Update on Asymmetric and Unilateral Hearing Loss Studies: Current Results and Future Considerations

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Disclosures

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  - Employed by WUSM—salary
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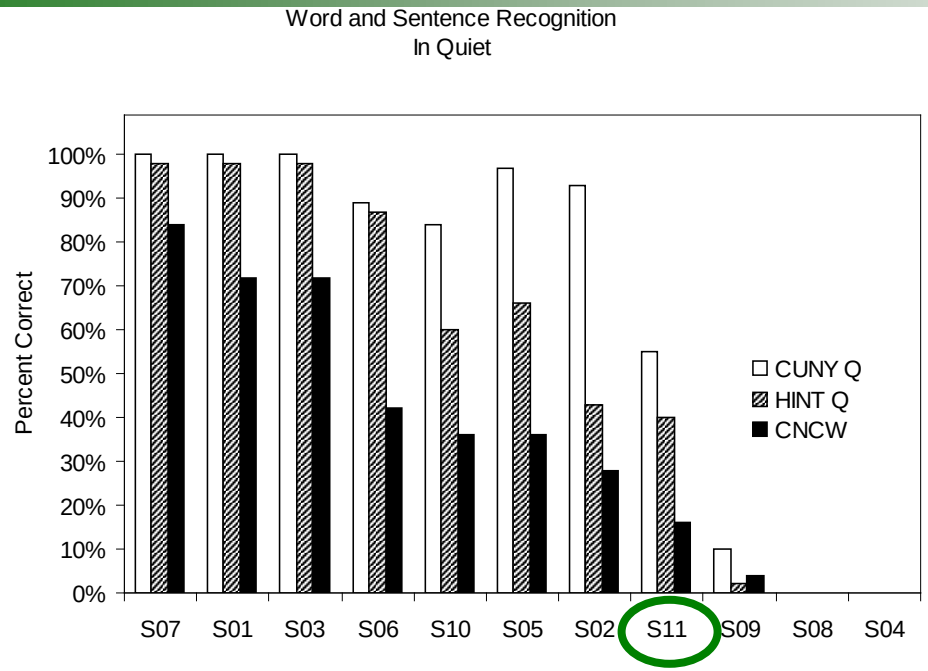
- Nonfinancial:
  - Serve as treasurer for the American CI Alliance (ACIA)

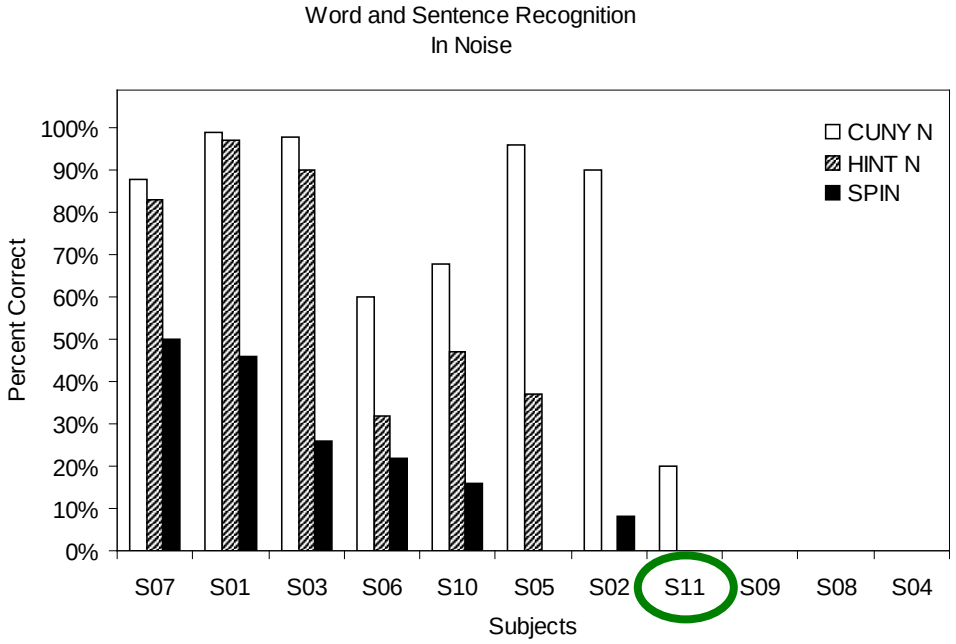
Overview of Presentation

- Case Study
- Unilateral Hearing Loss (UHL) (No CI)
- Effects of UHL/AHL from listener perspective
- Asymmetric Hearing Loss (AHL) (With CI)
- Primary focus today: Speech recognition in noise and Localization
- Variables: Length of deafness & Age at onset

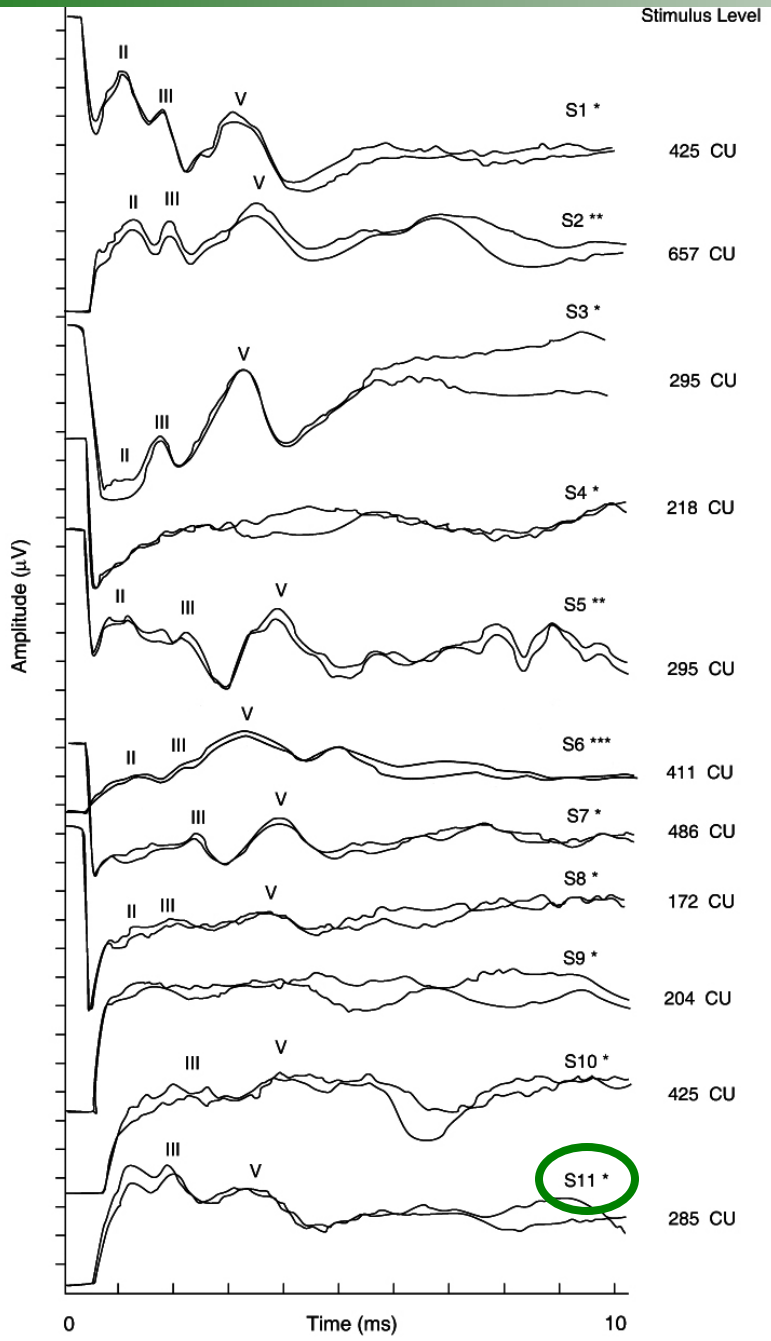
Individual Subject (S11)

- Hearing history
  - Mumps age 7 yrs, profound HL (LE)
  - Acoustic neuroma age 47, profound HL (RE)
  - 1 mo later, CI in LE, the ear without direct peripheral stimulation for 40 years



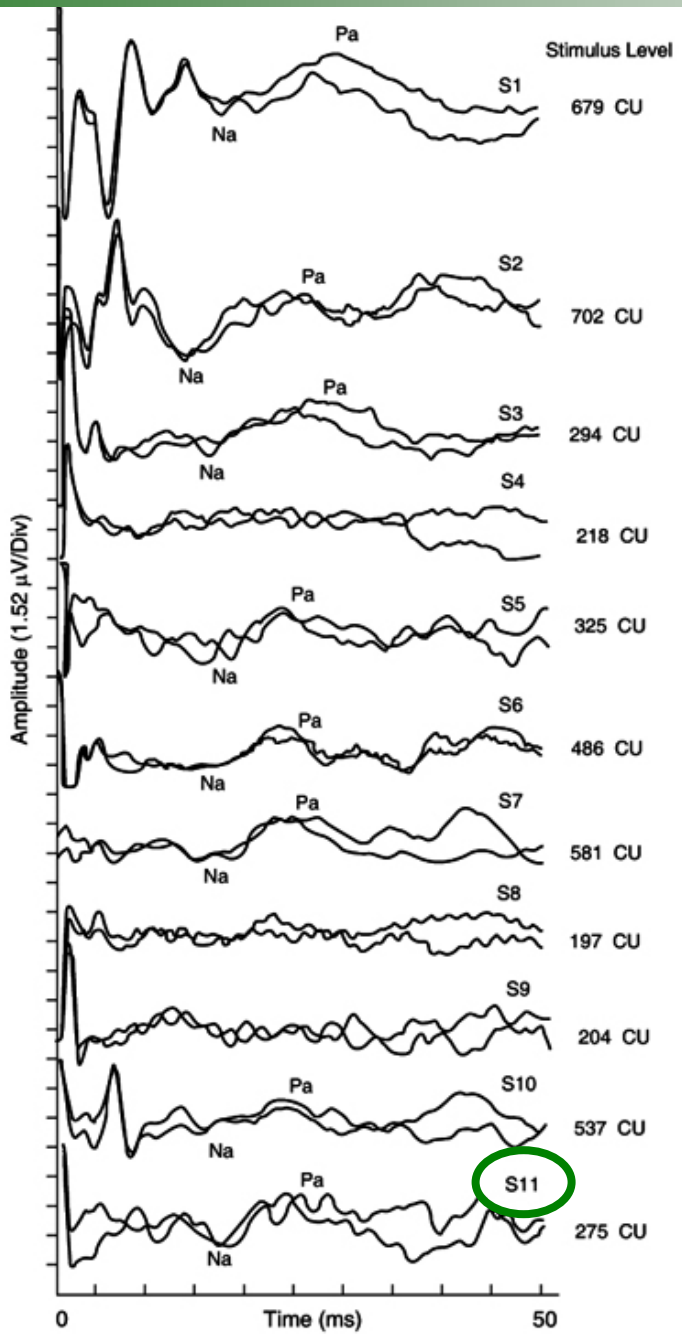


Firszt et al, 2002



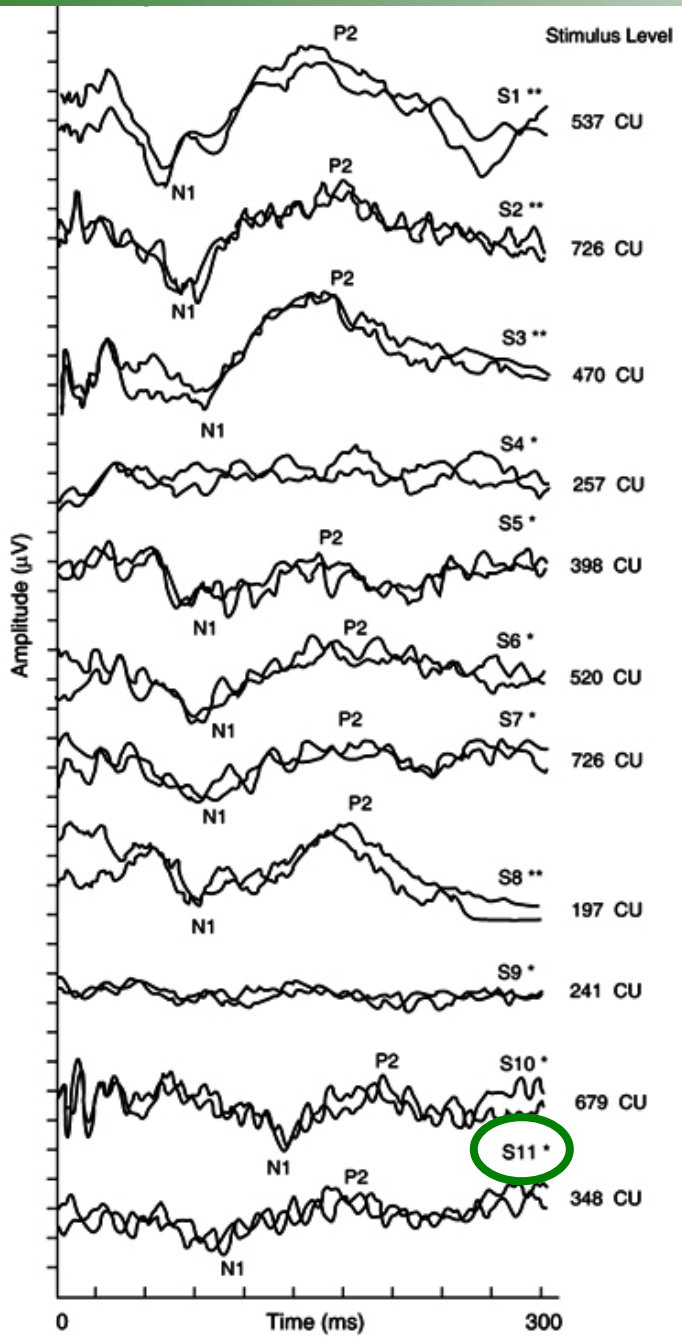
EABR
El #1
100% of DR
All subjects

Firszt et al, 2002



EMLR
El #1
100% of DR
All subjects

Firszt et al, 2002



El N1-P2
El #1
100% of DR
All subjects

Firszt et al, 2002

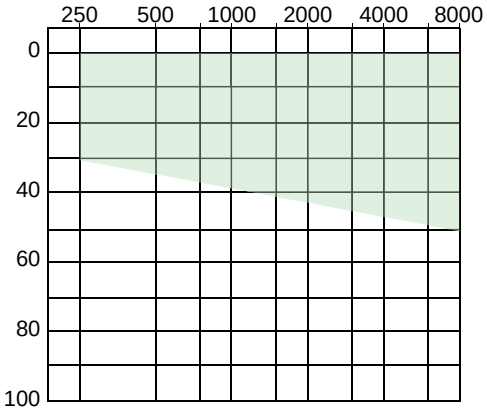
Individual Subject (S11)

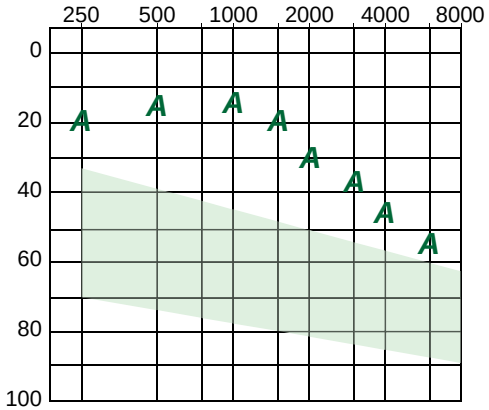
- Did having sound in one ear help to maintain the opposite poor ear for a good outcome?
- Was having hearing in both ears until age 7 and establishing binaural pathways the main reason?

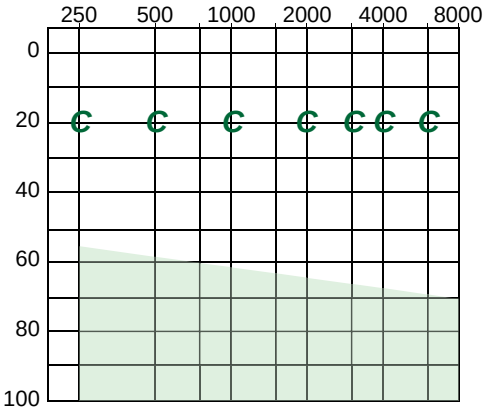
Studies underway at WUSM/SLCH

We are studying several patient populations with varied asymmetry between ears

- All have one deaf ear, rely on one better ear
- All are unilateral listeners







Better Ear	Normal or Near-normal hearing	Some hearing loss Uses amplification	Uses Cochlear implant
Poor Ear	Severe to profound hearing loss	Severe to profound hearing loss	Severe to profound hearing loss

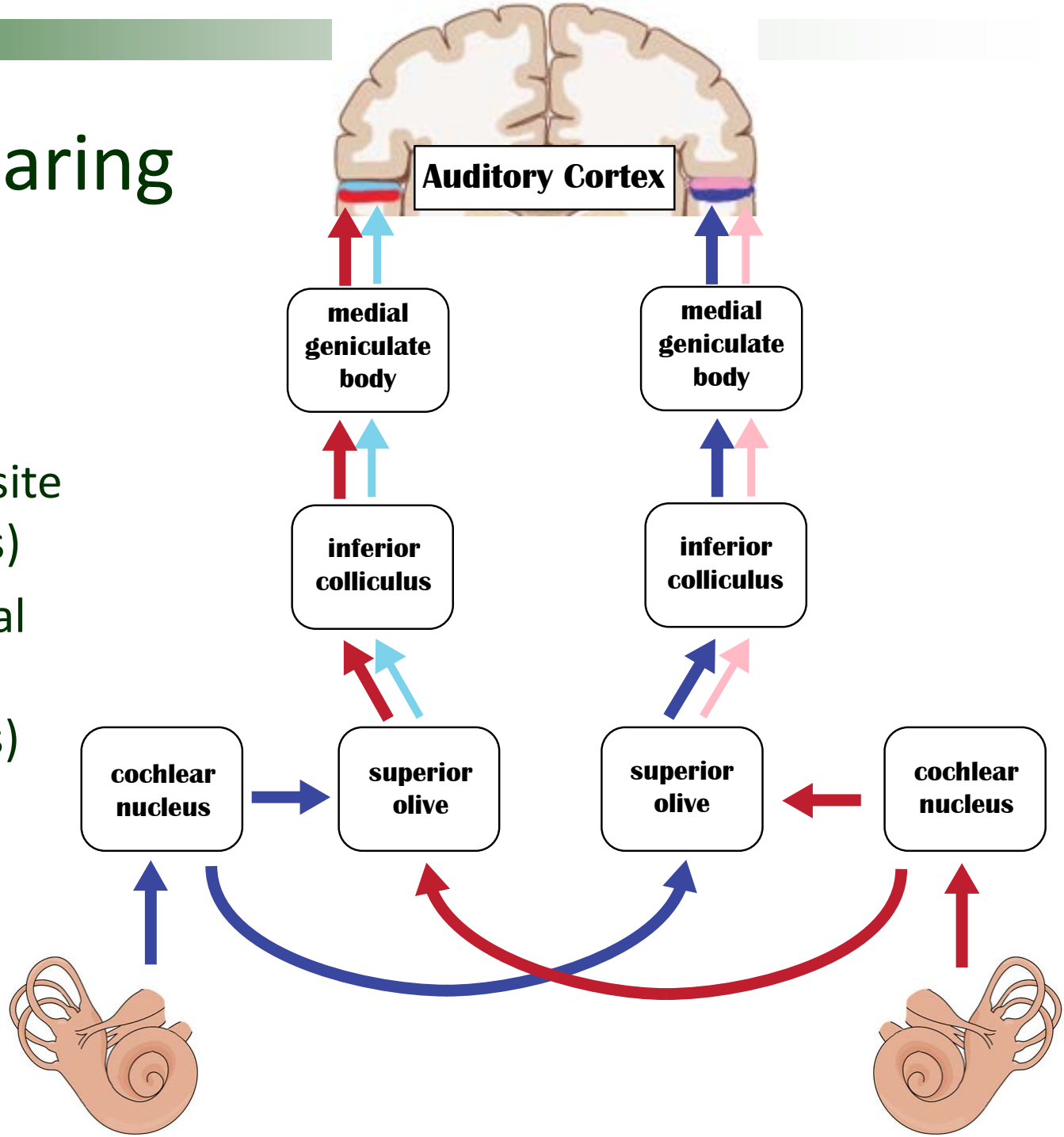
We Hear with Our Brain, Not Just Our Ears

