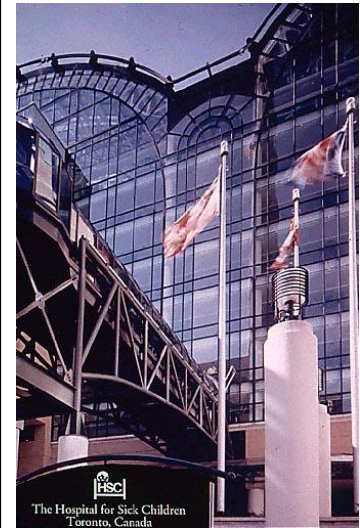


A 3-Dimensional Percept in the Absence of Fusion: What Cochlear Implants Have Taught us About the Developing Auditory System



Blake C. Papsin



PHONAK
life is on

Cochlear Implant Team 2018



- Blake Papsin
- Vicky Papaioannou
- Karen Gordon
- Sharon Cushing
- Gina Goulding
- Naureen Sohail
- Laurie MacDonald
- Patt Fuller
- Adrian James
- Mary Lynn Feness
- Pat Di Santos
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- Susan Druker
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- Gillian Lieberman
- Stephanie Jewell

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- William Parkes
- Shazia Peer

FUNDING

- CIHR
- SickKids Foundation

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- Bob Harrison
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- Frank Russo

International

- Robert Cowen
- Richard van Hoesel



CIHR IRSC



Introduction

- life survives
- evolution/plasticity
 - genetic
 - facultative



Introduction

- life survives
- evolution/plasticity
 - genetic
 - facultative

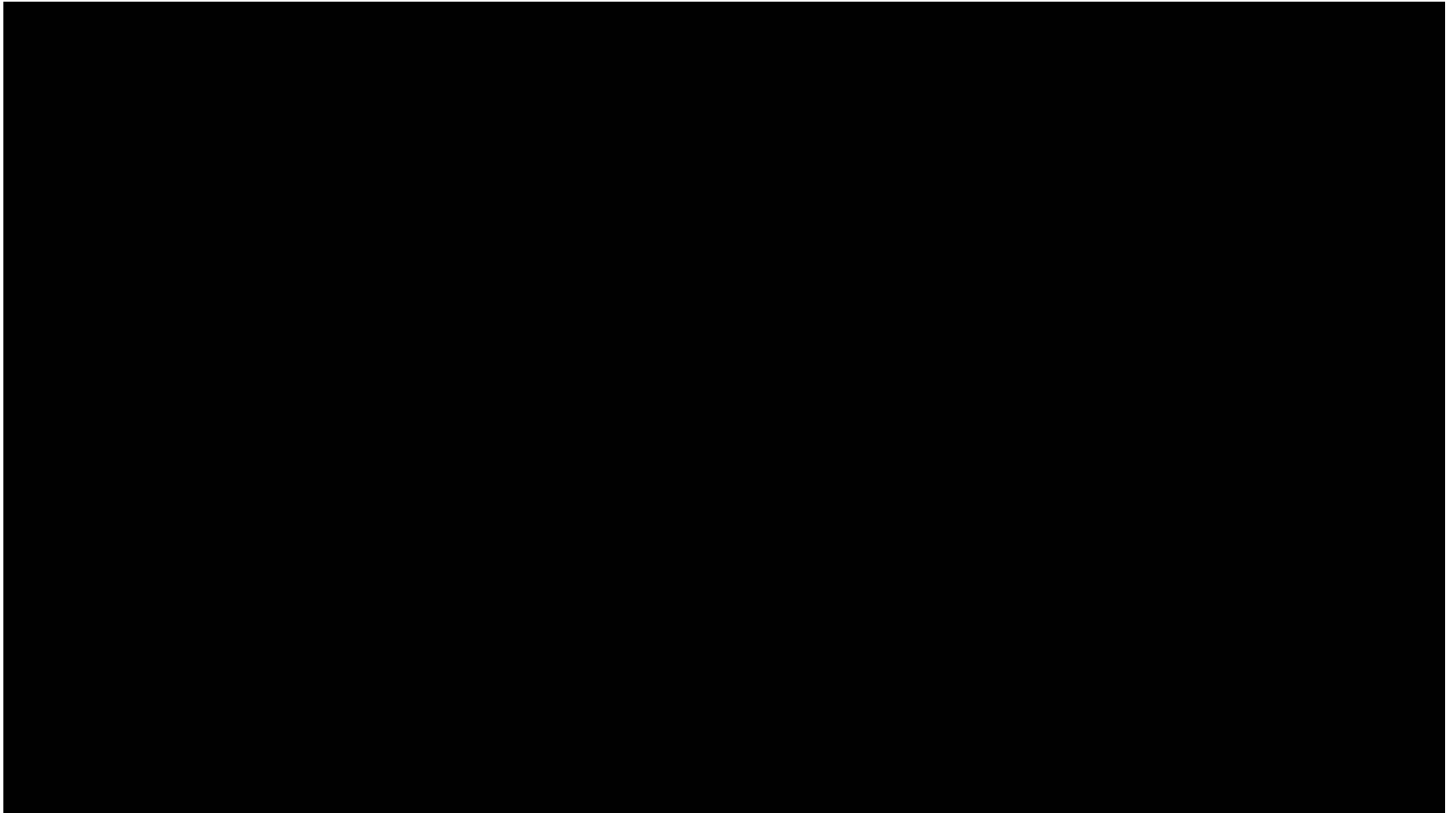


Introduction

- life survives
- evolution/plasticity
 - genetic
 - facultative



Facultative Evolution



Starlings at Otmoor <http://www.youtube.com/watch?v=XH-groCeKbE> (Dylan Winter)

Fusion of Auditory Information

- feature extraction
 - binaurality
 - fusion of the image
- assembly of the auditory environment
 - effort



Fusion of Auditory Information

- feature extraction
 - binaurality
 - fusion of the image
- assembly of the auditory environment
 - effort



Fusion of Auditory Information

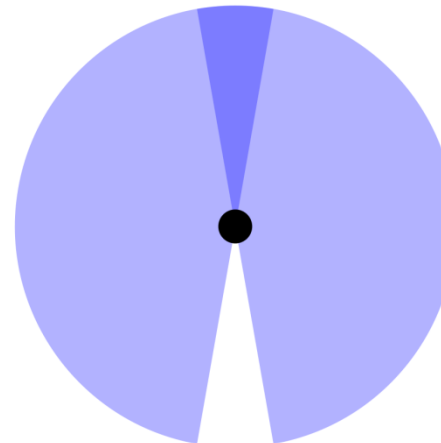
- feature extraction
 - binaurality
 - fusion of the image
- assembly of the auditory environment
 - effort



Fusion of Image

- functional requirement

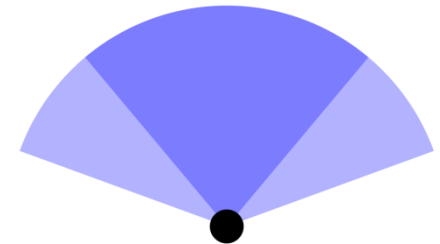
Pigeon



■ Binocular vision

Prey

Owl



■ Monocular vision

Predator

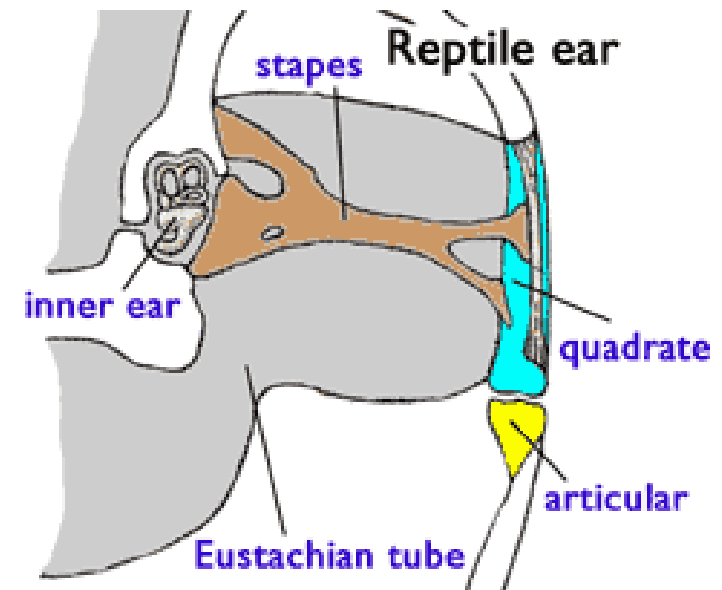
No Fusion of Auditory Image!

- *Mantis religiosa*
- 1 ear
- 2 eyes
 - 3 simple eyes between them
- prey comes to it



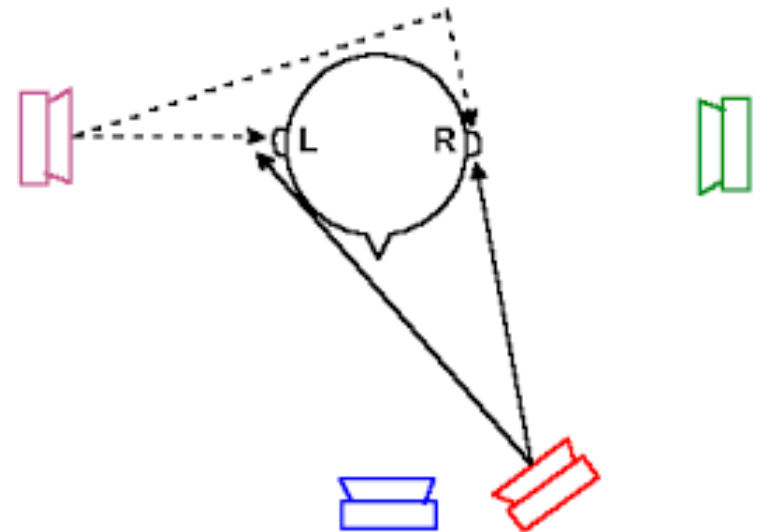
Snake's Ears

- no eardrum or external ear
- not coupled
- bone conduction
- rudimentary binaurality is possible



Binaural Perception

- source localization/position
 - timing cues/direction
 - loudness cues/speed
- effortful reassembly
 - experience
 - pattern perception

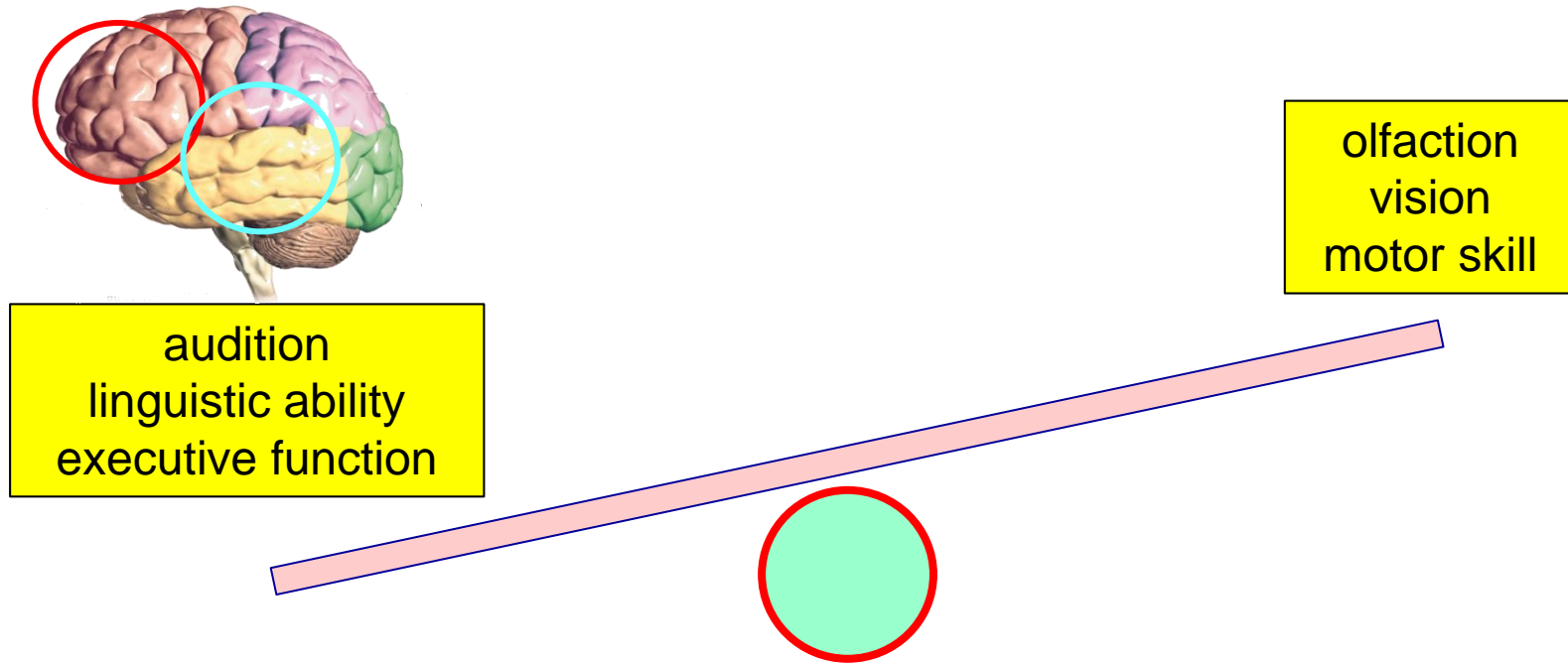


Binaural Perception

- source localization/position
 - timing cues/direction
 - loudness cues/speed
- effortful reassembly
 - experience
 - pattern perception



Human = Language Predators



SickKids Bilateral Experience

Simultaneous implants

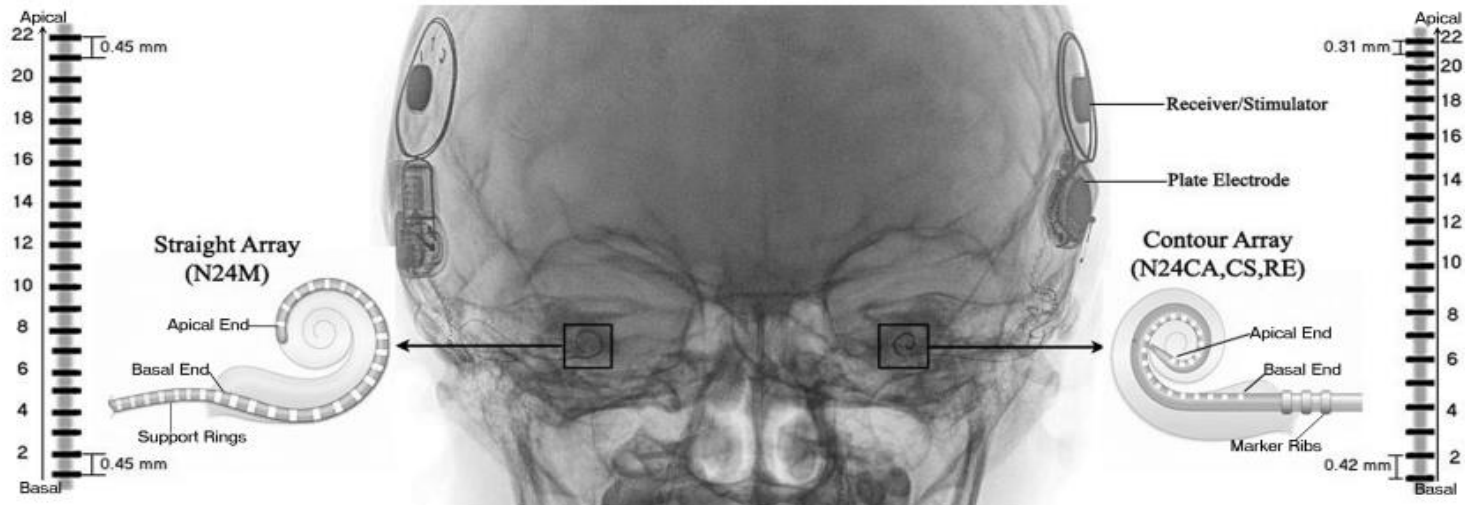
- n=257
- Age at implant = 3.1 ± 3.6 yrs

Sequential implants

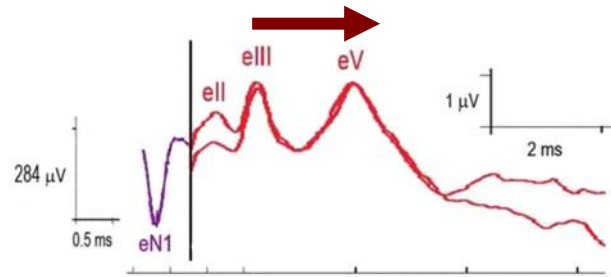
- n=195
- Age at 1st implant = 3.5 ± 3.2 yrs
- Age at 2nd implant = 9.8 ± 4.8 yrs
- Inter-implant delay = 6.3 ± 4.1 yrs

4214 • J. Neurosci., March 21, 2012 • 32(12):4212–4223

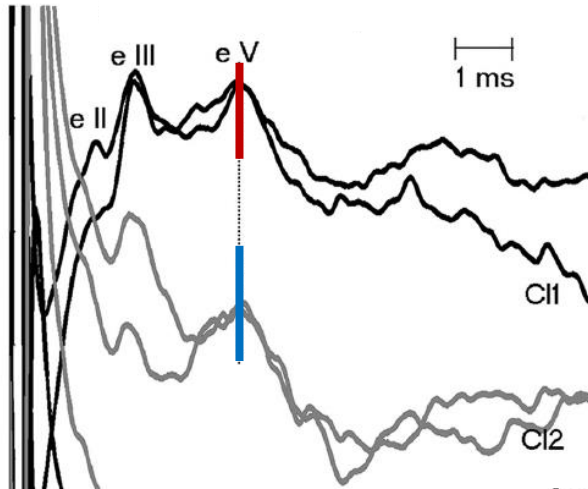
Gordon et al. • Binaural Interaction in Brainstem of Deaf Children



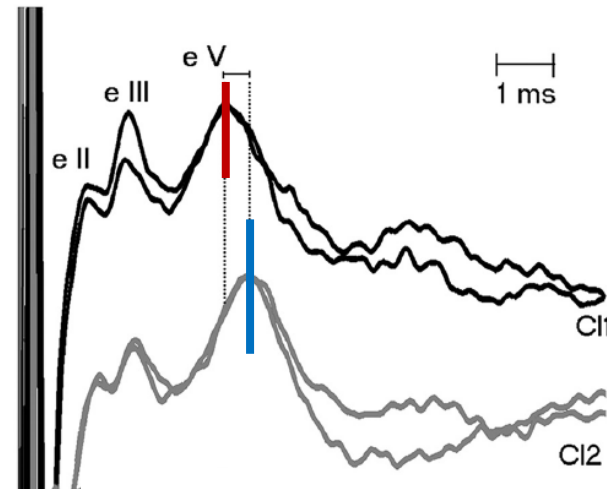
Brainstem Asymmetry (Bilateral)



