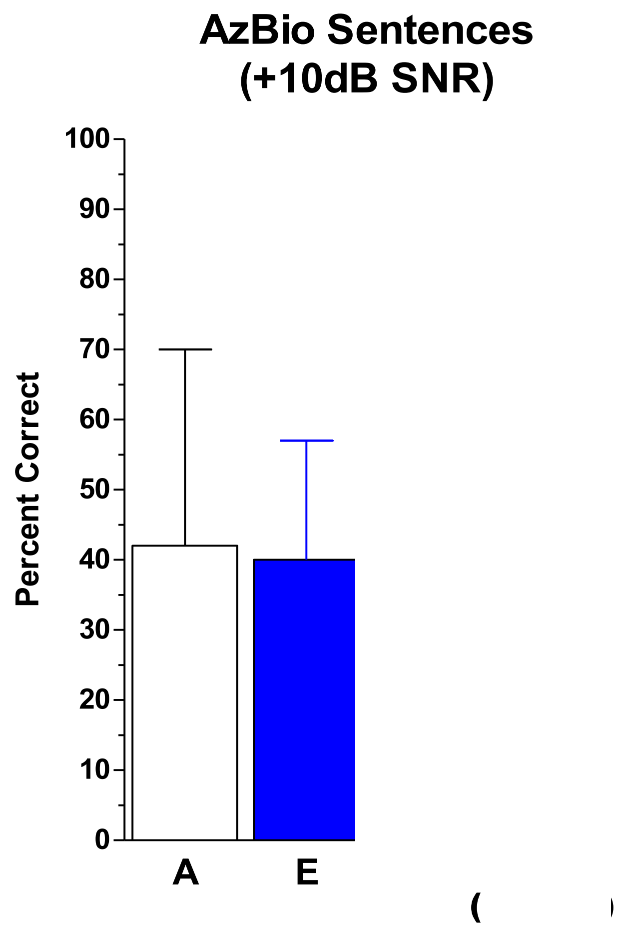


Formant Frequencies In Speech Signals

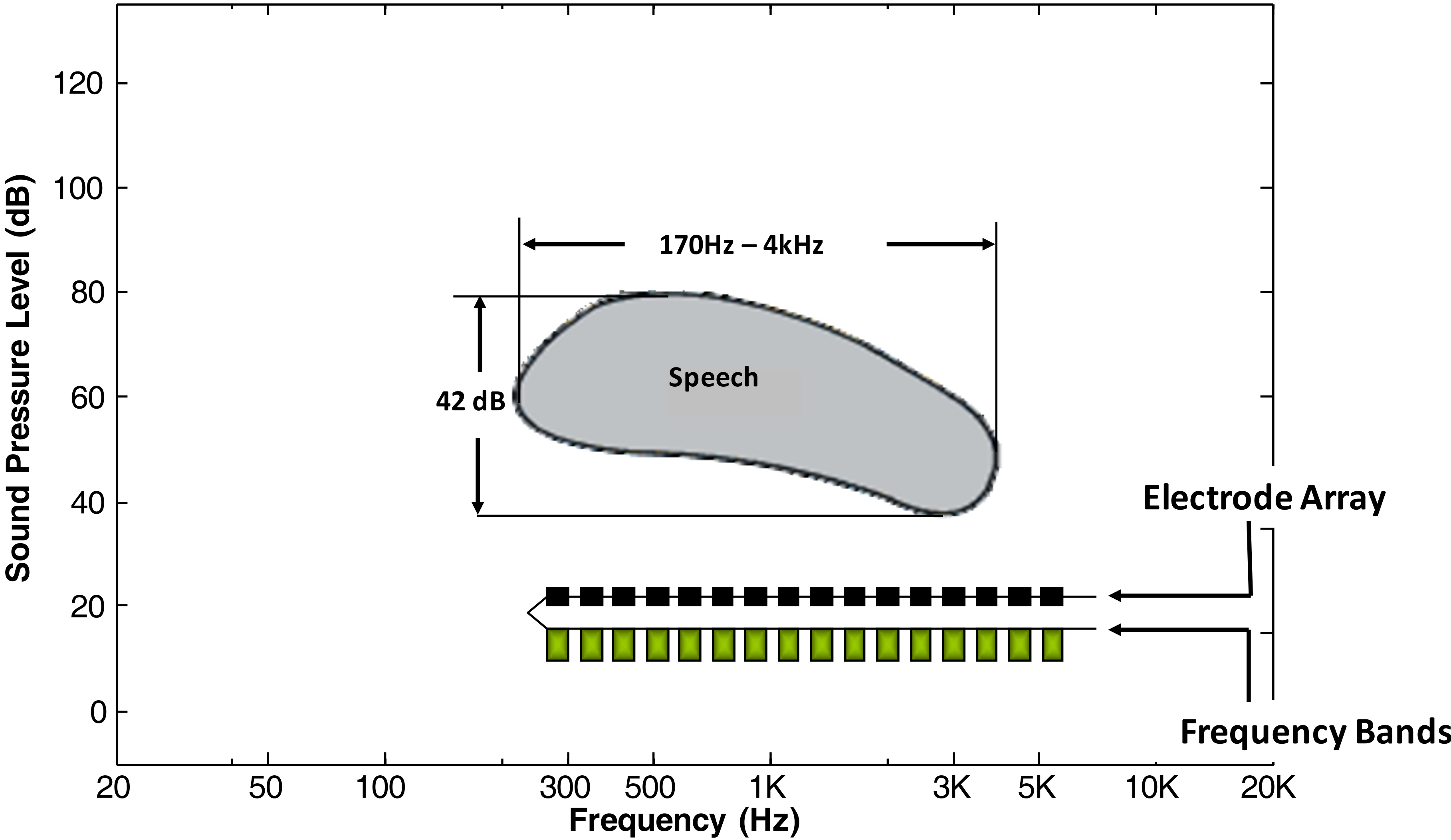


Importance of Low-Frequencies: Insight from EAS Benefit

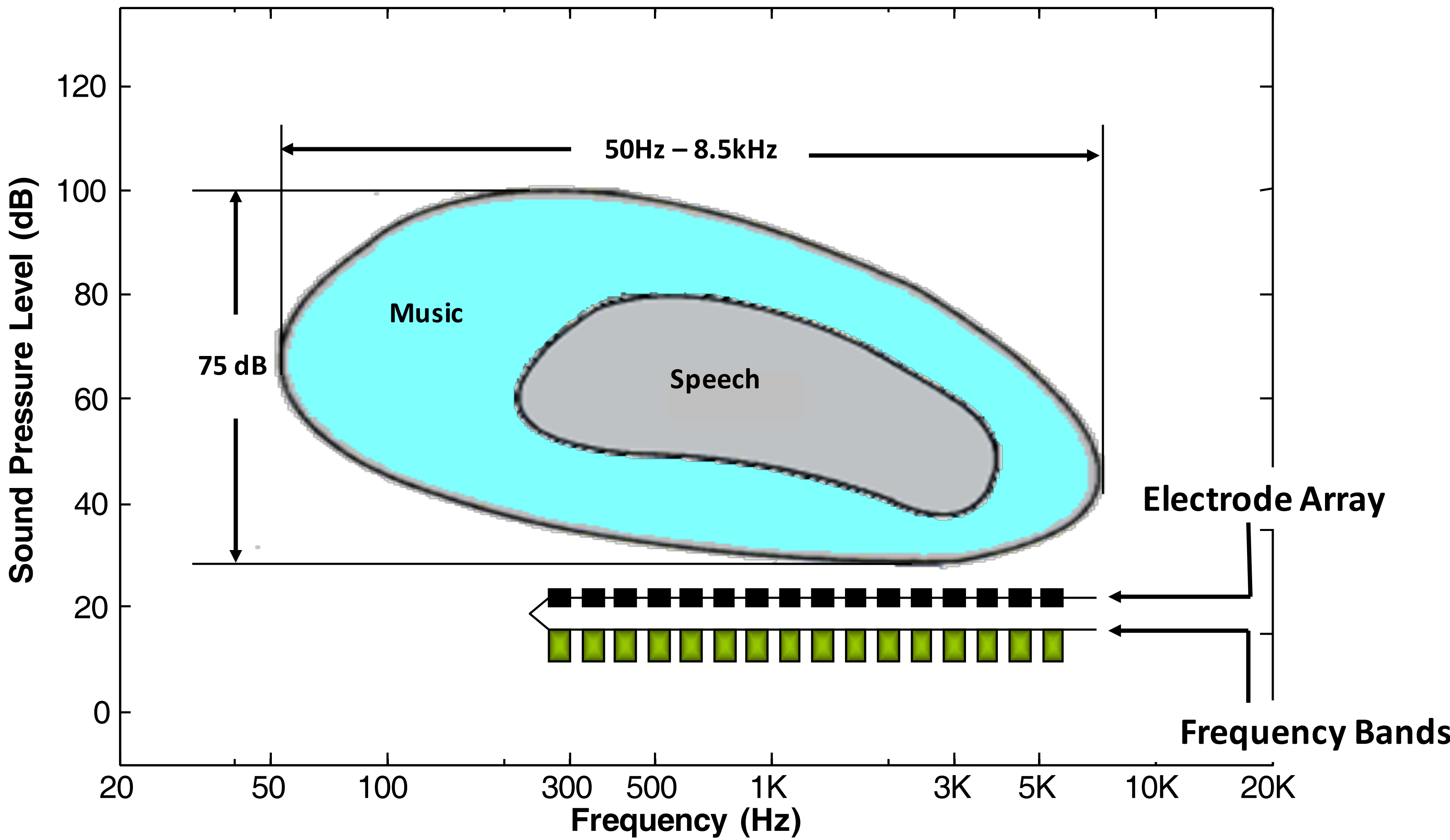


Zhang, Dorman and Spahr (2010)

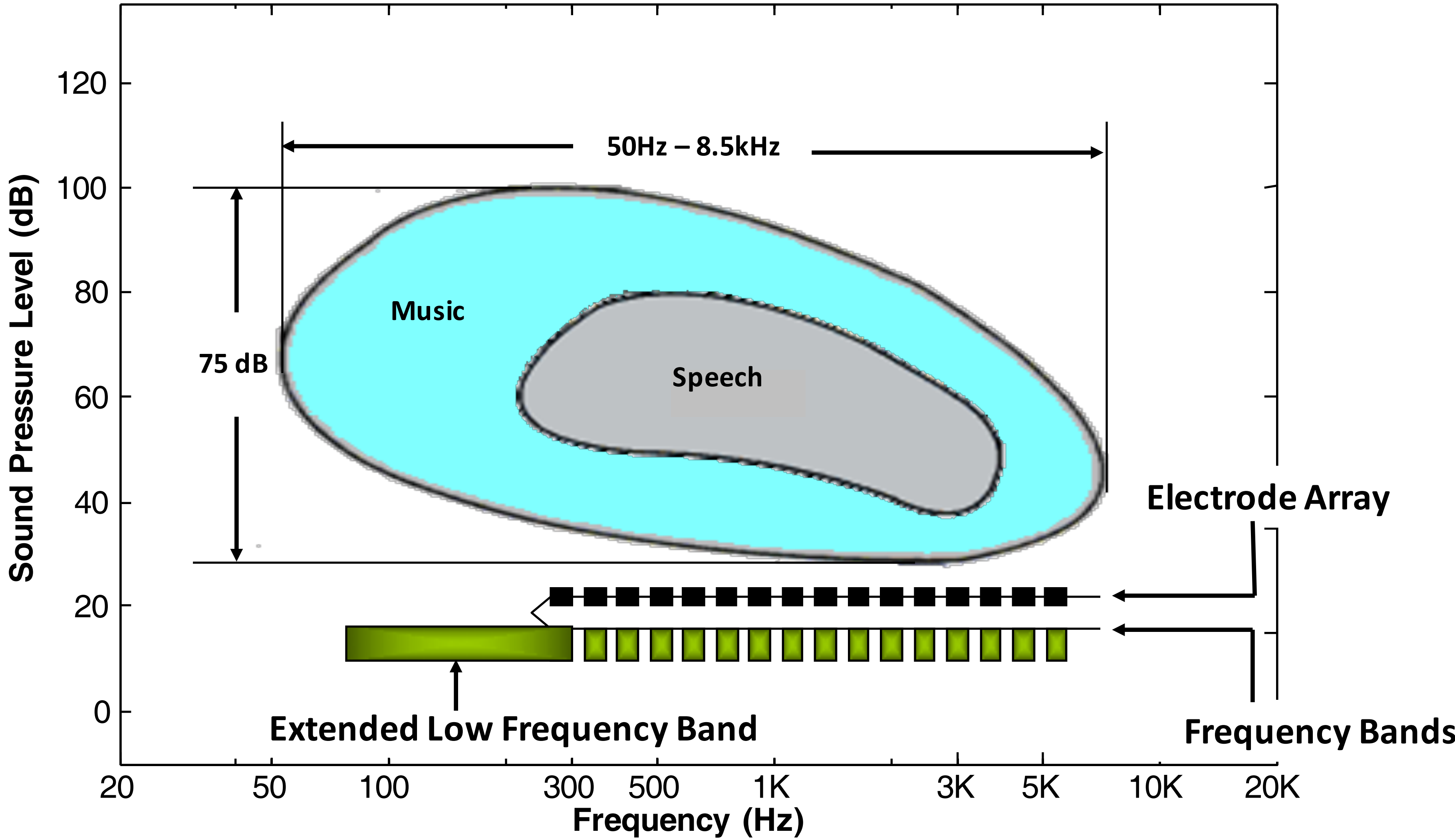
Spectral Representation in CIs



Spectral Representation in CIs



Spectral Representation in CIs



Intermediate Summary

- CI listeners can derive significant benefit from access to low frequencies
- Not a signal processing challenge!
- Challenge is overcoming the limitations of the Electrode-Nerve interface for conveying low-frequency information

Low Frequency Stimulation -- Why not put an electrode deeper in the cochlea?