- Contrast of
  - Bilateral normal hearing
  - Bilateral hearing loss
  - Asymmetric hearing loss

Normal Hearing

Results in

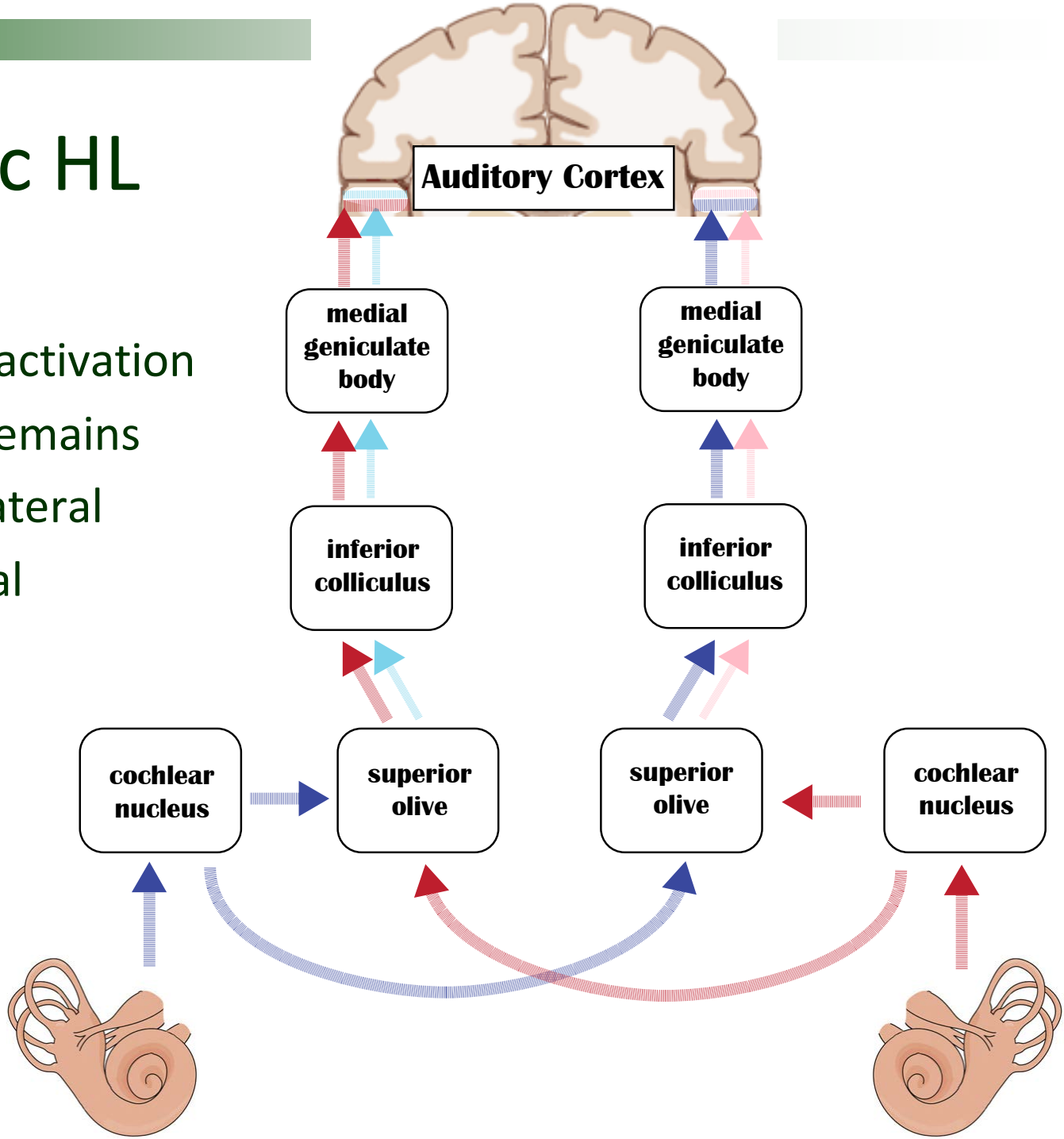
- Stronger contralateral activation (opposite side) (dark colors)
- Weaker ipsilateral activation (same side) (light colors)



Symmetric HL

Results in

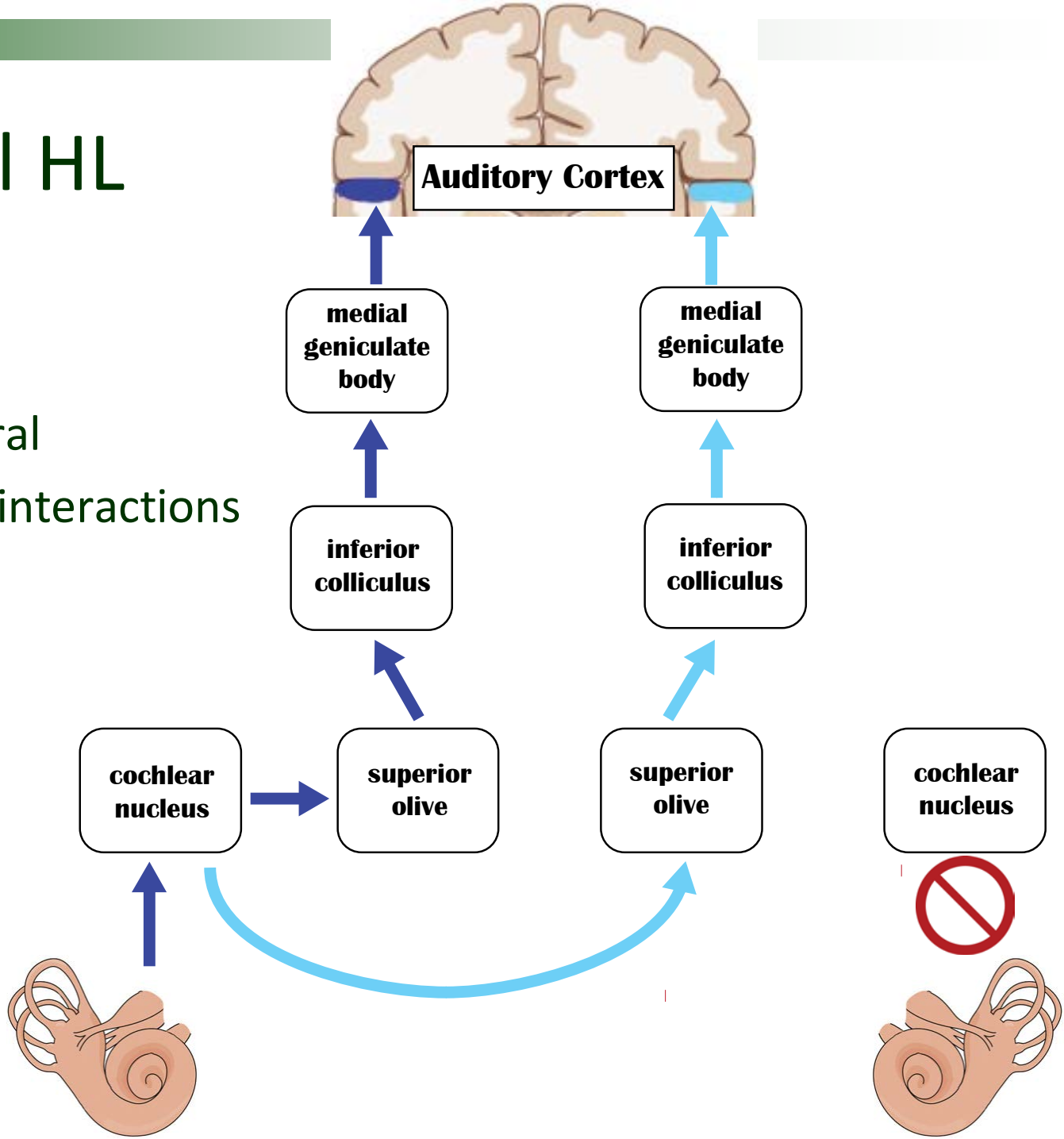
- Reduced overall activation
- Similar balance remains
  - Stronger contralateral
  - Weaker ipsilateral



Unilateral HL

Results in

- Loss of balance
- Stronger ipsilateral
- Altered binaural interactions
- Creates aural dominance



UHL Adults

Unilateral Hearing Loss (UHL) Study in Adults

Purpose:

- Quantify auditory deficits in adults with UHL
  - Need to quantify when considering treatment
- Identify sources of variability in outcomes
- Compare results with NH bilateral listeners
- Compare results with NH unilateral listeners
  - Introduce the condition of UHL acutely

Firszt JB, Reeder RM, Holden LK. Unilateral hearing loss: Understanding speech recognition and localization variability - implications for cochlear implant candidacy. Ear Hear, 2017, 38:159-173.

UHL Study – Demographics

Mean (SD) Range	Age (years)	*PTA (dB HL) from .25-8 kHz (tested ears)*	*PTA (dB HL) from .25-8 kHz in deaf ear*	Age Onset SPHL (years)	Length of Deafness (years)
UHL (n=26)	49.1 (12.9) 25 - 71	13.2 (7.1) 0.0 – 29.3	110.2 (10.5) 78.3 – 121.3+	27.3 (22.7) 0 - 61	21.9 (21.8) <1 - 72
NH - Plugged (n=25)	48.8 (13.7) 22 - 71	11.8 (11.8) 3.0 – 23.1	NA	NA	NA
NH - Bilateral (n=23)	49.7 (11.6) 22 - 67	12.2 (12.2) 2.5 – 26.1	NA	NA	NA

Firszt et al, 2017

UHL Study

Test Protocol addressed two known deficits

- Listening in noise
- Localization

HINT Sentences in Restaurant Noise R-Space™

- 8 loudspeakers surround the listener
- Sentences--front
- Restaurant noise from all loudspeakers
- Adaptive measure: Noise at 60 dB SPL, speech level is varied
- Participants repeat the sentence
- SNR-50 score (SNR for 50% correct)

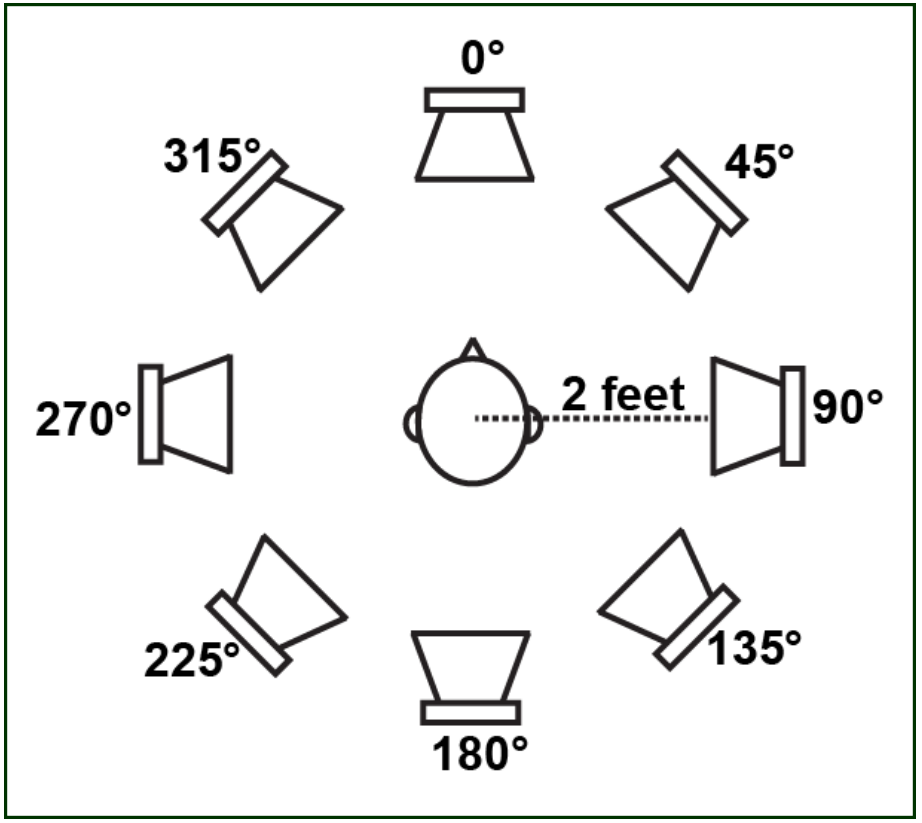
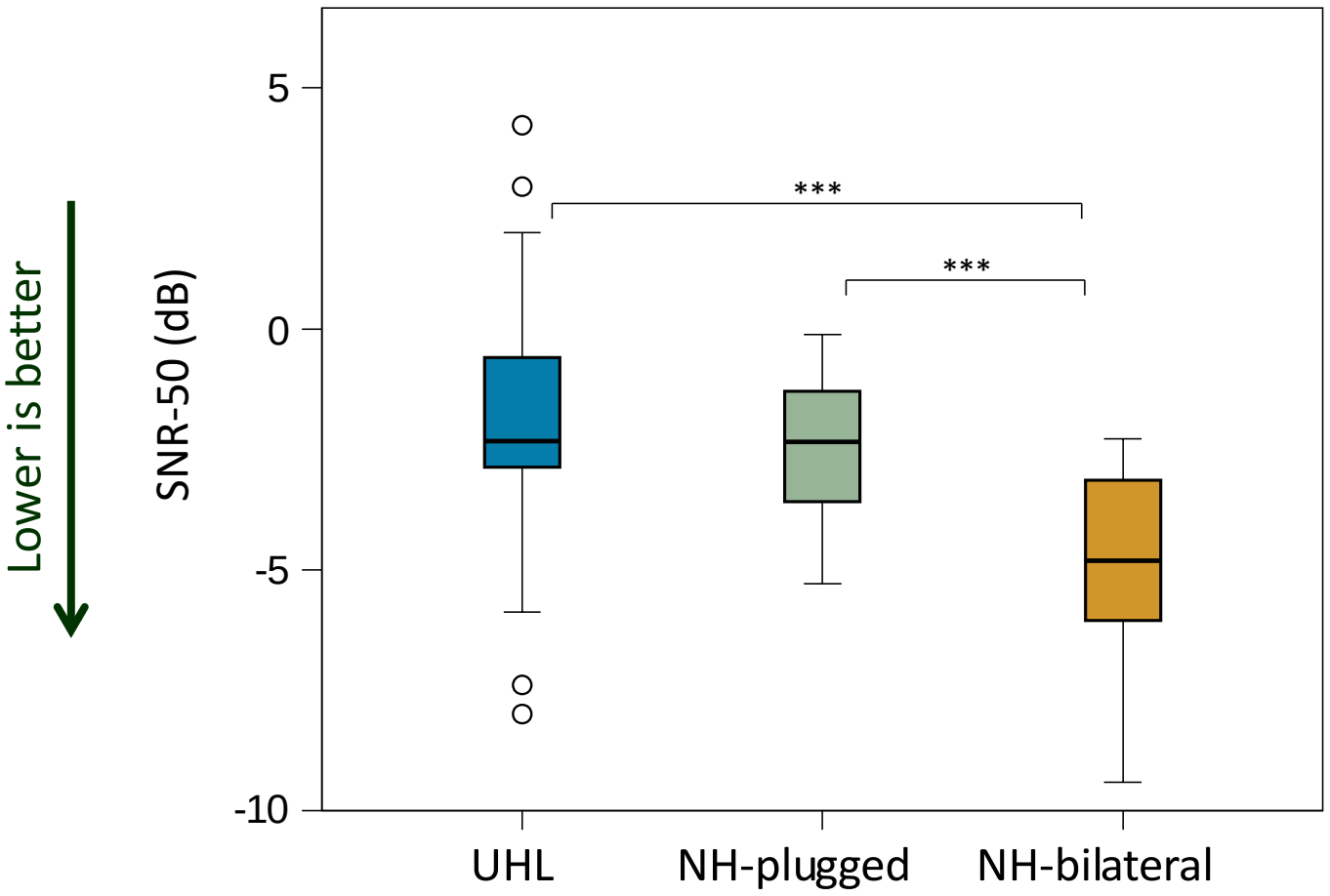