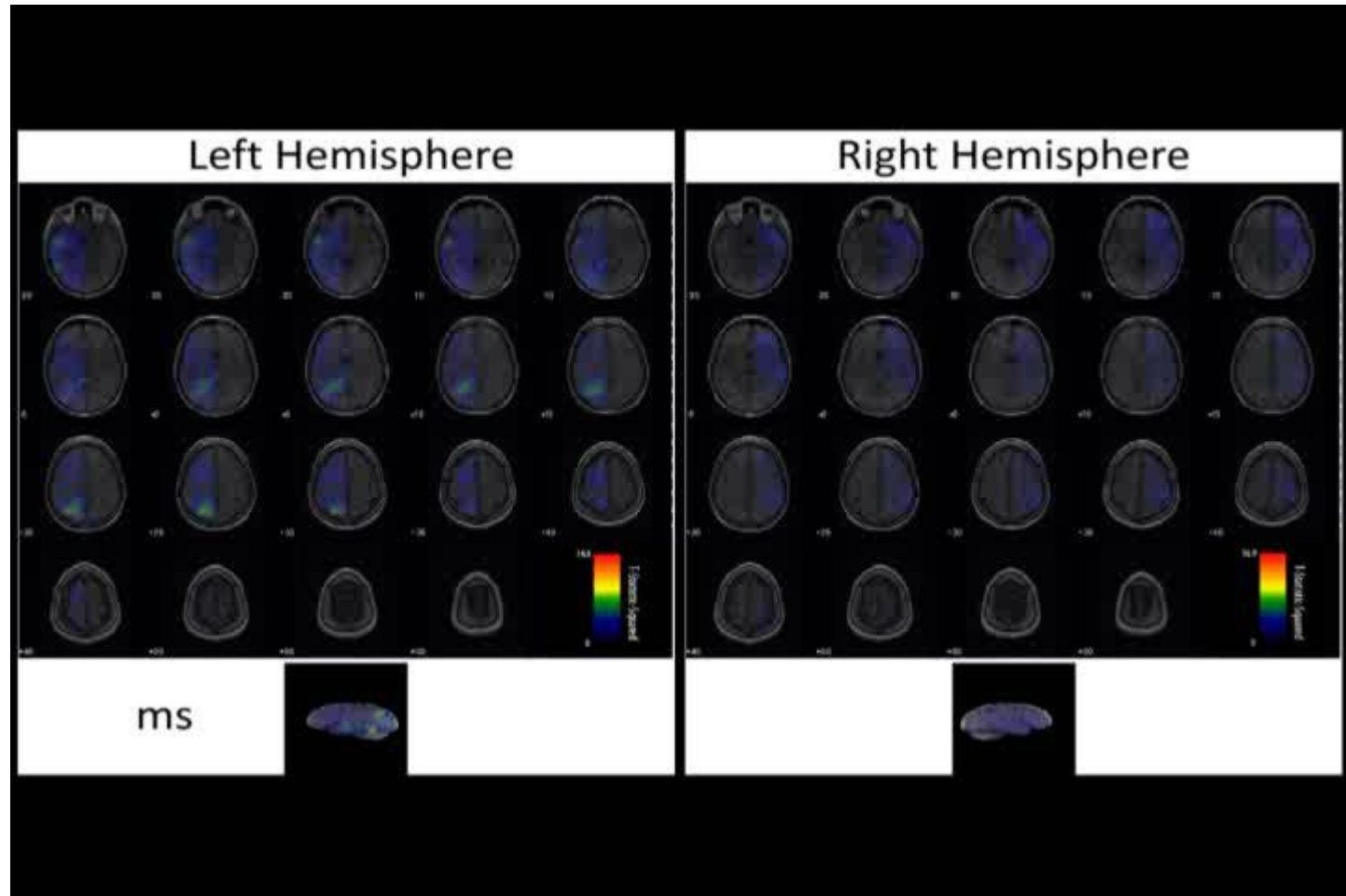
Simultaneous Implantation



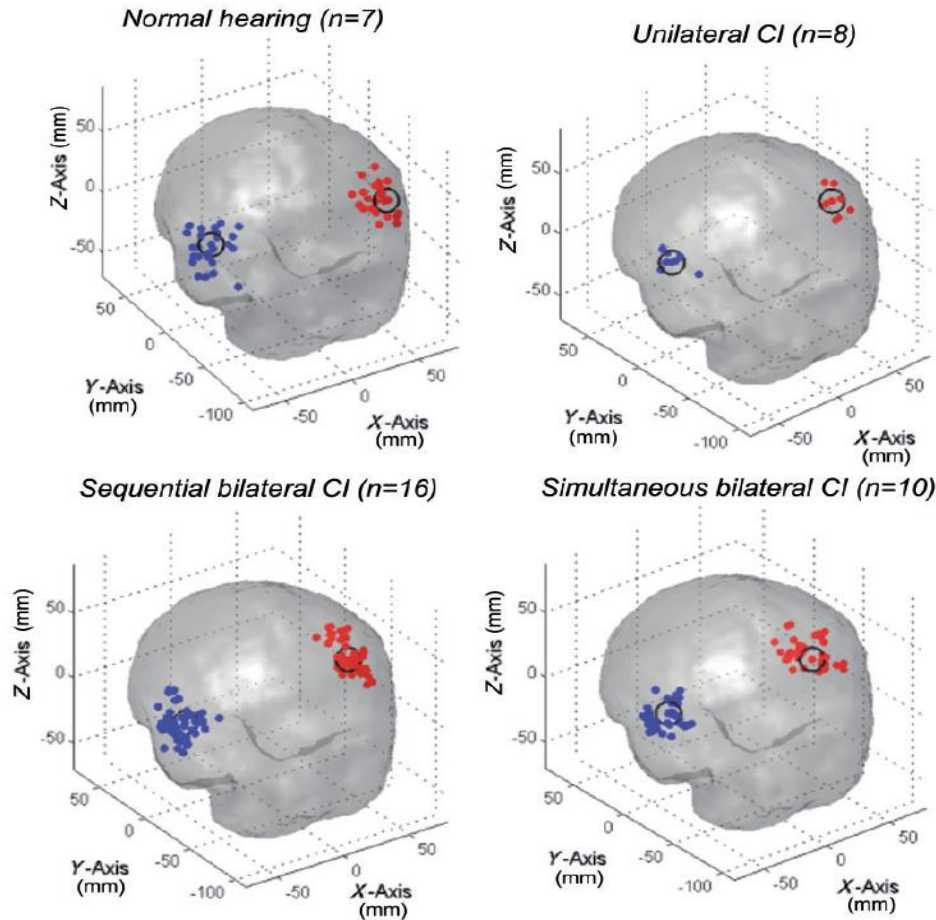
Sequential Implantation (>2 years)



Studying Binaural Perception



Studying Binaural Perception

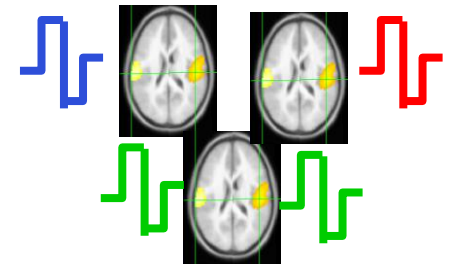
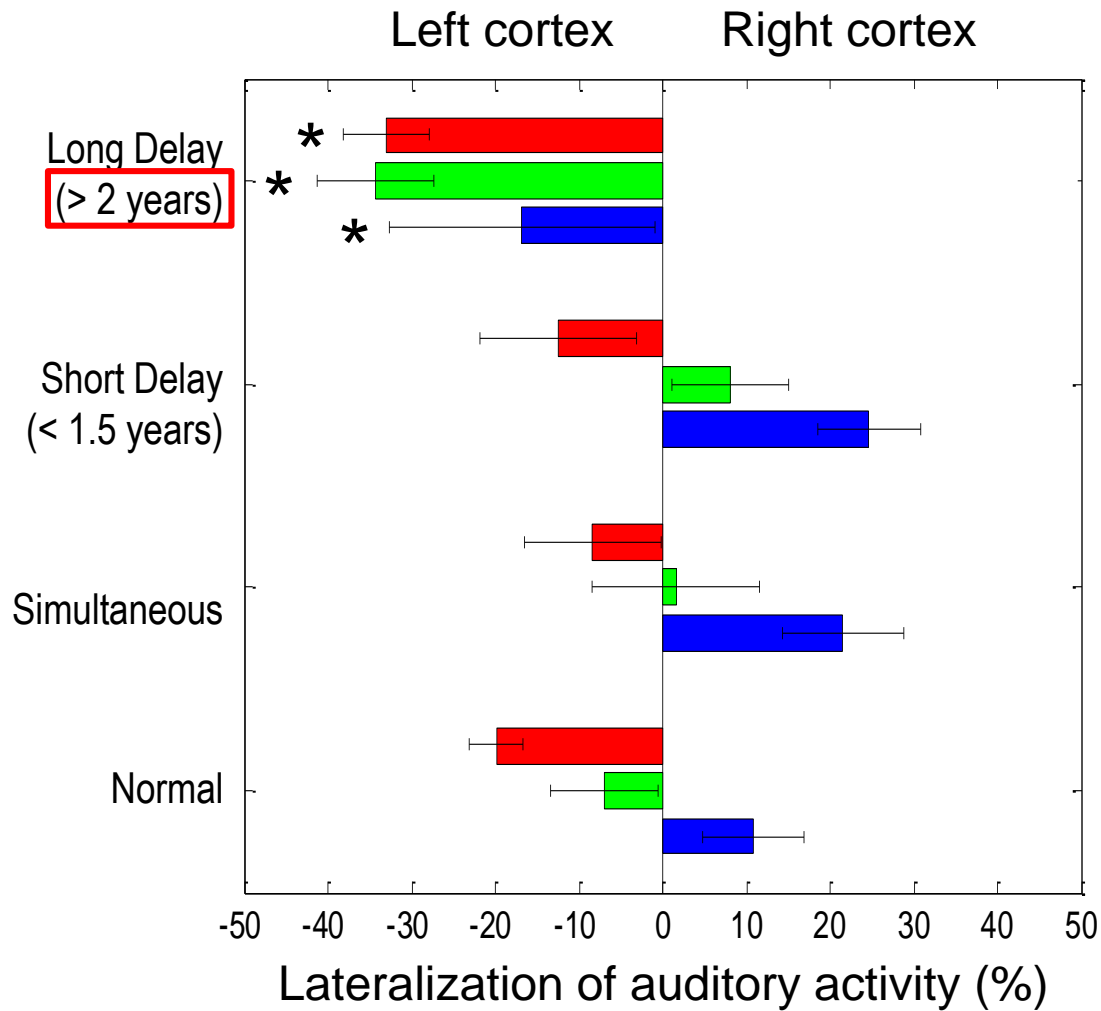


■ **Left auditory cortex**

■ **Right auditory cortex**

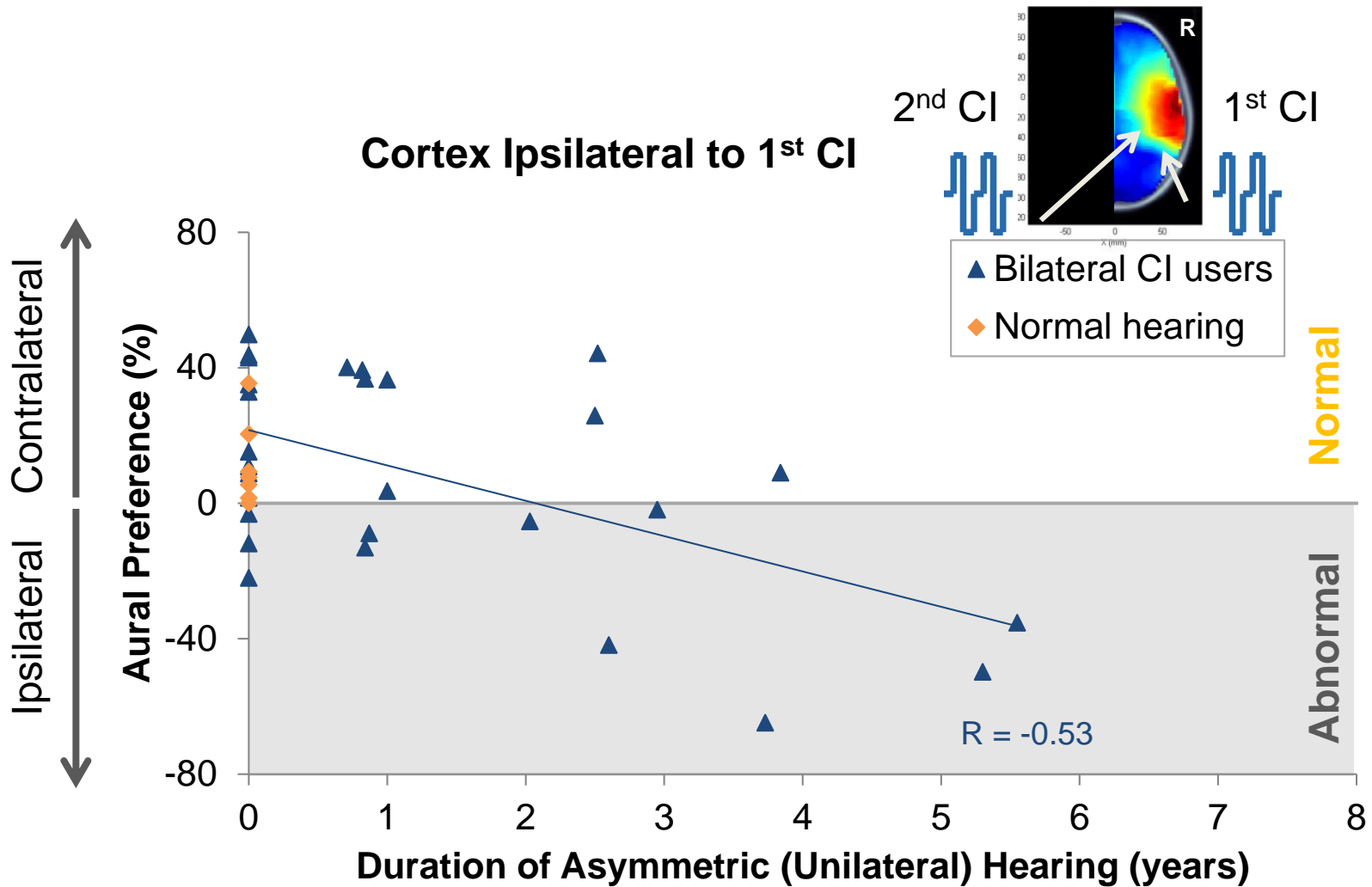
(Brain 2013)