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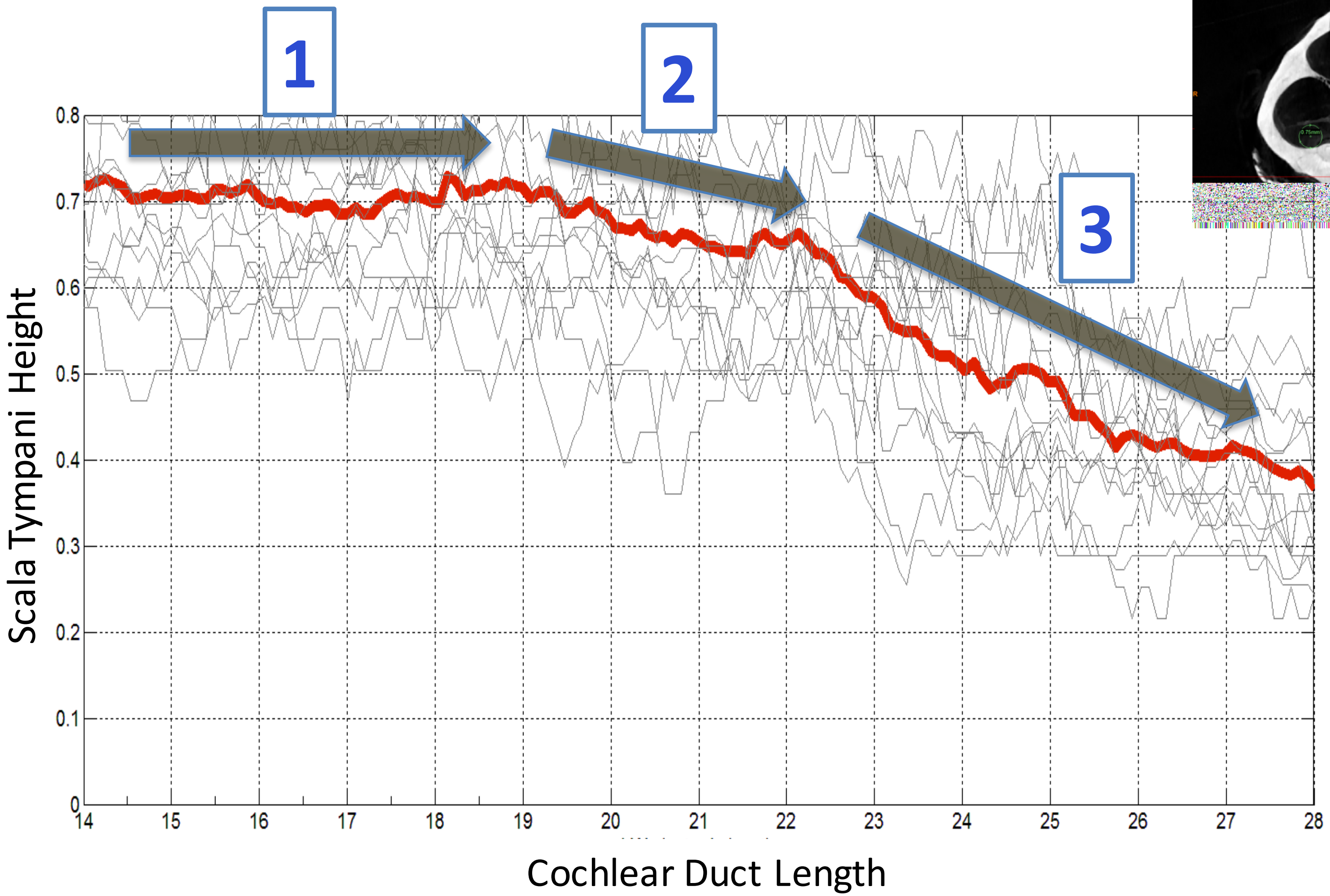
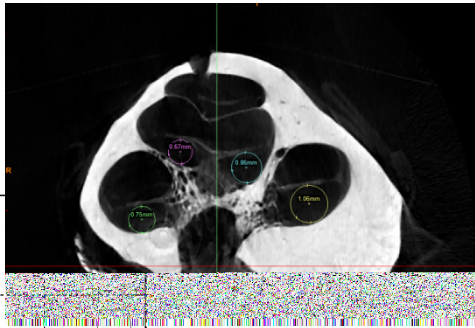
1. Cochlear Anatomy

Narrowing Cochlear Duct -- Deeper Insertions would cause greater trauma

Cochlear Anatomy: Geometrical Considerations





Low Frequency Stimulation -- Why not put an electrode deeper in the cochlea?

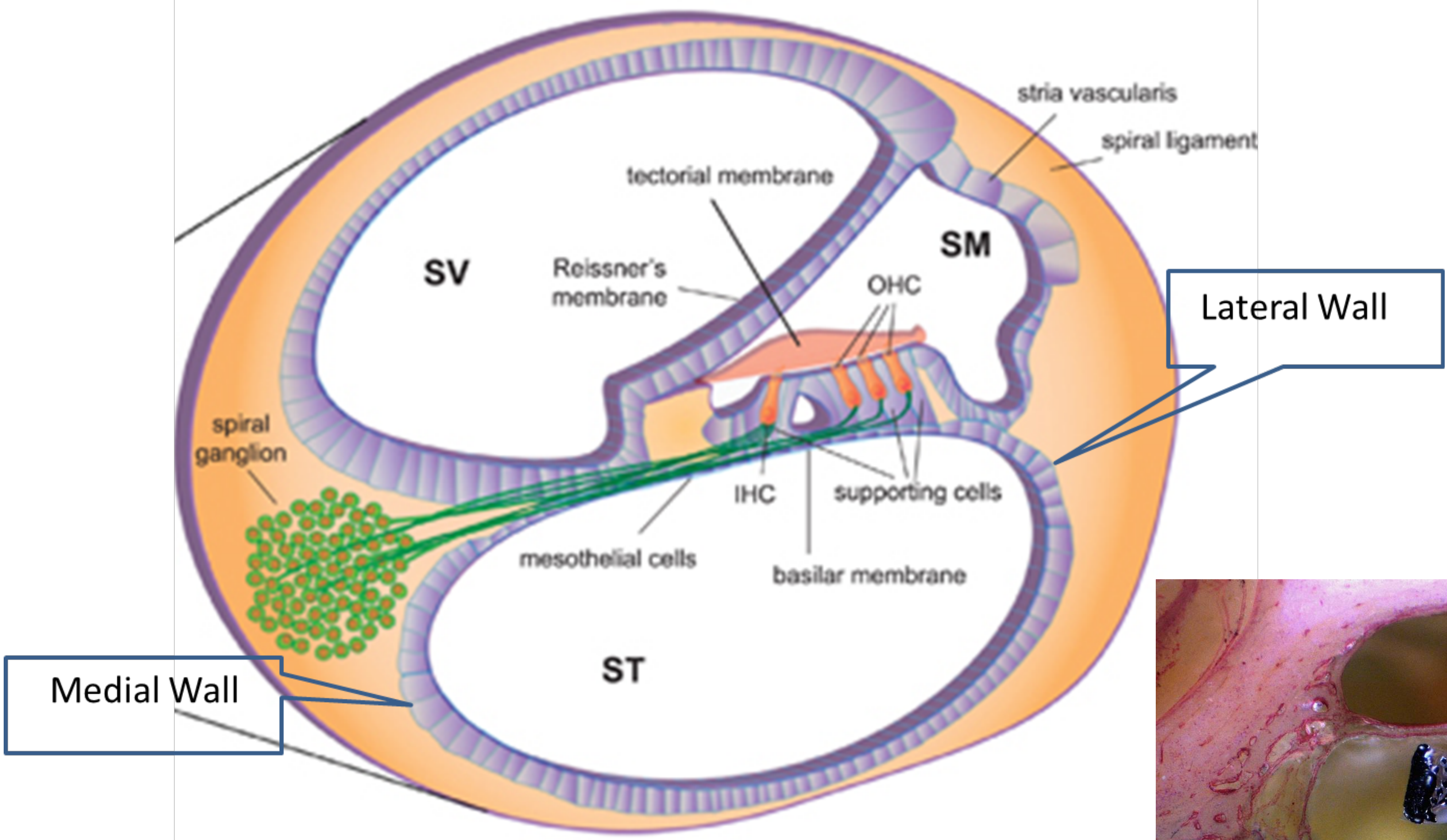
1. Cochlear Anatomy

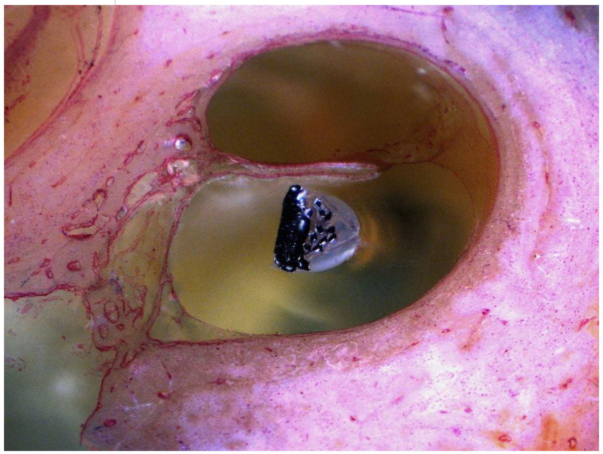
Narrowing Cochlear Duct -- Deeper Insertions would cause greater trauma

2. Cochlear Physiology

Compressed Neural Representation -- The spiral ganglion neurons in the apex of the cochlea are highly compressed and deeply inserted electrodes loose independence.

Cochlear Anatomy



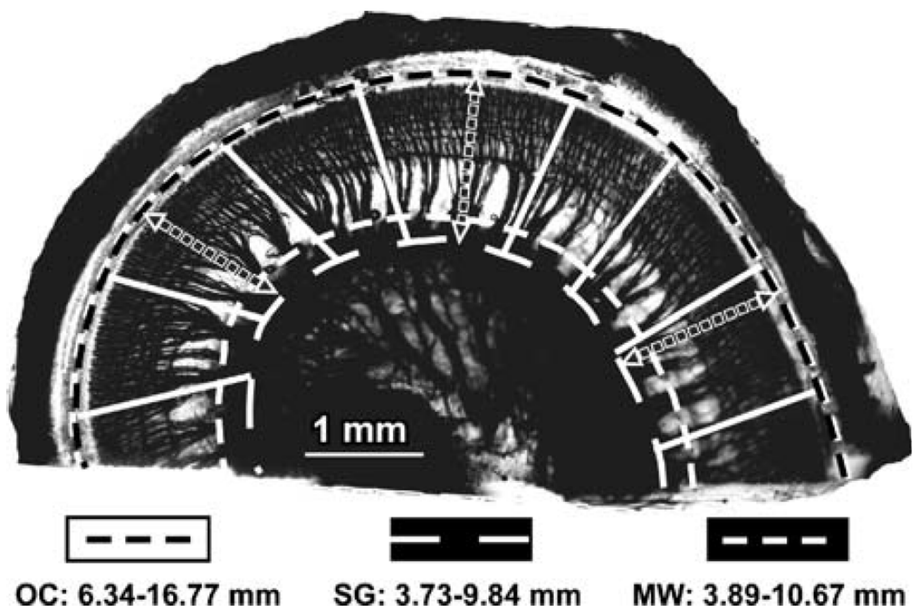


JARO 8: 220–233 (2007)
DOI: 10.1007/s10162-007-0076-9

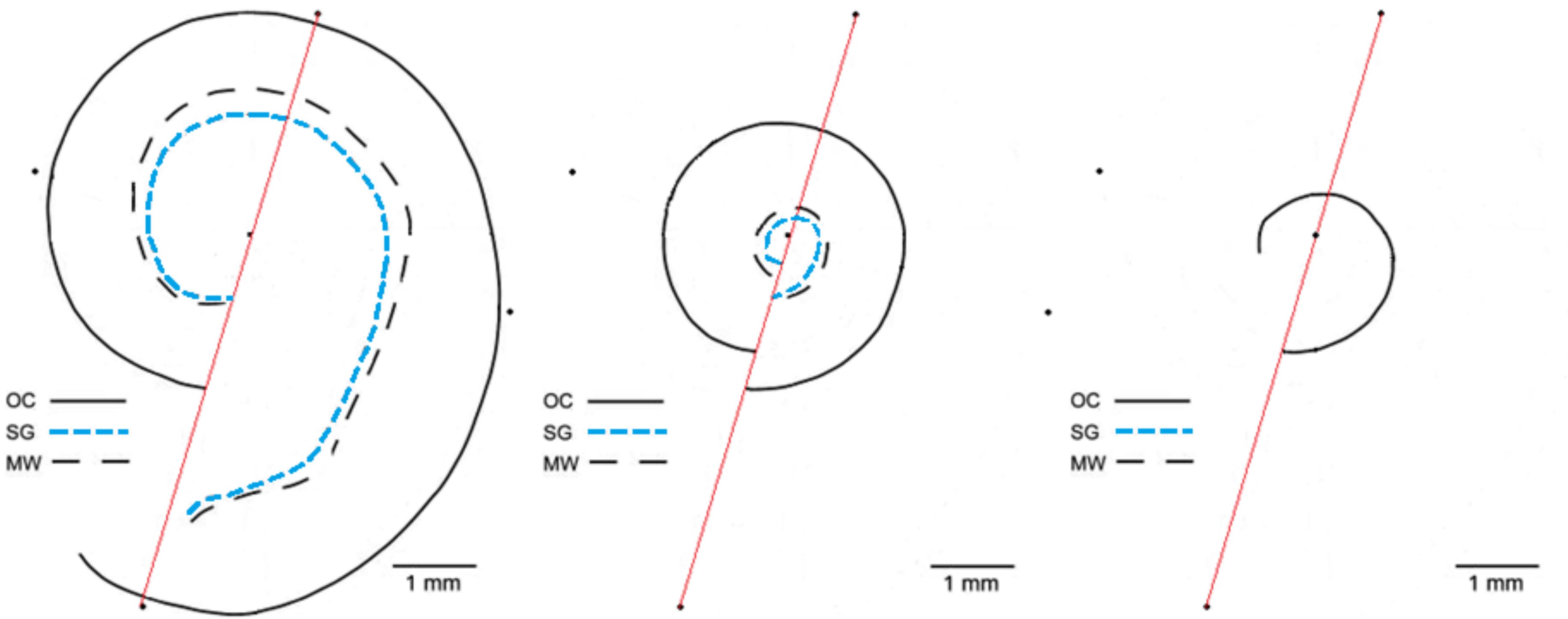
JARO
Journal of the Association for Research in Otolaryngology