Illustration from Revit et al, 2002

HINT Sentences in R-Space™



NH significantly better; no difference in Unilateral groups

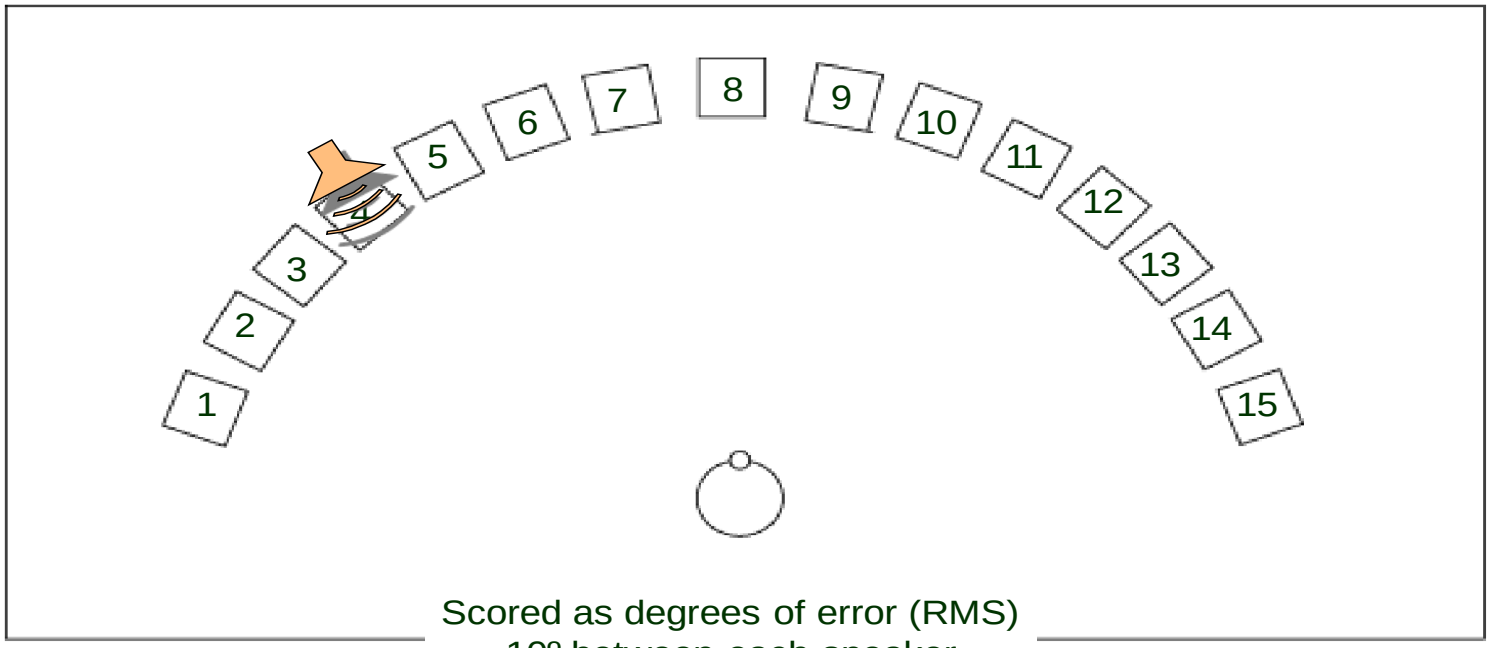
Firszt et al, 2017

Localization Methods

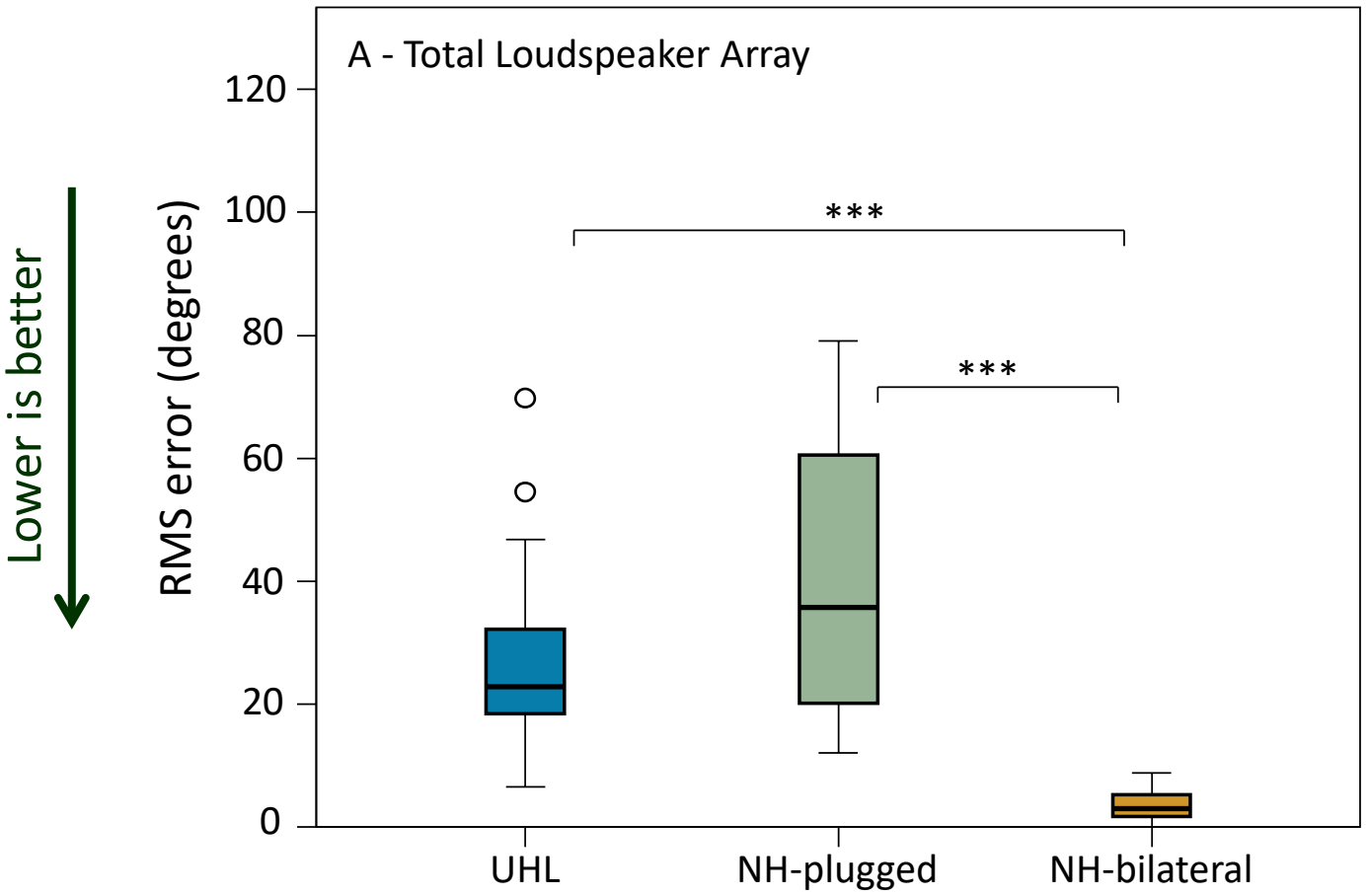
- CNC words (100) presented randomly via loudspeaker array
- 15 speakers; 10 active, 5 inactive
- 140 degree arc, speakers 10 degrees apart
- Roved at 60 dB SPL (+/- 3 dB)
- Asked to identify speaker location

Localization Methods

- Identify loudspeaker location
- Localization ability was scored as degrees of error (RMS) between source loudspeaker and participant response (0°= perfect localization)



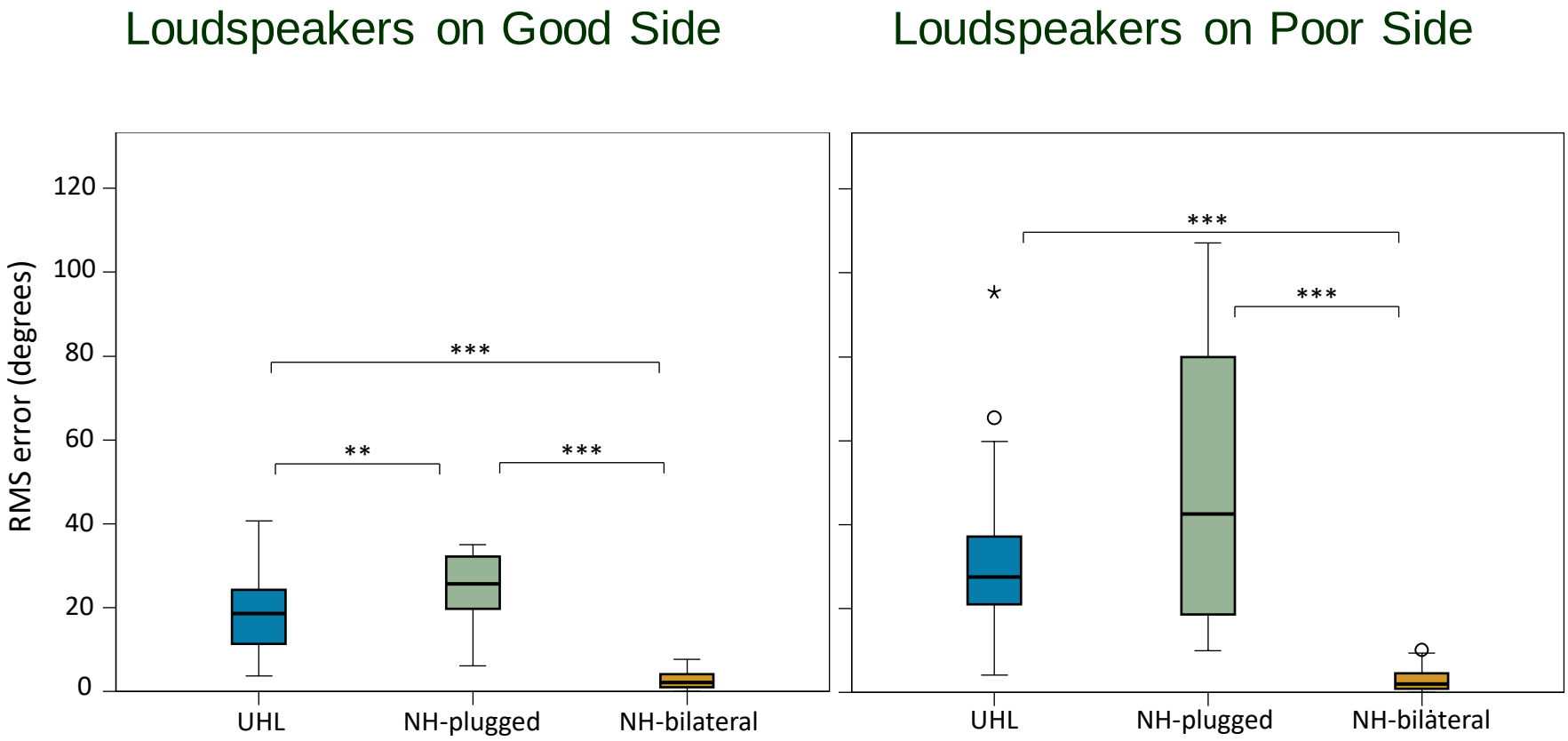
Localization



NH significantly better; Unilateral groups differ

Firszt et al, 2017

Localization Based on Side of Presentation



Firszt et al, 2017

Result

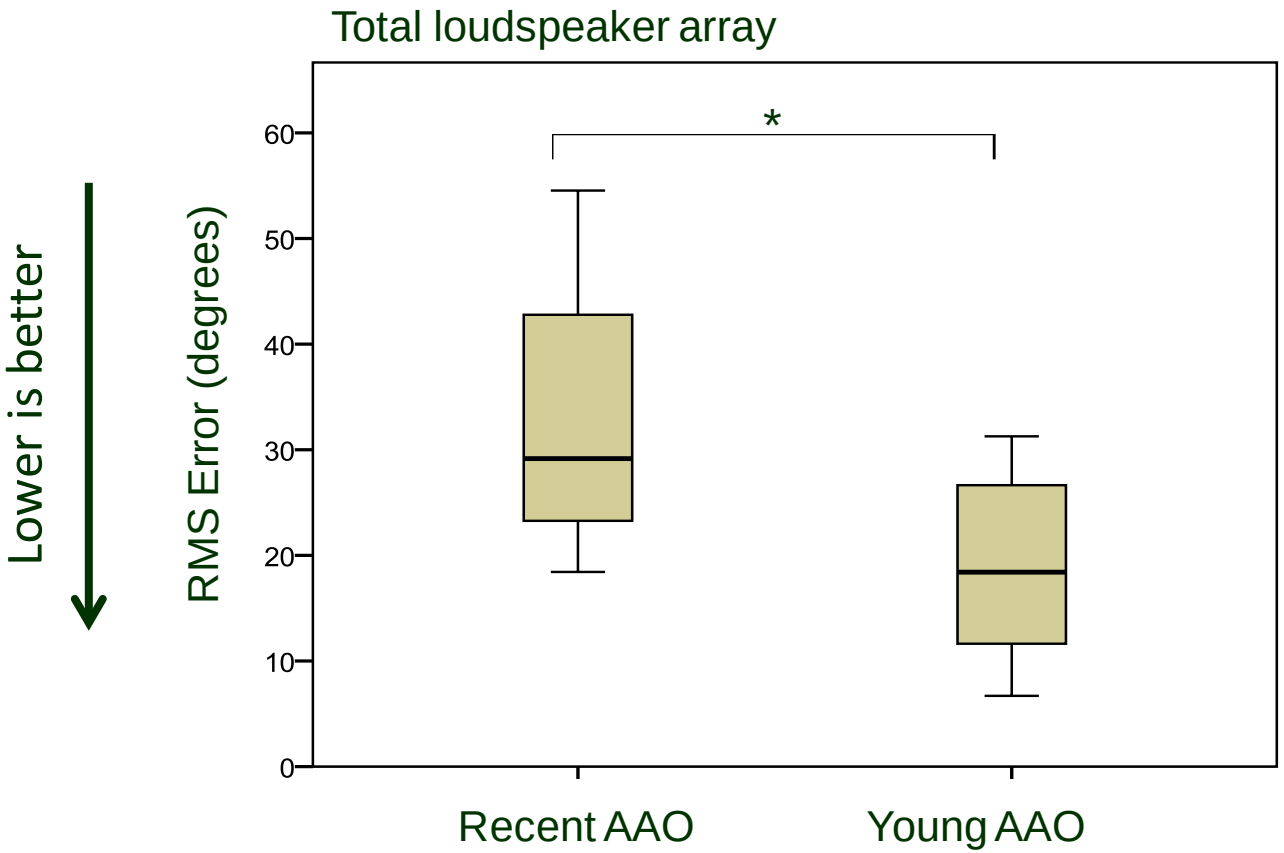
- NH considerably better than either unilateral group—need NH norms for all measures
- UHL affected localization differently than listening in noise
  - Localization better for UHL than NH-plugged
  - R space results show no differences between unilateral groups

Effects of Experience with UHL

Among the UHL participants:

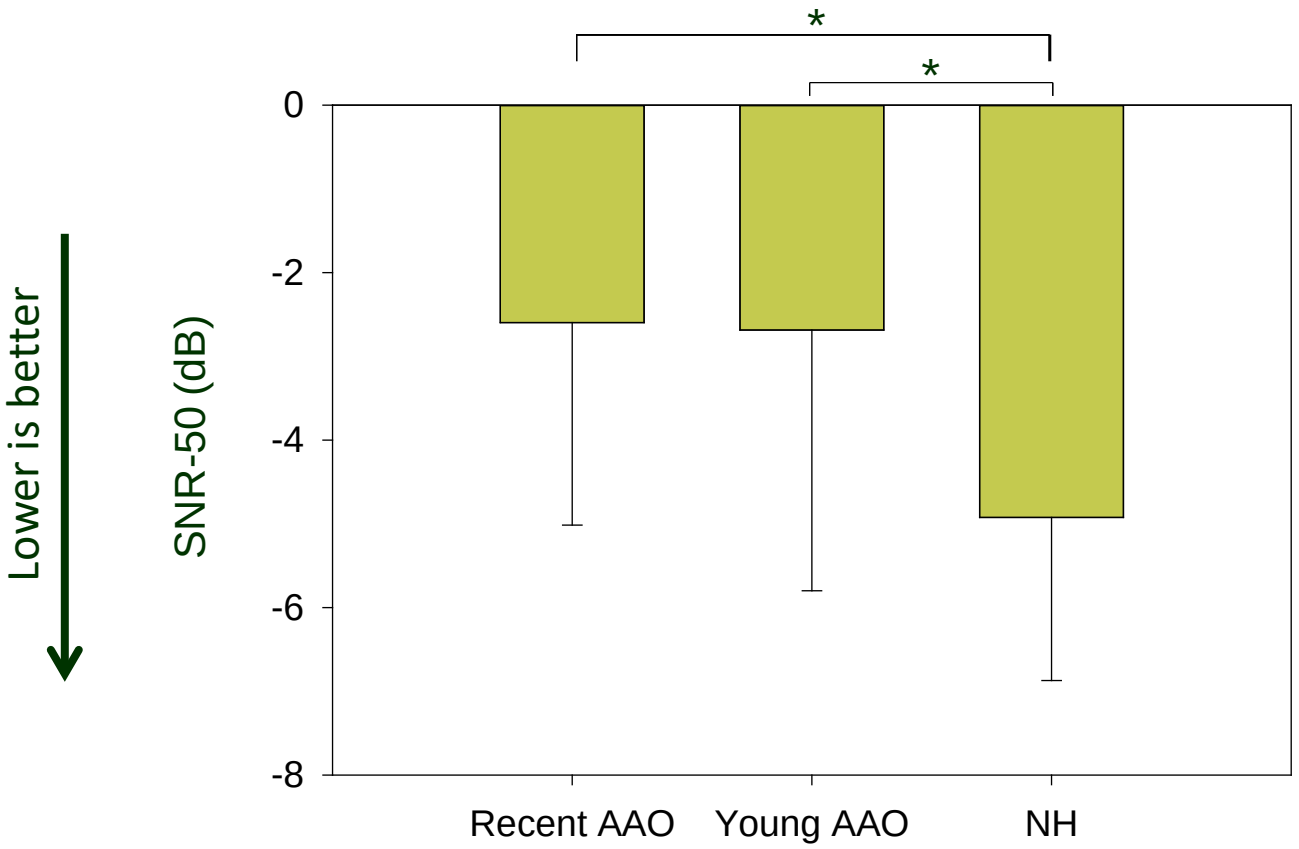
- 9 had recent onset of SPHL (onset within 3 yrs of study)
  - **Recent AAO**
- 8 had childhood onset of SPHL (onset by 3 yrs of age)
  - **Young AAO**

Localization by Age at Onset



Firszt et al, 2017

HINT Sentence in R-Space by Age at Onset



Firszt et al, 2017

Result

- Localization better for Young AAO versus Recent AAO
  - Those with early onset of SPHL in one ear appear to have learned strategies to improve localization but this did not transfer to speech understanding in noise

UHL Children

Introduction

- Aims of pediatric study:
  - Identify abilities of children with UHL on measures that address known deficits, and quantify deficits on these measures
  - Investigate sources of variability
  - Compare performance and variability to NH peers

Reeder RM, Cadieux J, Firszt JB. Quantification of speech-in-noise and sound localization abilities in children with unilateral hearing loss and comparison to normal hearing peers. Audiol Neurotol, 2015, 20:31-37.