Aural Preference

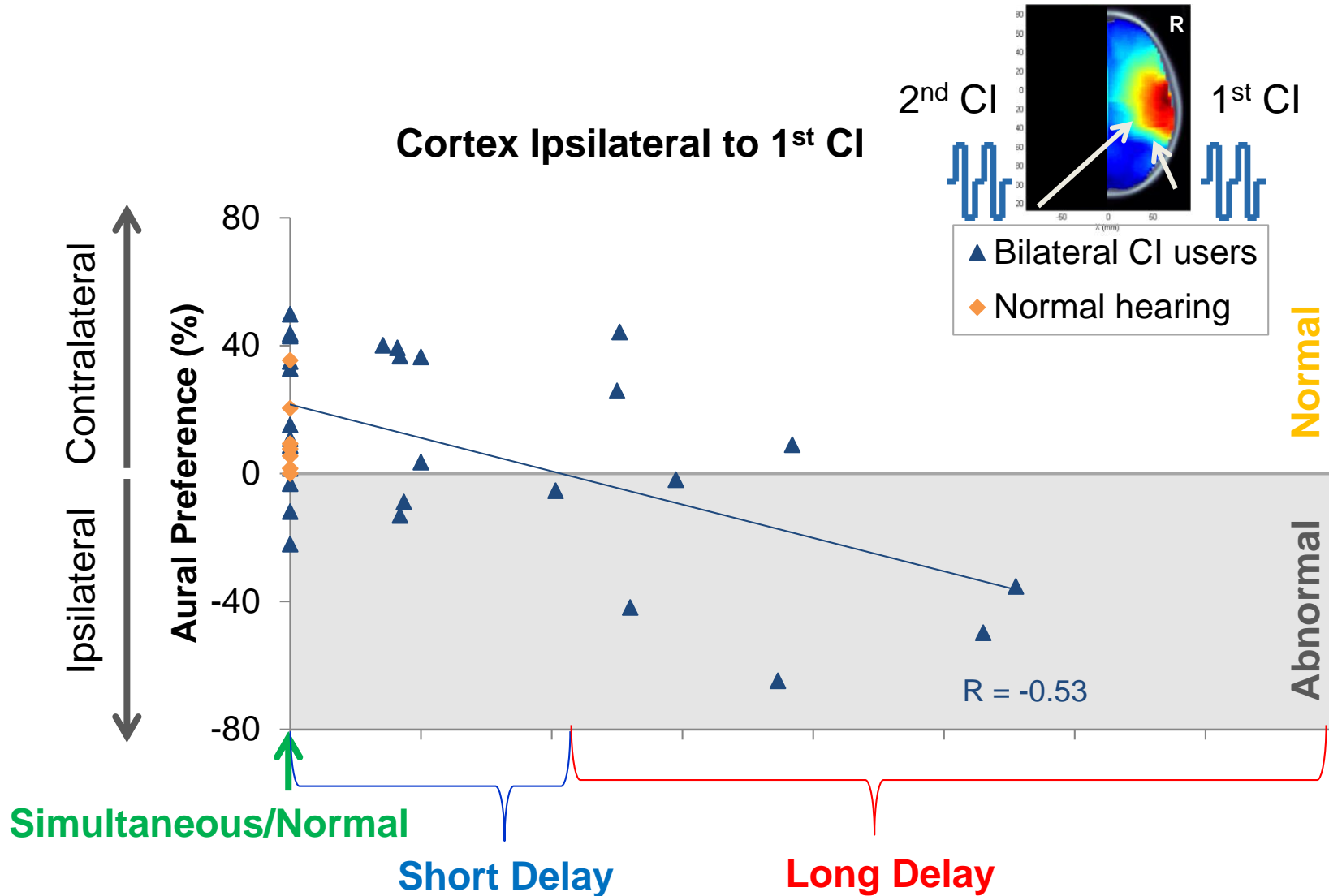


* P < 0.05

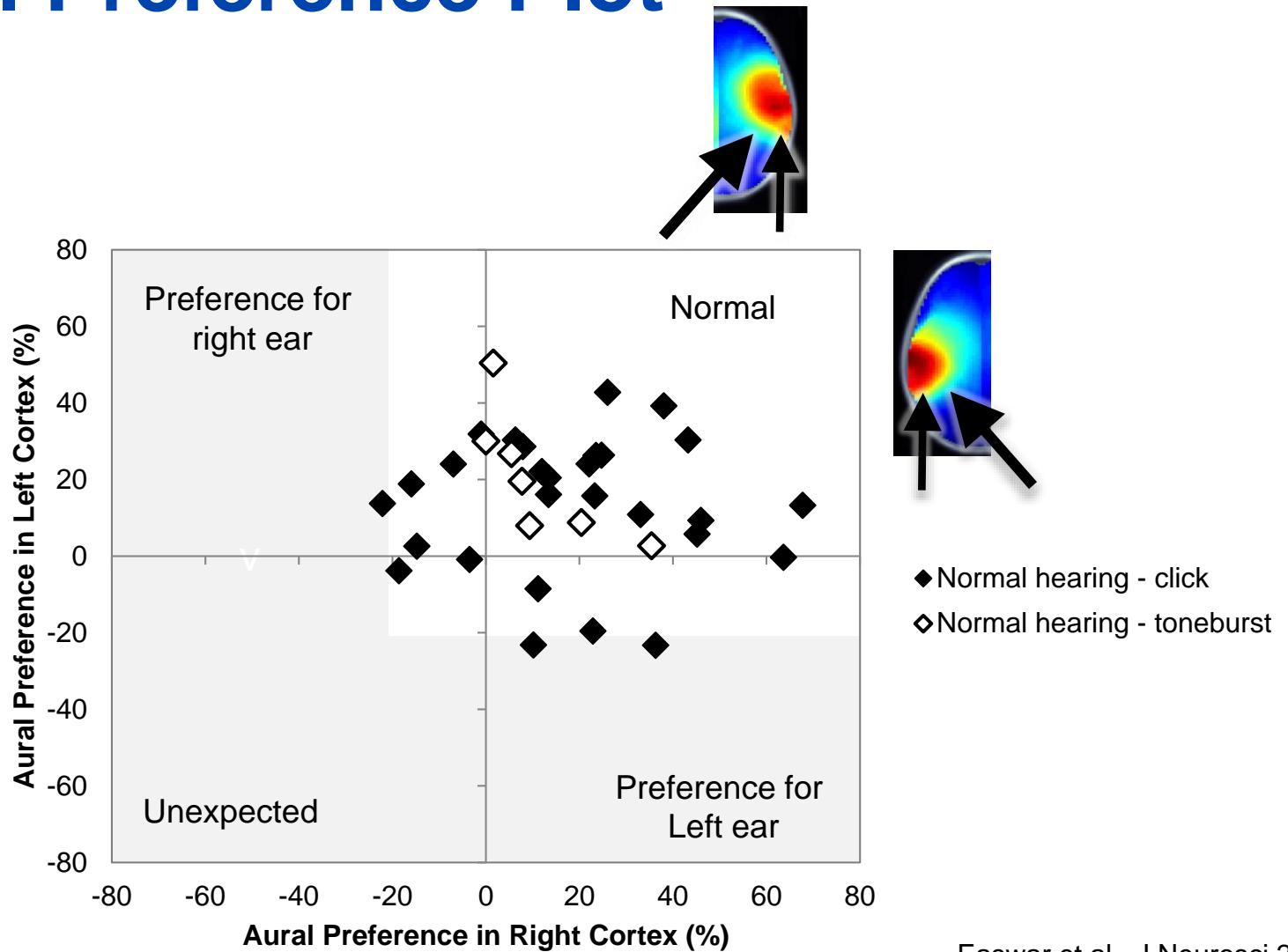
Abnormal Aural Preference



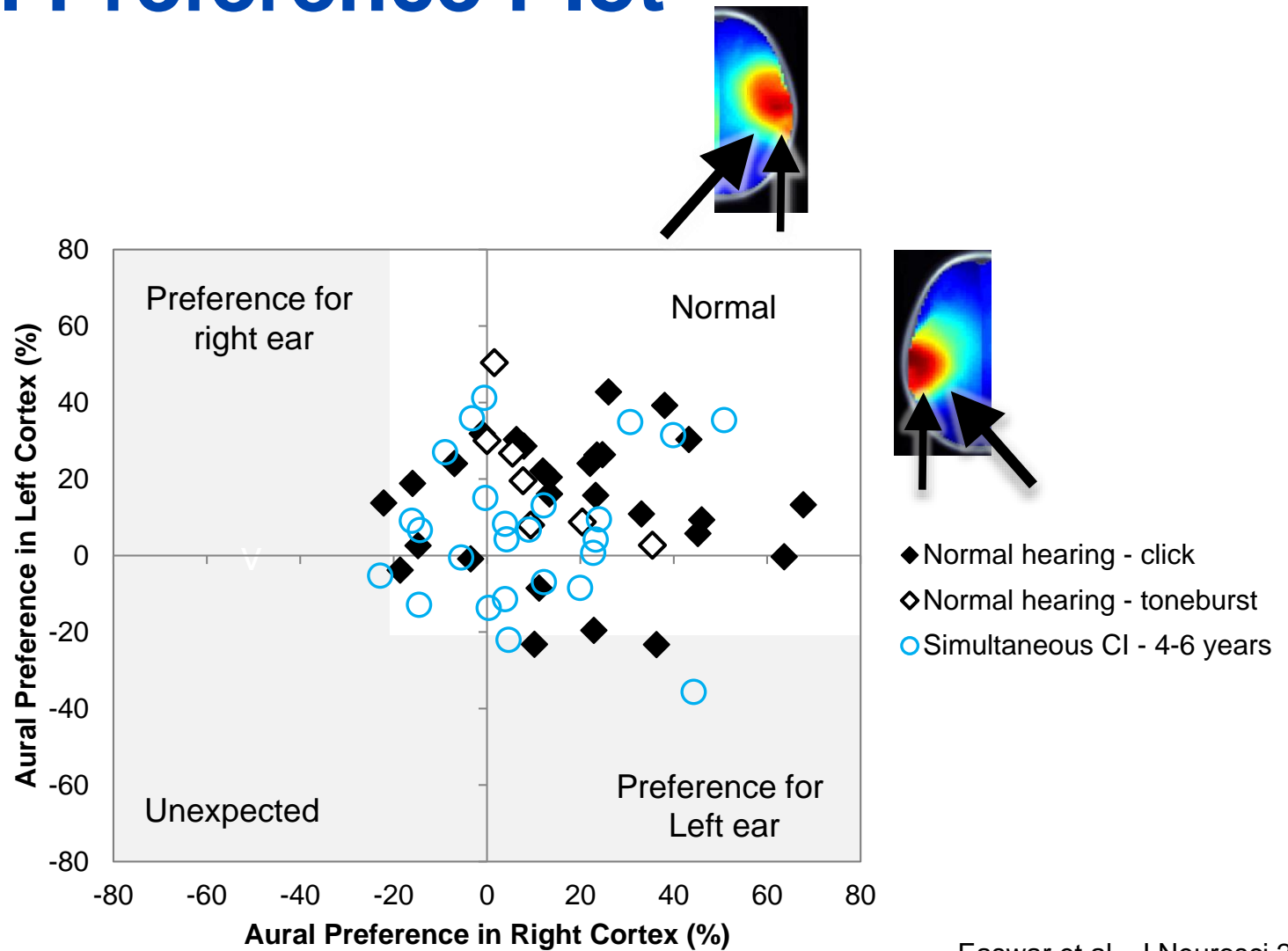
Abnormal Aural Preference



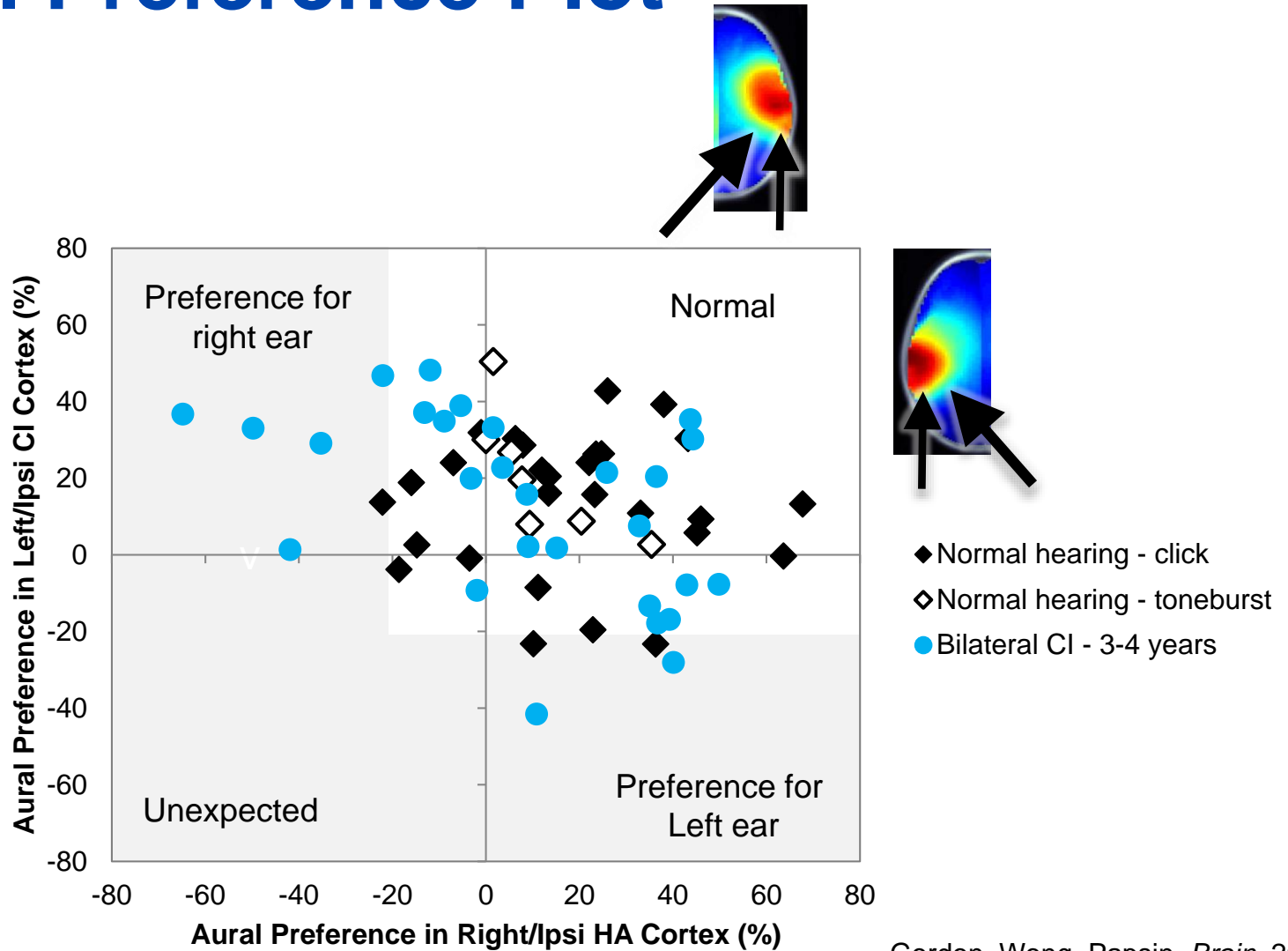
Aural Preference Plot



Aural Preference Plot

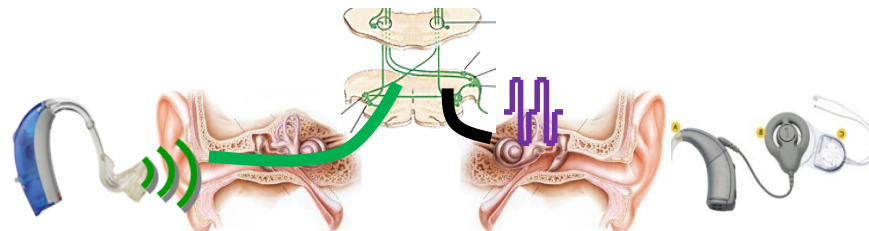
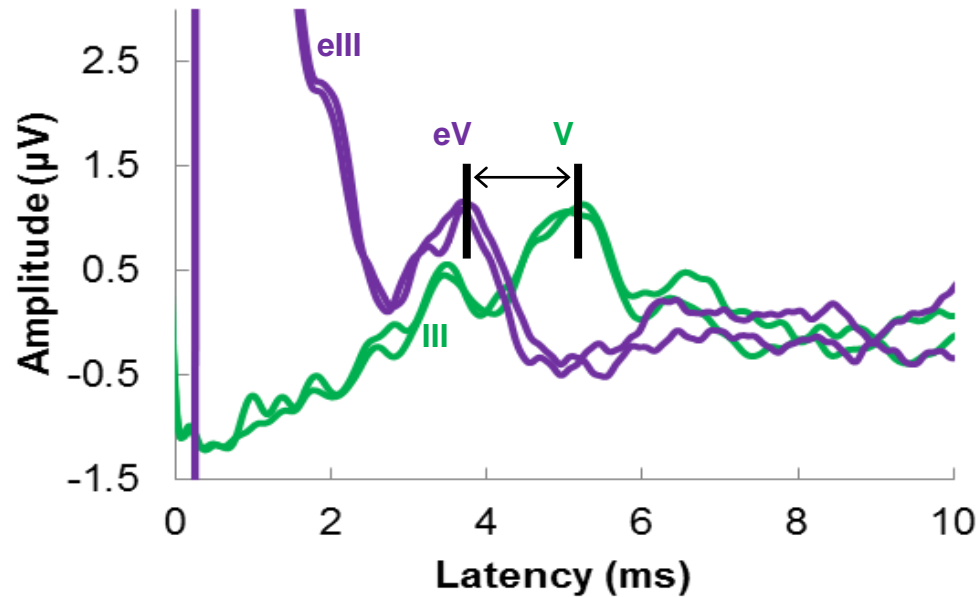


Aural Preference Plot

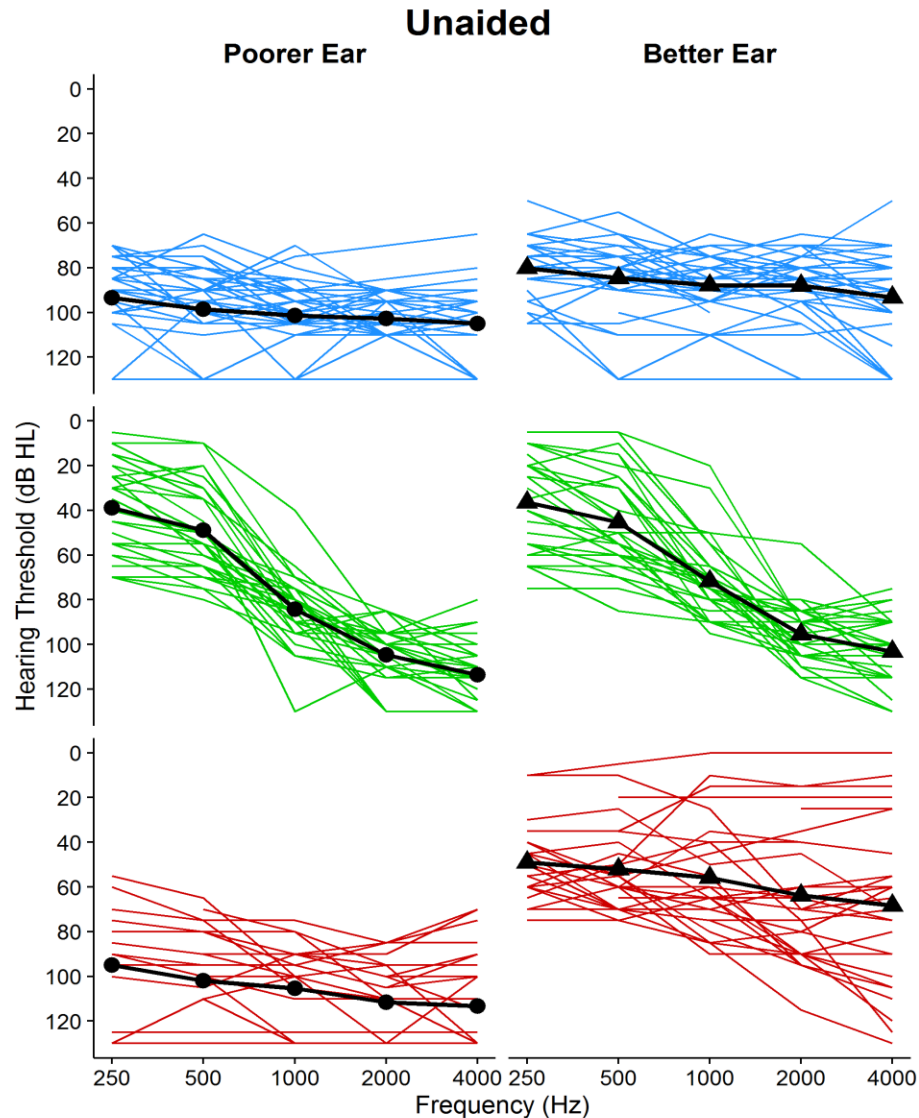


Brainstem Asymmetry (Bimodal)

Absolute Latency (immediately and always)



Bimodal Hearing

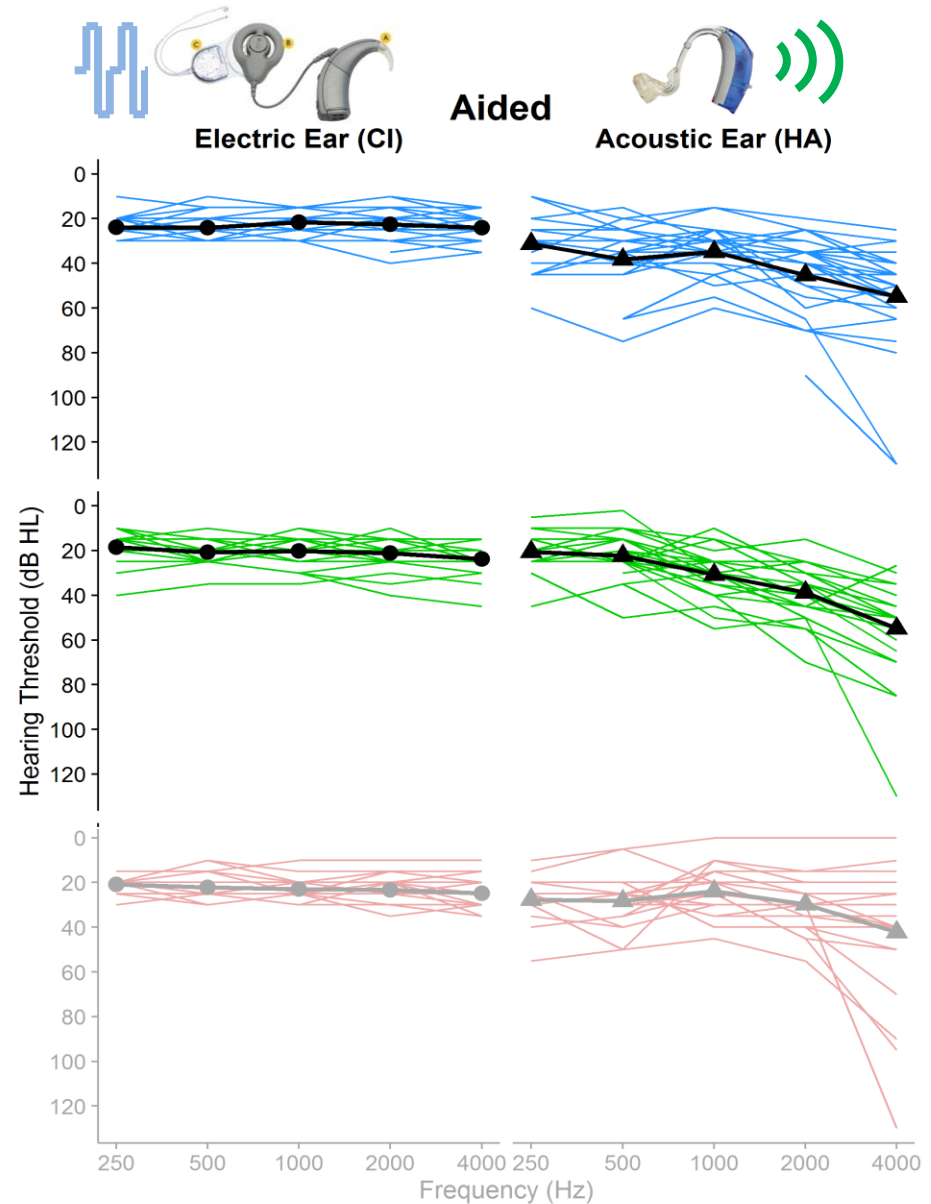
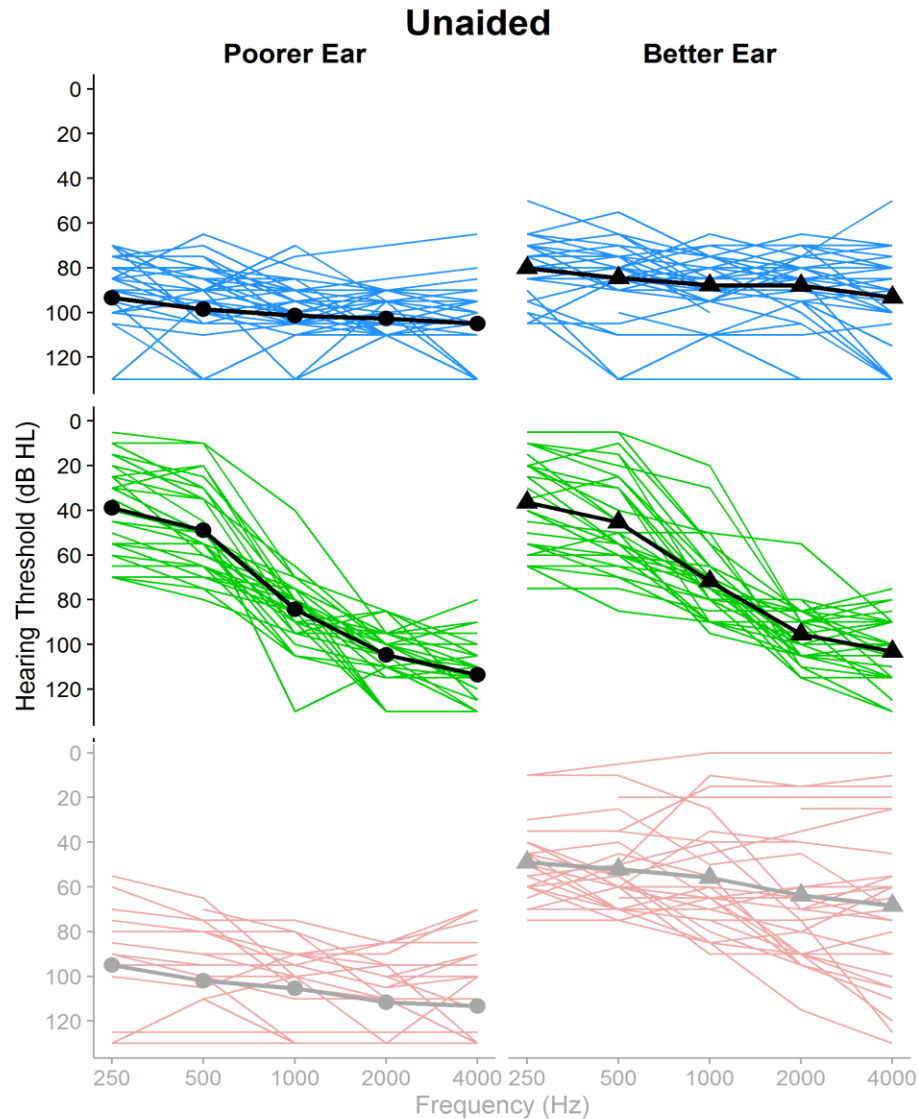


Traditional
n=44 (40%)

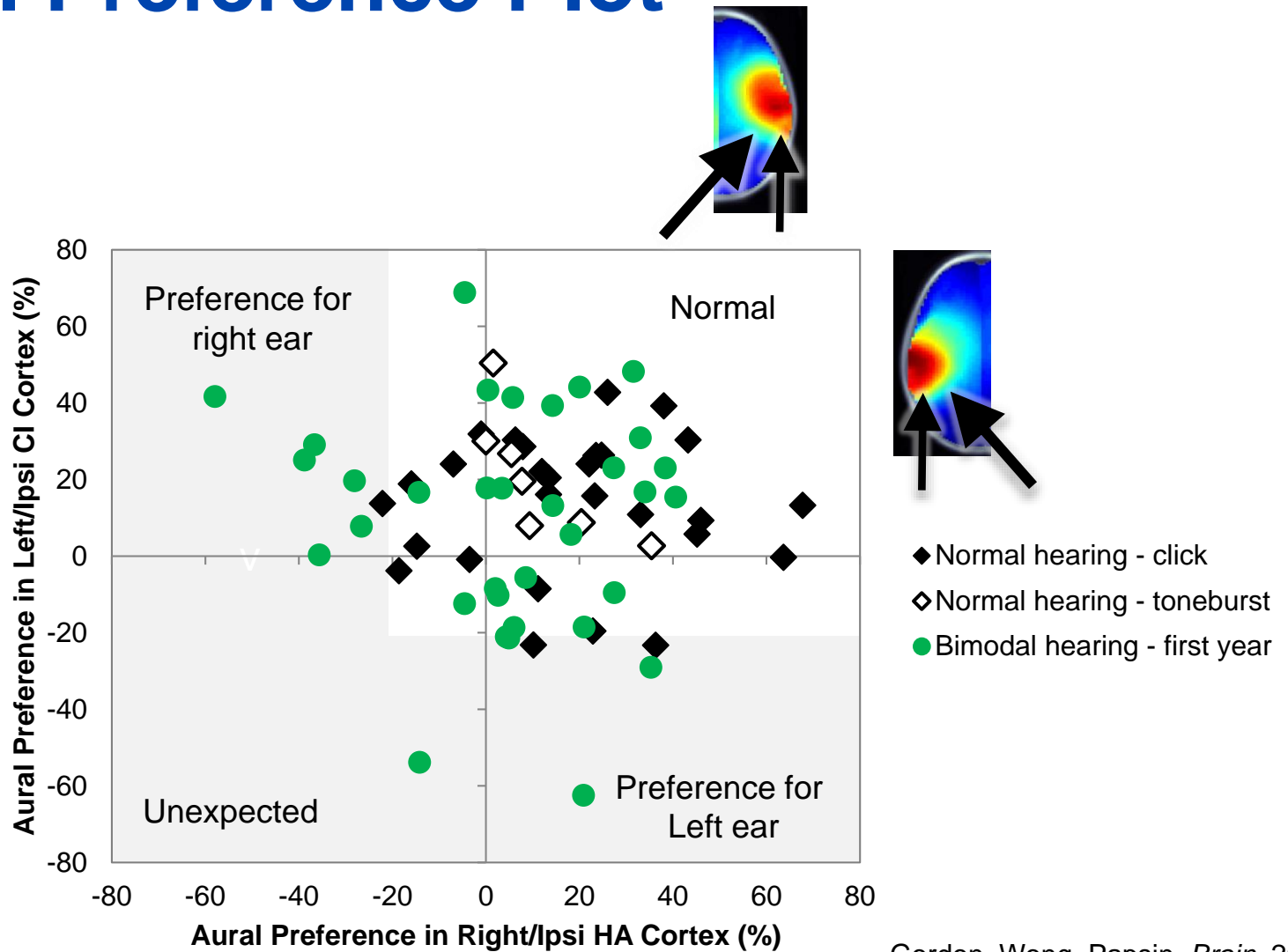
Non-Traditional Symmetric
n=32 (30%)