Frequency Map for the Human Cochlear Spiral Ganglion: Implications for Cochlear Implants

Olga Stakhovskaya, Divya Sridhar, Ben H. Bonham, and Patricia A. Leake

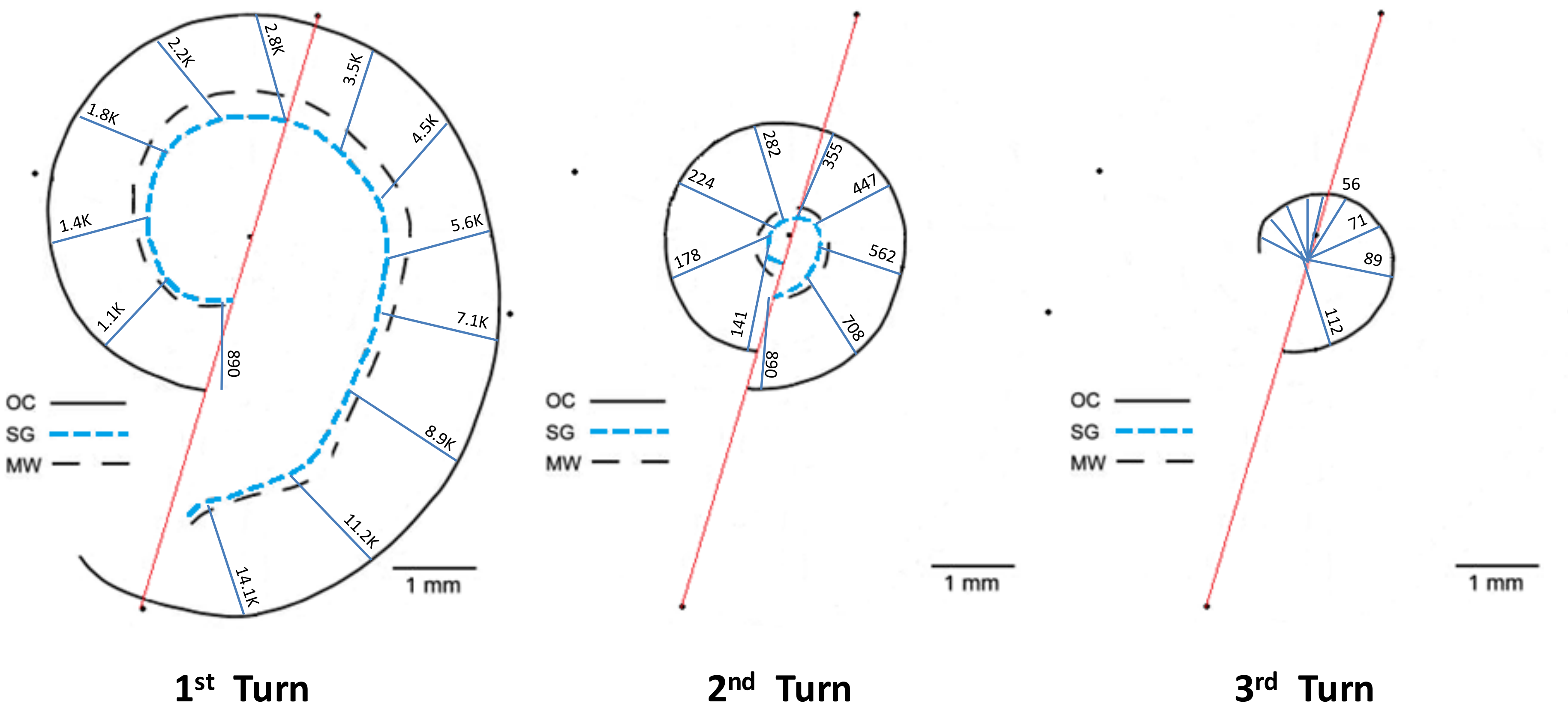


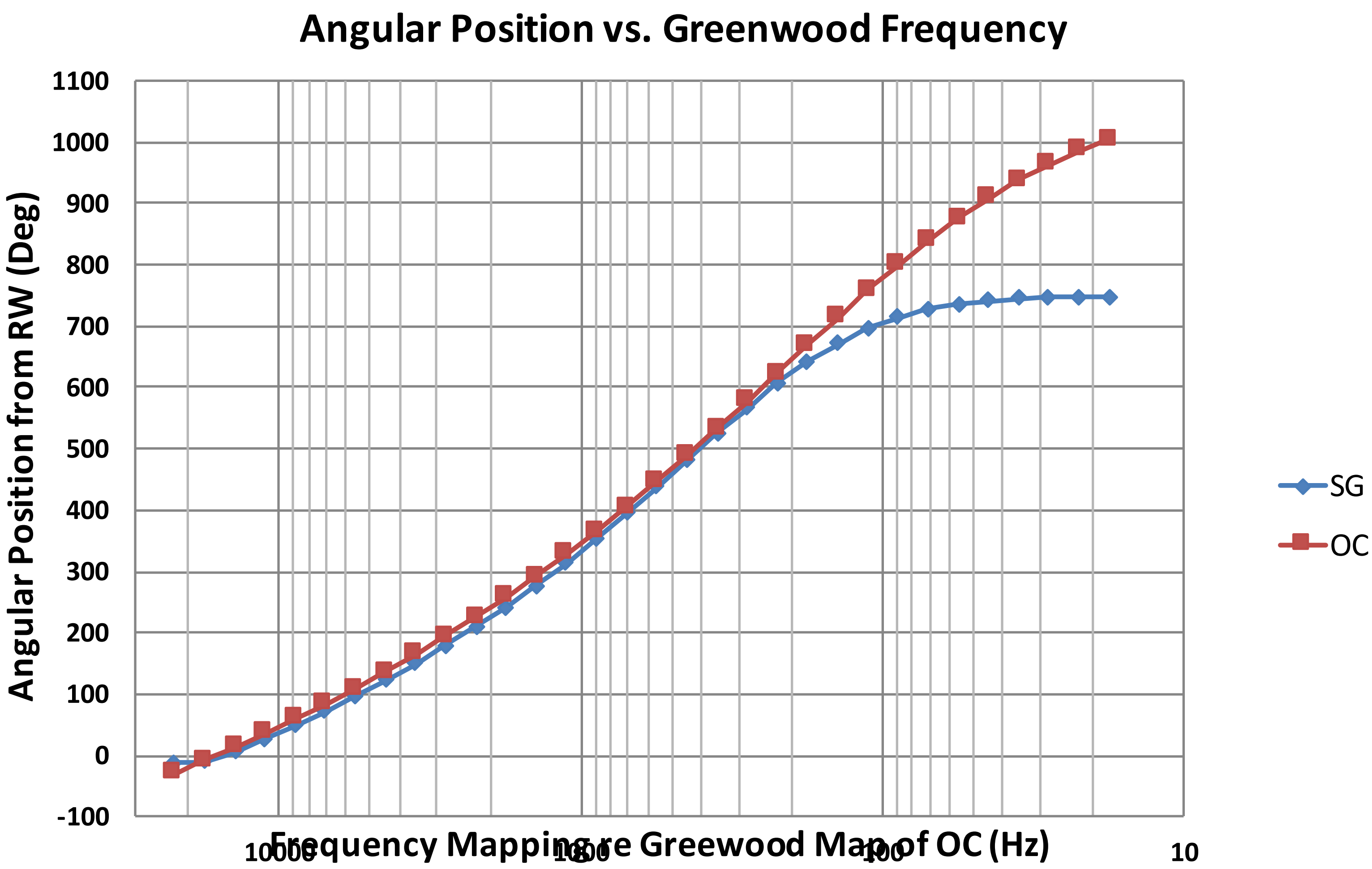
Neural Target Distribution Saturates in the Apex



1st Turn **2nd Turn** **3rd Turn**

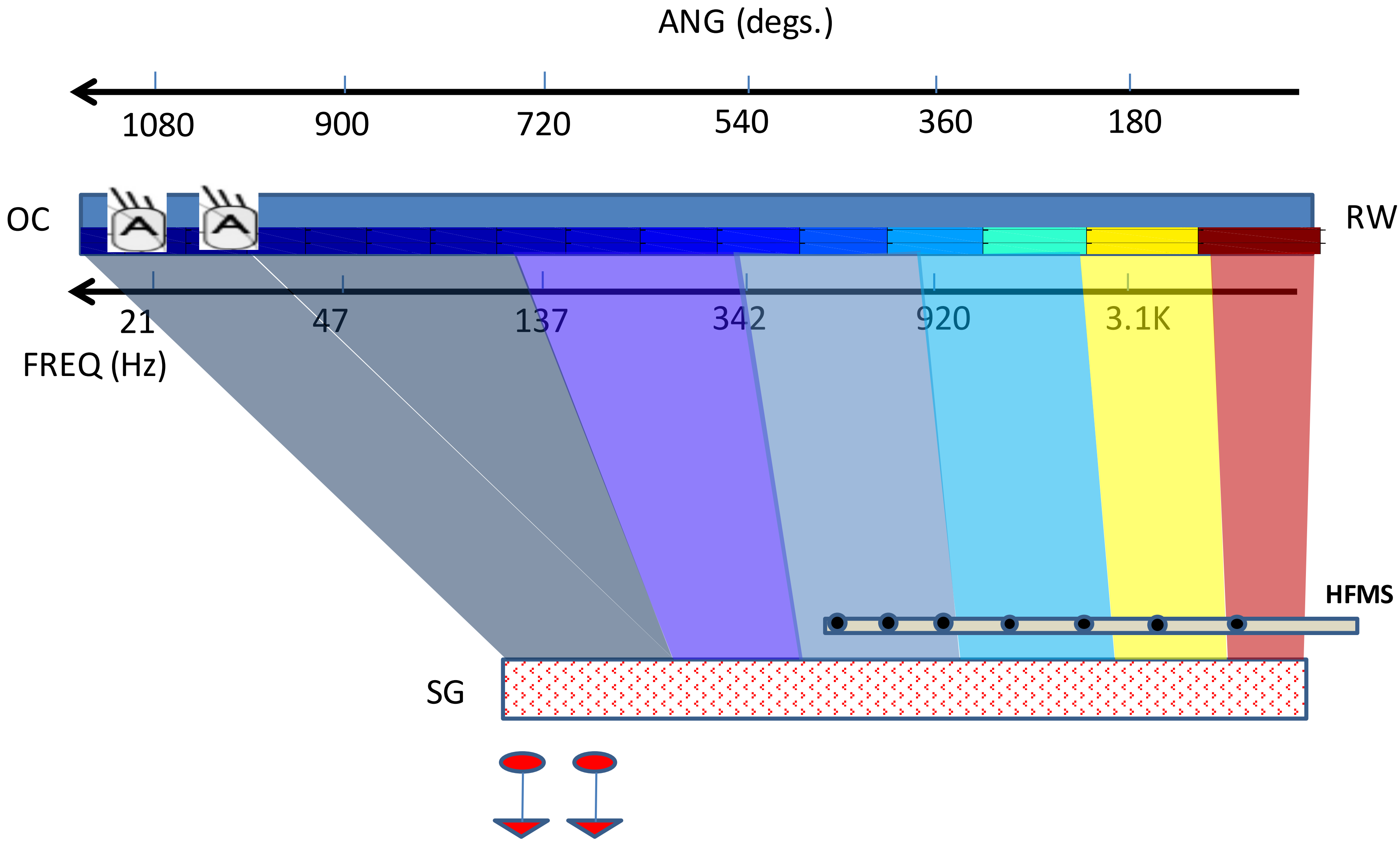
Consequences of Neural Organization on Frequency Allocation