UHL Children and NH Matches

Mean (Range)	Age at Test (years)	Unaided FF PTA (dB HL) Poorer Ear	Unaided FF PTA (dB HL) Better Ear	Age SPHL Onset (years)	Length of Deafness (years)
UHL (n = 20)	12.0 (6.9 – 16.3)	100.8 (61 – 120+)	6.6 (-2 – 20)	1.0 (0.0 – 7.9)	9.7 (0.3 – 15.3)

Mean (Range)	Age at Test (years)	Unaided FF PTA (dB HL) Right Ear	Unaided FF PTA (dB HL) Left Ear
NH (n = 20)	12.0 (7.5 – 17.8)	4.2 (0 - 17)	4.9 (-1 – 16)

Reeder et al, Audiol Neurotol, 2015

UHL Children and NH Matches

Mean (Range)	Age at Test (years)	Unaided FF PTA (dB HL) Poorer Ear	Unaided FF PTA (dB HL) Better Ear	Age SPHL Onset (years)	Length of Deafness (years)
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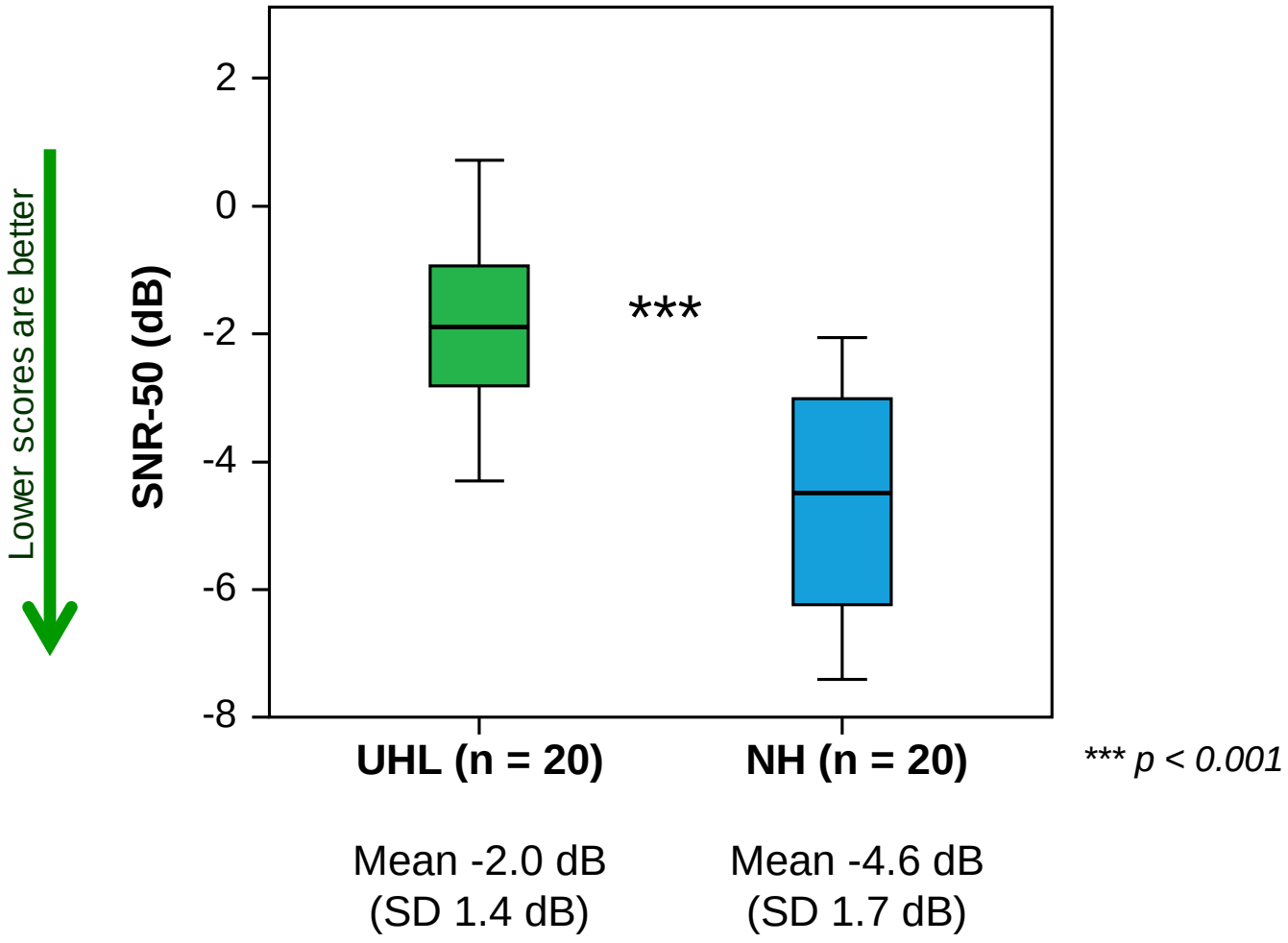
UHL (n = 11)	10.5 (6.9 – 13.4)	95.2 (61 – 120+)	5.9 (-2 – 20)	1.3 (0.0 – 7.9)	8.2 (0.3 – 12.1)

Mean (Range)	Age at Test (years)	Unaided FF PTA (dB HL) Right Ear	Unaided FF PTA (dB HL) Left Ear
NH (n = 20)	12.0 (7.5 – 17.8)	4.2 (0 - 17)	4.9 (-1 – 16)
NH (n = 10)	10.4 (7.5 – 15.5)	4.4 (0 – 17)	4.7 (-1 – 12)

Reeder et al, Audiol Neurotol, 2015

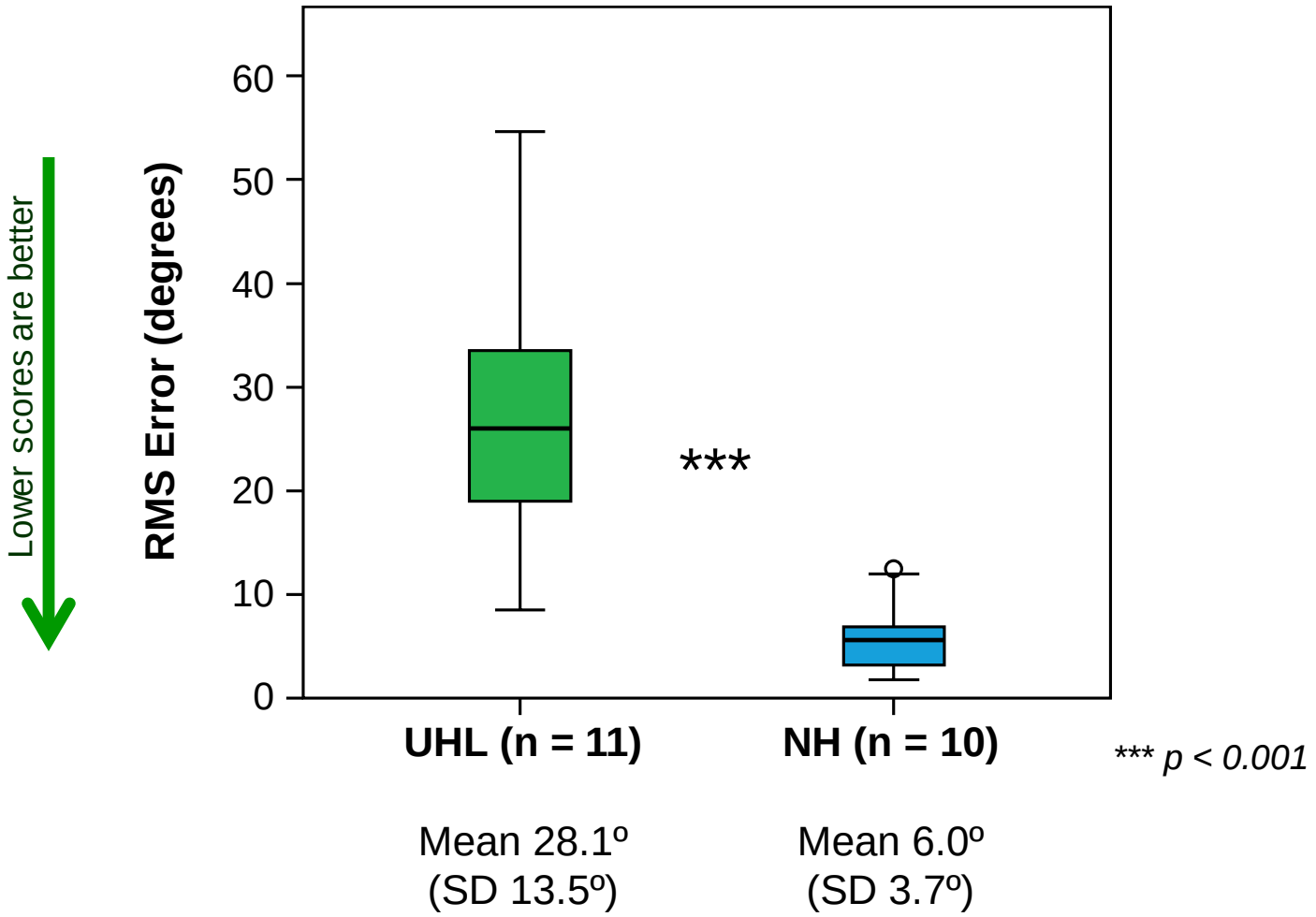
R-Space



Mean NH Adults = -5 dB

Reeder et al, Audiol Neurotol, 2015

Localization



Mean NH Adults = 3 degrees

Reeder et al, Audiol Neurotol, 2015

Result

- Results poorer for UHL than NH - most measures
- Considerable variability on all measures with UHL
  - Some UHL children had scores within the range of NH children
- Localization – older children performed better, had more experience. No relation to listening in noise

Listener Perspective

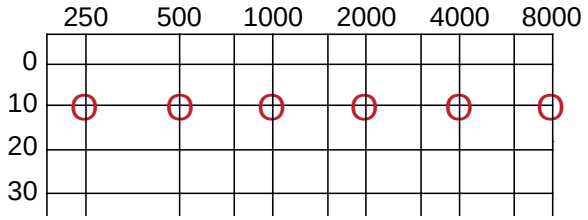
How do adults with asymmetric hearing perceive their hearing and communication abilities?

Dwyer NY, Firszt JB, Reeder RM. Effects of unilateral input and mode of hearing in the better ear: self-reported performance using the Speech, Spatial and Qualities of Hearing Scale. Ear Hear, 2014, 35:126-136.

Participants

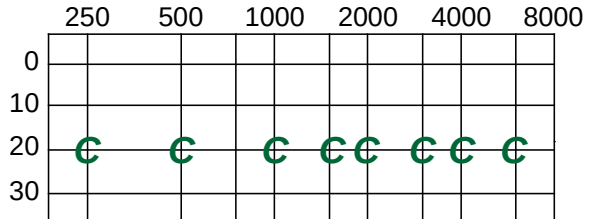
UHL group (n=30) **One deaf ear**

- Mean PTA 13 dB HL (0 - 27 dB HL)
- Mean age 51 yrs (25 - 76 yrs)



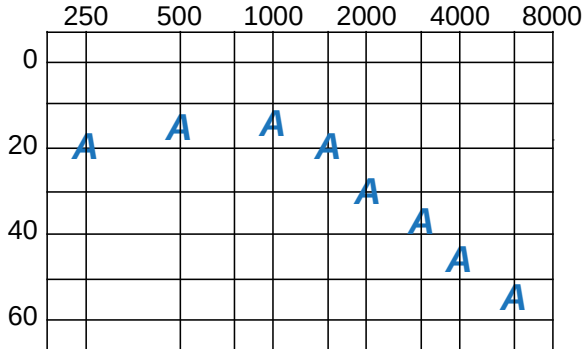
CI group (n=20) **One deaf ear**

- Mean PTA 20 dB HL w/CI (13 - 33 dB HL)
- Mean age 53 yrs (33 - 75 yrs)



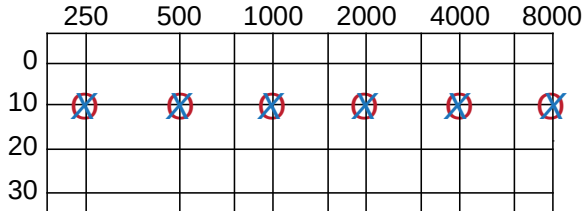
HA group (n=16) **One deaf ear**

- Mean PTA 40 dB HL w/HA (29 - 52 dB HL)
- Mean age 60 yrs (26 - 77 yrs)



NH group (n=21)

- Mean bilat PTA 10 dB HL (4 - 23 dB HL)
- Mean age 50 yrs (27 - 73 yrs)



Speech, Spatial and Qualities of Hearing Scale (SSQ)

- 49-item questionnaire designed to evaluate the effects of hearing loss in terms of function
- Uses a 10-point scale (0-10), where “0” indicates great difficulty and “10” indicates no difficulty
- Questions divided into 3 Domains: Speech, Spatial, and Qualities, or divided into 10 Subscales

(Gatehouse and Noble 2004)

Ten Subscale Analysis

Gatehouse and Akeroyd (2006)

SiQ = speech in quiet

SiN = speech in noise

SiSCont = speech in speech contexts

MultStream = multiple speech stream processing/switching

Speech Domain

Loc = localization

DisMov = distance and movement

Spatial Domain

SegSnds = segregation of sounds

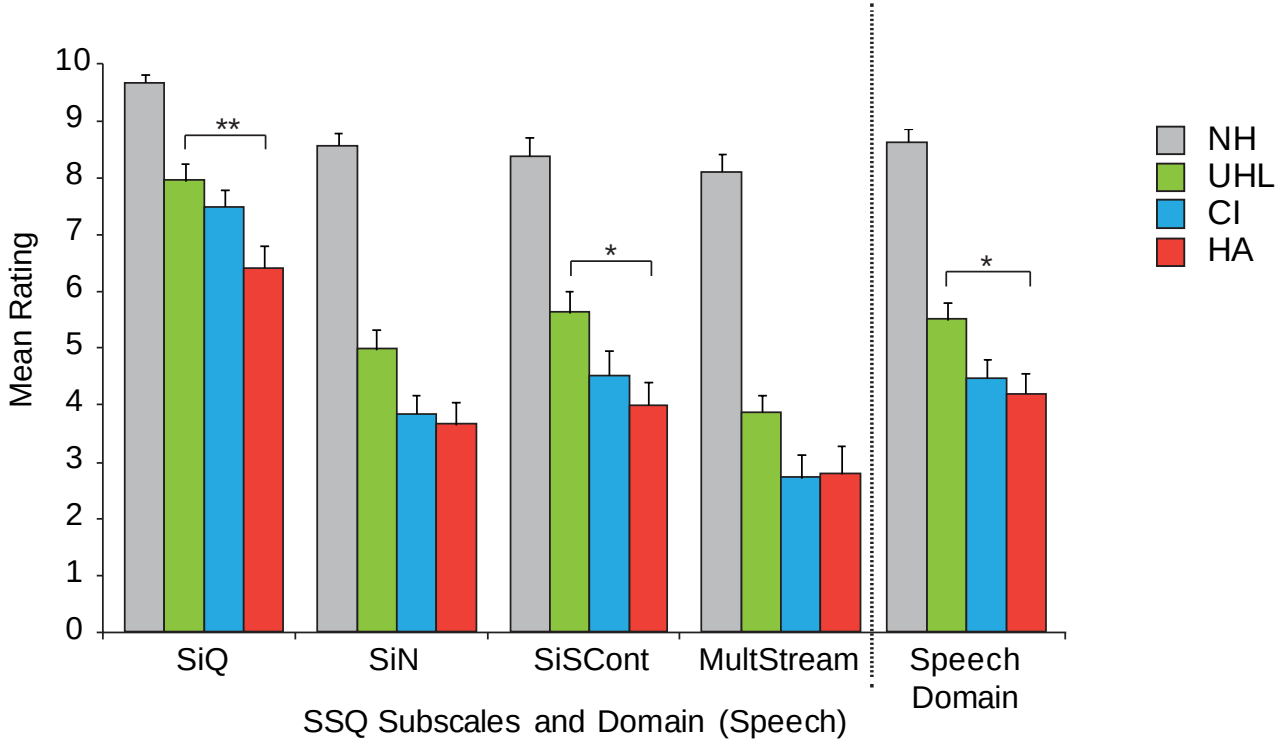
IdSnd = identification of sound and objects