Non-Traditional Asymmetric
n=33 (30%)

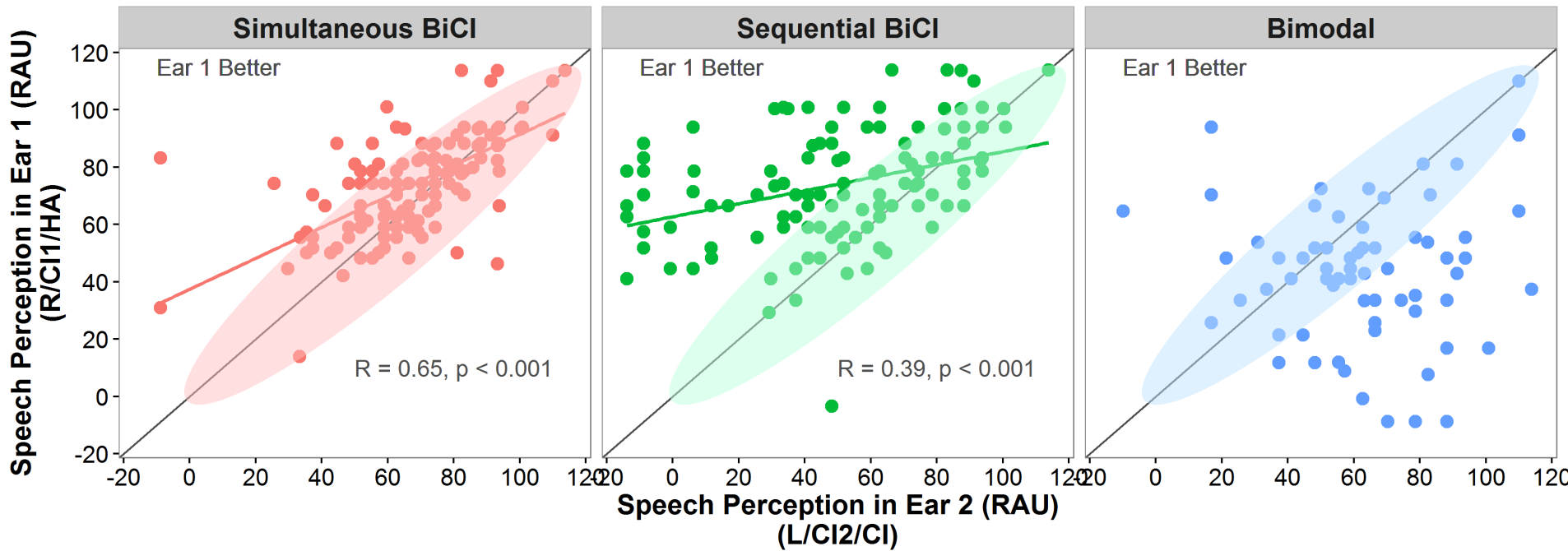
Bimodal Hearing



Aural Preference Plot

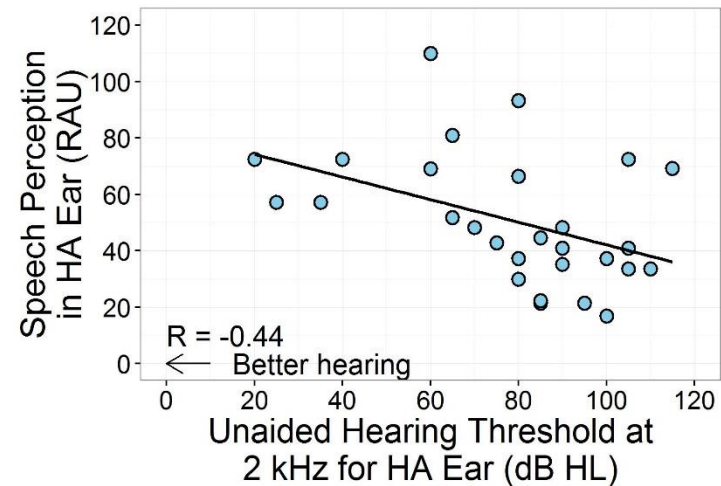
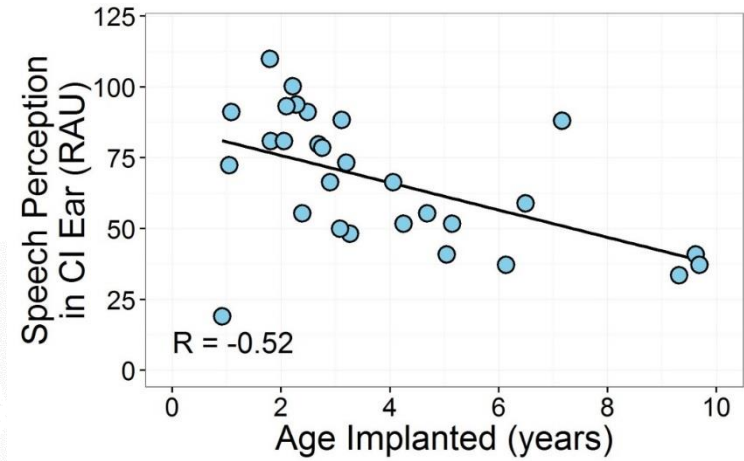
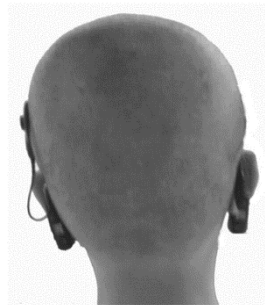
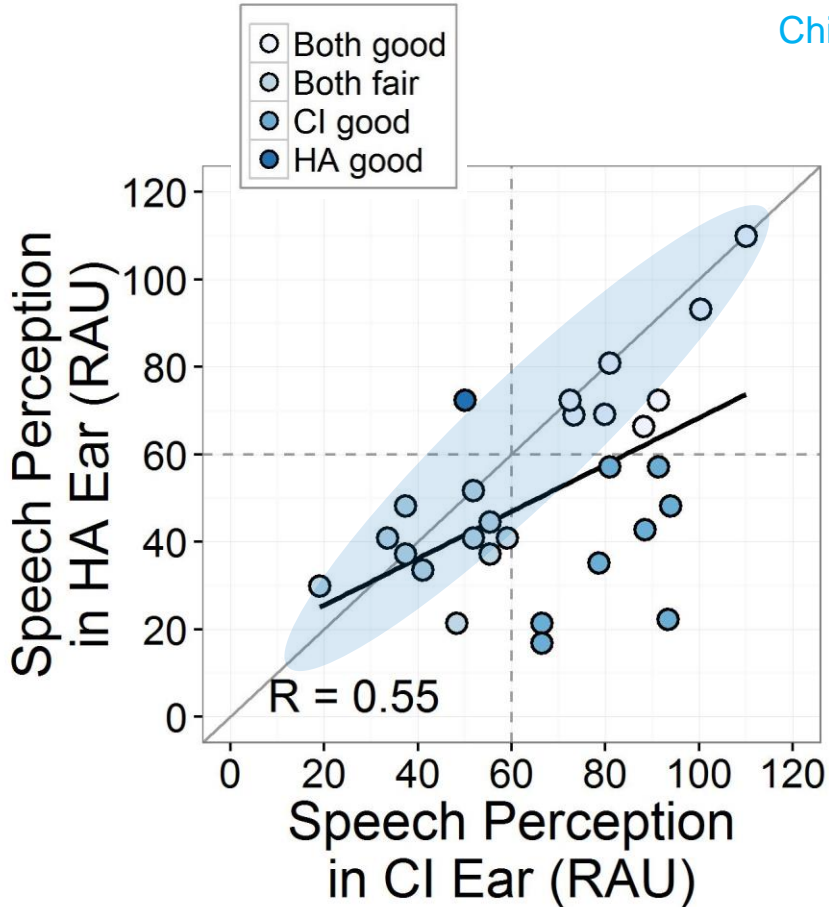


Speech Perception in Binaural Listeners



Preserving Residua Harmful?

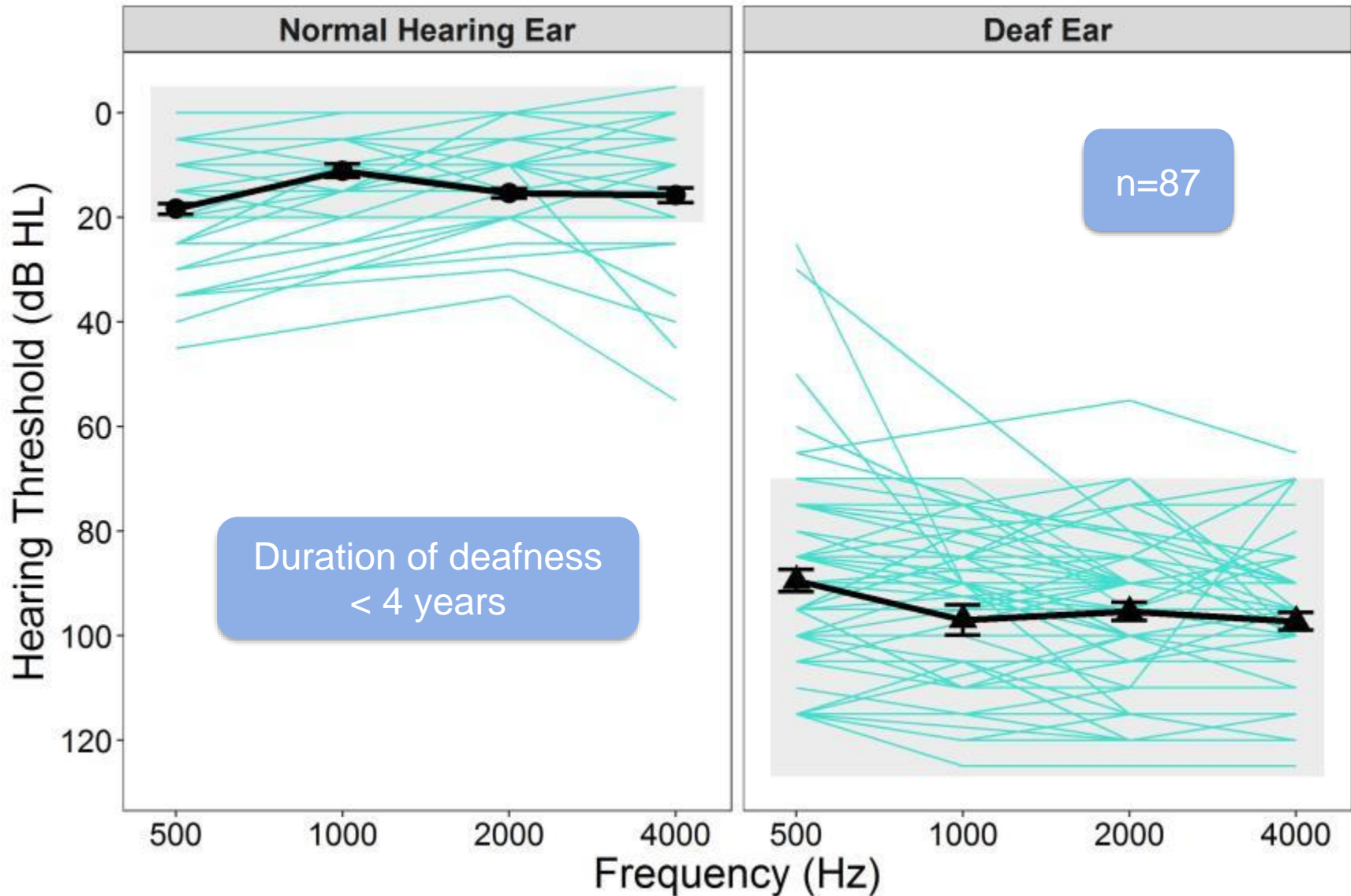
Children using bimodal devices

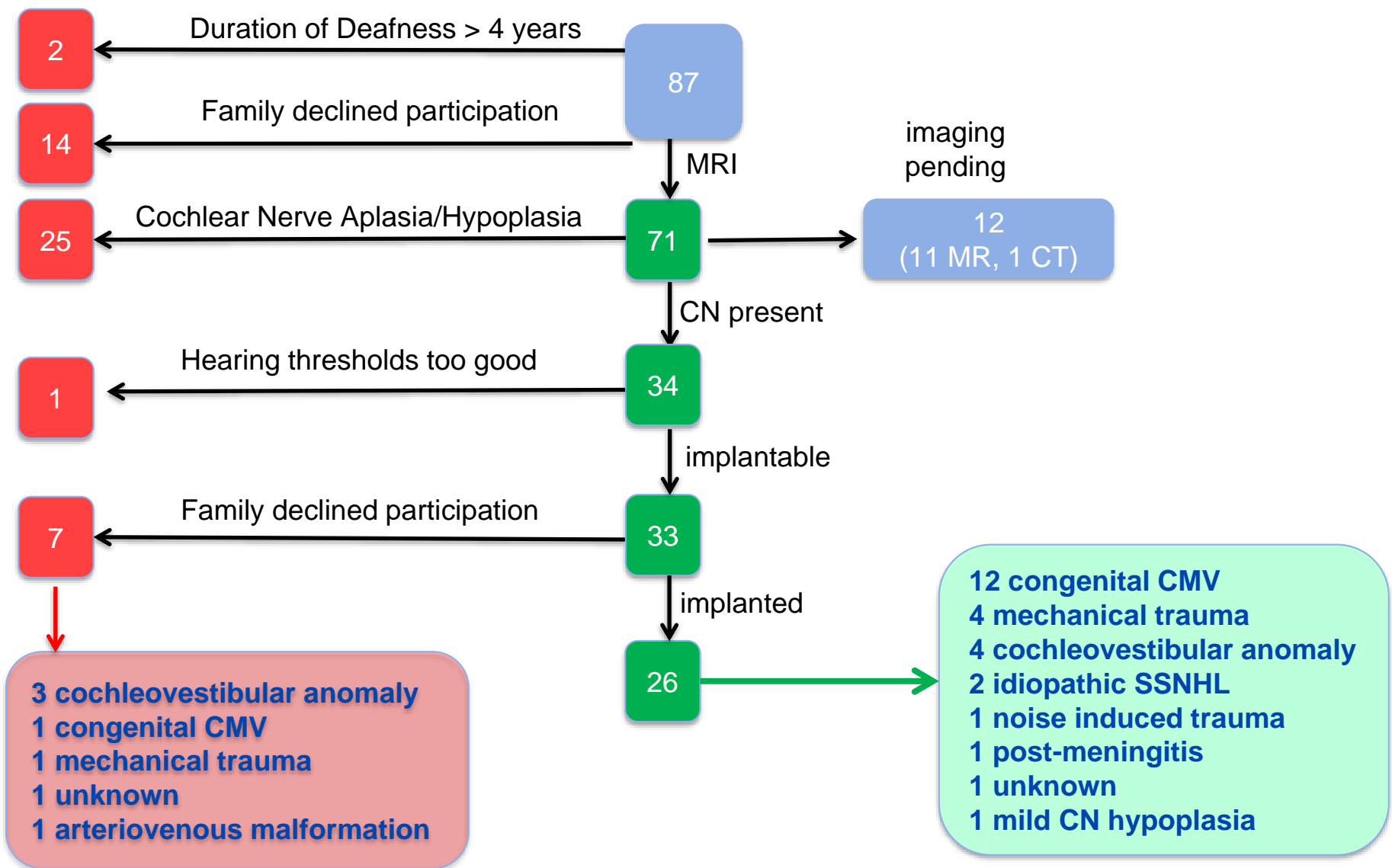


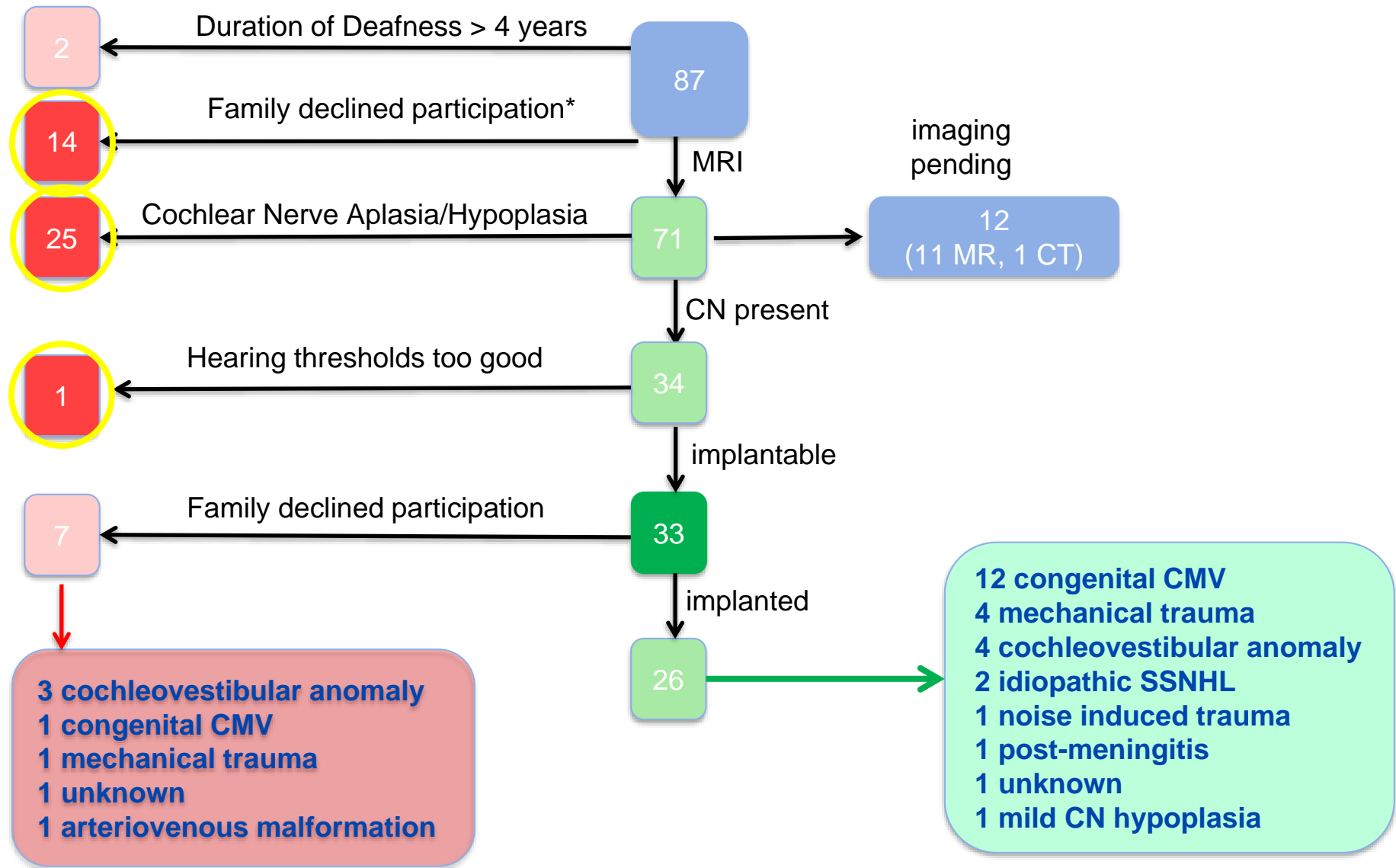
Implications

- auditory pathways develop abnormally with asymmetric hearing
 - **asymmetric** input **before** implantation
 - **unbalanced** input **after** implantation (bilateral devices)
- informed our actions
 - changed implantation criteria
 - **bilateral balance** in addition to unilateral target fitting