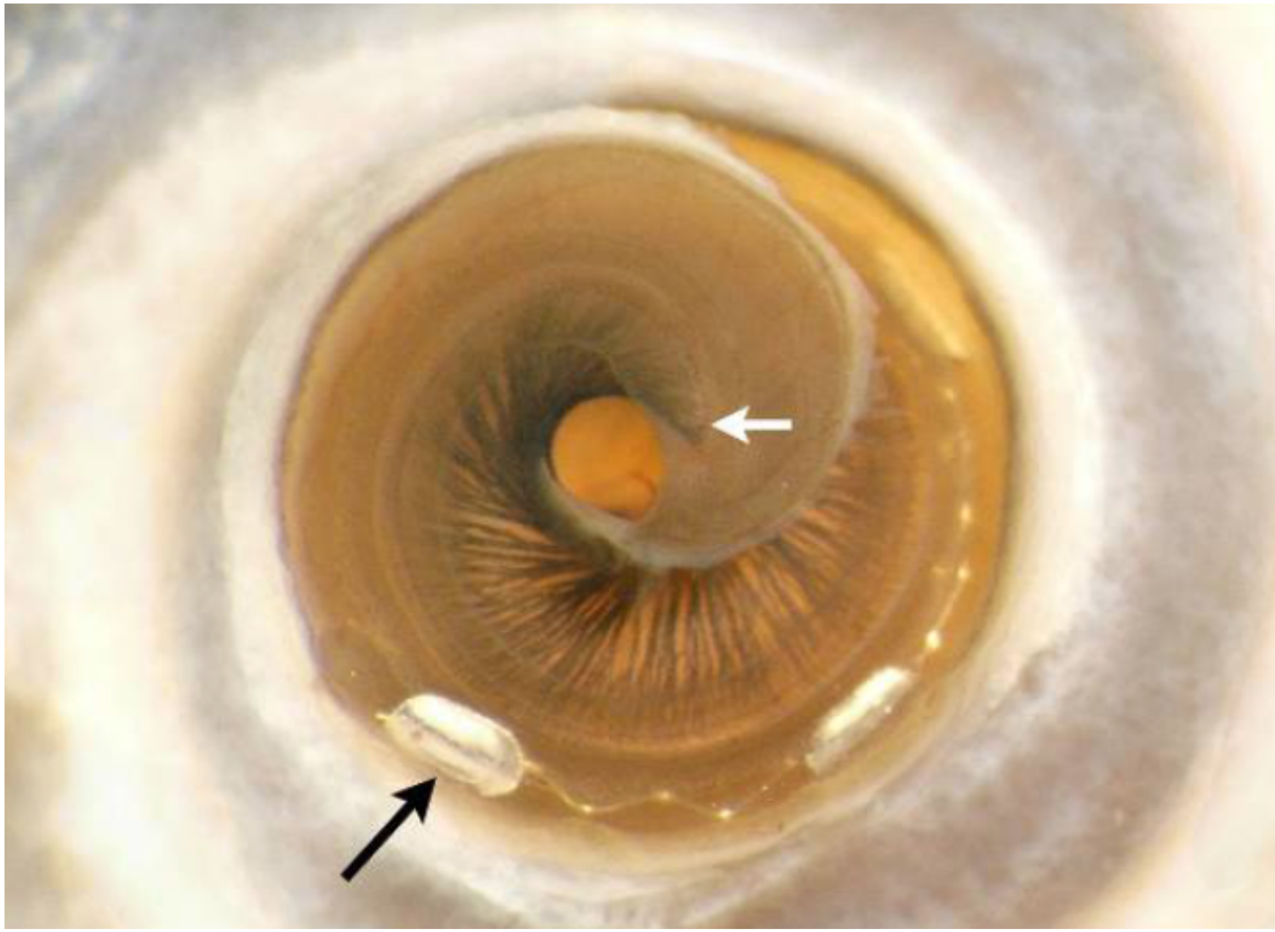


Angular Position vs. Greenwood Frequency
Angular Position from RW (Deg)
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
10000
1000
100
10
Frequency Mapping re Greewood Map of OC (Hz)
SG
OC

Distribution of Neural Targets in Cochlea

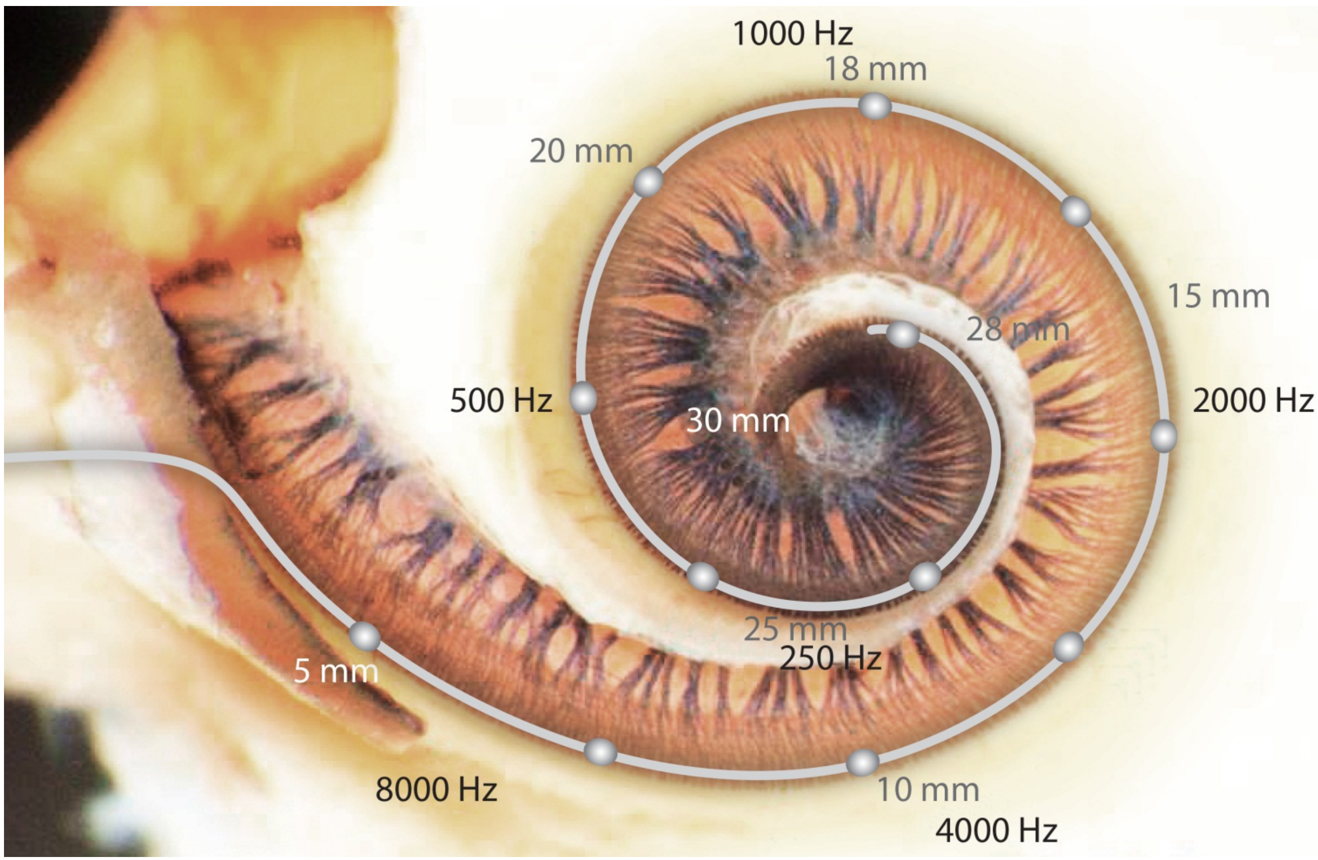


Neural Organization in Apex



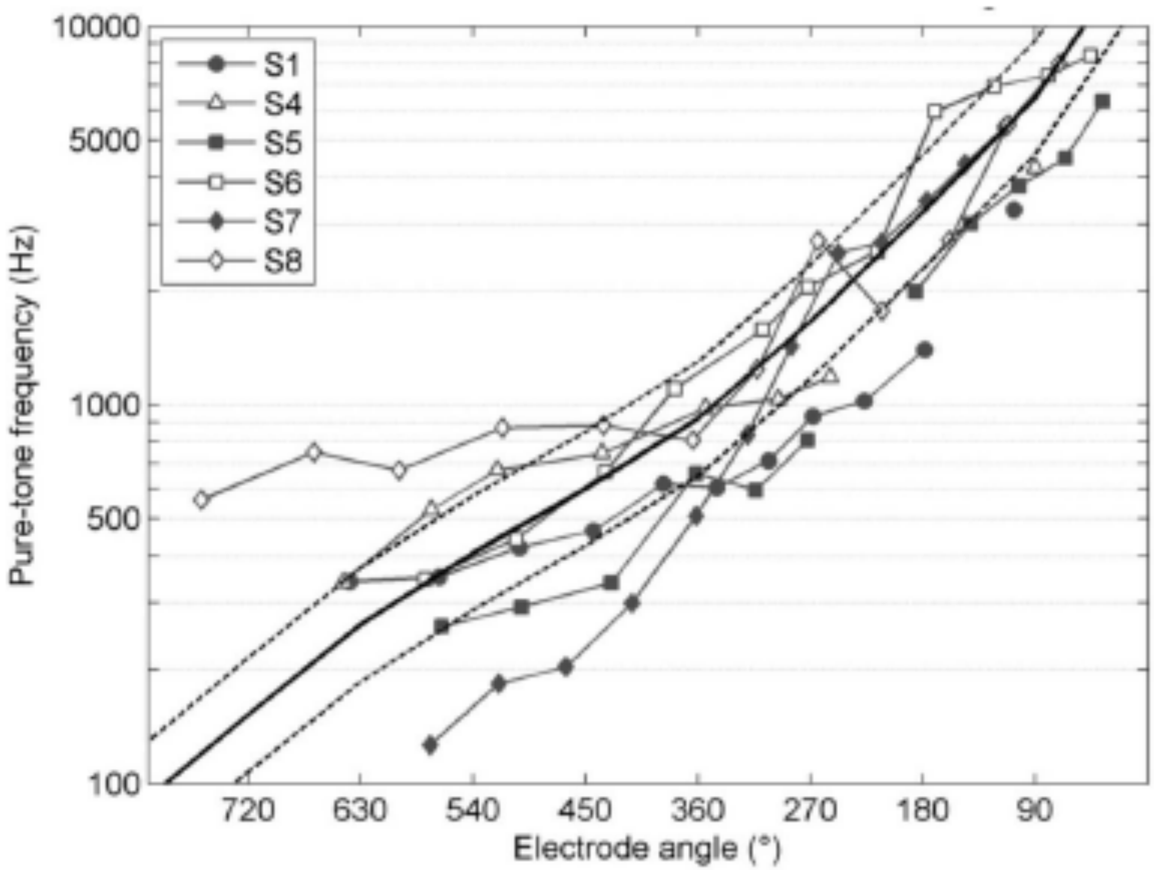
Courtesy Gary Wright, UTSW)

Spectral Coverage with Deeply Inserted Electrodes – Not Effective!!



Source: **medel.com**

Place Pitch in CIs: Saturates at ~ 300-500 Hz



Schatzer et al., 2013

Pitch Confusions with Deep Insertions

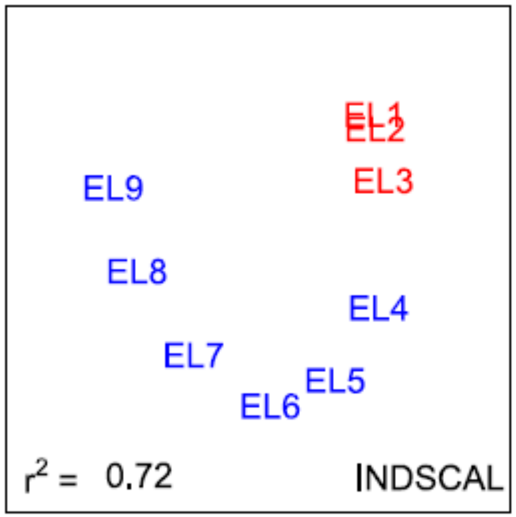
Multi Dimensional Scaling (MDS)

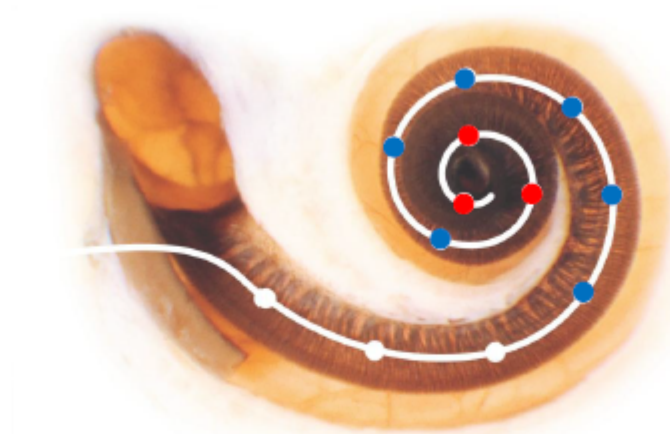
Subjects

14 deeply inserted 31.5 mm MED-EL users

Stimuli

9 single electrode pulse trains





(from Landsberger et al., JASA 2014)

- Place Coding appears to exist past 1.25 turns
- Diminishing returns at the apex

Can we Achieve More Effective Apical Stimulation with "Standard" Electrodes??