Qlty = sound quality and naturalness

Eff = listening effort

Qualities Domain

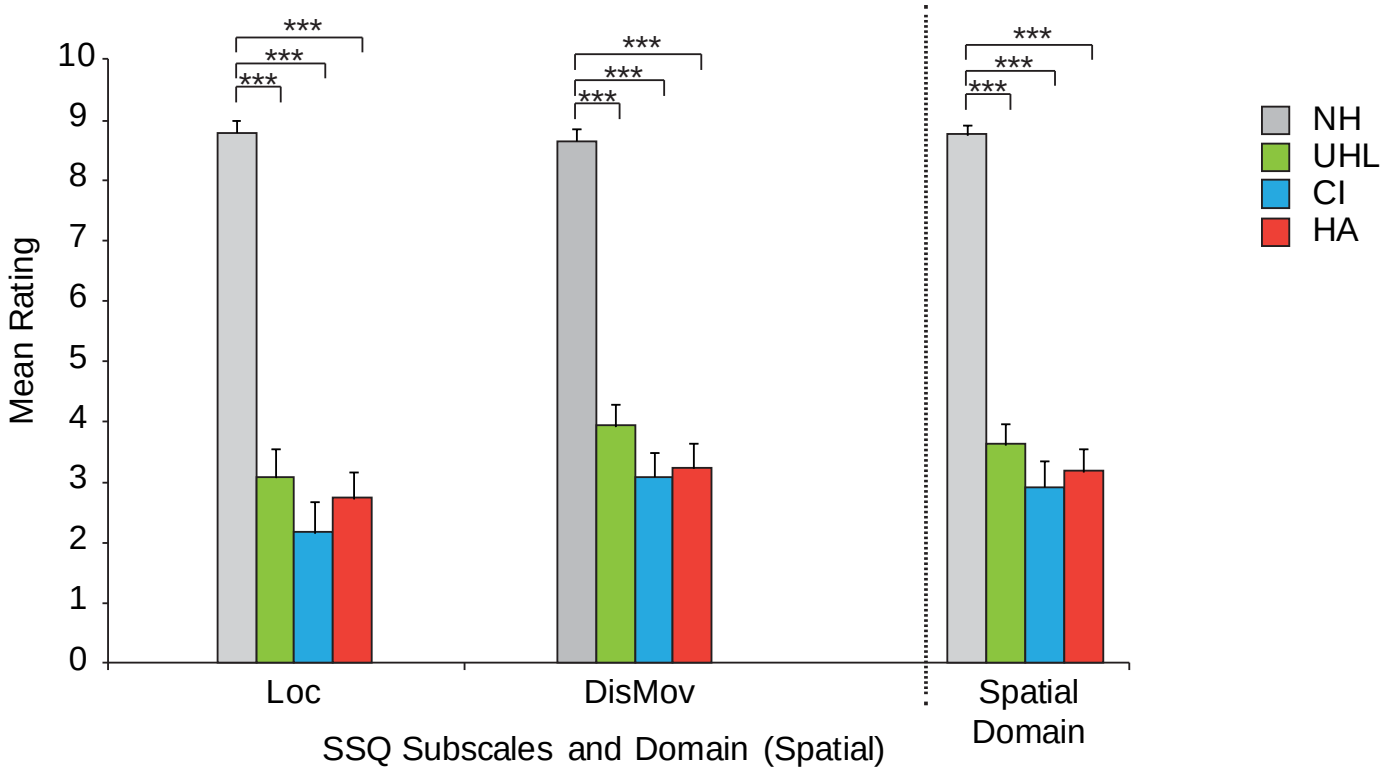
Results – Speech



** p < 0.05, ** p < 0.01, *** p < 0.001*

Dwyer et al, Ear Hear, 2014

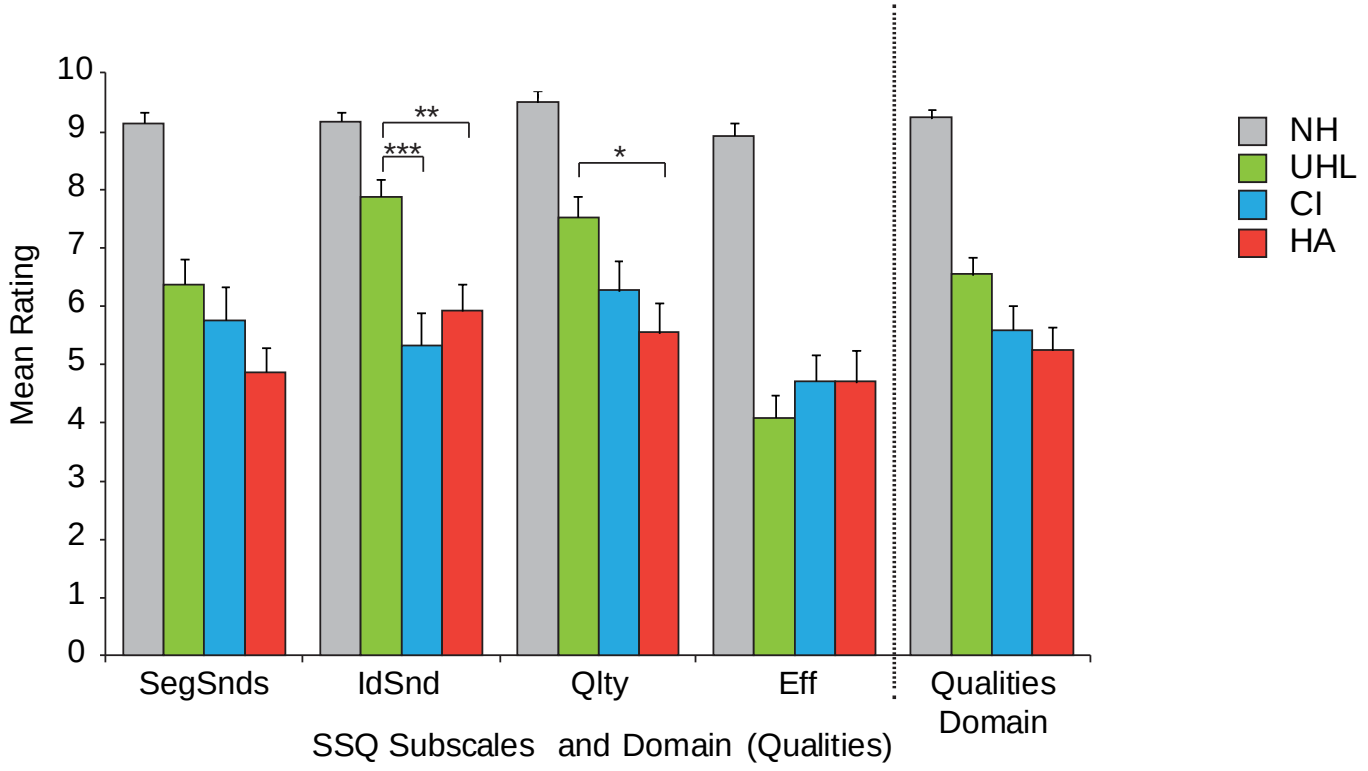
Results – Spatial Hearing



** p < 0.05, ** p < 0.01, *** p < 0.001*

Dwyer et al, Ear Hear, 2014

Results – Qualities of Hearing



** p < 0.05, ** p < 0.01, *** p < 0.001*

Dwyer et al, Ear Hear, 2014

Result

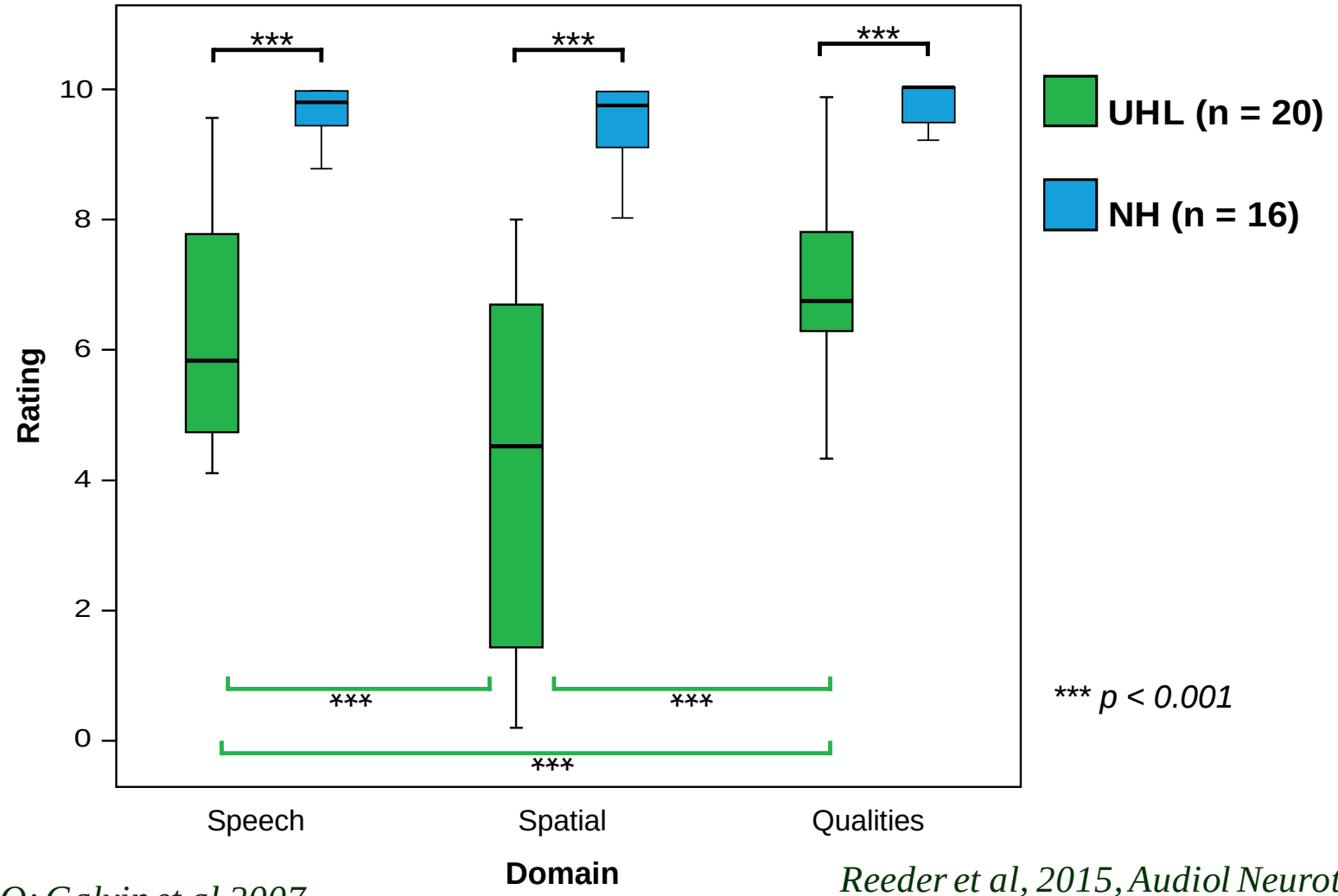
- The 3 groups with one deaf ear, did not differ in their perceived hearing disability for 6 of 10 subscales
- In other words, NH in only one ear was as disabling as listening with a unilateral CI or a unilateral HA
- Adults reliant on a single ear, irrespective of the mode of hearing, report difficulties in many aspects of everyday listening and communication

Parent Perspective

How do parents rate the abilities of their children with UHL when listening in everyday situations?

Reeder et al, 2015, Audiol Neurotol

(Pediatric) Speech, Spatial, and Qualities of Hearing Scale (SSQ)



Pediatric SSQ: Galvin et al 2007

Reeder et al, 2015, Audiol Neurotol

Result

- Parents ratings for UHL significantly poorer than ratings of children with NH
- Among UHL, Qualities ratings highest (7.2), followed by Speech (6.2) and then Spatial (4.3)
  - Similar pattern to that of UHL Adults (Qualities 6.5, Speech 5.5, Spatial 3.6)
- Parents report their children have difficulties in real-world environments

Asymmetric Adults: Treatment with CIs

Adult Asymmetric Hearing Loss Study

- What is the relation between length of deafness & use of a hearing aid in the poorer ear and outcomes with a CI?
  - Speech Recognition in Quiet
  - Speech Recognition in Noise
  - Localization

Study in Adults with Asymmetric Hearing Loss

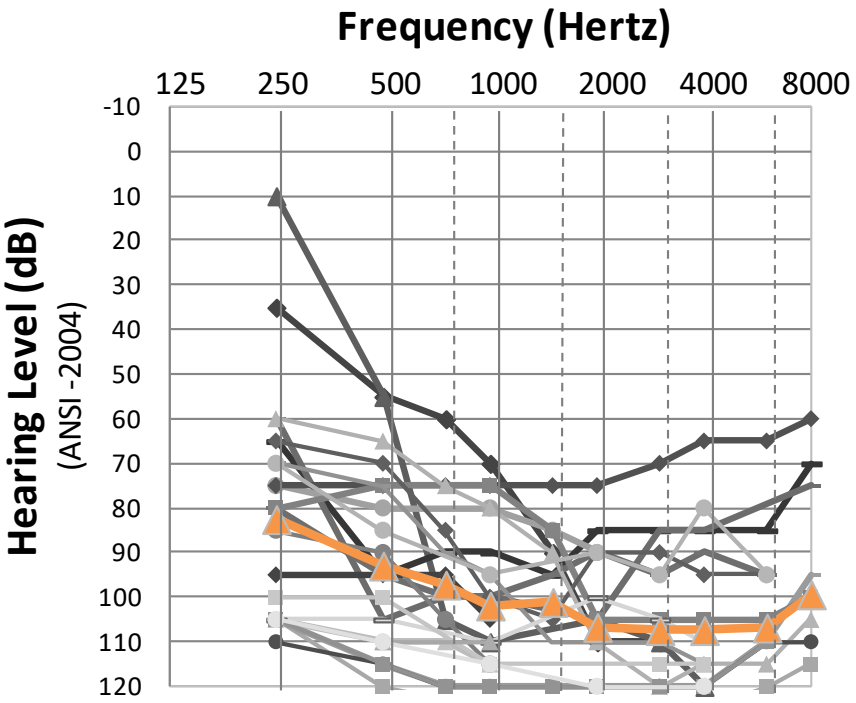
- All have:
- One poorer ear that meets CI criteria, the poorer ear is implanted
- One better ear that uses a hearing aid (HA)
- N = 24
  - 20 = Postlingual
  - 4 = Prelingual

Group Demographics
Postlingual Participants (n = 20)

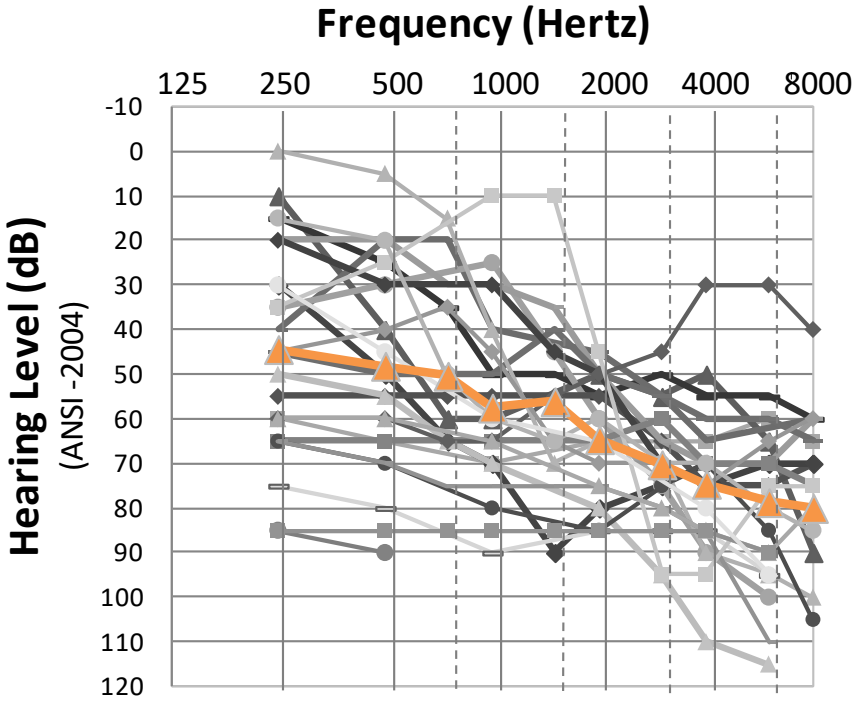
- HA use
  - Better ear -- All wore a HA
  - Poor ear
    - 11/20 had never worn a HA
    - 9/20 had worn a HA for some time
      - Only 3/9 were wearing a HA at the time of implantation