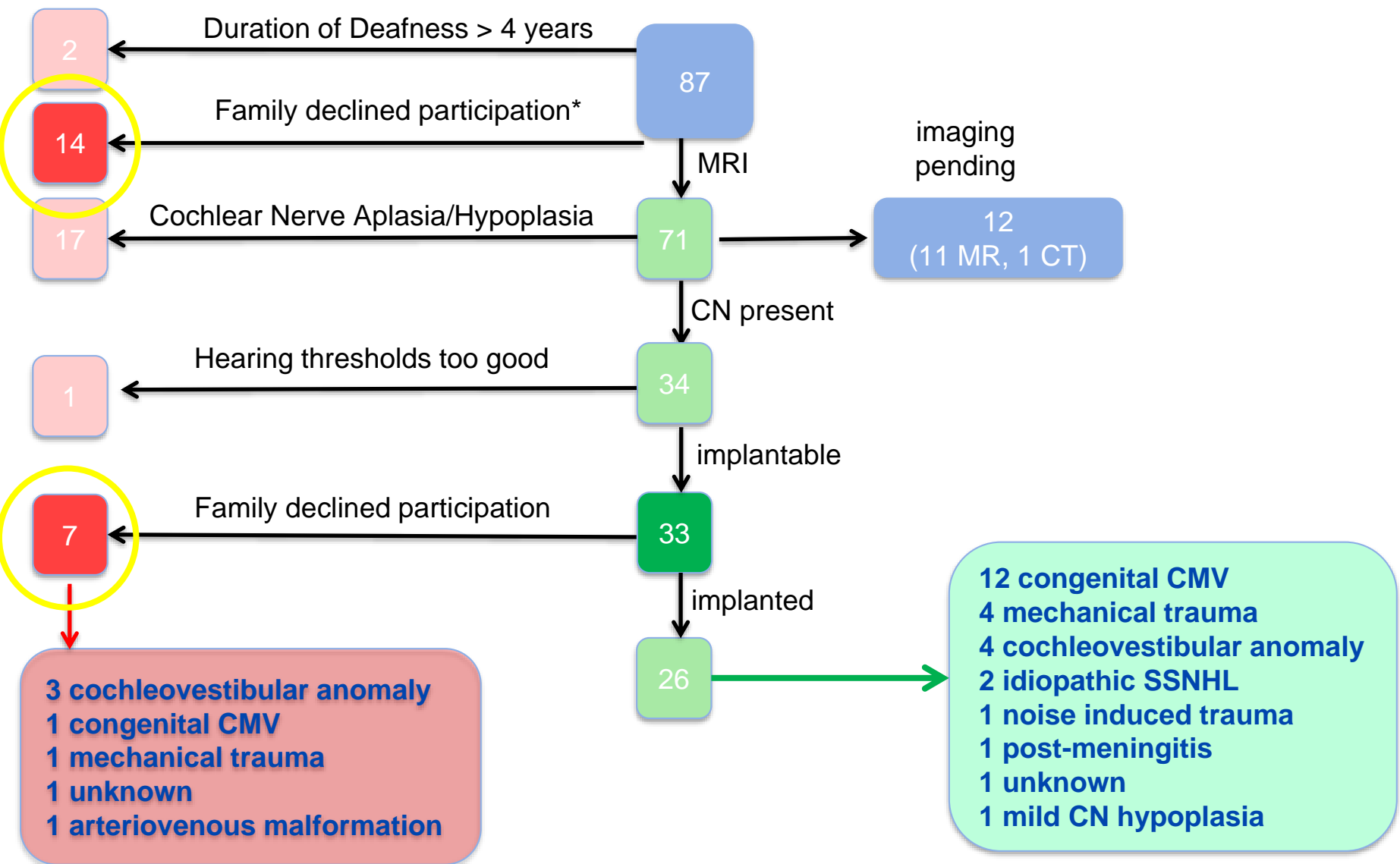
Single Sided Deafness in Children



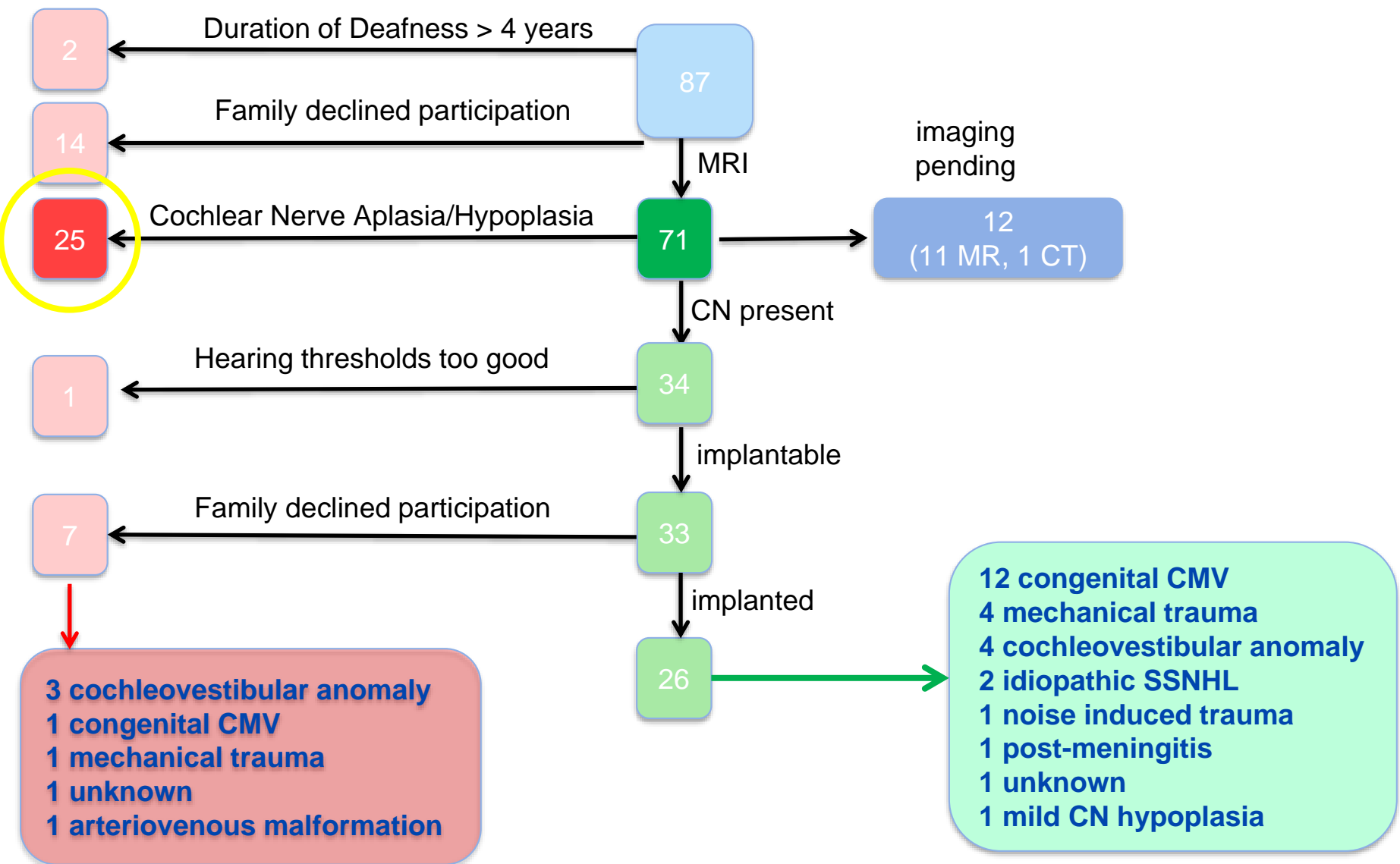




68% of children are candidates

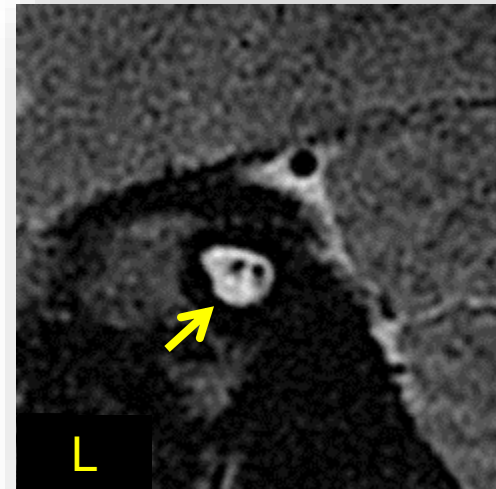
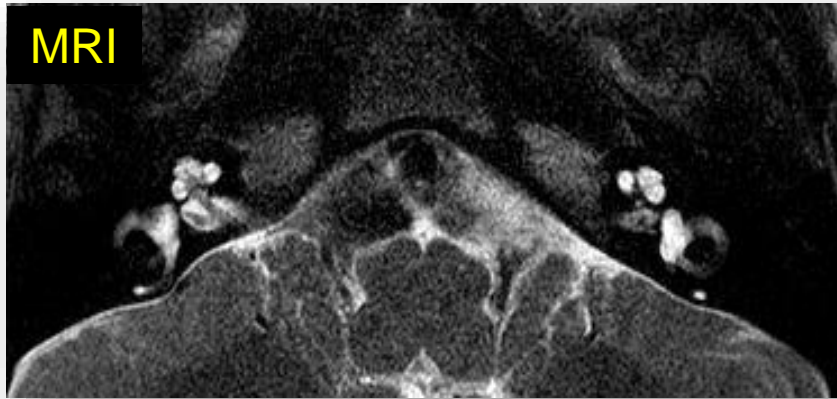


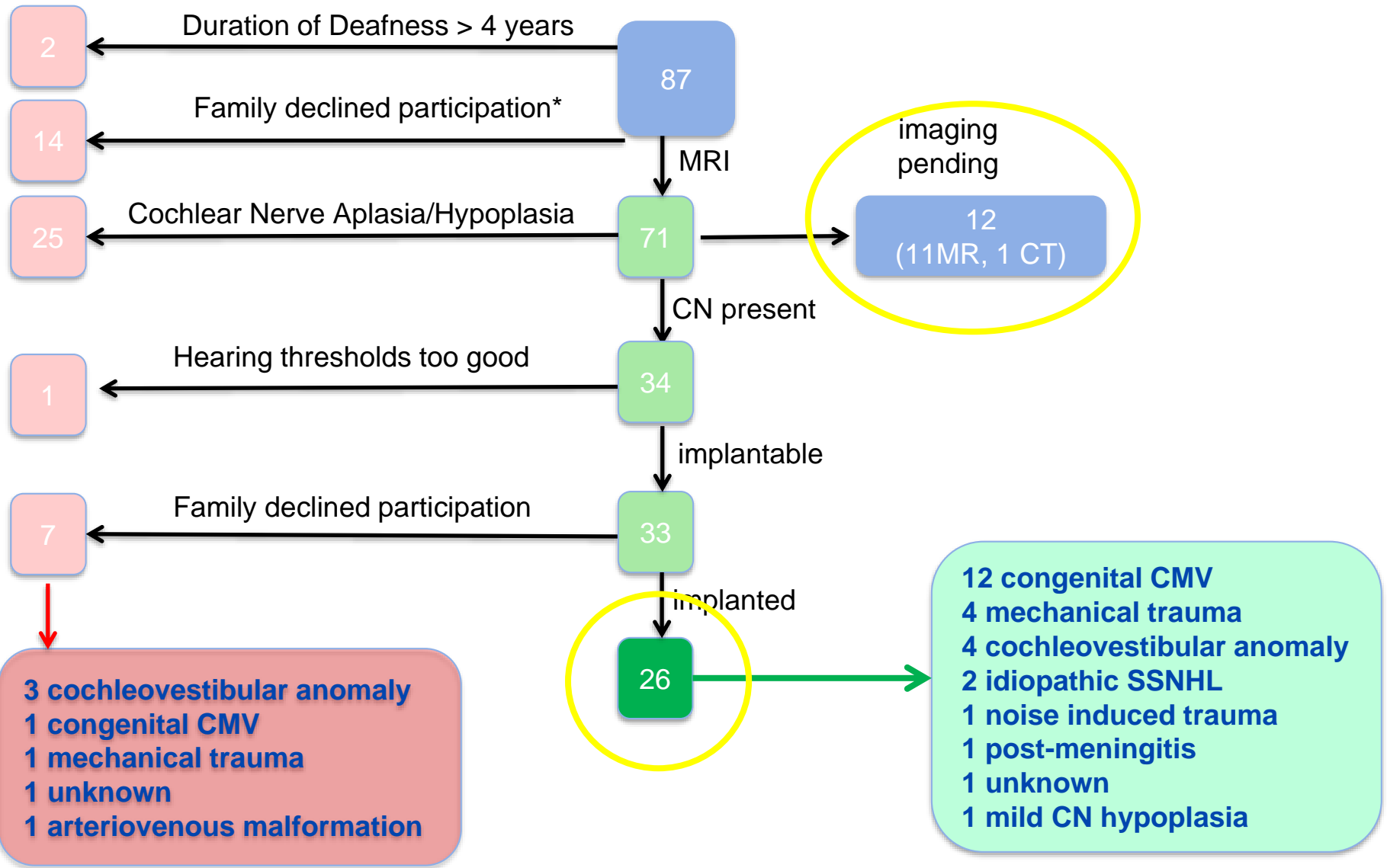
27% decline implantation (↓)



35% have cochlear nerve aplasia (=)

Cochlear Nerve Aplasia





33% of children go on to implant

Risk of Progression

**Sudden Onset
Post-lingual**

- 10 congenital CMV**
- 4 mechanical trauma**
- 3 cochleovestibular anomaly**
- 1 noise induced trauma**
- 1 post-meningitis**
- 1 idiopathic SSNHL**
- 1 unknown**
- 1 mild CN hypoplasia**

33% of children go on to implant

Risk of Progression

Sudden Onset
Post lingual

- 10 congenital CMV
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Risk of Progression

Sudden Onset
Post lingual

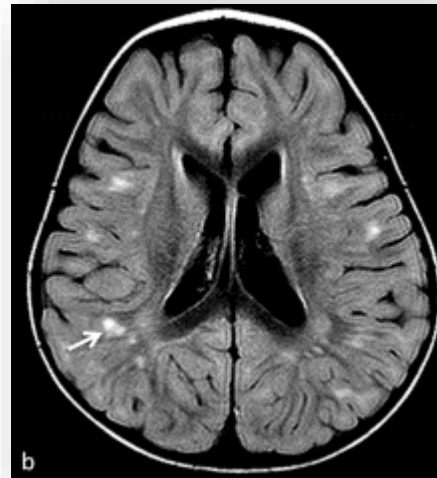
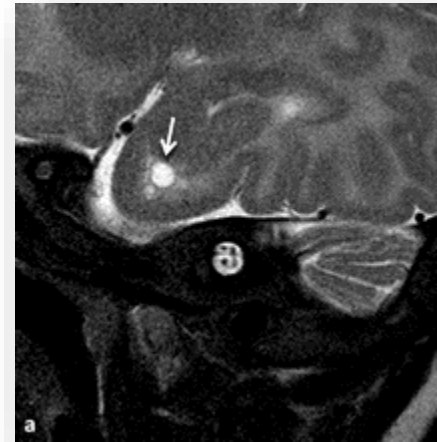
- 10 congenital **CMV**
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33% of children go on to implant