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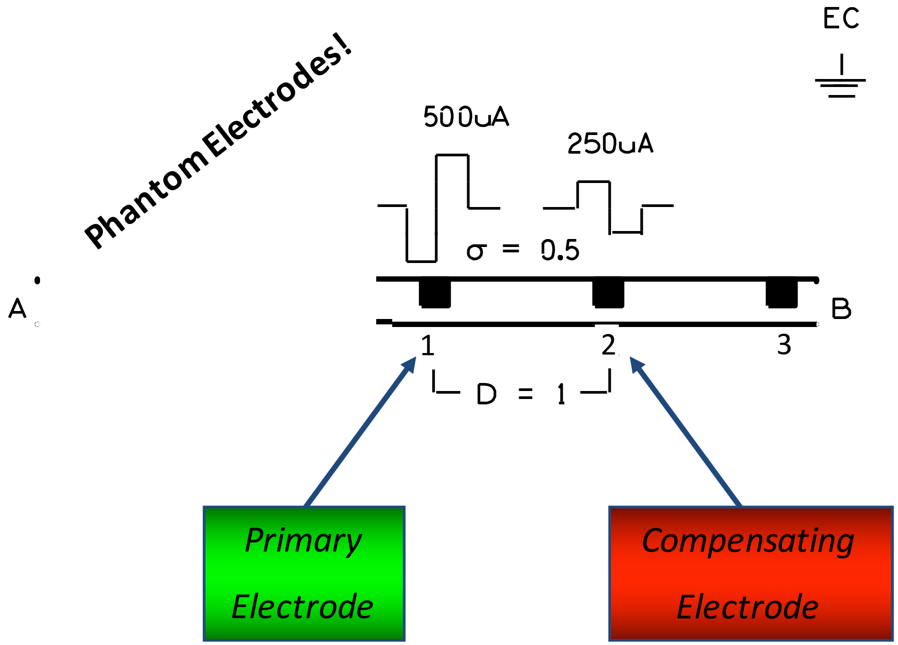
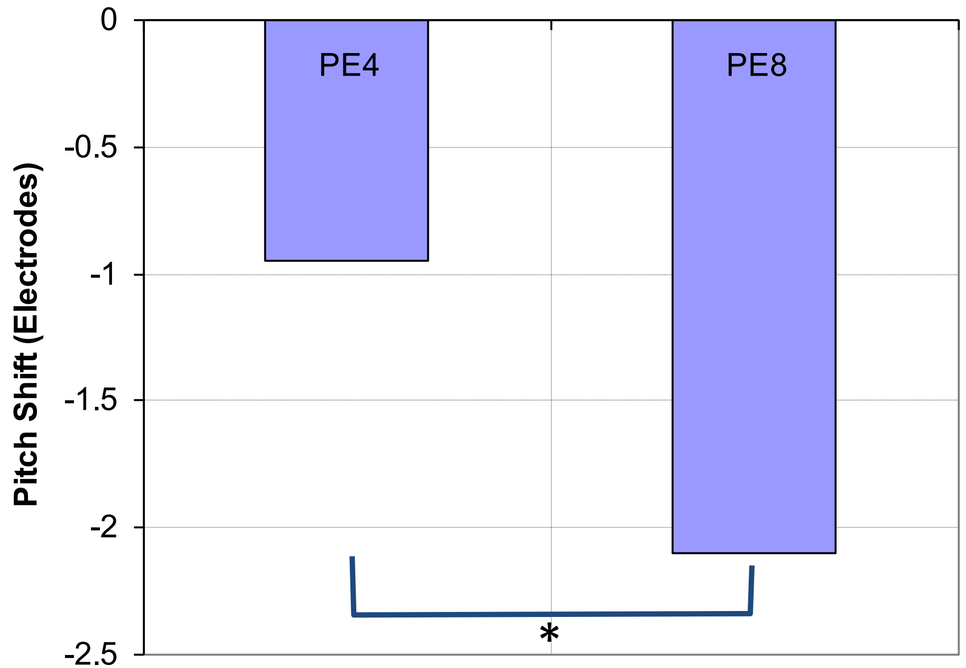


Litvak and Saoji (2010)

Macherey and Carlyon (2011)

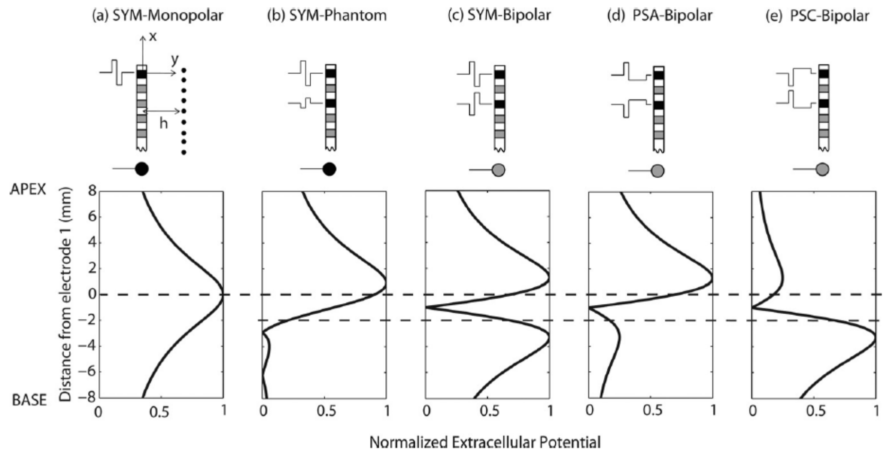
- Pitch shift:
  - Average: 1 electrode (1 mm).
  - Varies from 0.5 to 3 electrodes.

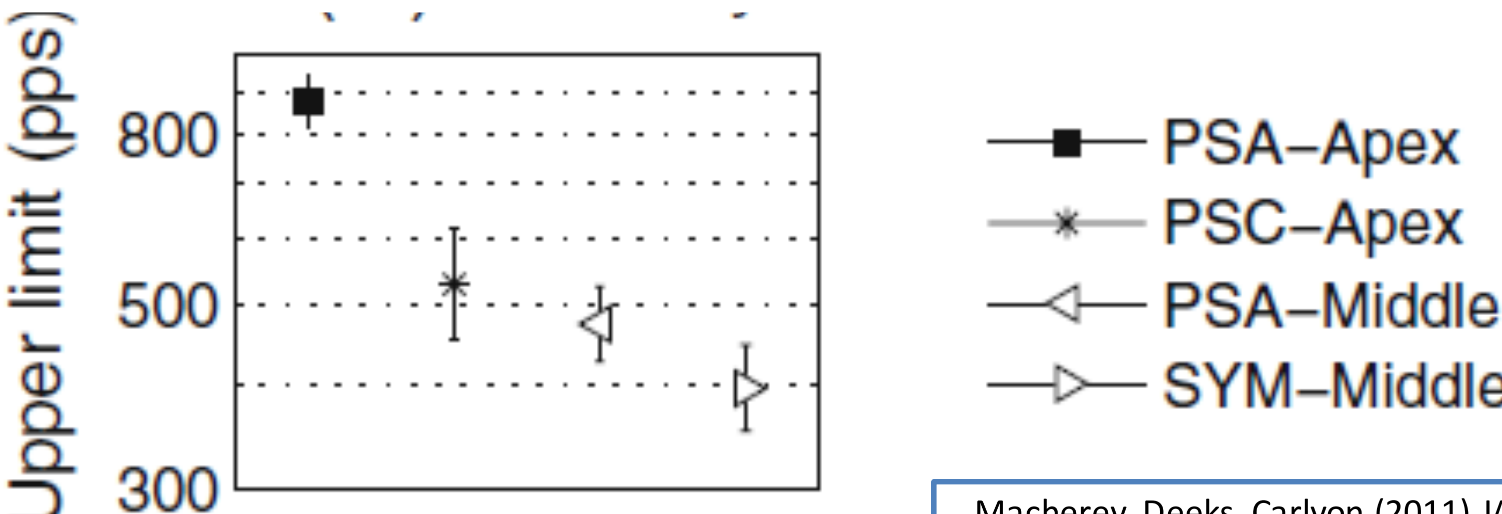
Average Pitch Shift



Saoji and Litvak (2010)

Better Temporal Pitch Encoding with PSA-Apex (Phantom) stimulation

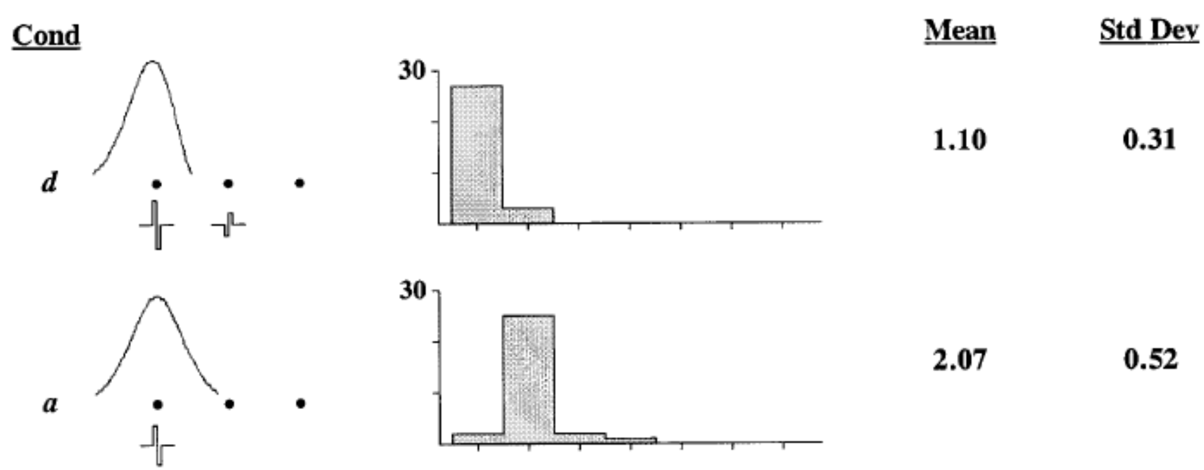




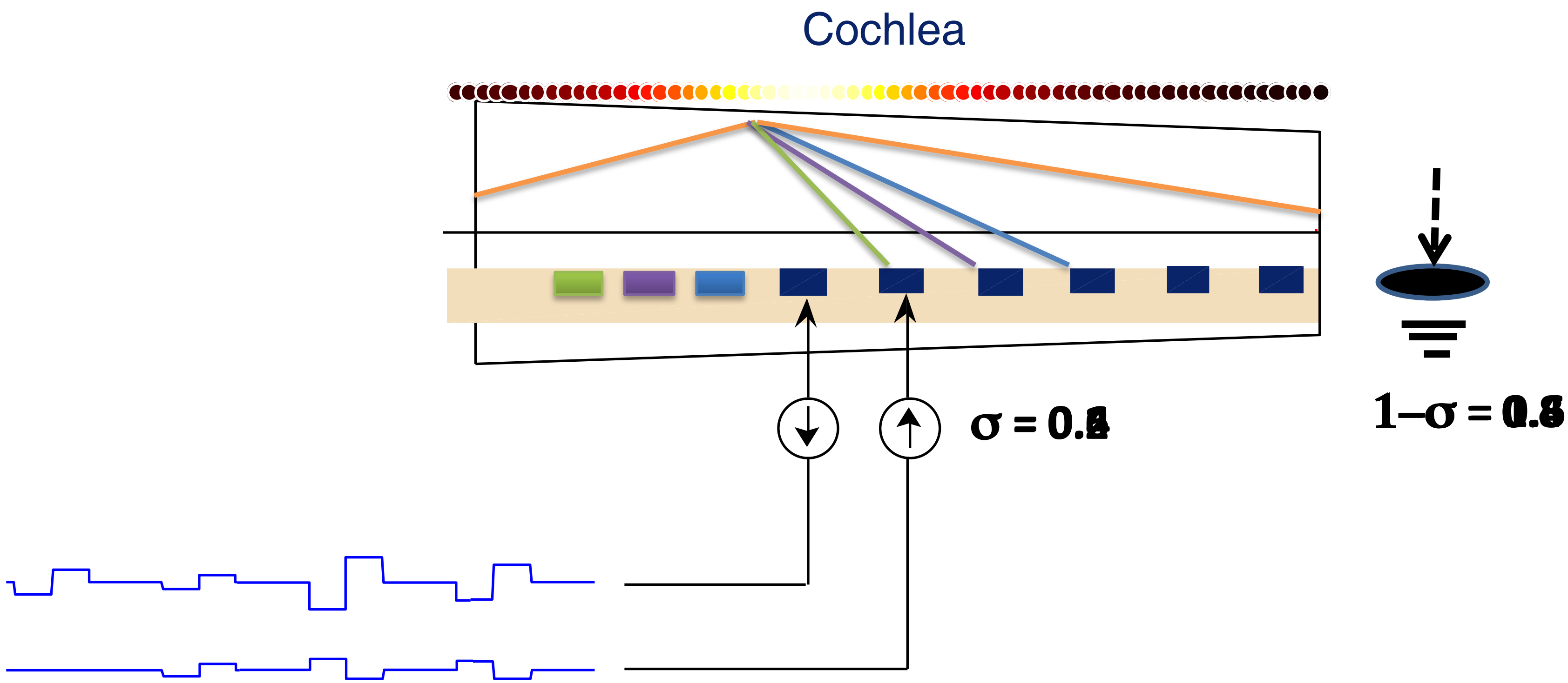
Macherey, Deeks, Carlyon (2011) JASA

Scooped!!