Unaided Hearing Thresholds

Poorer Hearing Ear

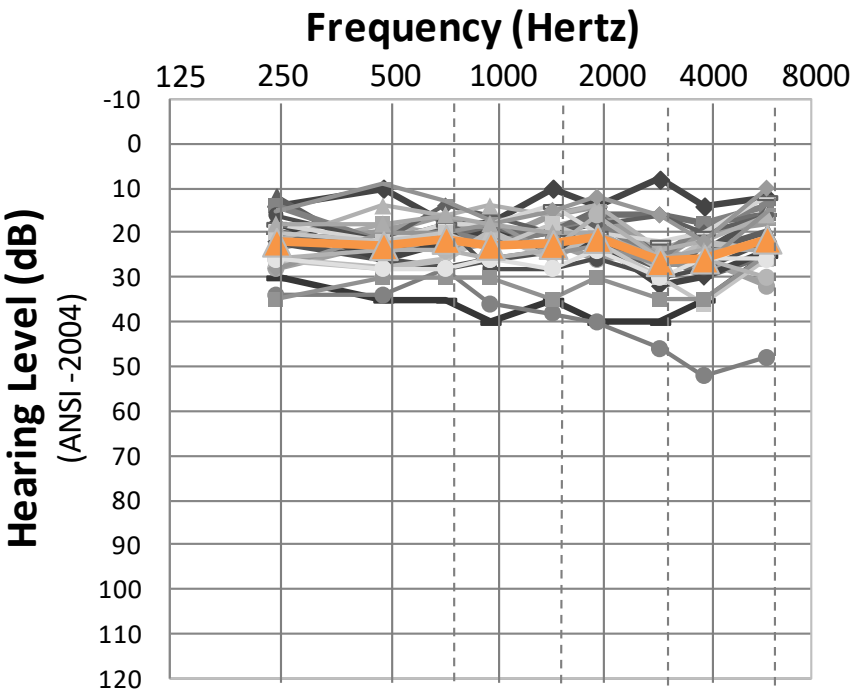


Better Hearing Ear

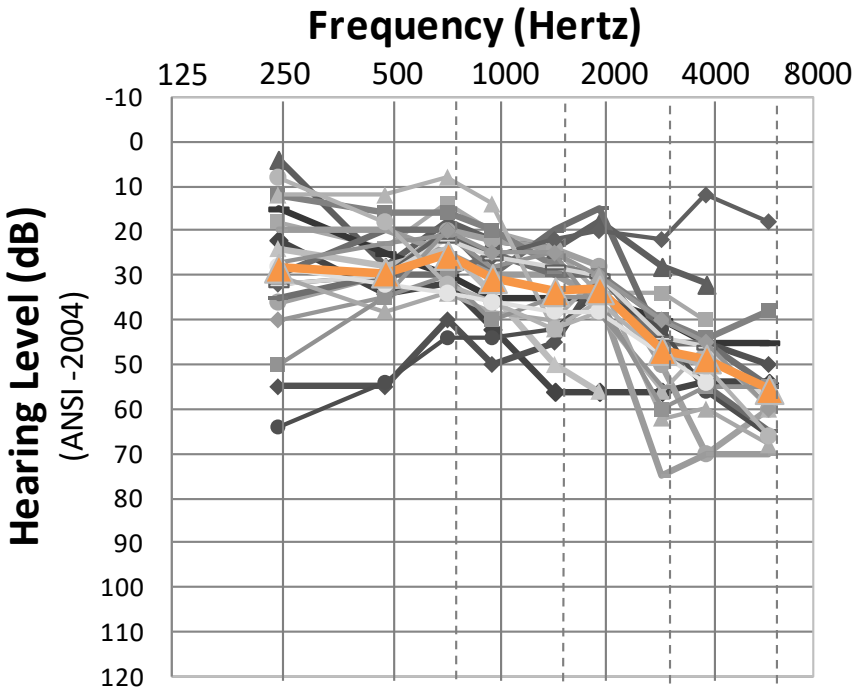


Implanted/Aided Sound-field Thresholds

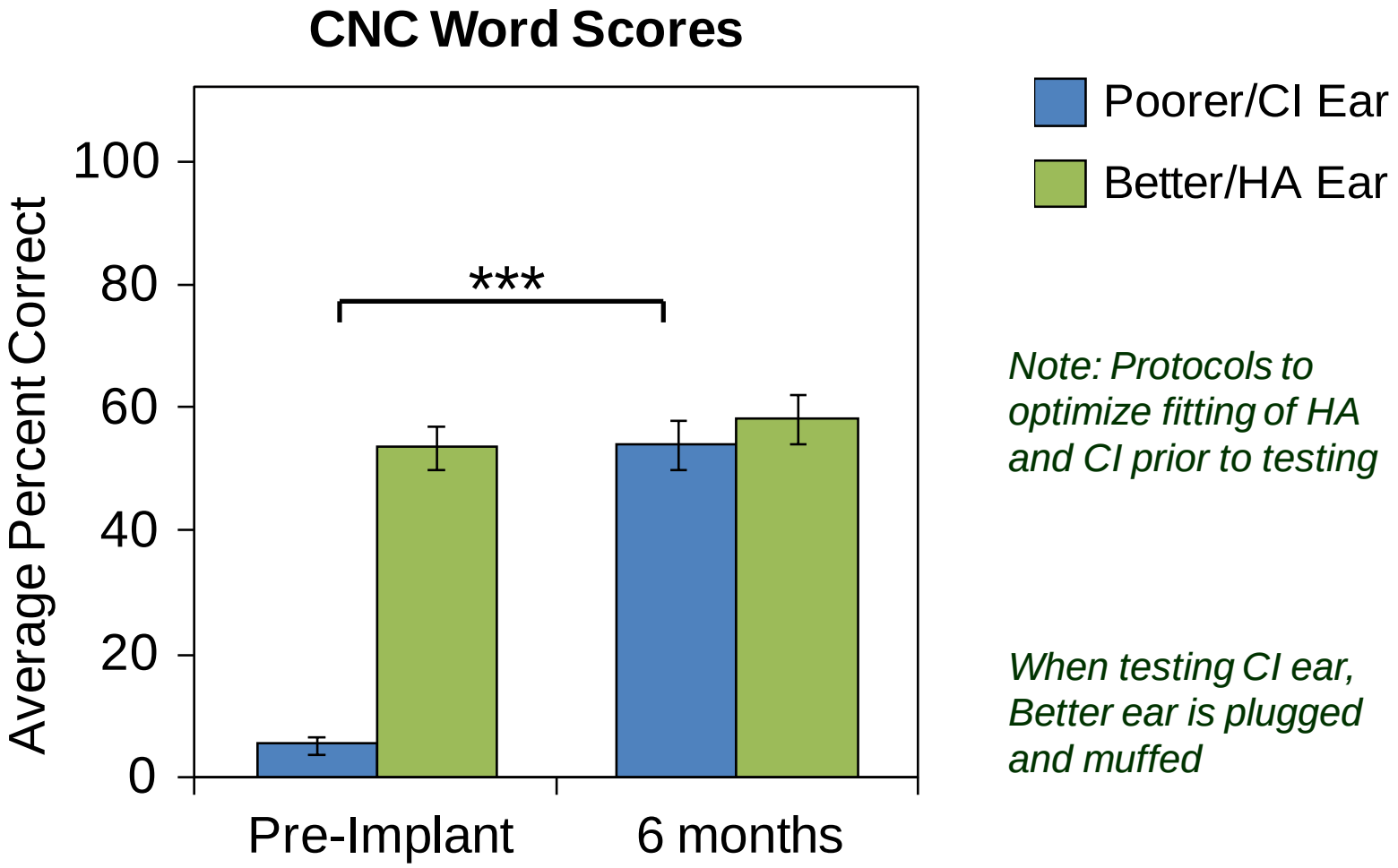
Poorer Hearing Ear CI SF Thresholds



Better Hearing Ear HA SF Thresholds



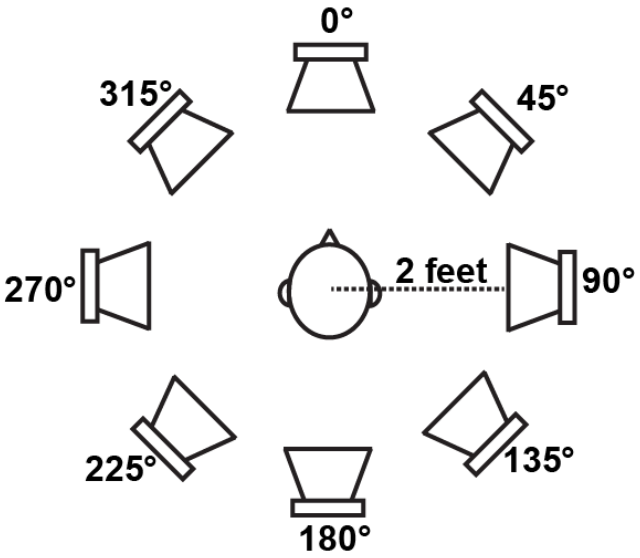
Speech Recognition-Postlingual (n=20)

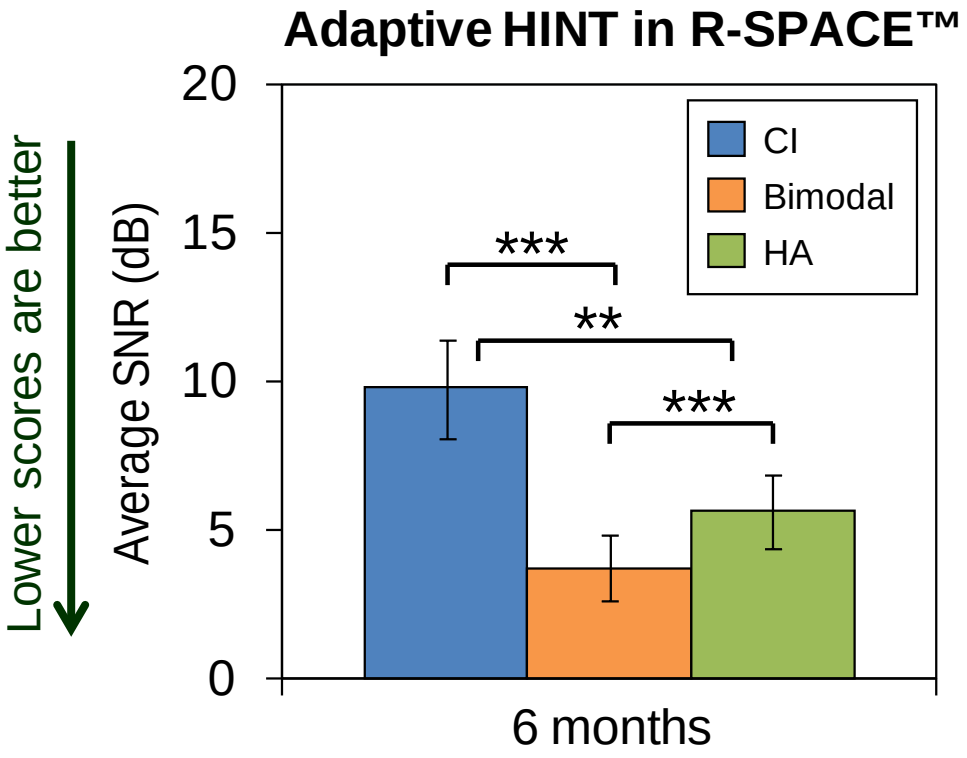


Note: Protocols to optimize fitting of HA and CI prior to testing

When testing CI ear, Better ear is plugged and muffed

Adaptive HINT in Restaurant Noise: R-Space (n=20)

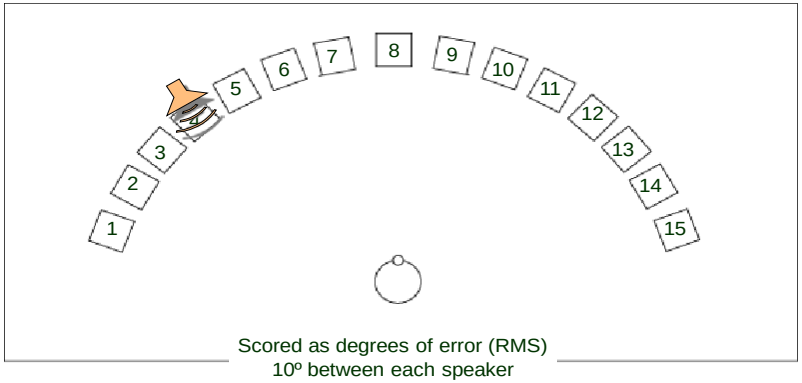




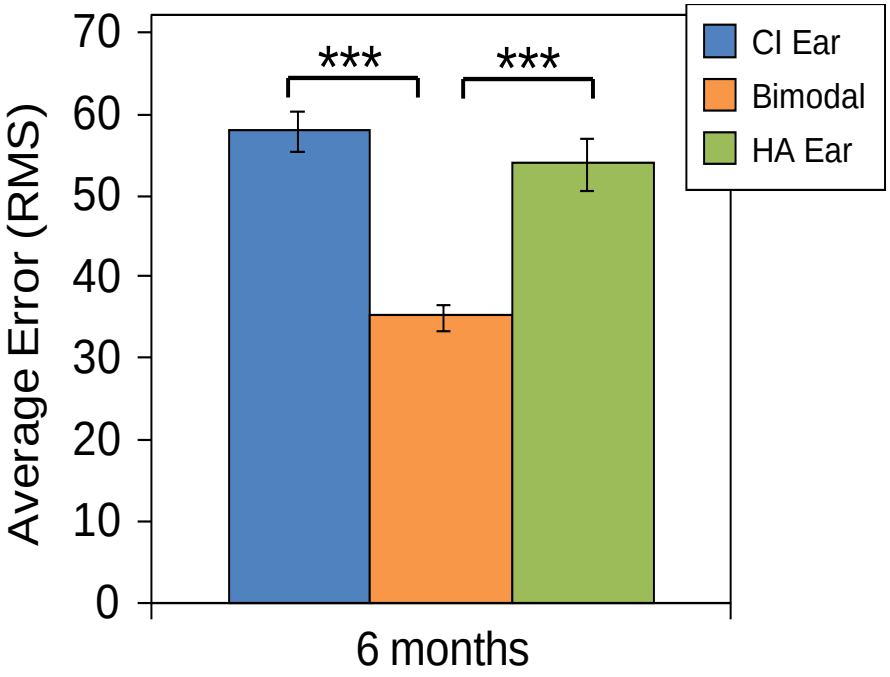
*Error bars = + 1 SEM; **p < 0.01; ***p < 0.001*

Mean NH Adults = -5 dB

Localization (n=20)



Lower scores are better



Mean NH Adults = 3 degrees

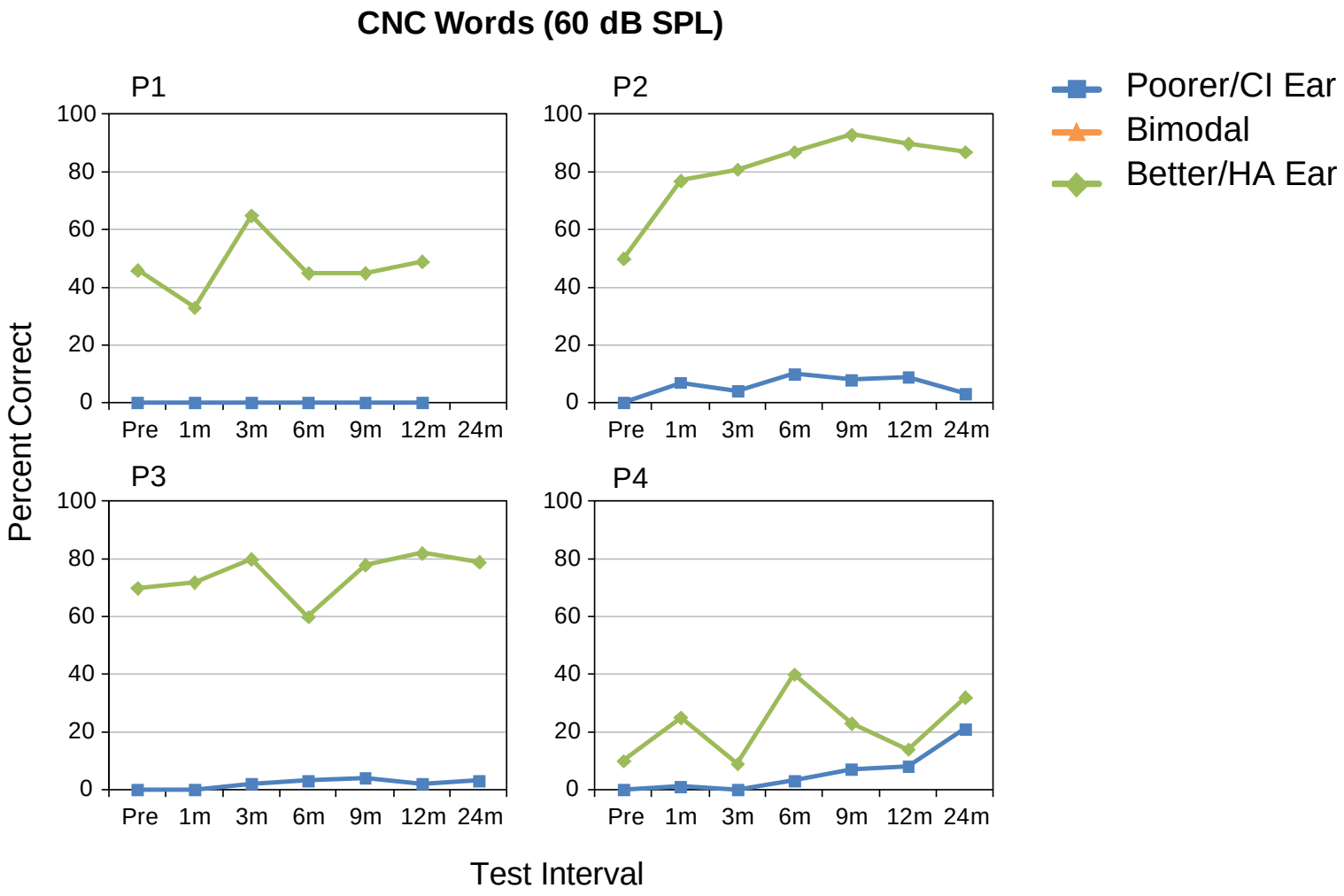
*Error bars = + 1 SEM; **p < 0.01; ***p < 0.001*

Individual Demographics Pre/perilingual Participants

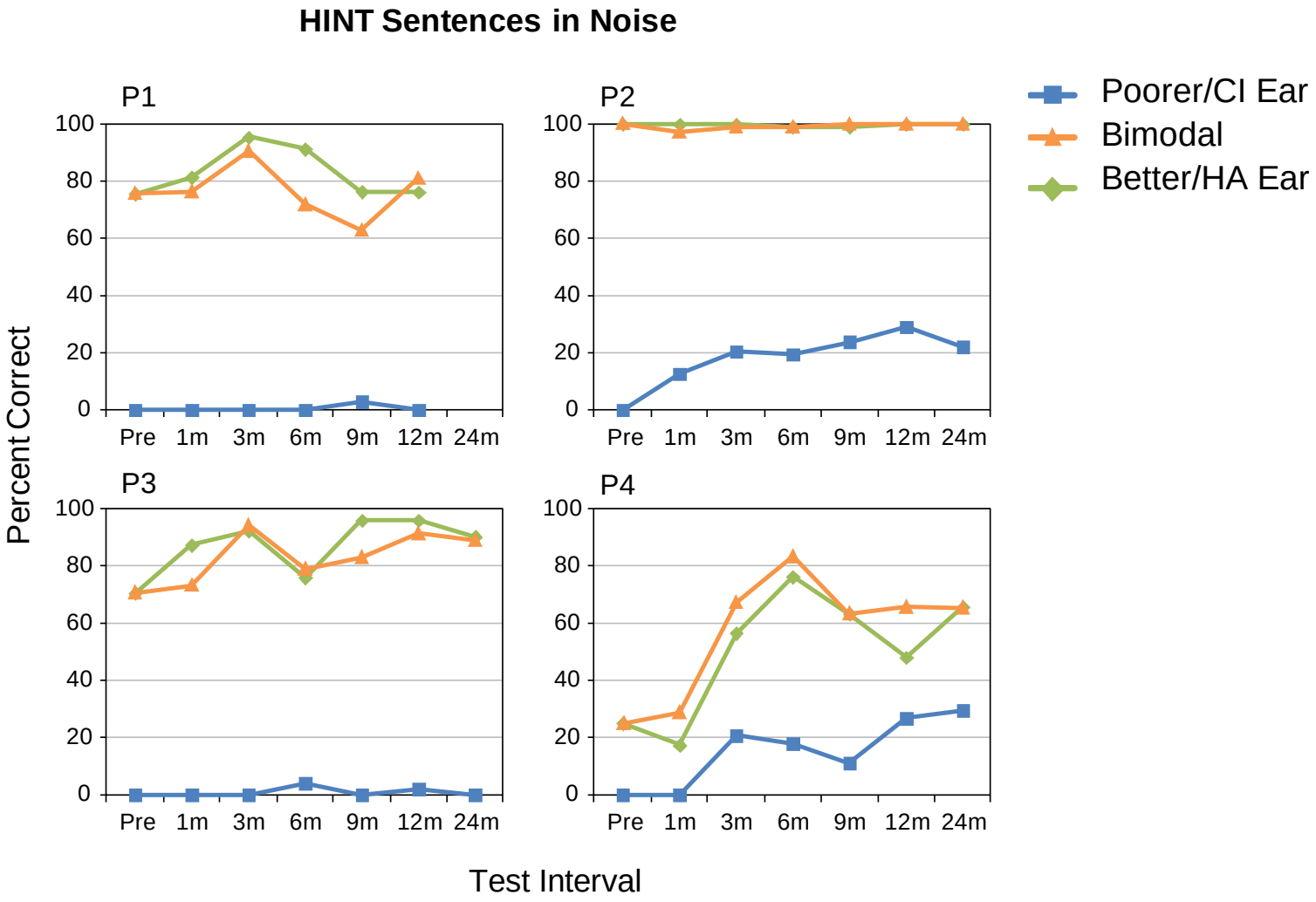
	AAI	Etiology	AAO HL (P/B)	Age Began HA Use (P/B)	Duration SPHL CI Ear
P1	28	High Fever	3 / 3	Never / 3	25
P2	28	Unknown/EVA	birth / 23	Never / 28	23
P3	26	Meningitis	7m / 7m	Never / 1	25
P4	43	Unknown	birth / birth	3** / 3	40