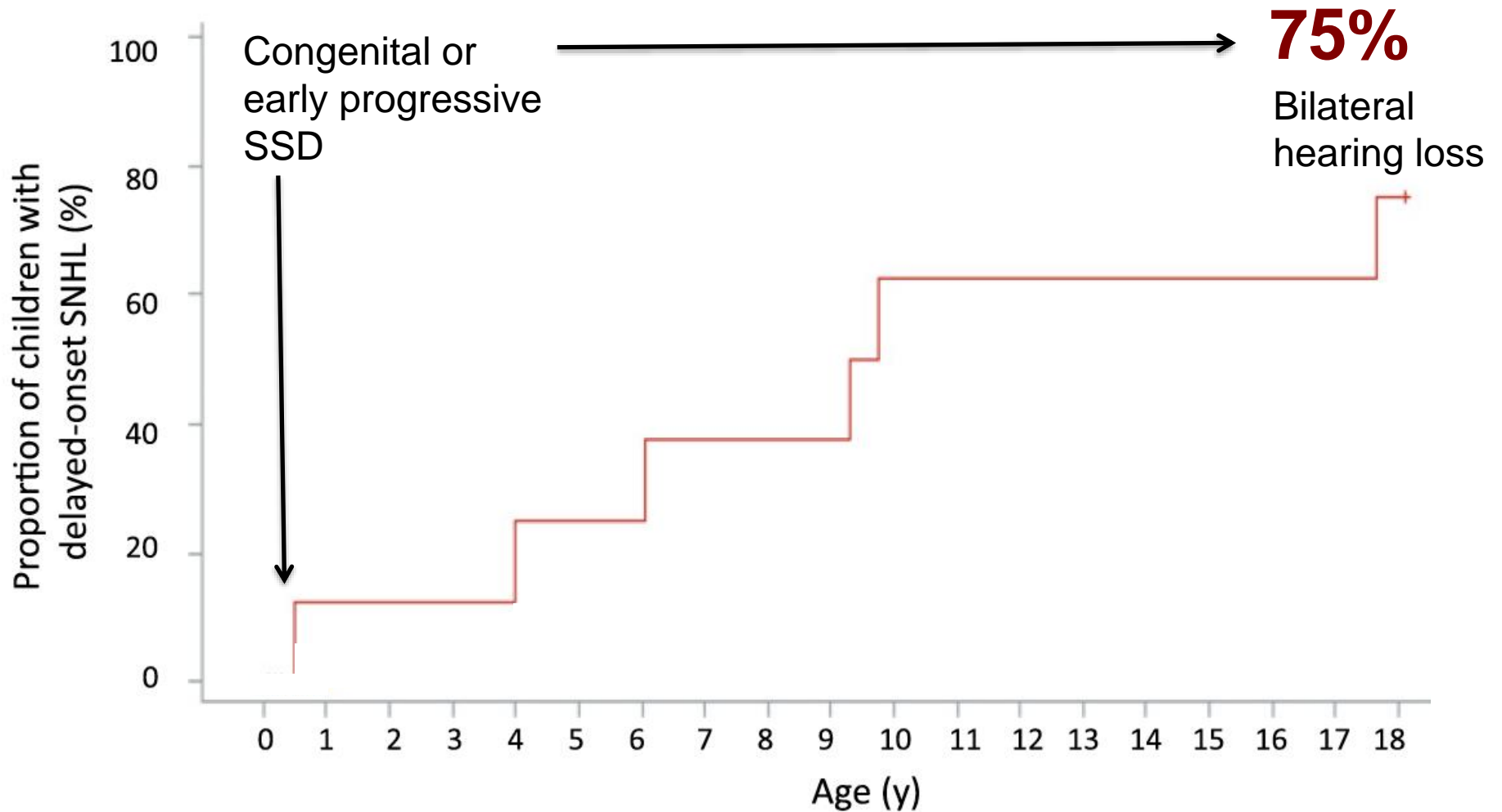
Congenital CMV and SSD

- **22%** of the total cohort
 - almost as common as nerve aplasia/hypoplasia

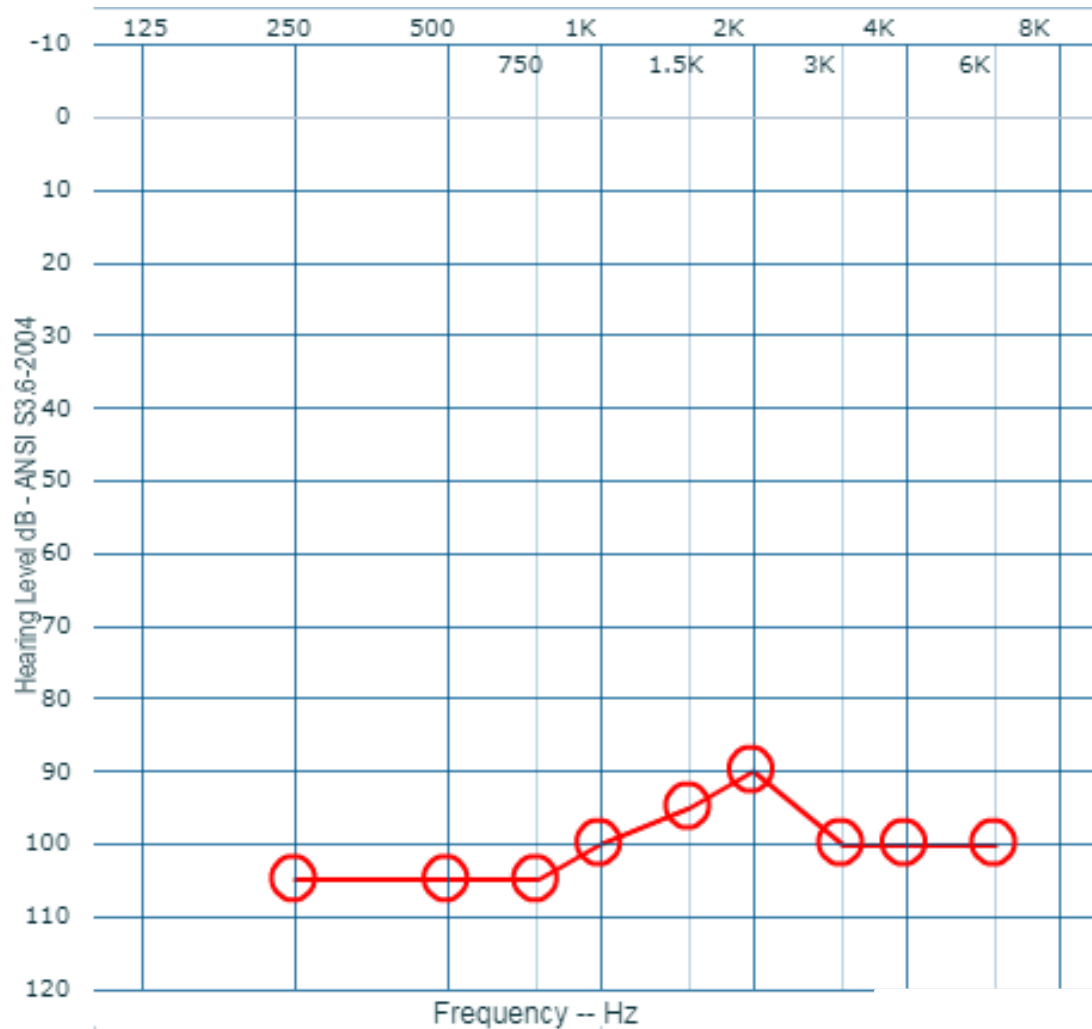
- **46%** of those implanted



SSD in cCMV Progresses to Bilateral



Progression of Hearing Loss in cCMV



October 2005 – September 2015

2005

2006

2007

2008

2009

2010

2011

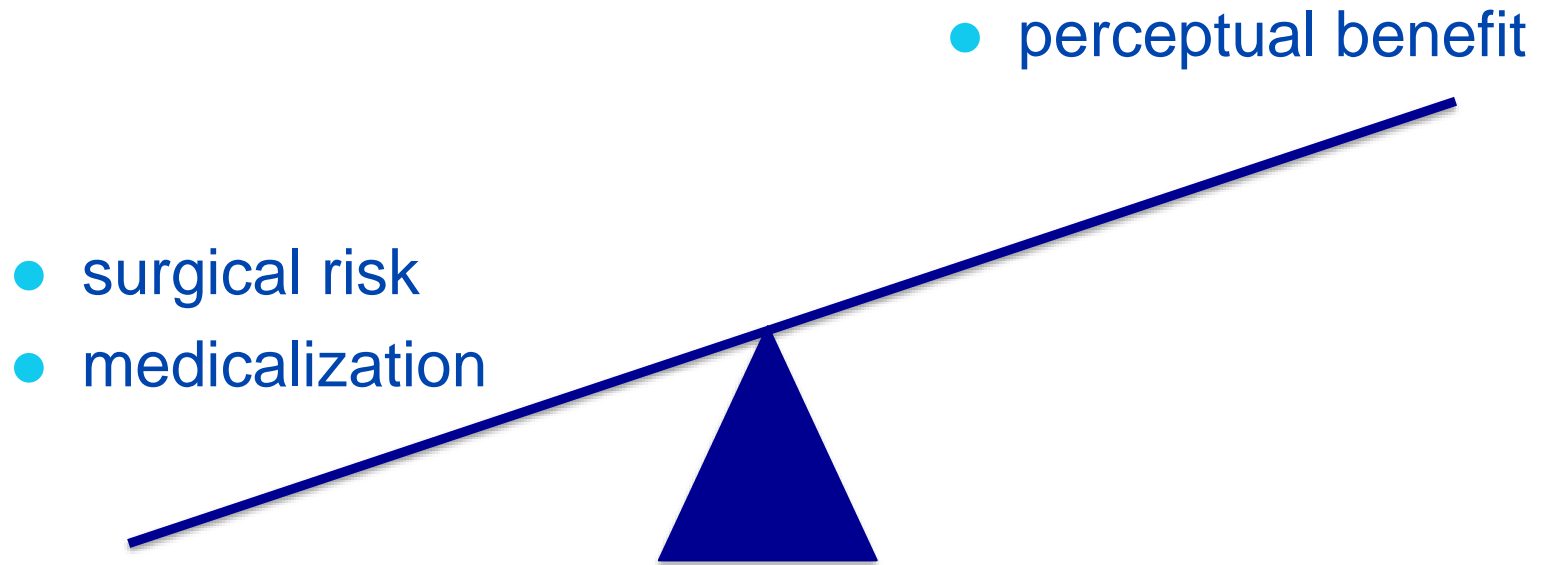
2012

2013

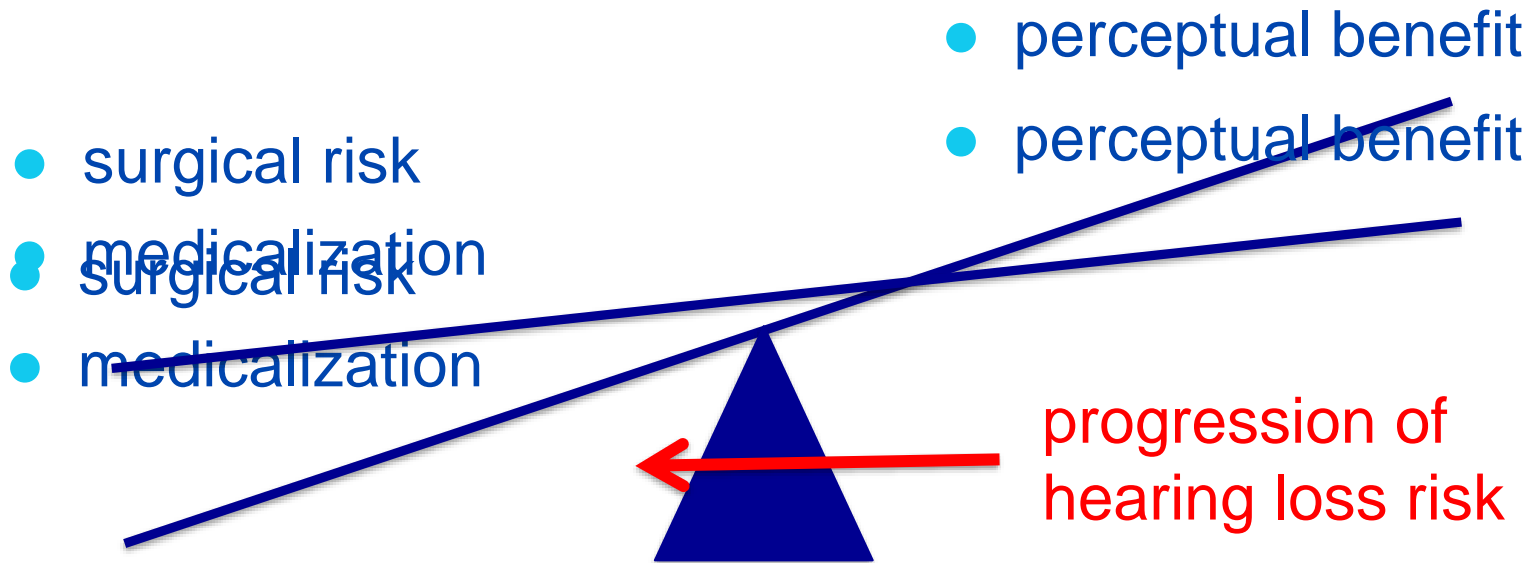
2014

2015

Acceptability of Implants in SSD



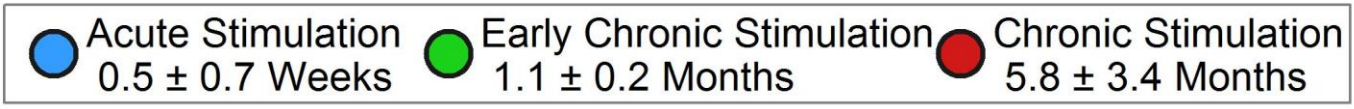
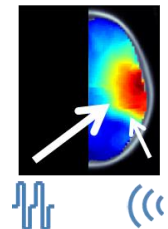
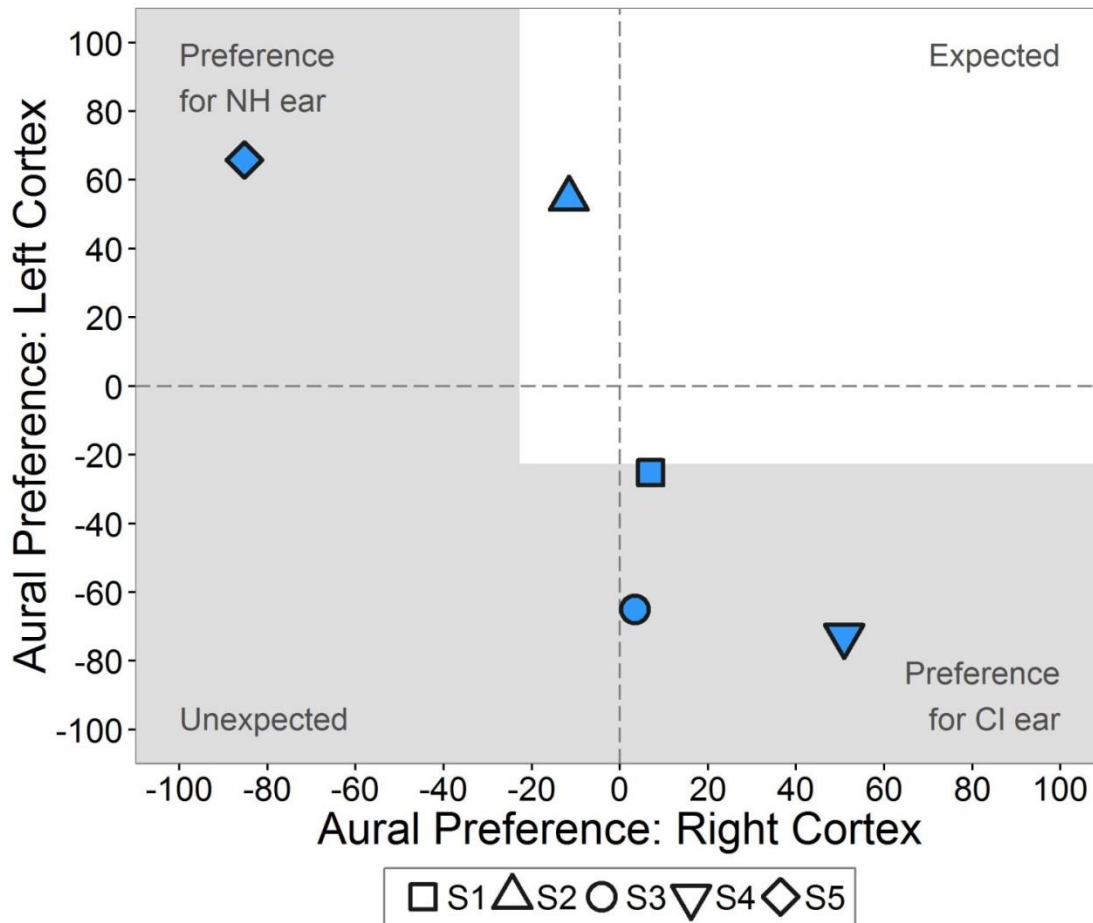
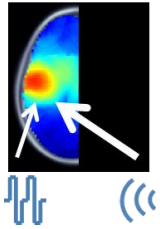
Acceptability of Implants in SSD



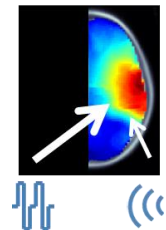
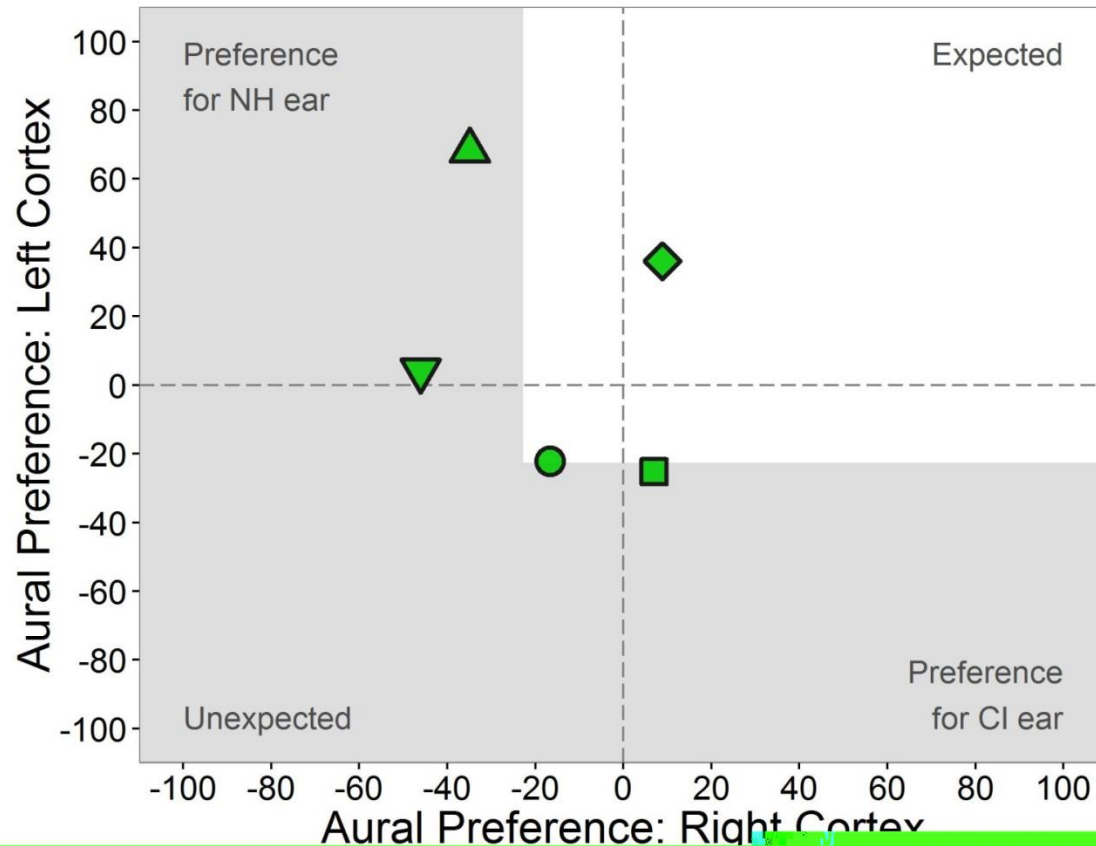
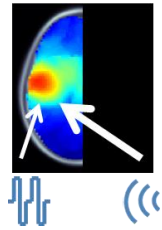
Implants in SSD

- 1/3 decline, 1/3 CN aplasia, 1/3 cCMV,
- risk of progression, sudden onset

Aural Preference Plot - SSD

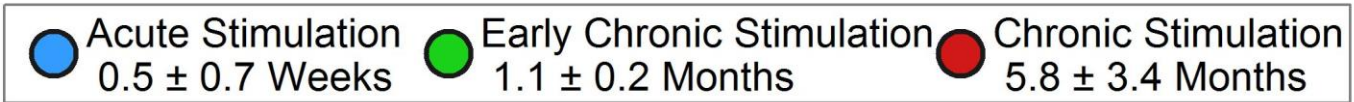
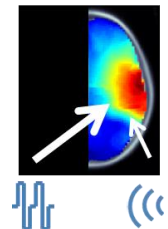
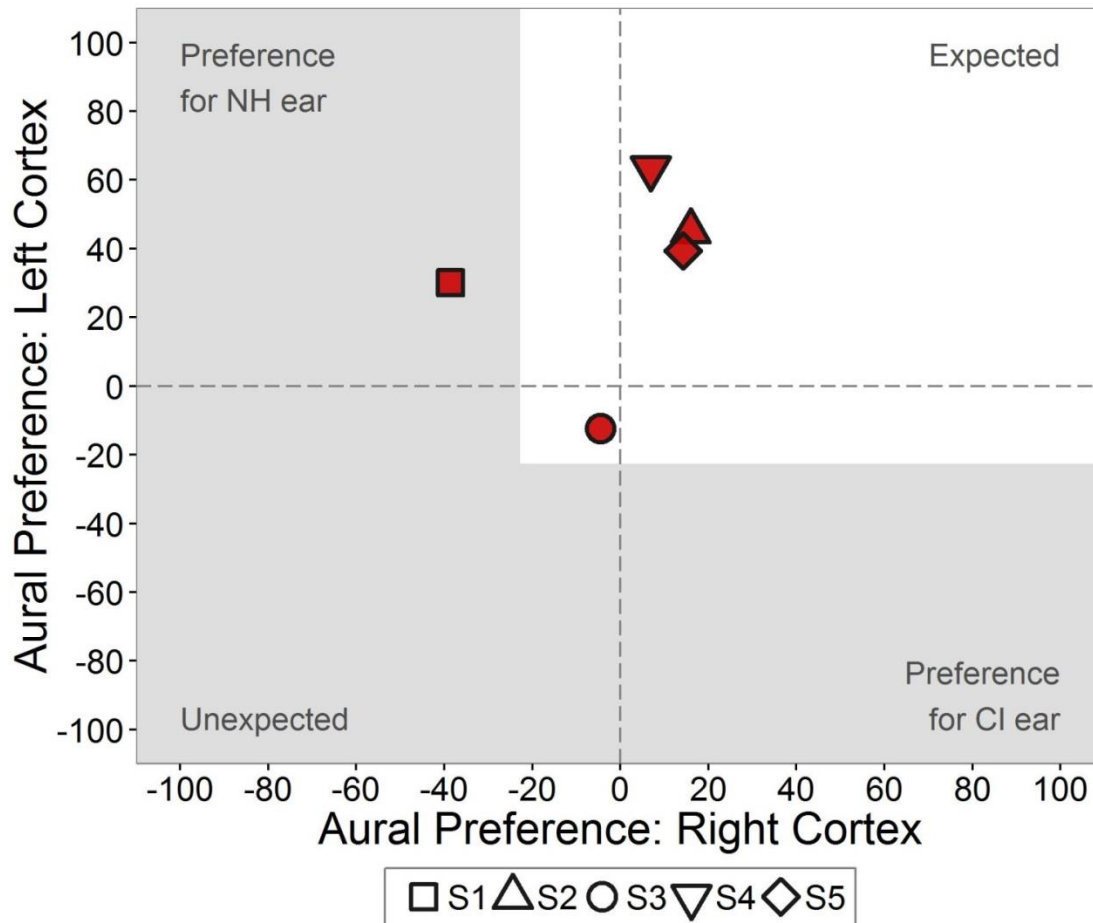
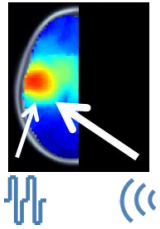


Aural Preference Plot - SSD



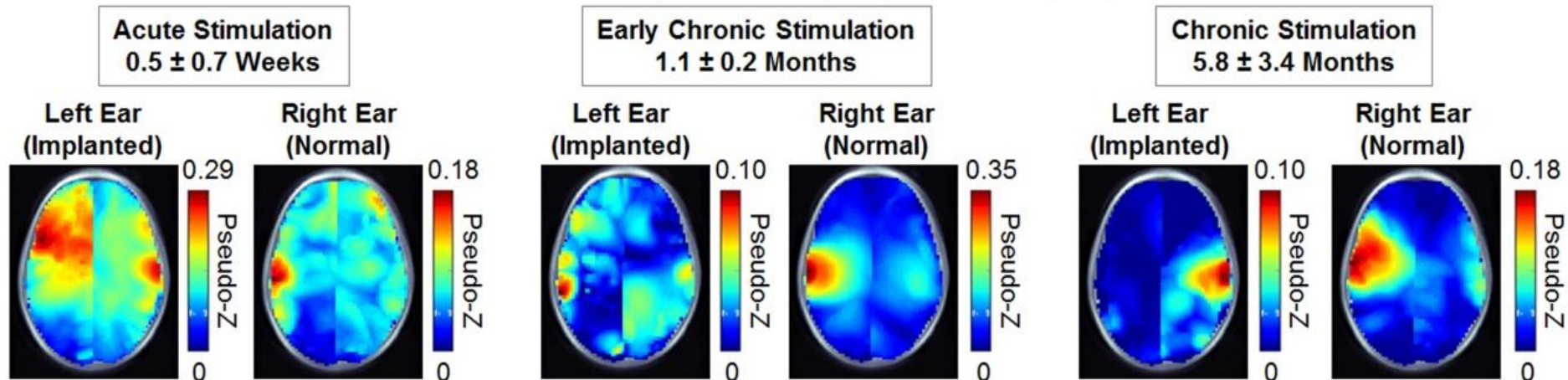
- Acute Stimulation 0.5 ± 0.7 Weeks
- Early Chronic Stimulation 1.1 ± 0.2 Months
- Chronic Stimulation 5.8 ± 3.4 Months

Aural Preference Plot - SSD



P1 Localizes to Temporal Lobes

Source Activity Underlying Peak 1 (P1)



Duration of Stimulation

CI in Congenital SSD

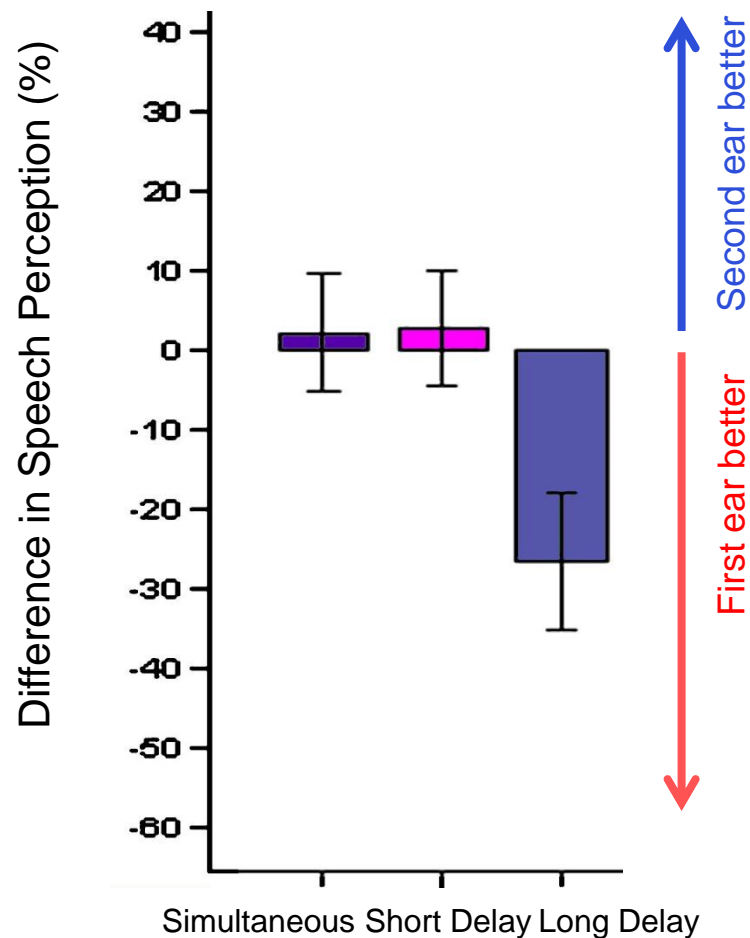
- period of deprivation critical
- abnormal aural preference **resolvable**

- cochlear implantation very promising in young children with congenital single sided deafness

Functional Impact?