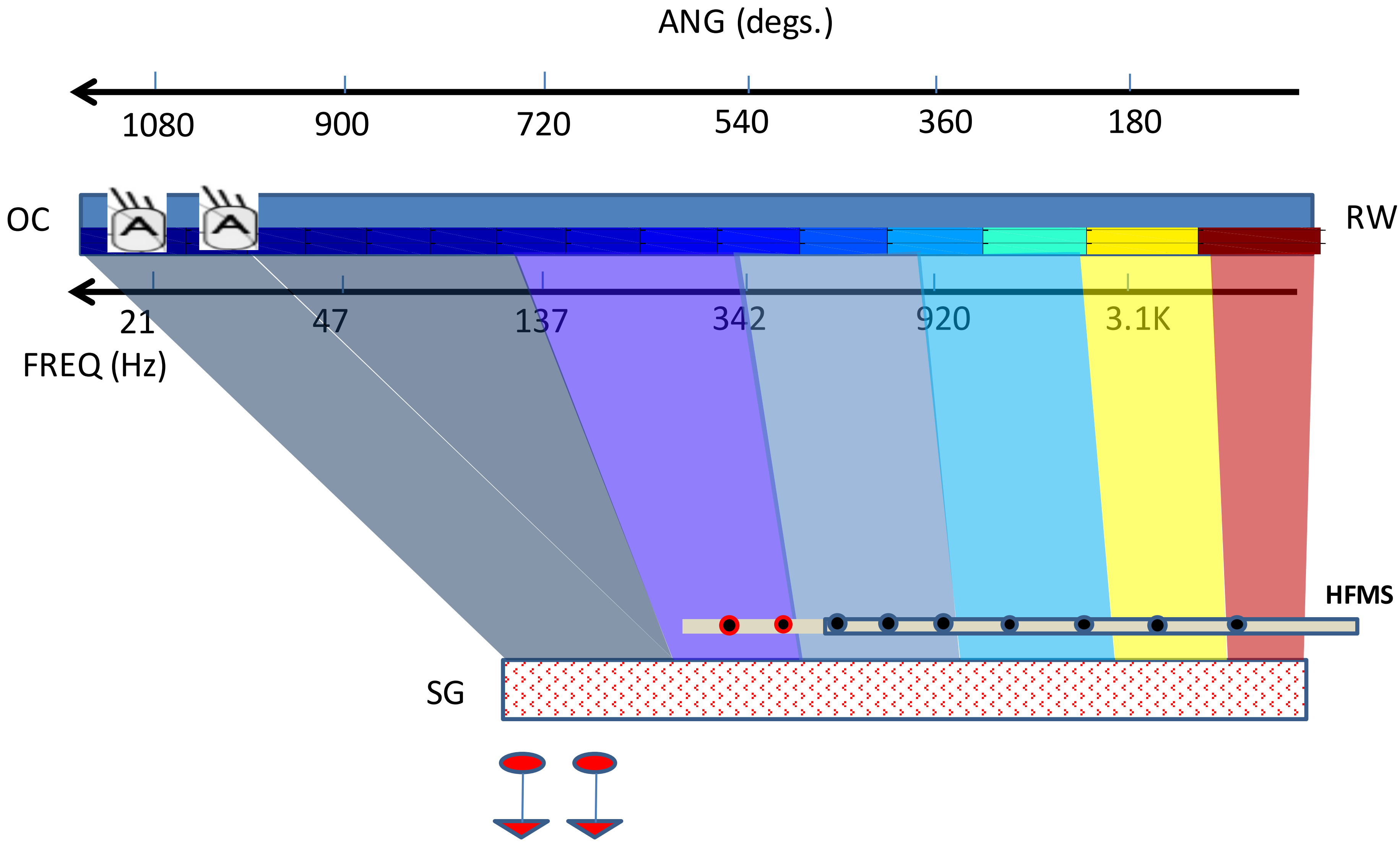
- Wilson (1993), NIH progress report N01-DC-2-2401QPR03