*** Stopped wearing HA in poor ear 10 years prior to CI*

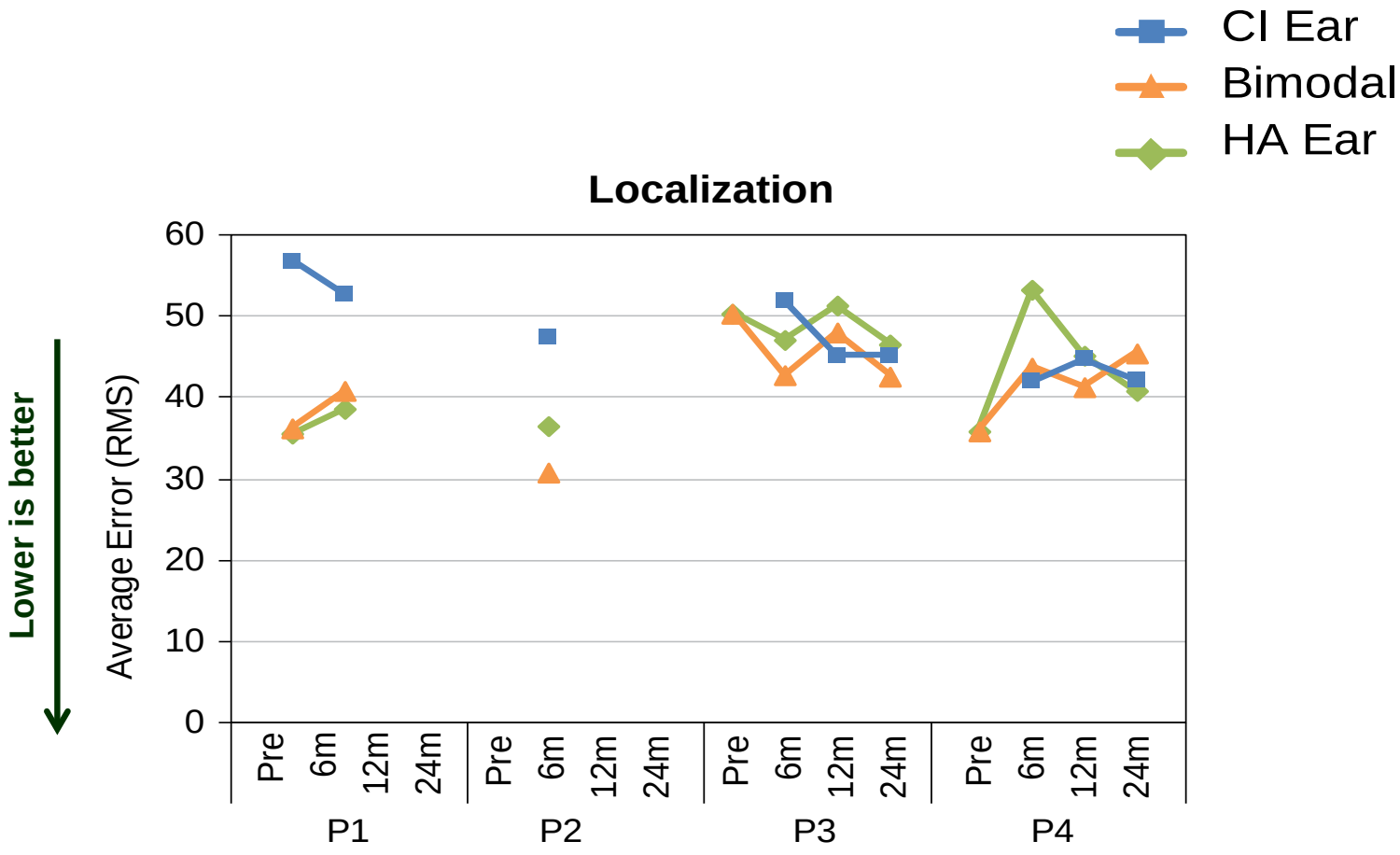
Pre-Lingual Results: CNC Words



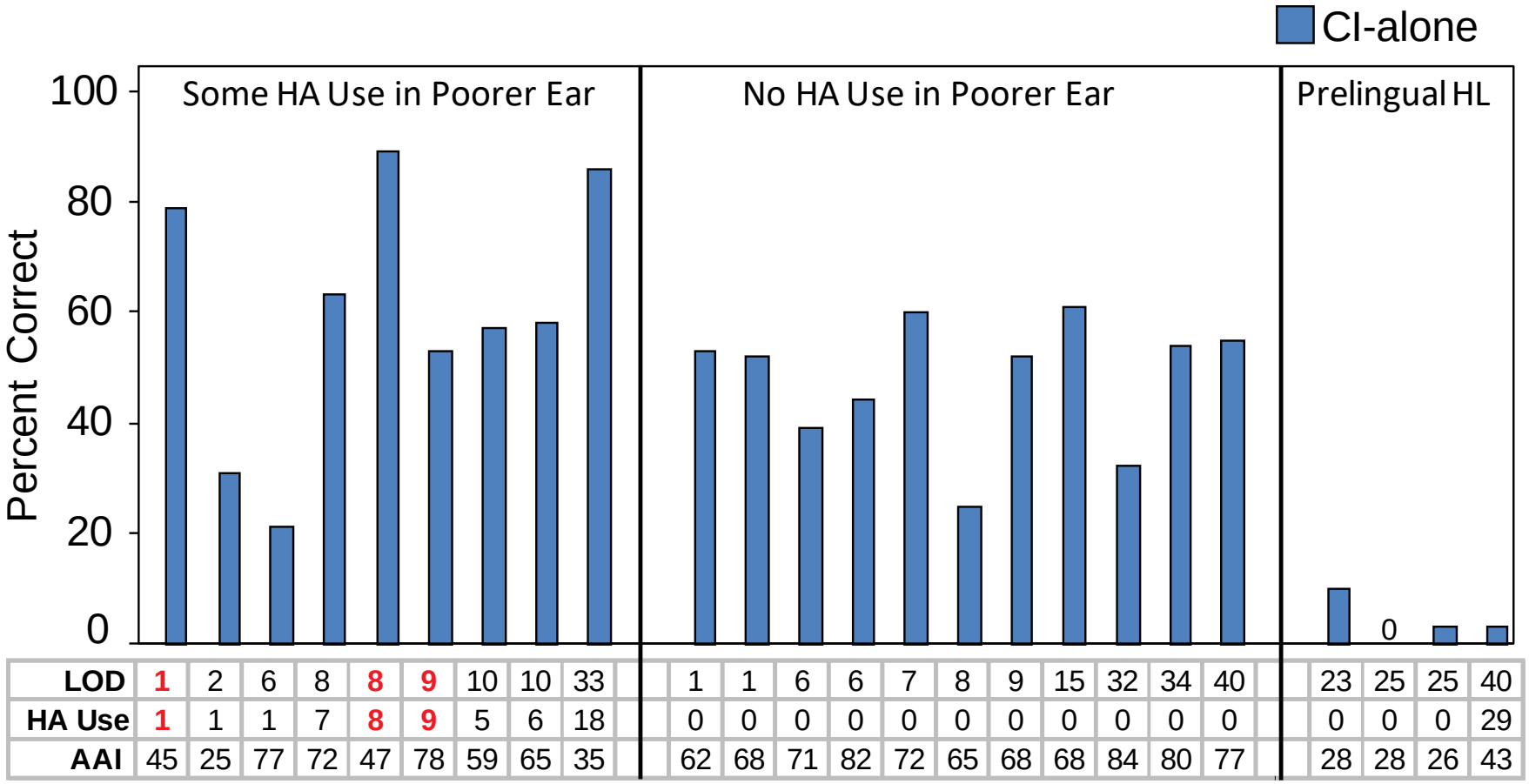
Pre-Lingual Results: HINT Sentences



Pre-Lingual Results: Localization



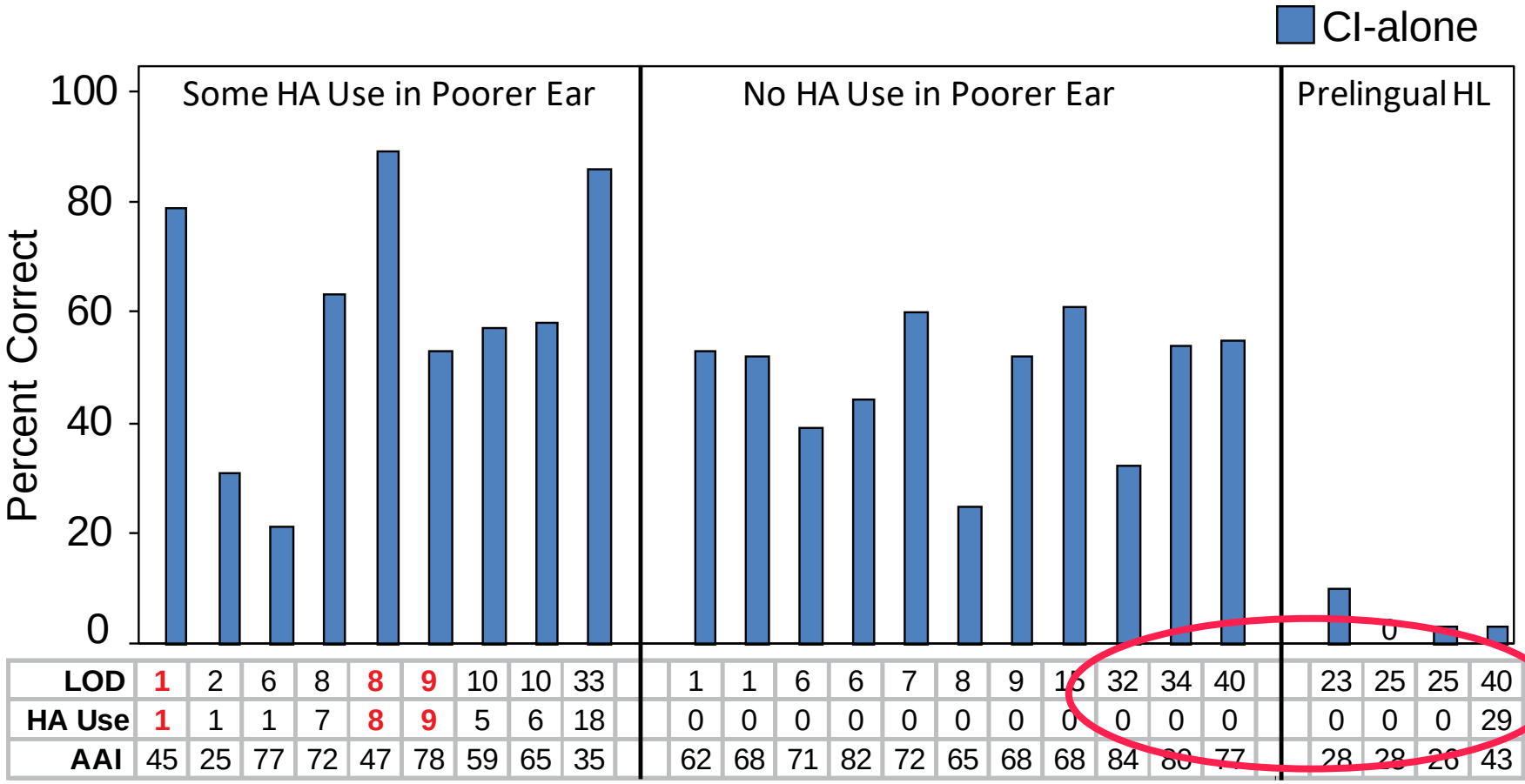
CNC Word Scores-CI Ear



LOD	**1**	2	6	8	**8**	**9**	10	10	33		1	1	6	6	7	8	9	15	32	34	40		23	25	25	40
HA Use	**1**	1	1	7	**8**	**9**	5	6	18		0	0	0	0	0	0	0	0	0	0	0		0	0	0	29
AAI	45	25	77	72	47	78	59	65	35		62	68	71	82	72	65	68	68	84	80	77		28	28	26	43

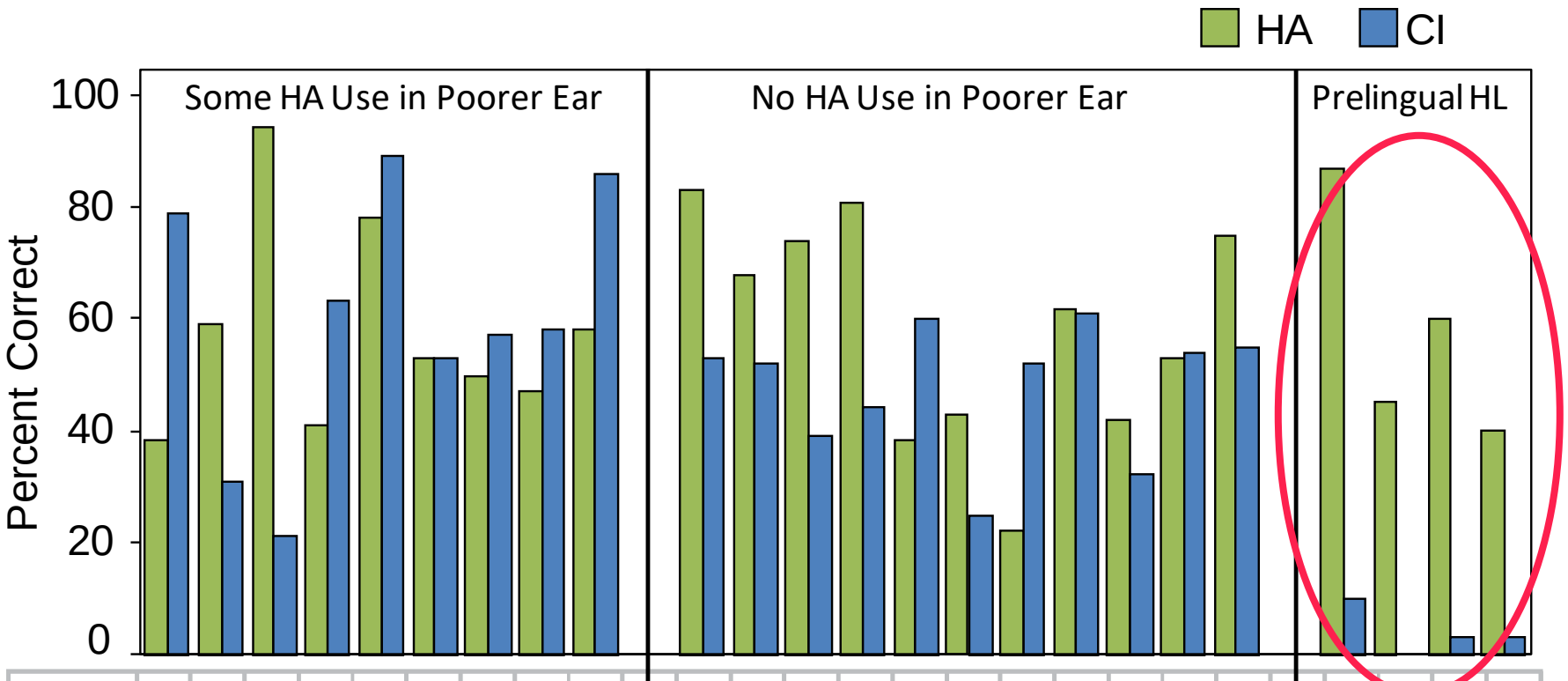
Participants Ordered by Length of Deafness and HA Use (years)

CNC Word Scores-CI Ear



LOD	**1**	2	6	8	**8**	**9**	10	10	33		1	1	6	6	7	8	9	15	32	34	40		23	25	25	40
HA Use	**1**	1	1	7	**8**	**9**	5	6	18		0	0	0	0	0	0	0	0	0	0	0		0	0	0	29
AAI	45	25	77	72	47	78	59	65	35		62	68	71	82	72	65	68	68	84	80	77		28	28	26	43

CNC Word Scores Each Ear



LOD	**1**	2	6	8	**8**	**9**	10	10	33		1	1	6	6	7	8	9	15	32	34	40		23	25	25	40
HA Use	**1**	1	1	7	**8**	**9**	5	6	18		0	0	0	0	0	0	0	0	0	0	0		0	0	0	29
AAI	45	25	77	72	47	78	59	65	35		62	68	71	82	72	65	68	68	84	80	77		28	28	26	43

Participants Ordered by Length of Deafness and HA Use (years)

Result

- All postlingual participants had open-set speech recognition in the CI ear, even those with long periods of deafness (32-40 yrs) and no HA use
- The prelingual participants had little speech recognition with similar lengths of deafness, but early age at onset

Asymmetric Children: Treatment with CIs

Participants

- 5 children/teens with asymmetric hearing loss (ages 10-19 years)
- P1 - P3: more favorable hearing history with more CI experience
- P4 & P5: profound SNHL in the poorer ear from birth, were never aided in that ear, and have only 6 mos CI experience

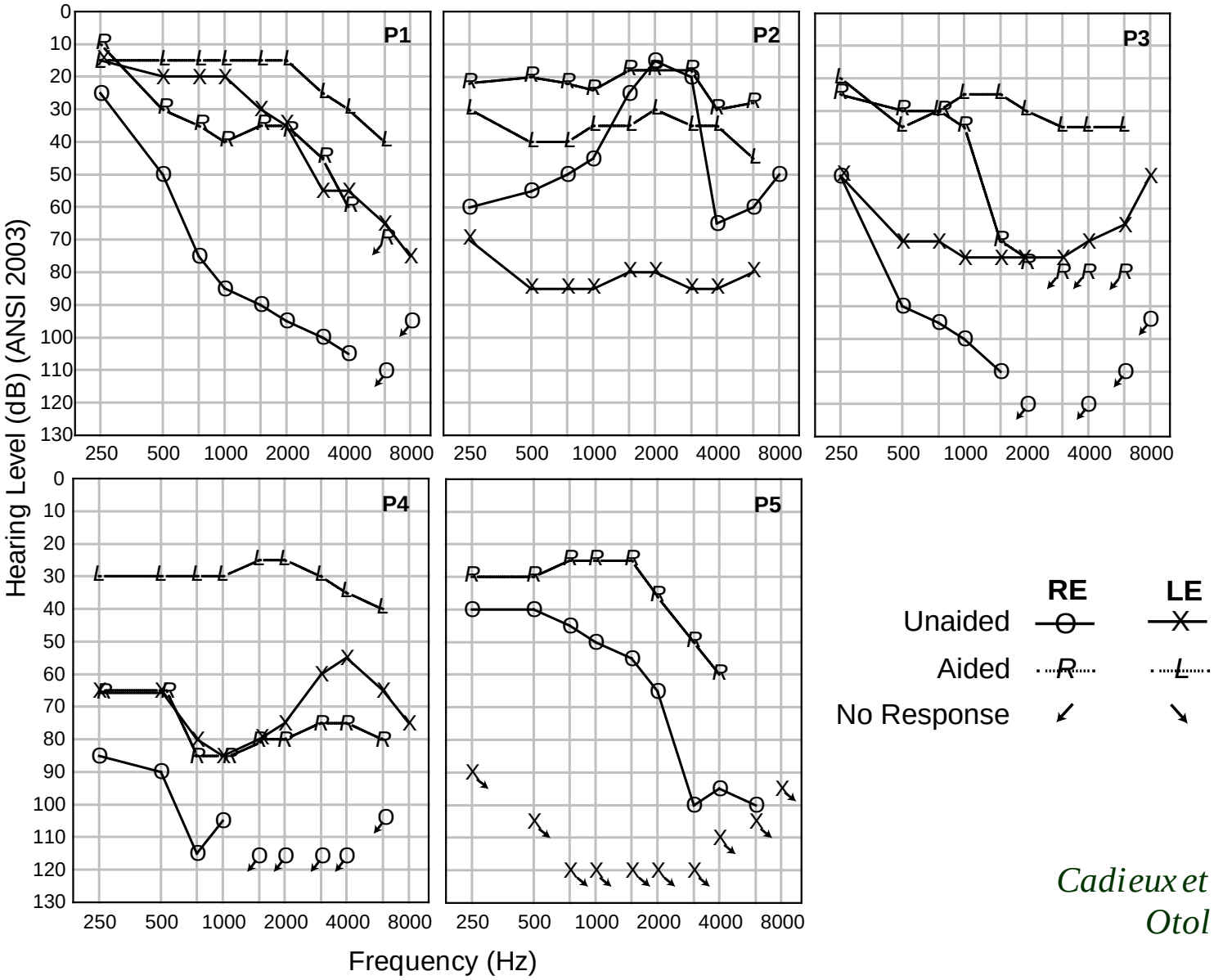
Cadieux J, Firszt JB, Reeder RM. Cochlear implantation in non-traditional candidates: preliminary results in adolescents with asymmetric hearing loss. Otol Neurotol, 2013, 34:408-415.