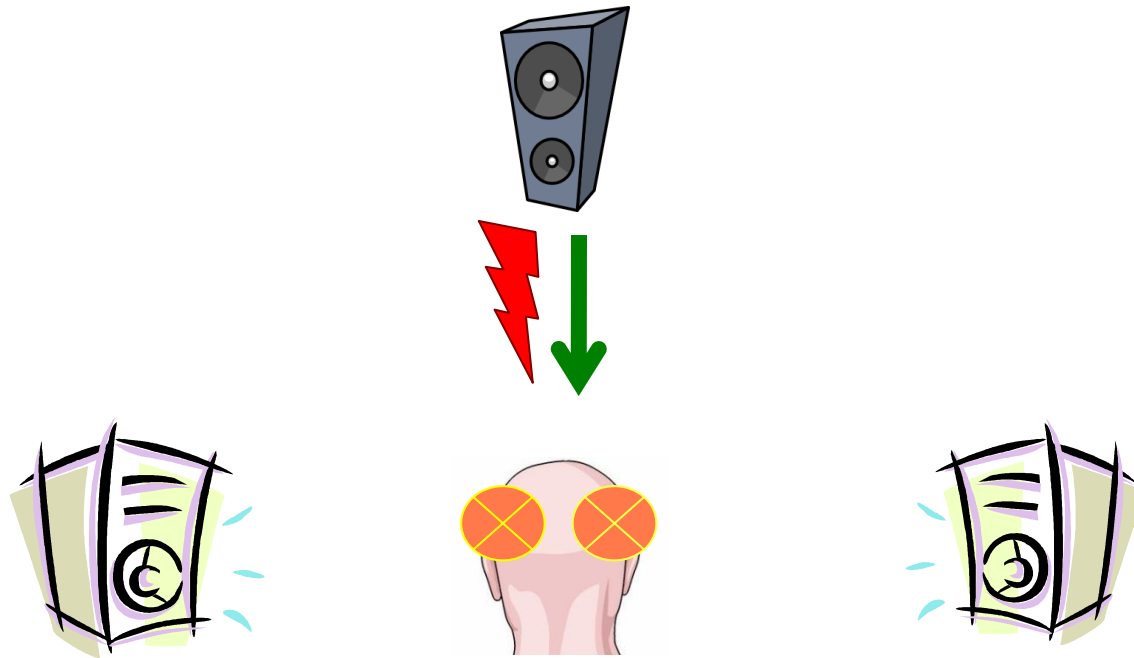
Asymmetry & Speech Perception



(*Otolneurotol.* 2000)

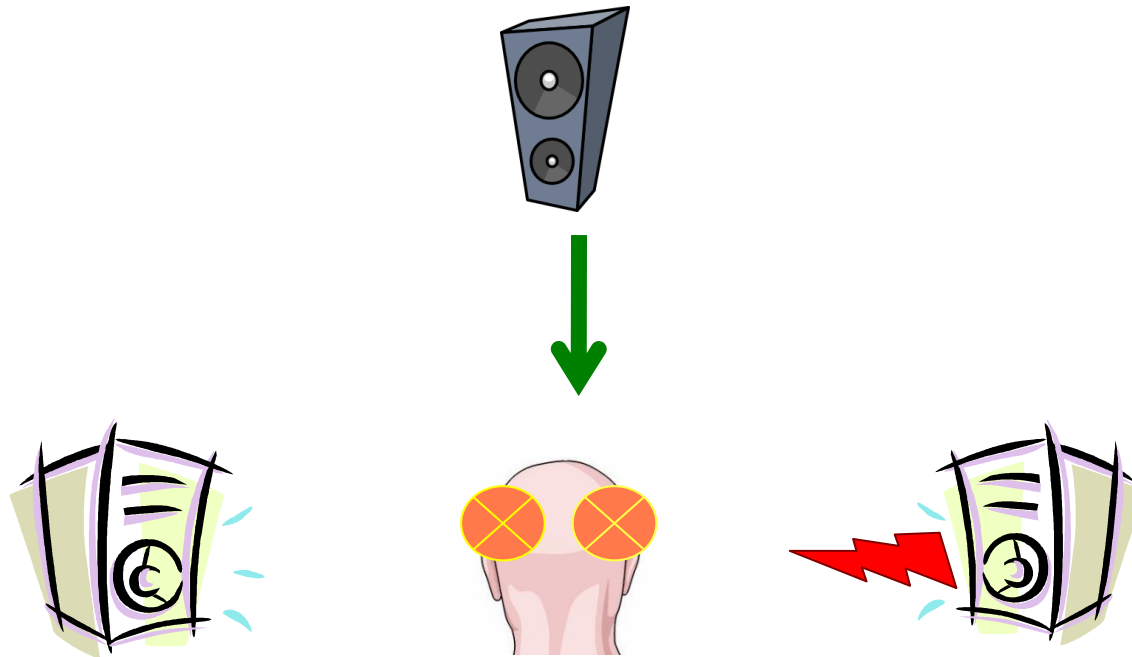
Calculation: Spatial Unmasking

(noise at 0°) vs. (noise at 90°)

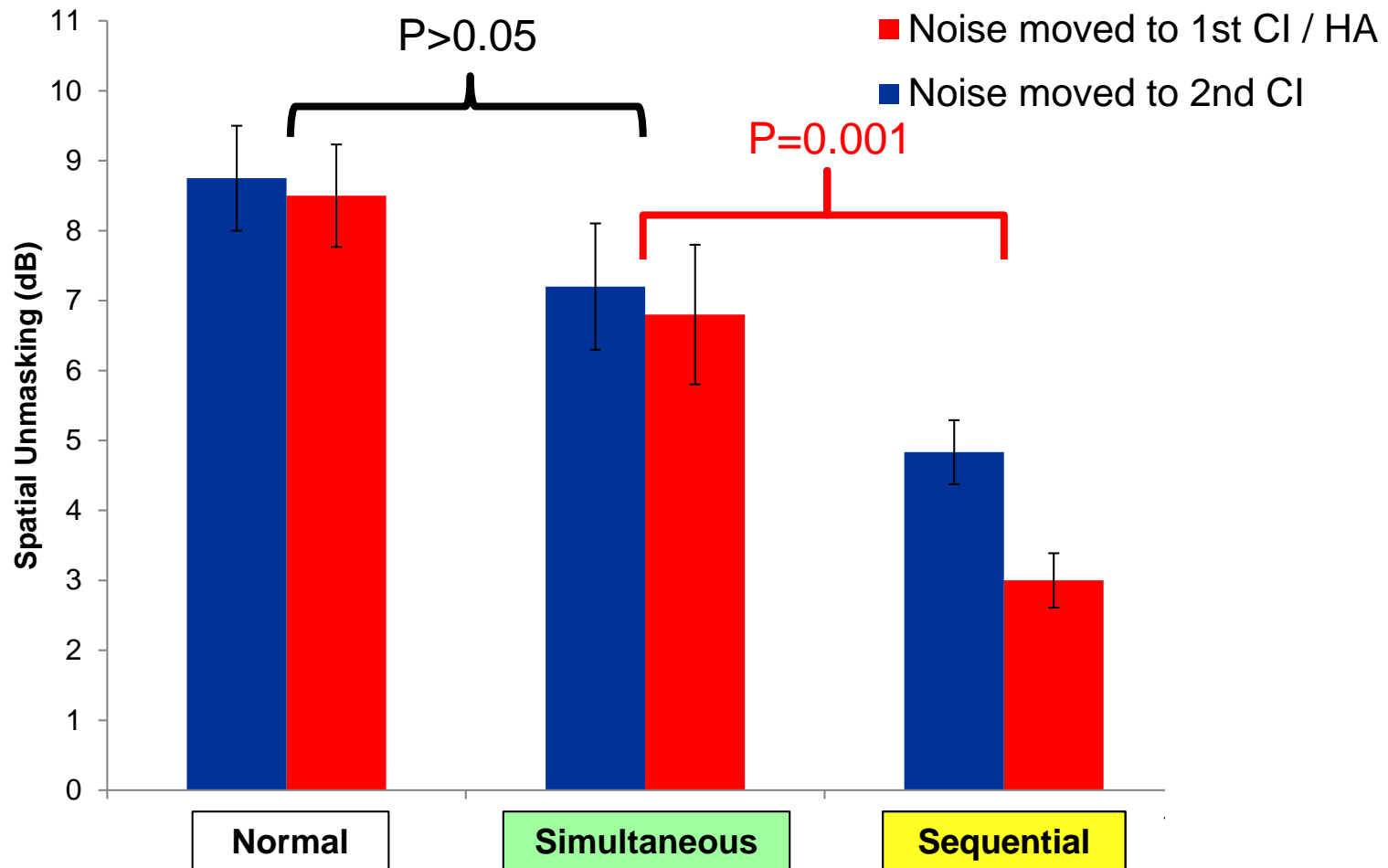


Calculation: Spatial Unmasking

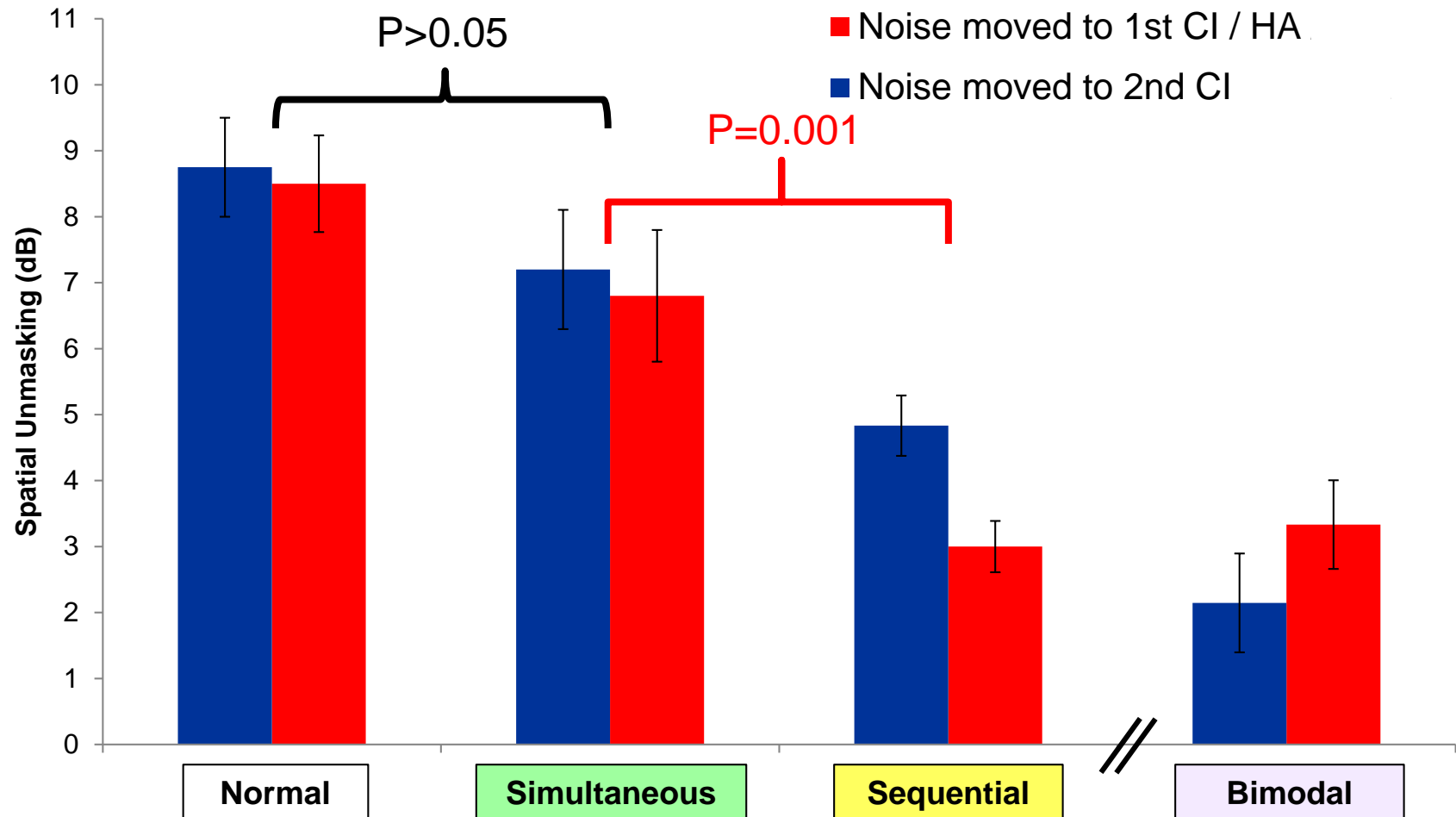
(noise at 0°) vs. (noise at 90°)



Spatial Unmasking is Possible

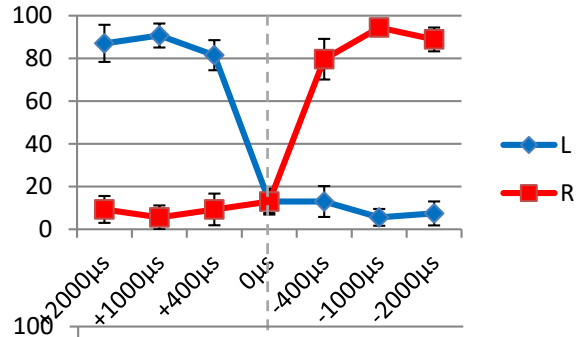
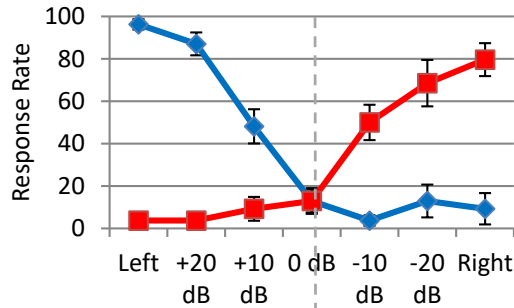


Spatial Unmasking is Possible

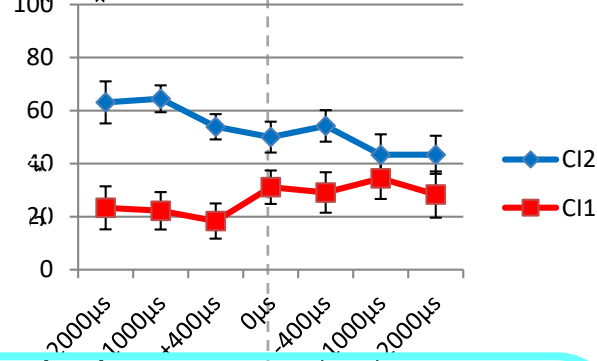
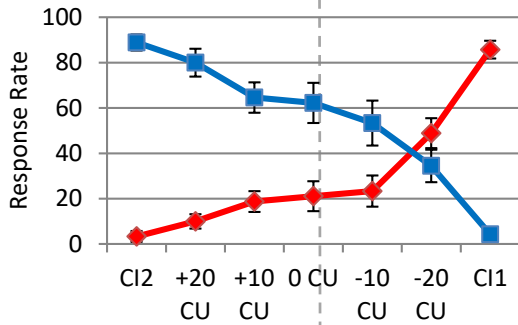


Inter-Aural/Implant Level & Timing Differences

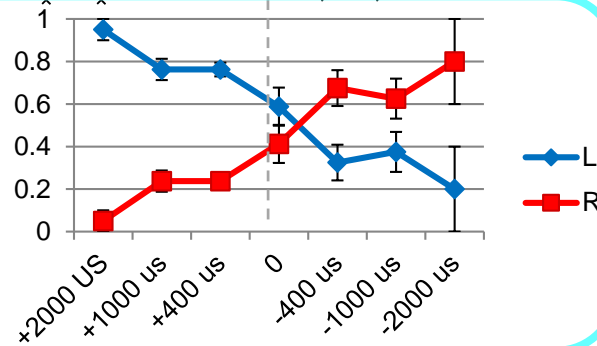
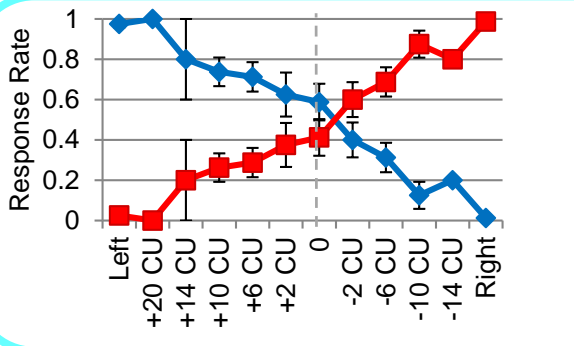
Normal



Sequential



Simultaneous



Intra-Aural/Implant Loudness Difference Condition

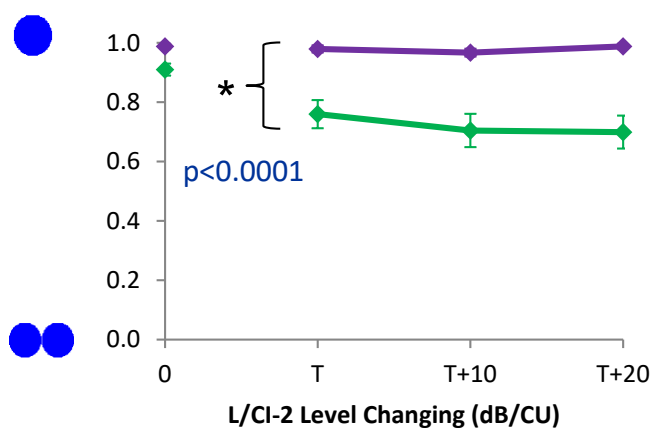
Intra-Aural/Implant Timing Difference Condition

Binaural Fusion



Inter-Aural/Implant Level & Timing Differences and “Fusion”

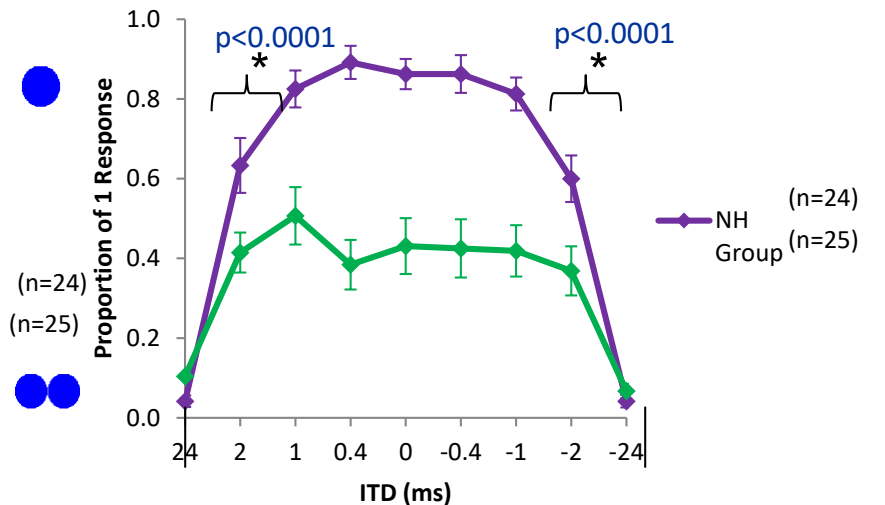
Level Cues



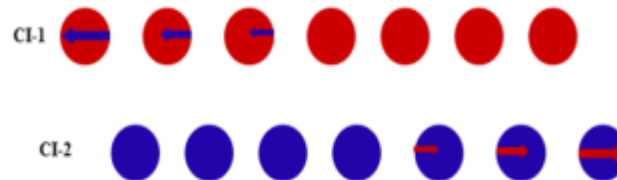
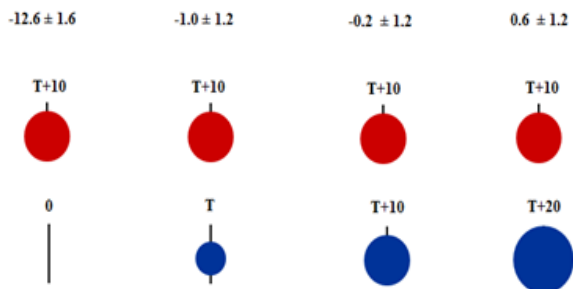
Unilateral control