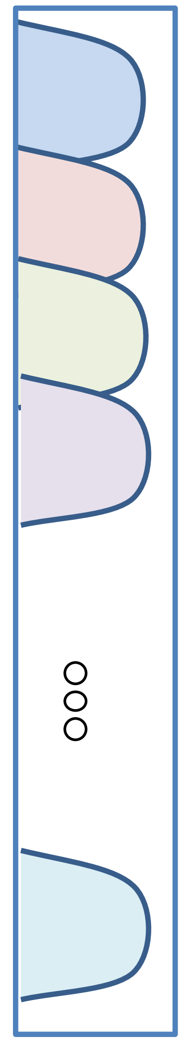
Virtual Extension of Electrode Length

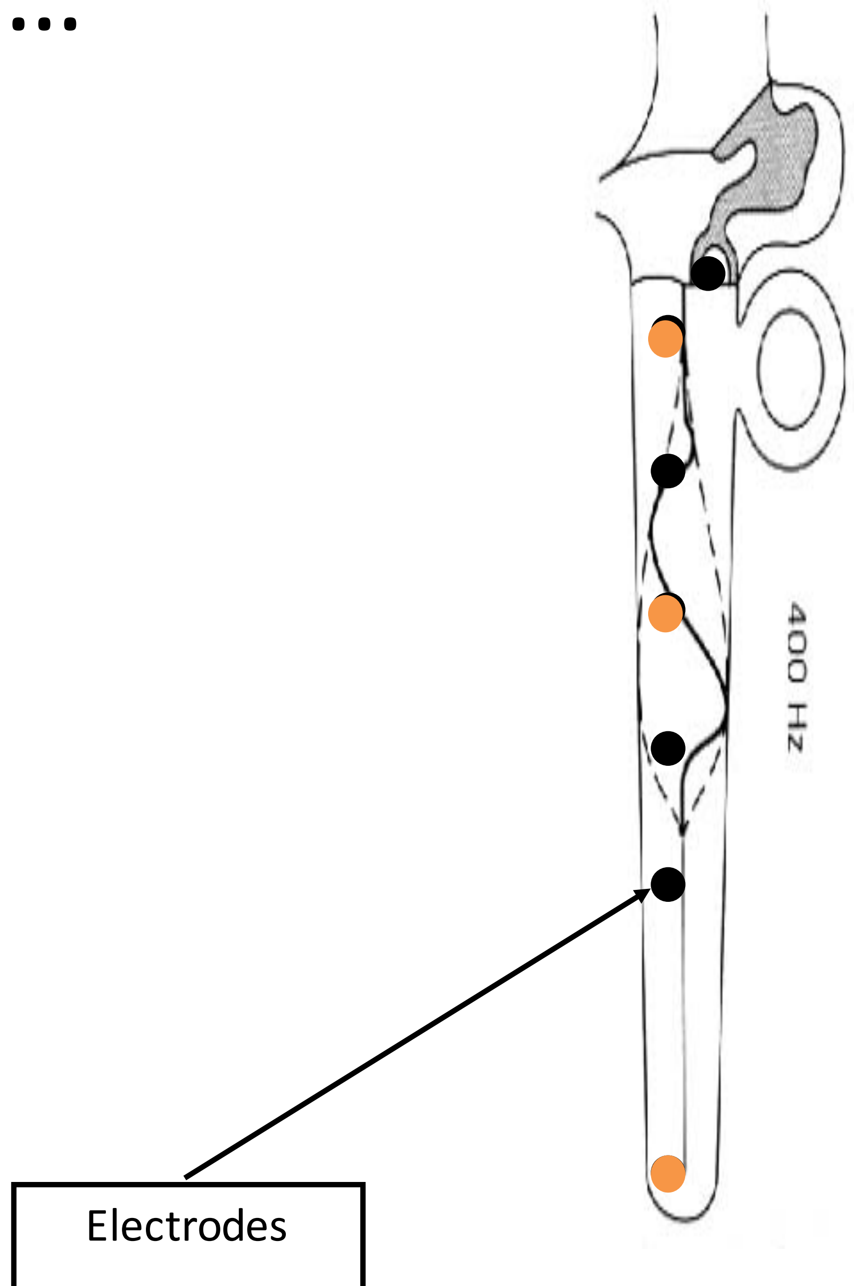


Distribution of Neural Targets in Cochlea

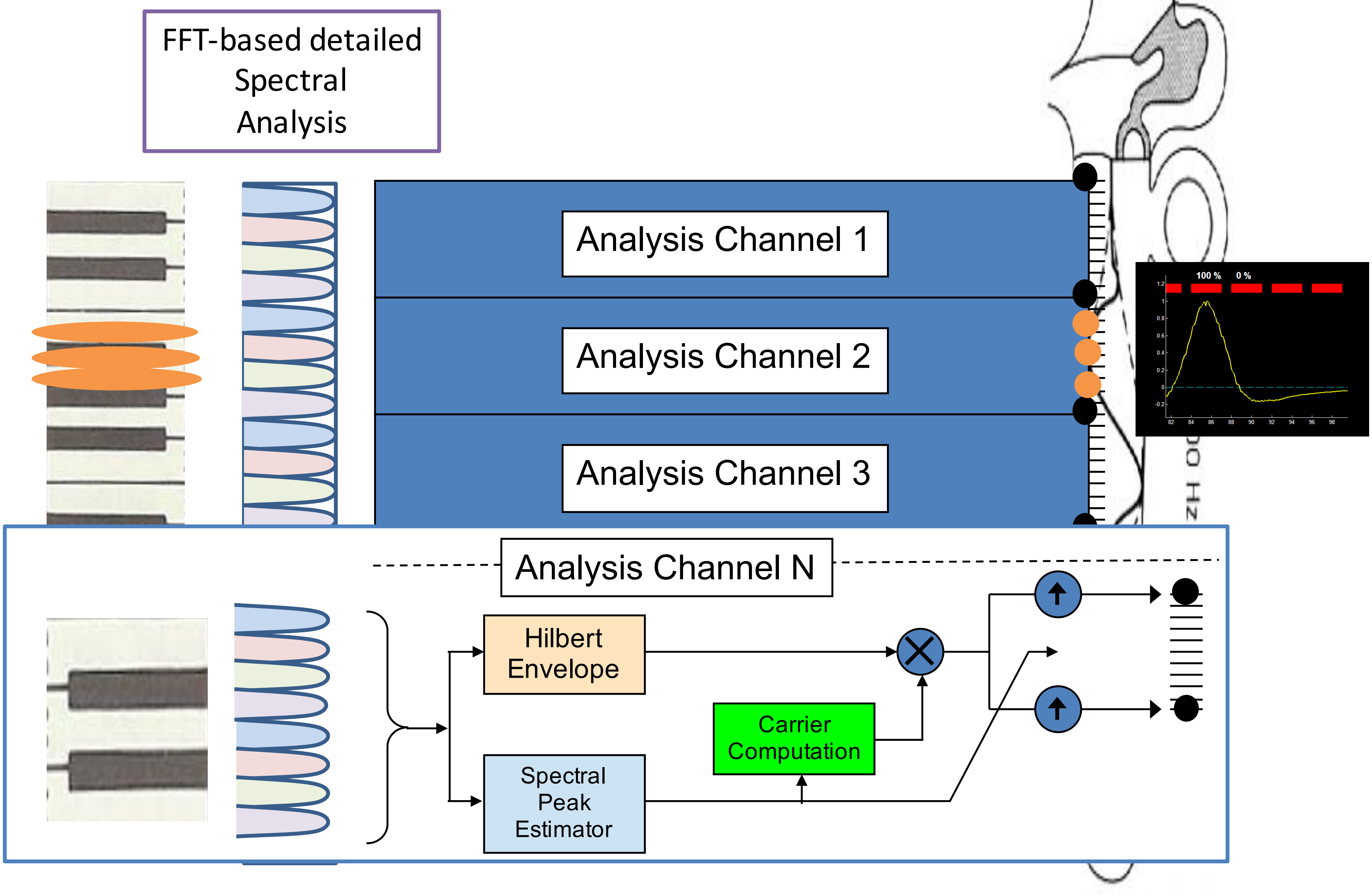


HiRes…

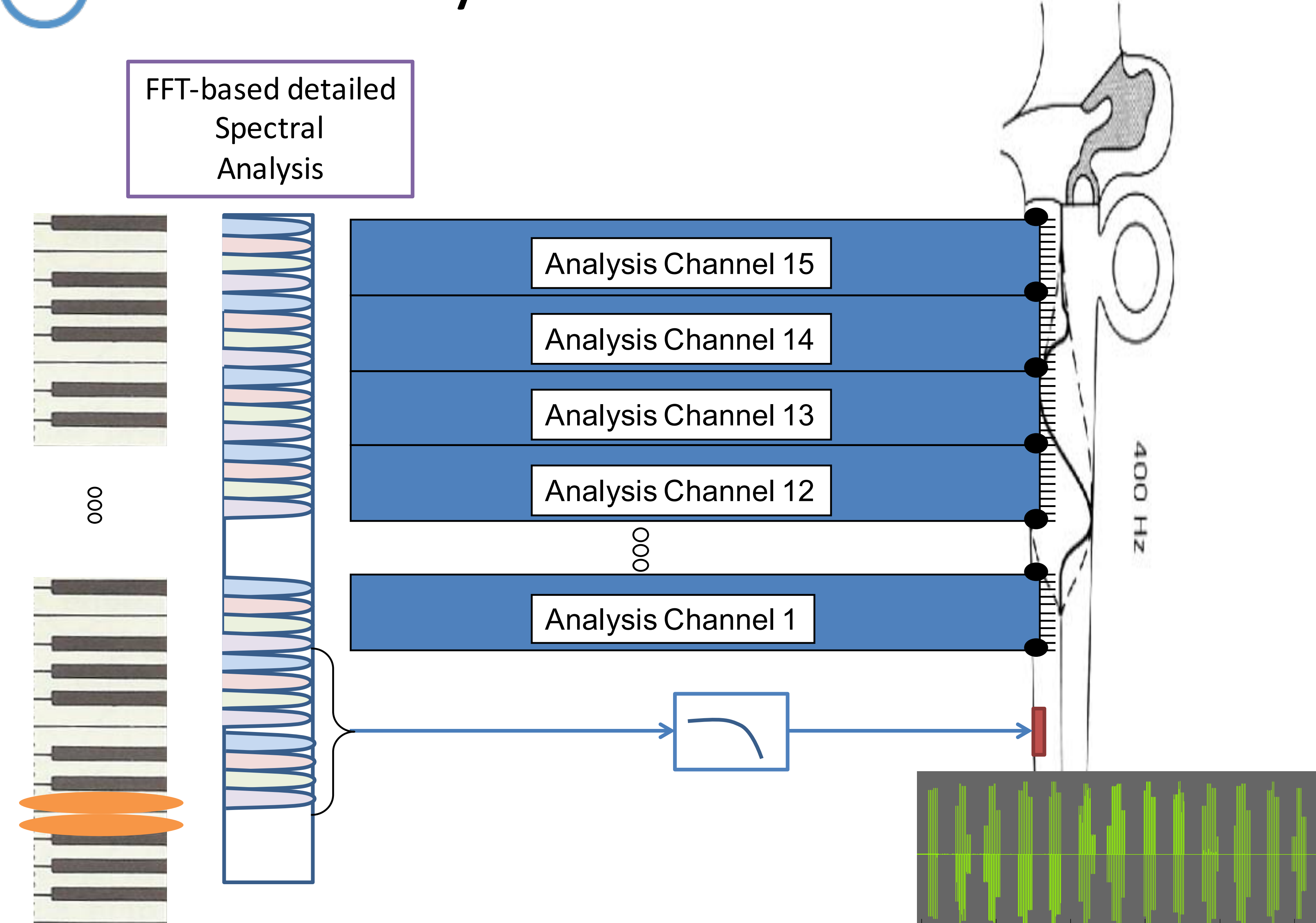




Fidelity120....

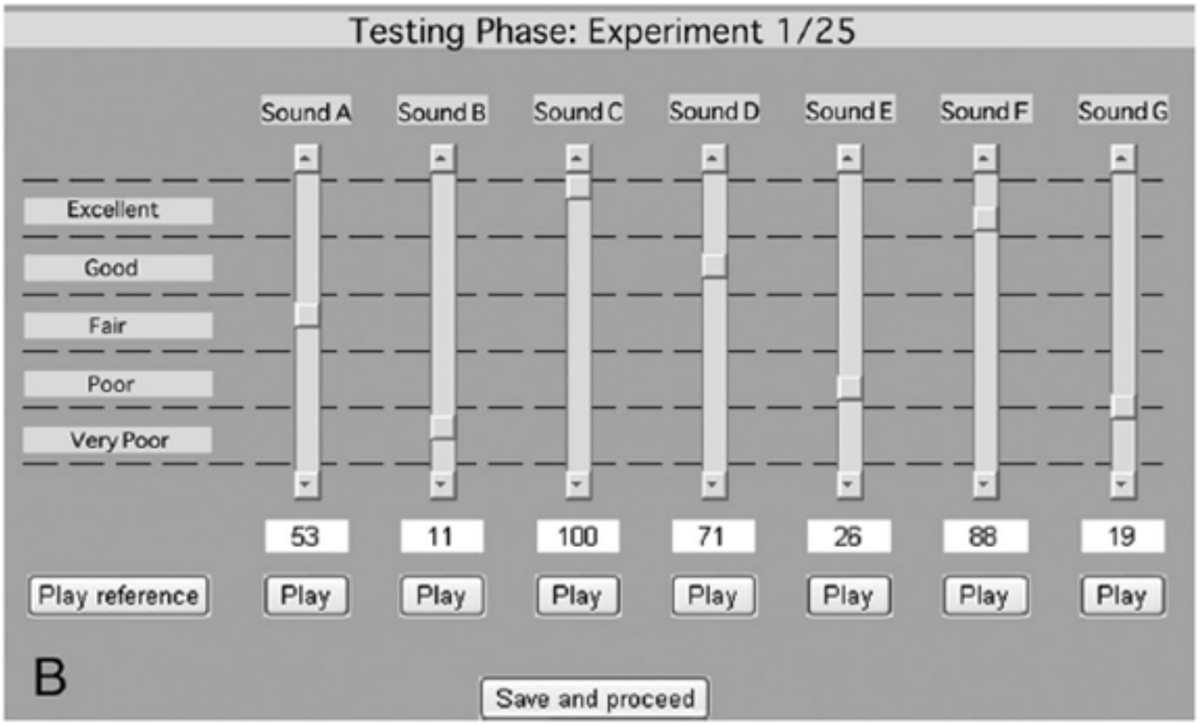


Fidelity120 with Phantom



Quantifying Contribution of Phantom Stimulation to Music Quality

- CI-MUSHRA

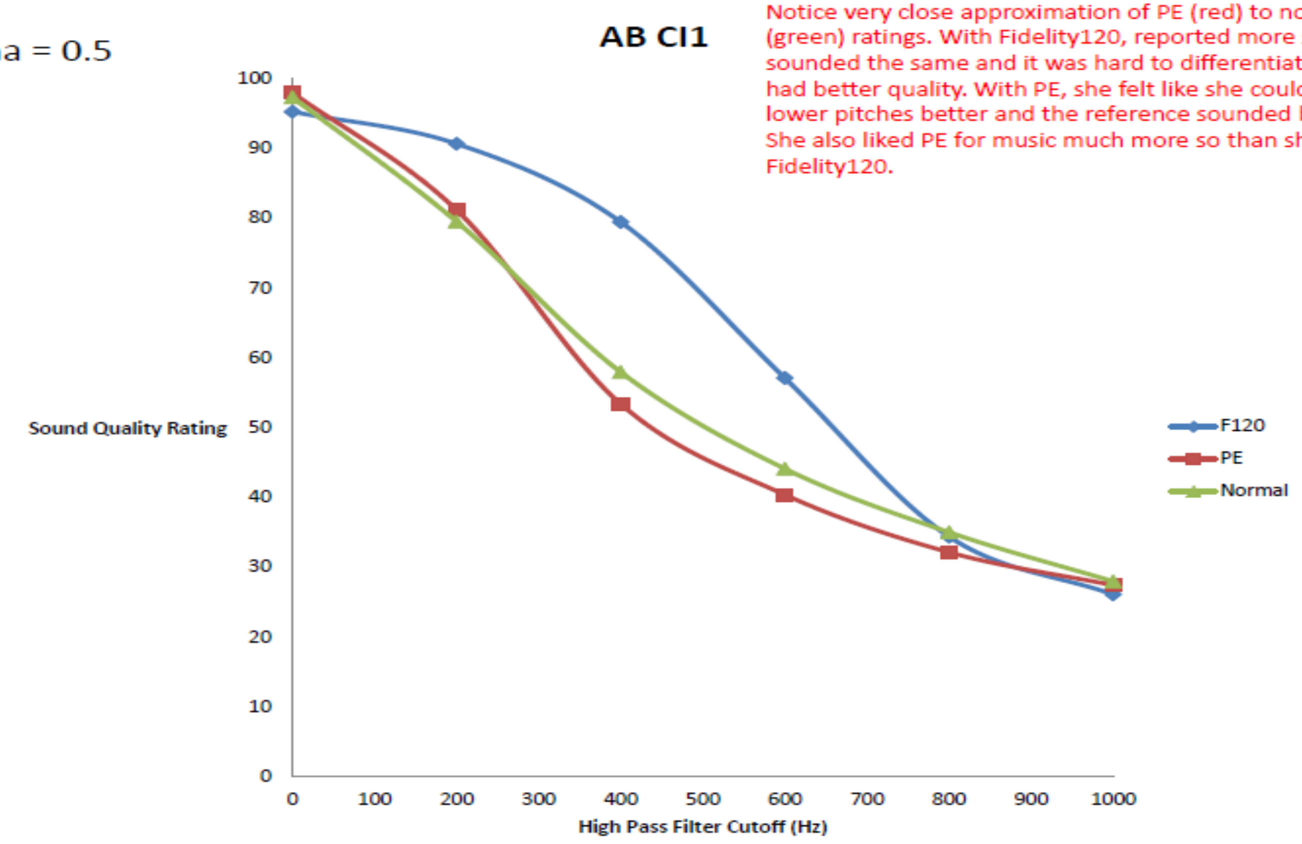


Roy et al (2012) Otology Neurotology

Phantom Evaluation: MUSHRA Test

Sigma = 0.5

Notice very close approximation of PE (red) to normal (green) ratings. With Fidelity120, reported more stimuli sounded the same and it was hard to differentiate which had better quality. With PE, she felt like she could hear lower pitches better and the reference sounded better. She also liked PE for music much more so than she did Fidelity120.



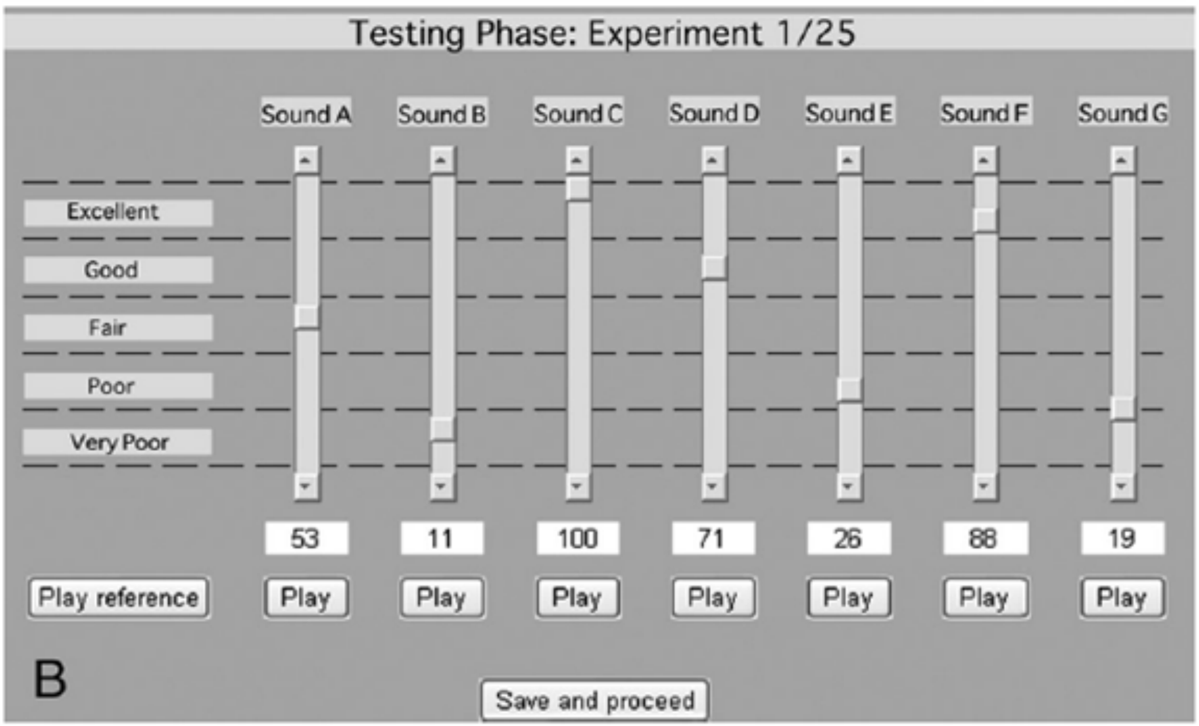
Feedback Has Been Very Positive

- Overall speech quality
  - “Filled in the missing stuff…”
- With Music
  - “Fuller”, “Deeper”, “Richer”
- Voice quality of received speech
  - “More natural”
- Speech Production
  - “Lower production effort”
  - Report of more natural sounding speech
- Speech performance outcomes under investigation
- Application to enhancement of tonal languages being developed

Questions?

Quantifying Contribution of Phantom to Music Quality

- CI-MUSHRA



Roy et al (2012) Otology Neurotology

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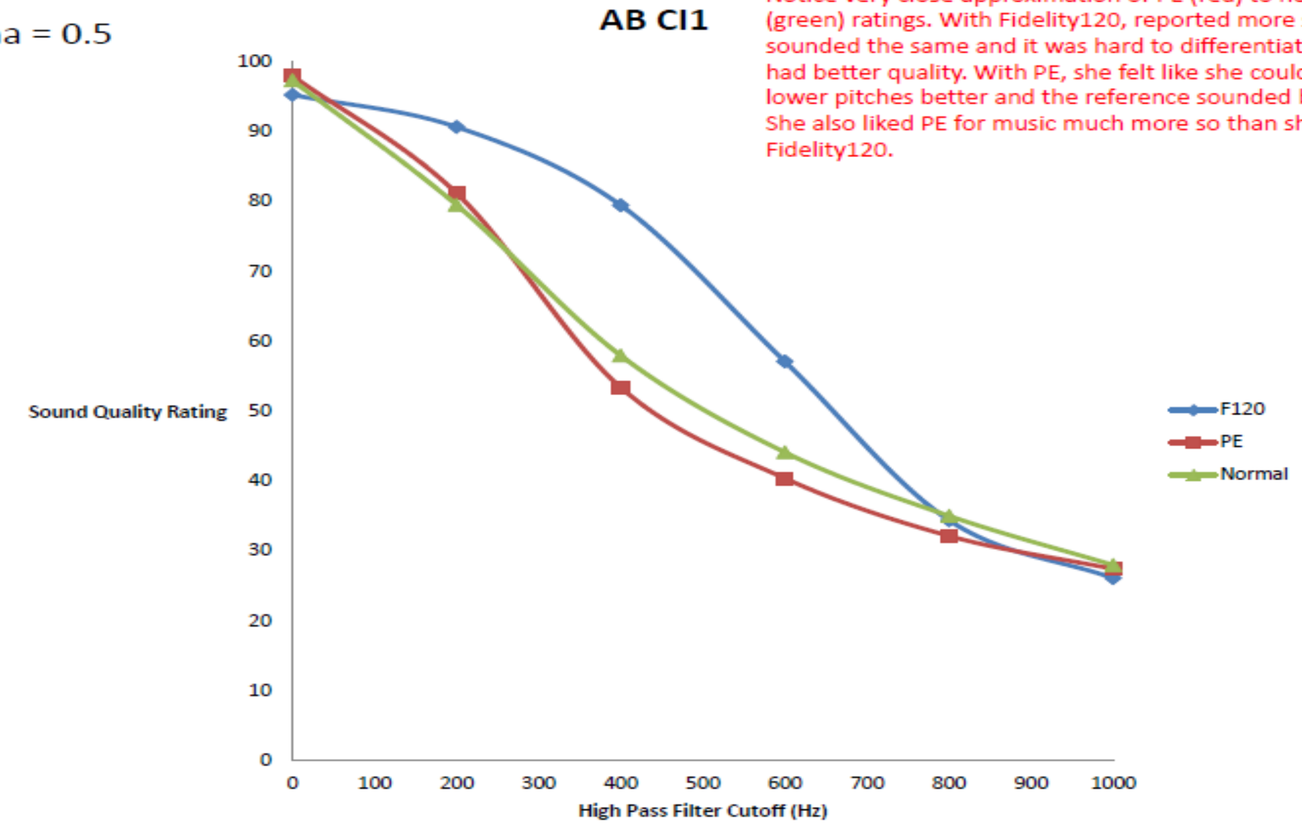

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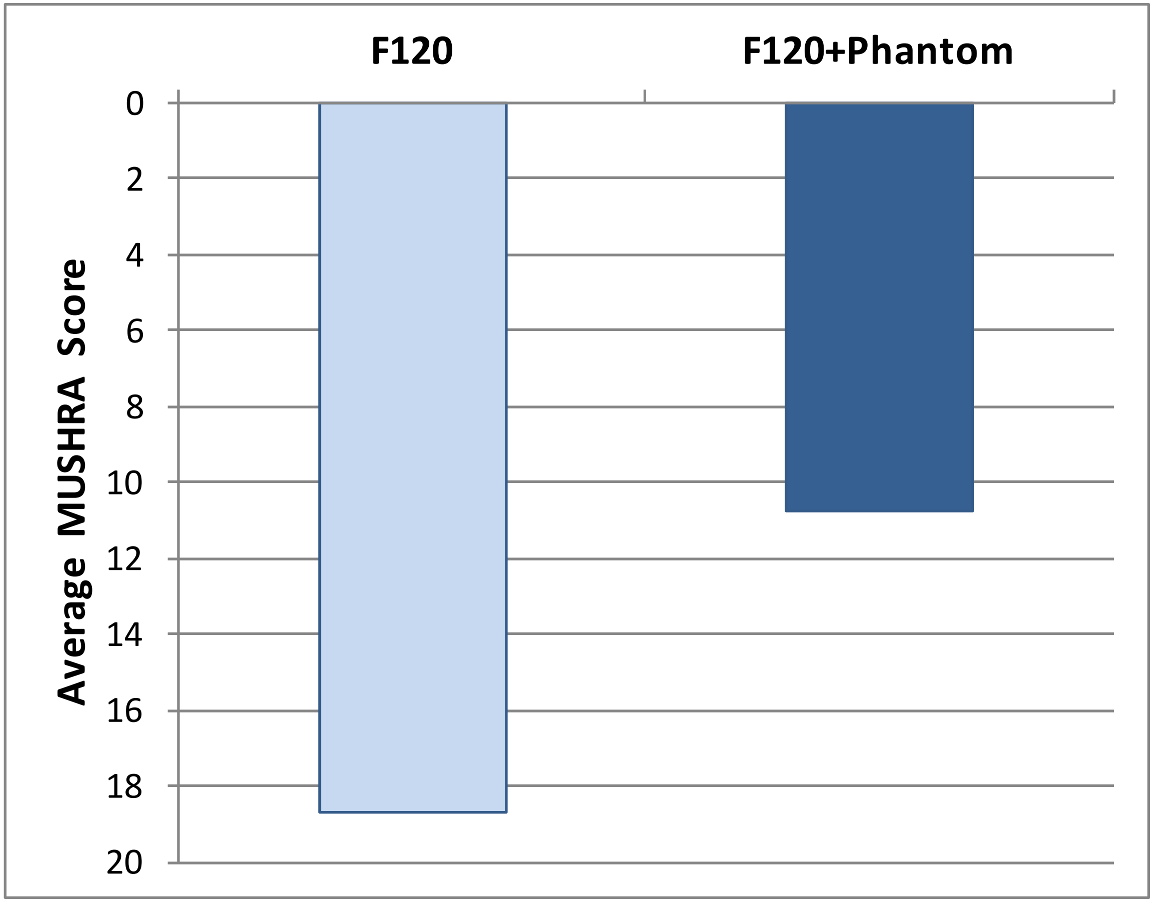
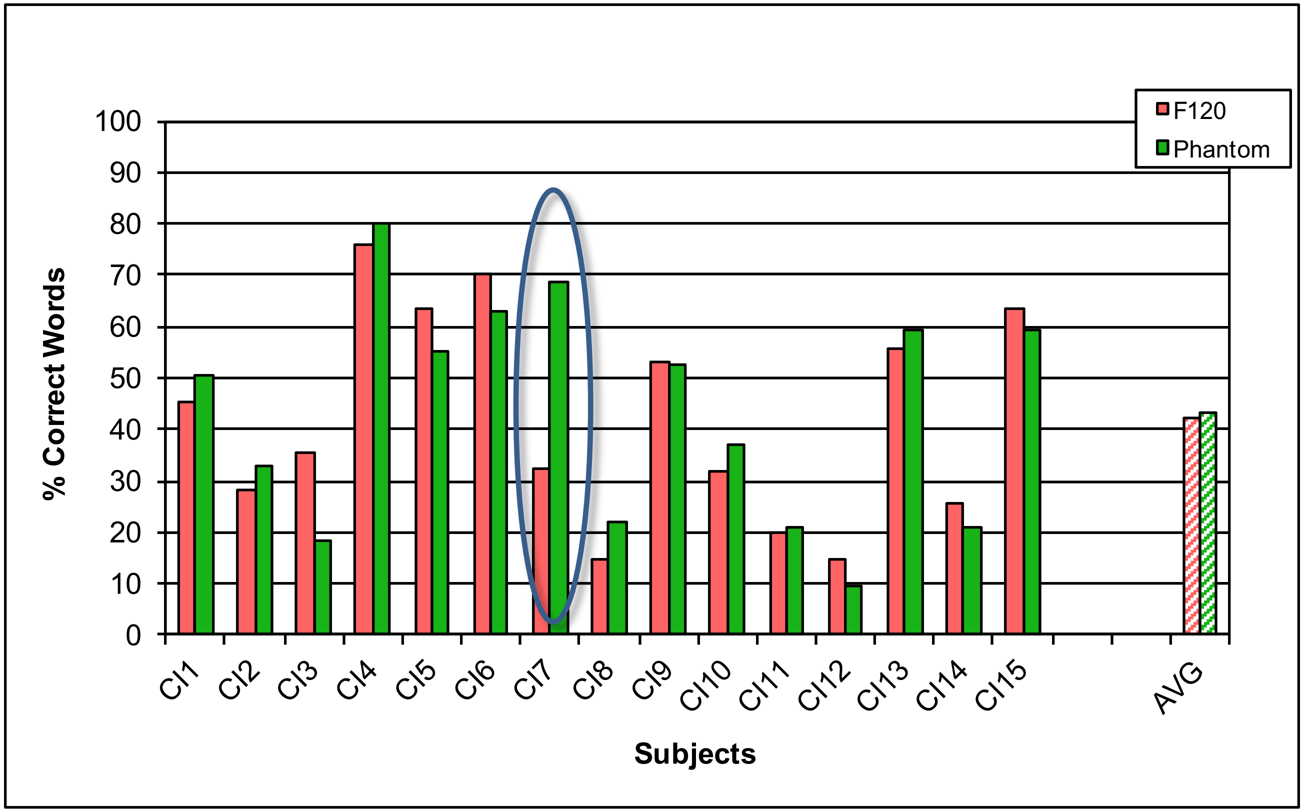
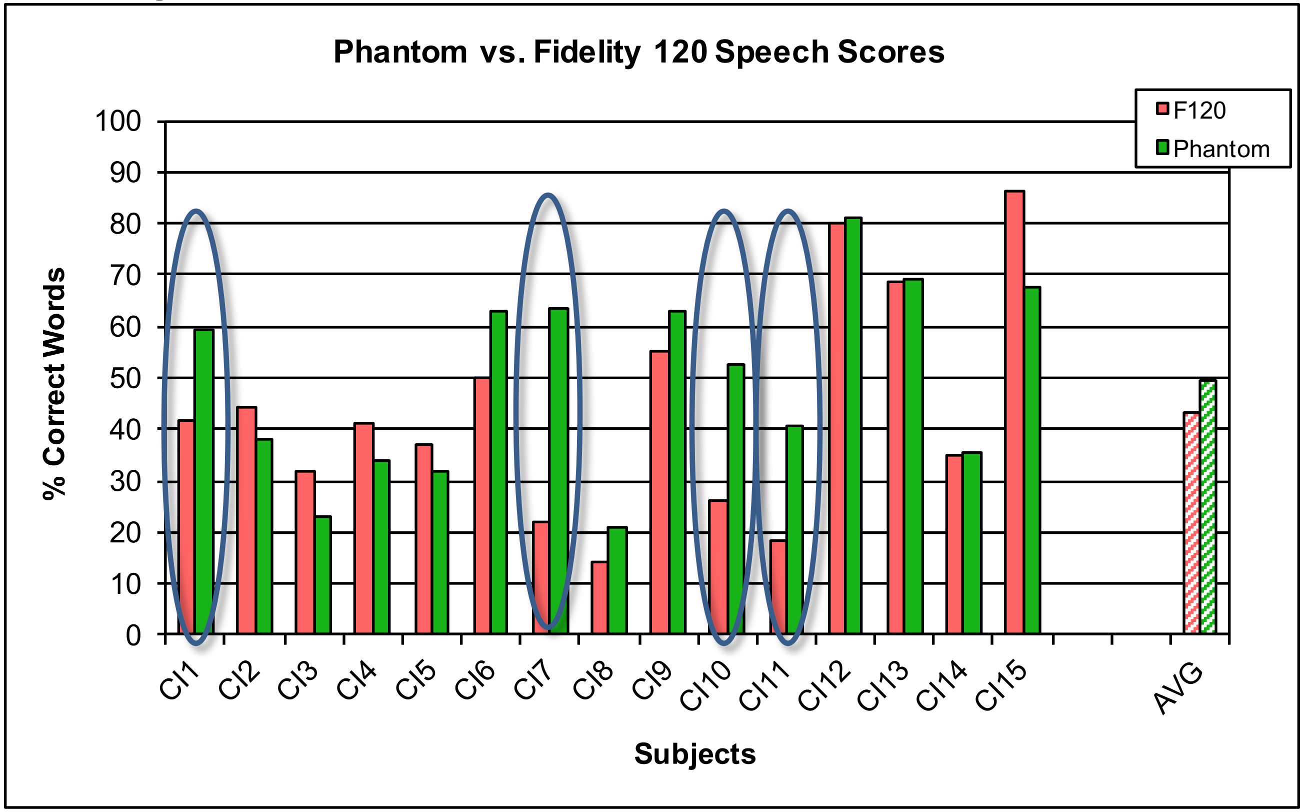


Acute Speech-in-Noise Results



Buechner and Nogueira, 2010 (unpublished)

Speech-in-noise results



Buechner and Nogueira, 201 (unpublished)