ITD = 0 ms
Electrode = 20

Timing Cues

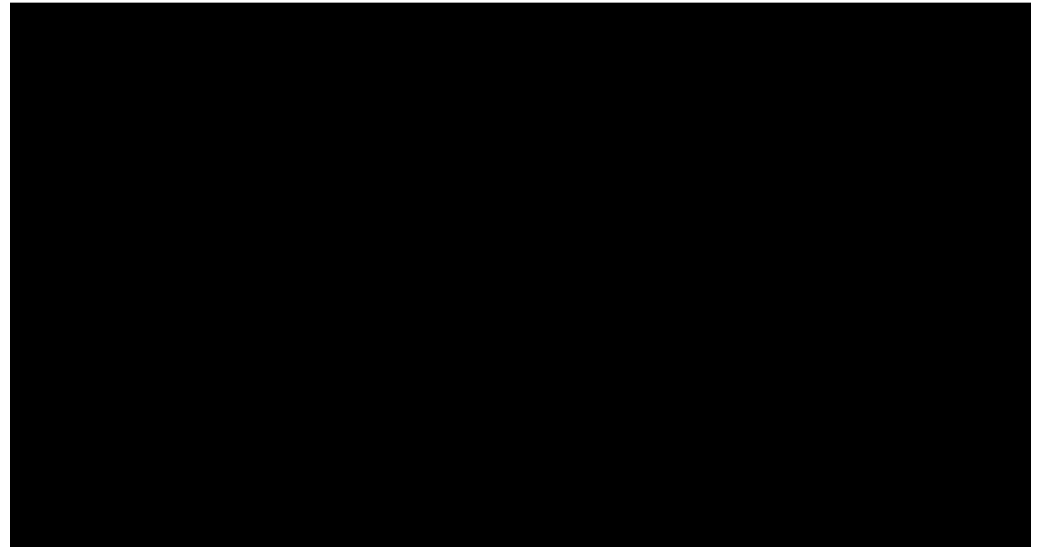


(Mean ILD = -0.34 ± 0.9 dB)



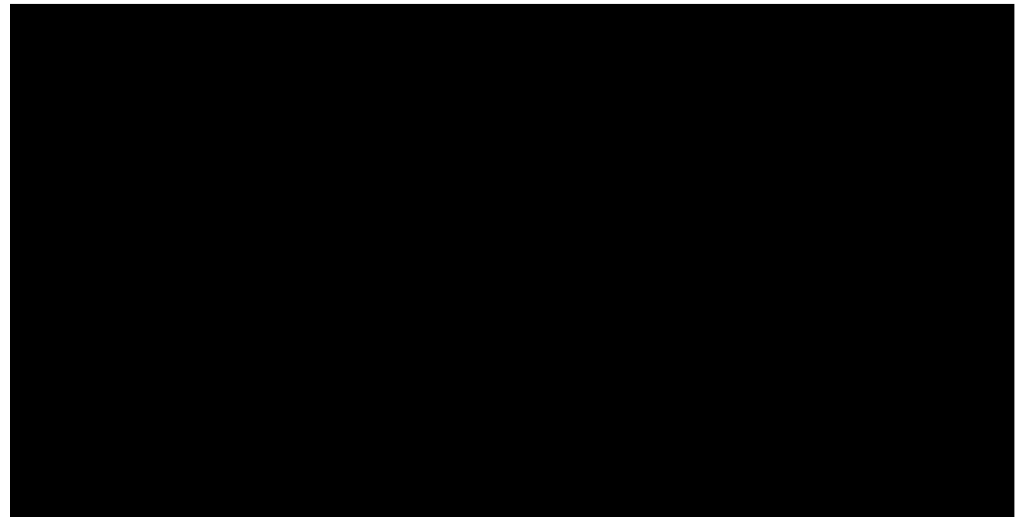
Fusion – Image Assembly

- chameleon
 - independent eyes
 - depth perception
 - accurate hunters

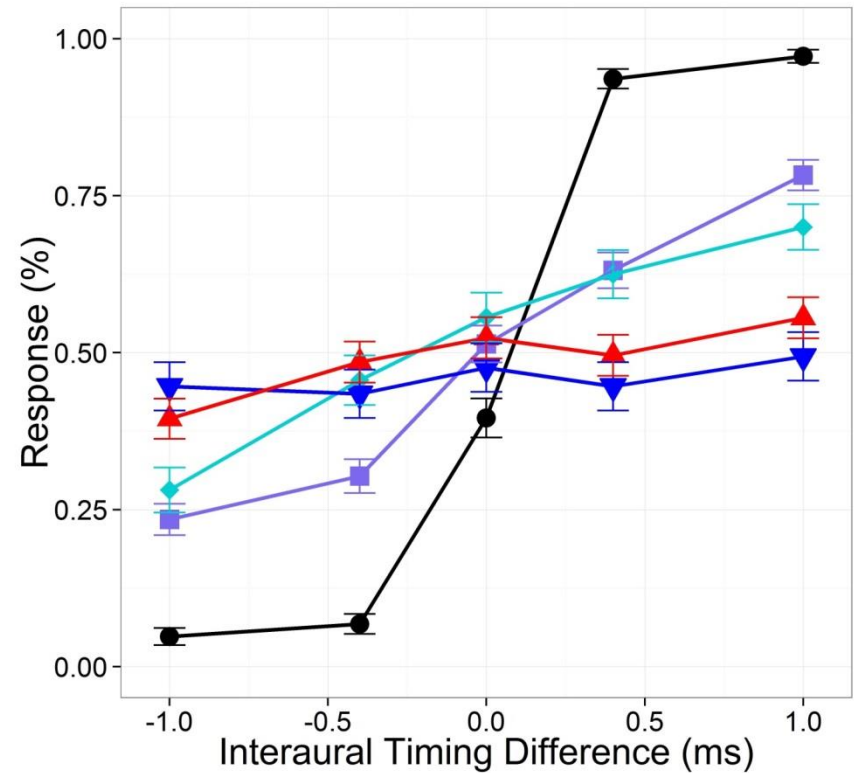
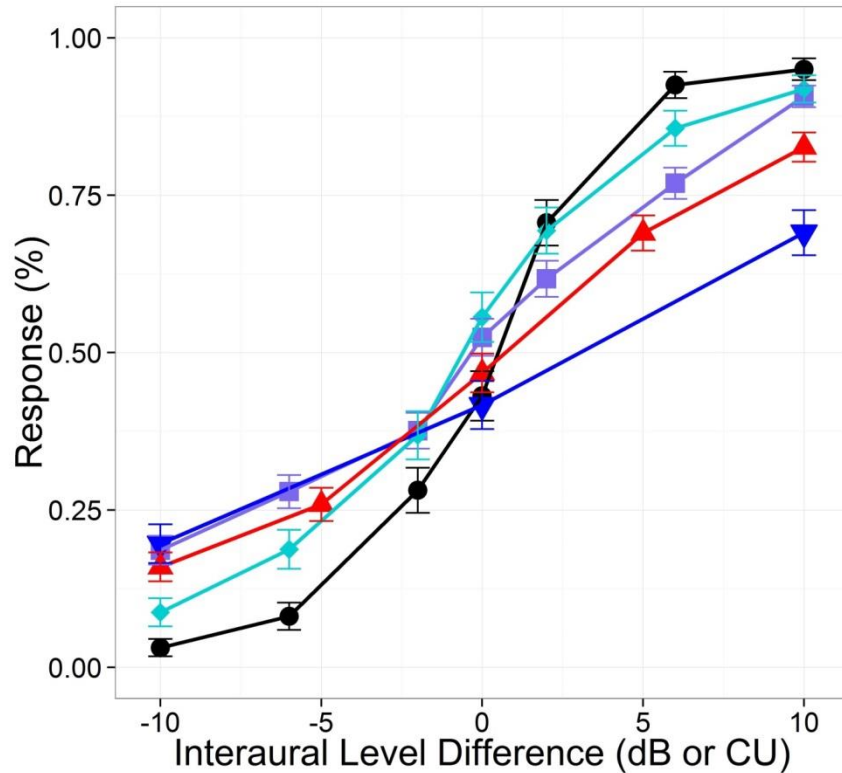


Fusion – Image Assembly

- chameleon
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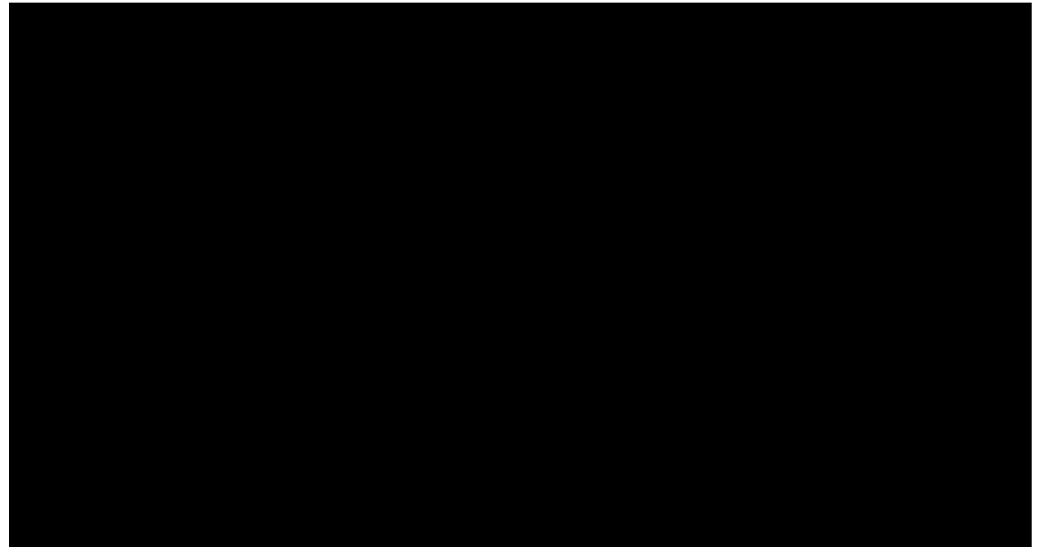


Inter-Aural/Implant Level & Timing Differences



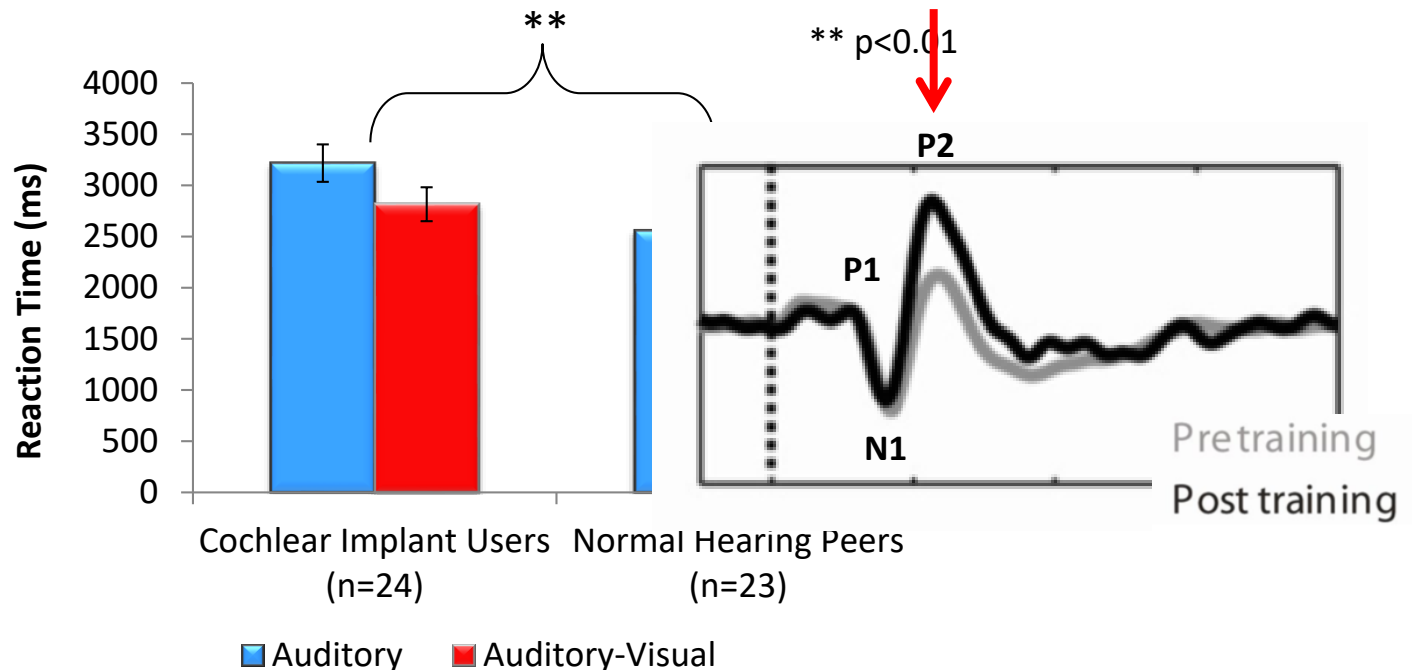
Fusion – Image Assembly

- chameleon
 - slow prey
 - pseudo-fusion



Increased Time & Increased P2 Amplitude

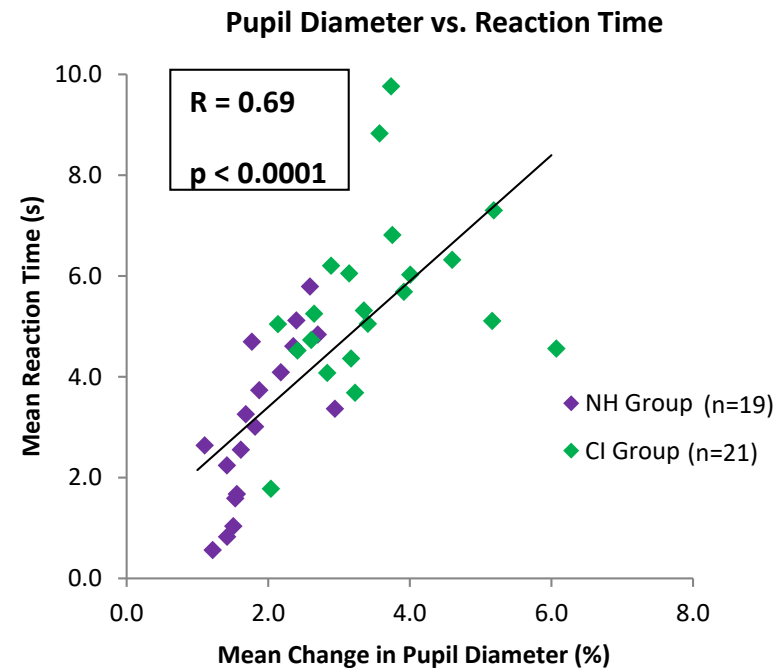
Increased reaction time - emotion in speech after auditory training

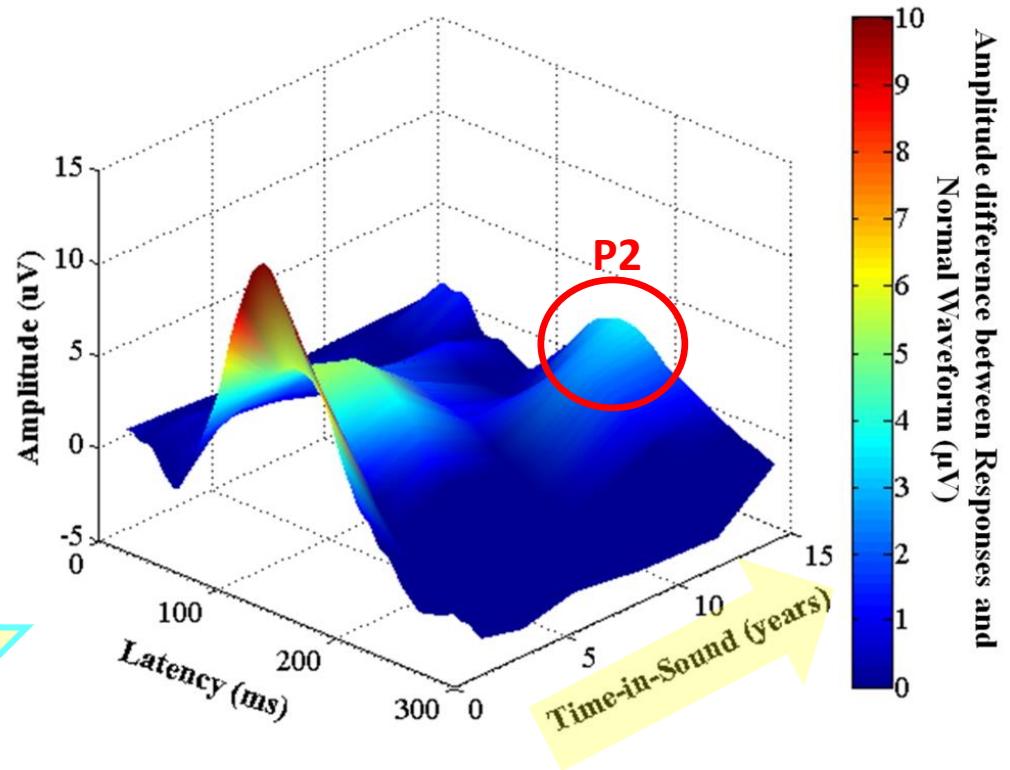
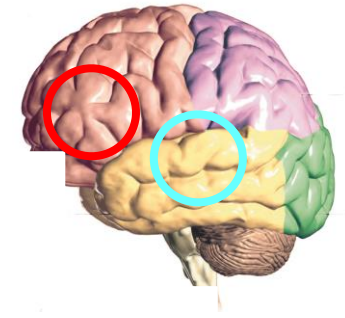
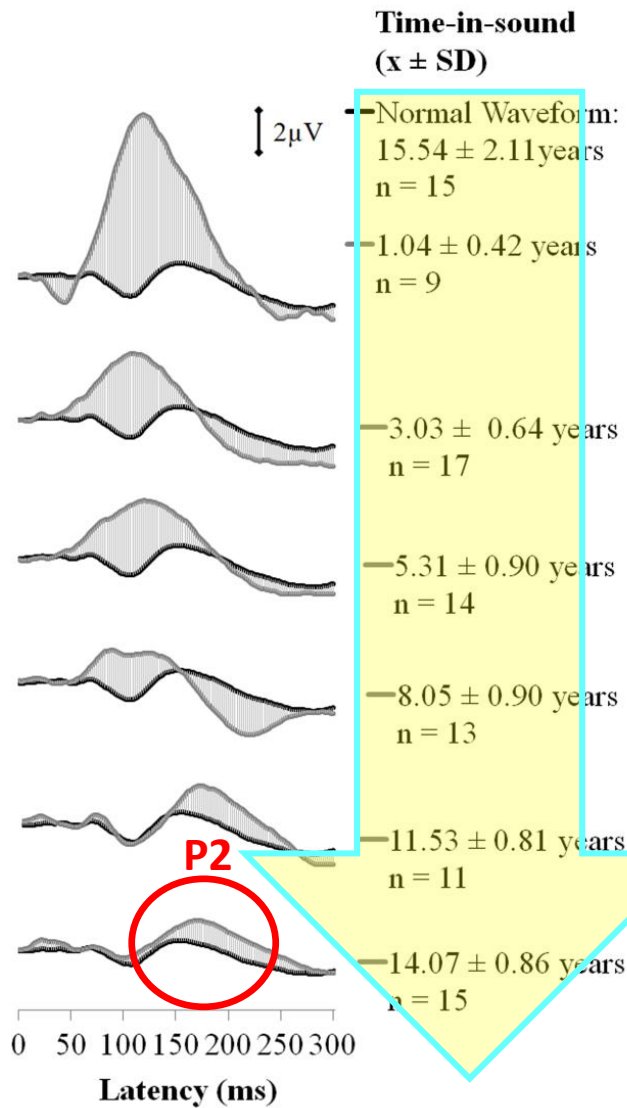


Hopyan et al. *Child Neuropsychology* (2009) / Tremblay et al. *Clinical Neurophysiology* (2009)

Processing = Effort

Binaural fusion & listening effort





Jiwani et al. *Clinical Neurophysiology* (2013)

Gordon et al. *Frontiers in Auditory Cognitive Neuroscience* (2013)

Conclusion

- conventional auditory image **fusion** does not occur
 - absent timing cues
 - disparate time of arrival
- **effort** required for sensory assembly
 - pseudo fusion
 - time
 - cognitive resource



Understanding Audition

- the “auditory system” makes full use of sensory data
- novel methods of data processing are employed.....
- ...precisely because assembling correctly promotes facultative evolution