Demographic Information

	Age (y)	Etiology	AAO SPHL (P)	Age Began HA Use (P/B)	AAI (P)	Length CI Use (y;m)
P1	11	EVA	8	4 / 4	8	3;2
P2	10	Unknown	Birth	2 / 2	5	5;2
P3	19	Unknown	4	4 / 4	14	5;4
P4	12	EVA	Birth	Never / 4	12	0;6
P5	15	Unknown	Birth	Never / 4	15	0;6

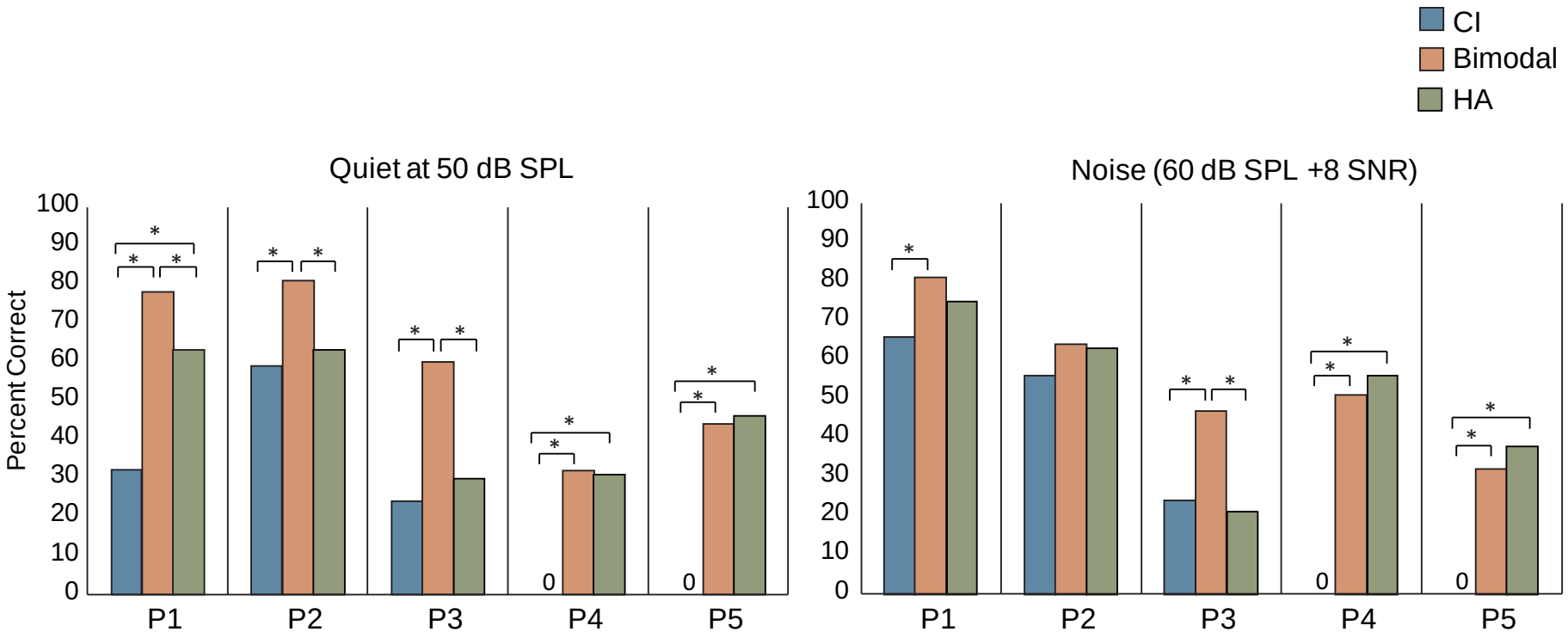
Cadieux et al, 2013, Otol Neurotol

Pediatric Participant Audiograms



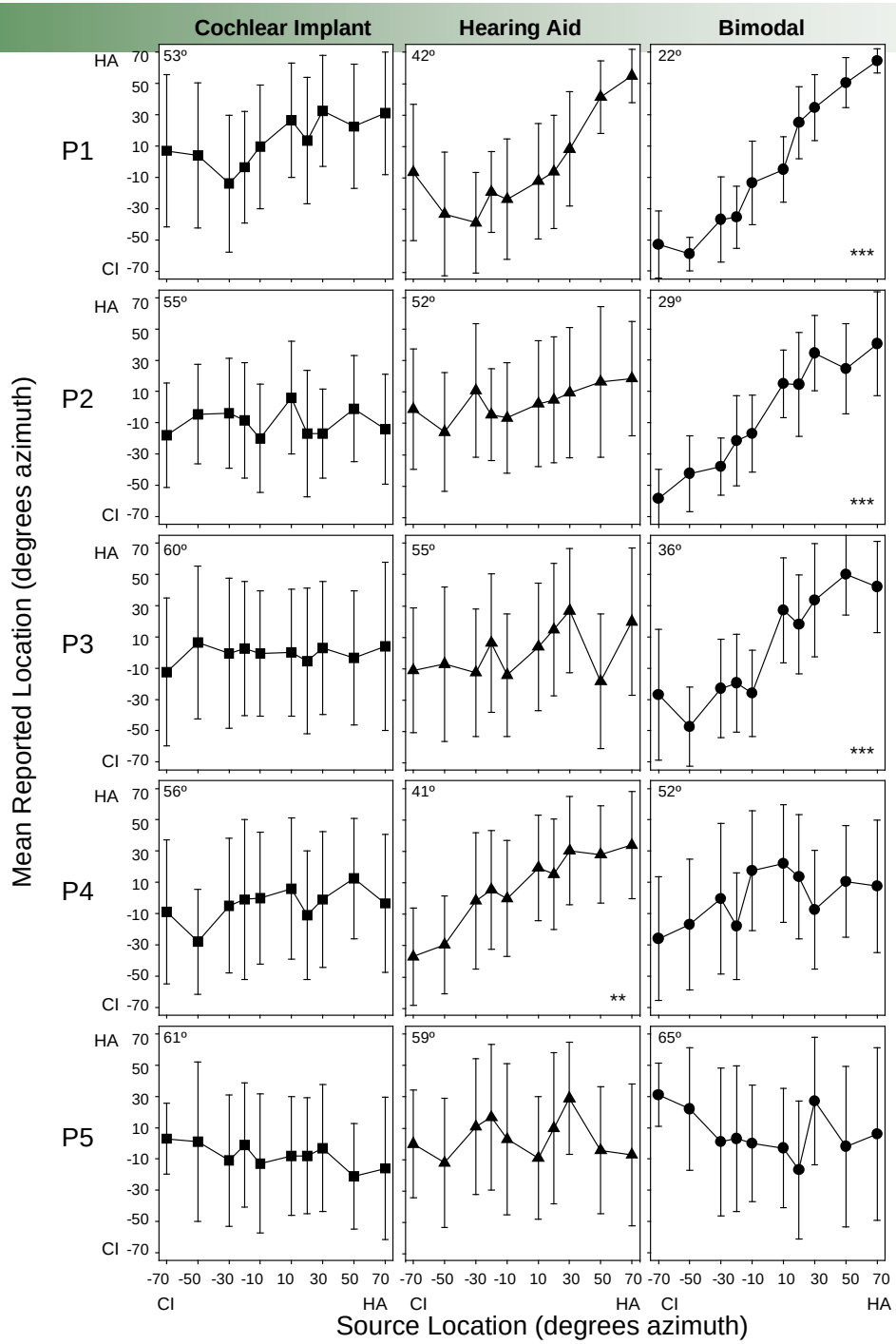
Cadieux et al, 2013, Otol Neurotol

CNC Words in Quiet and Noise



* p<0.05

Cadieux et al, 2013, Otol Neurotol



Cadieux et al, 2013, Otol Neurotol

Result

- Some children with AHL show significant benefit from CI in the poorer ear
- Effects of congenital AHL requires further investigation
- Consider the implications of unilateral input, when this occurs early in life, and whether hearing abilities in the poor ear can be accessed later, or whether binaural abilities can be achieved

UHL (SSD) Adults: Treatment with CIs

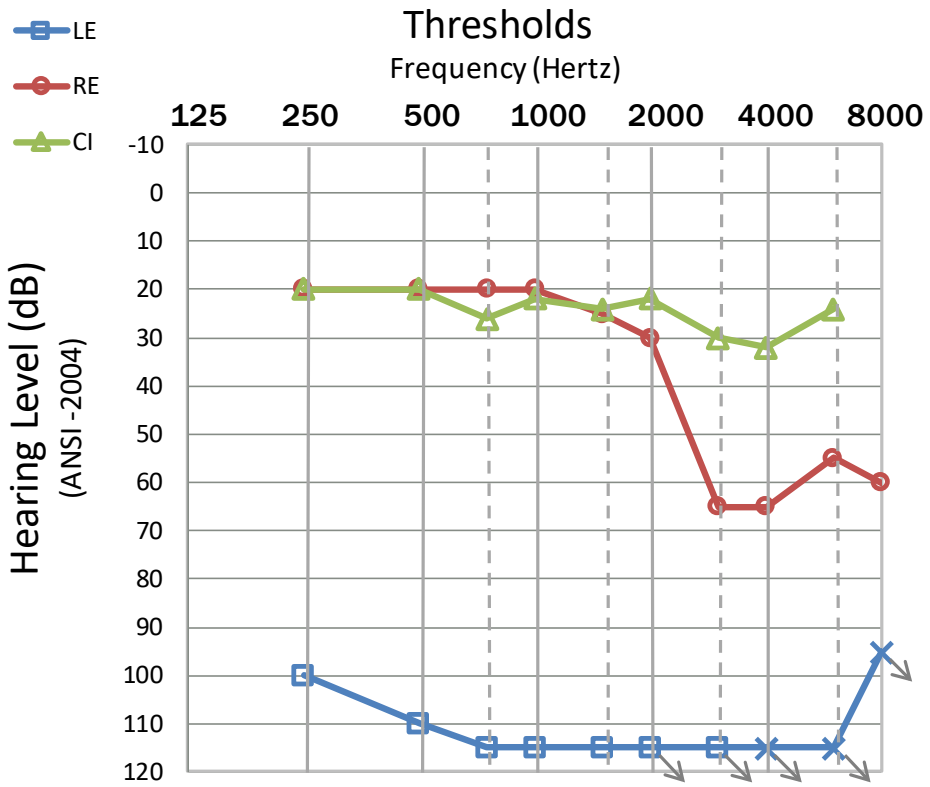
Speech Recognition in Cochlear Implant Recipients with SSD (St. Louis VA)

- Inclusion criteria
  - Severe to profound SNHL in the poor ear and WRS ≤ 40%
  - Normal or near-normal hearing in other ear, with 3 frequency PTA (.5, 1, 2 kHz) ≤ 30 dB HL; thresholds above 30 dB allowable > 3kHz
  - Adult onset of SPHL
  - Duration of deafness < 20 years
  - Previously tried CROS, BiCROS or Baha softband

VA Participants

- P1: Age 50, sudden SPHL
  - Implanted age 52 (Med-El)
  - Length of deafness 17 mos
- P2: Age 58, sudden SPHL
  - Implanted age 65 (Nucleus)
  - Length of deafness 7 years
- P3: Age 53 SPHL, but not sudden (prior HL)
  - Implanted age 63 (Adv Bionics)
  - Length of deafness 10 years

VA Participant 1 - Audibility in dB HL

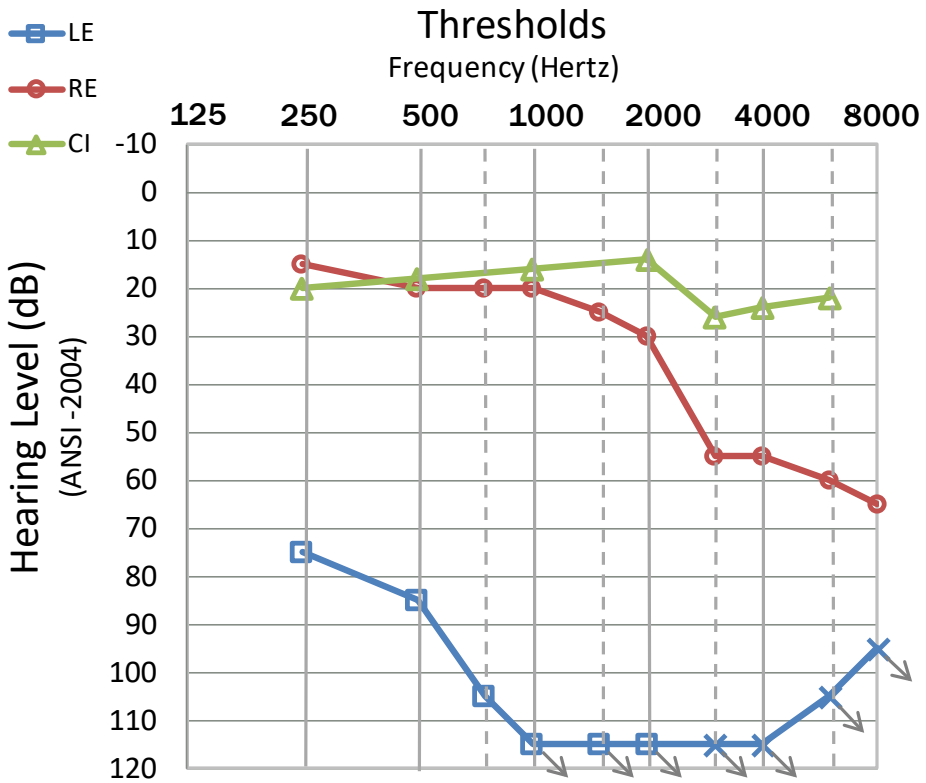


AAI = 52 years
LOD = 17 mos
Med-El

WRS = 0% LE

High frequency threshold levels with the CI (green) are better than his high frequency threshold levels in his good ear (red).

VA Participant 2 - Audibility in dB HL

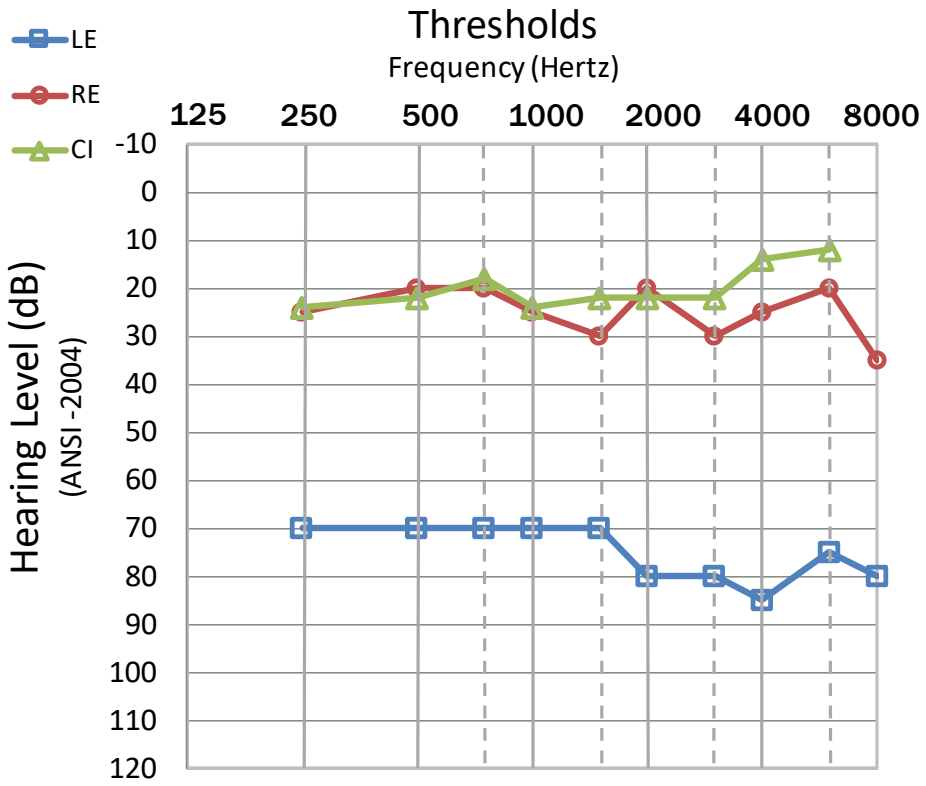


AAI = 65 years
LOD = 7 yrs
Nucleus

WRS = 0% LE

Again, high frequency threshold levels are better with the CI than thresholds in the good ear.

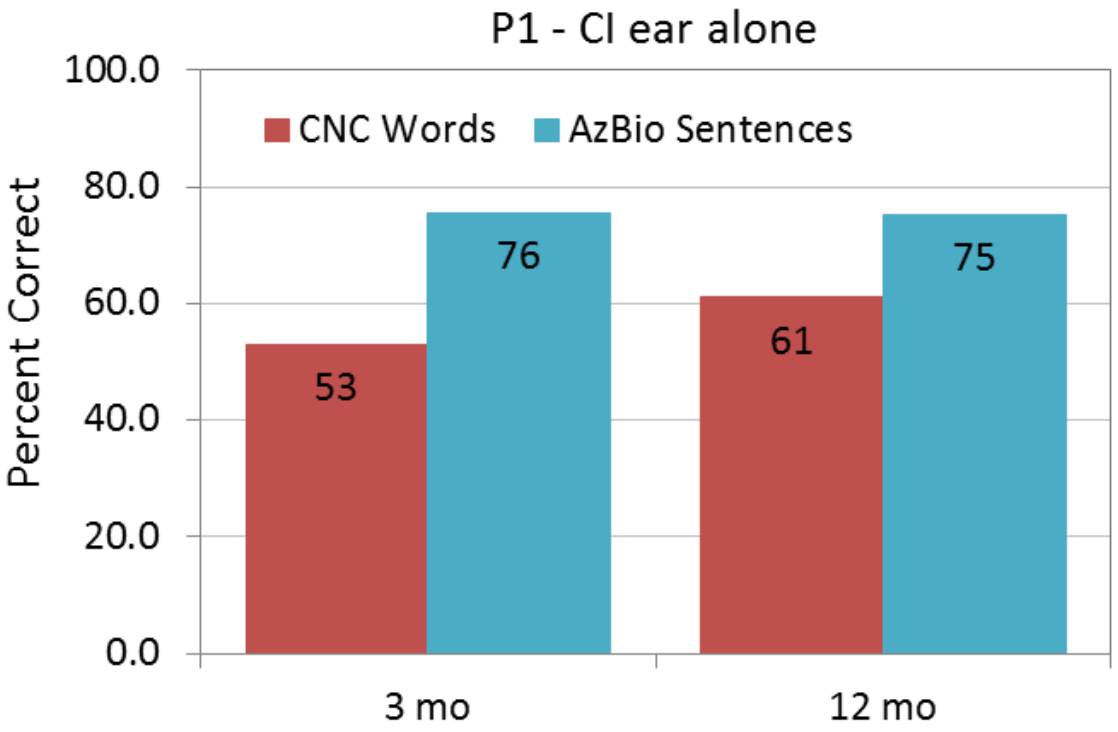
VA Participant 3 - Audibility in dB HL



AAI = 63 years
LOD = 10 yrs
Adv Bionics

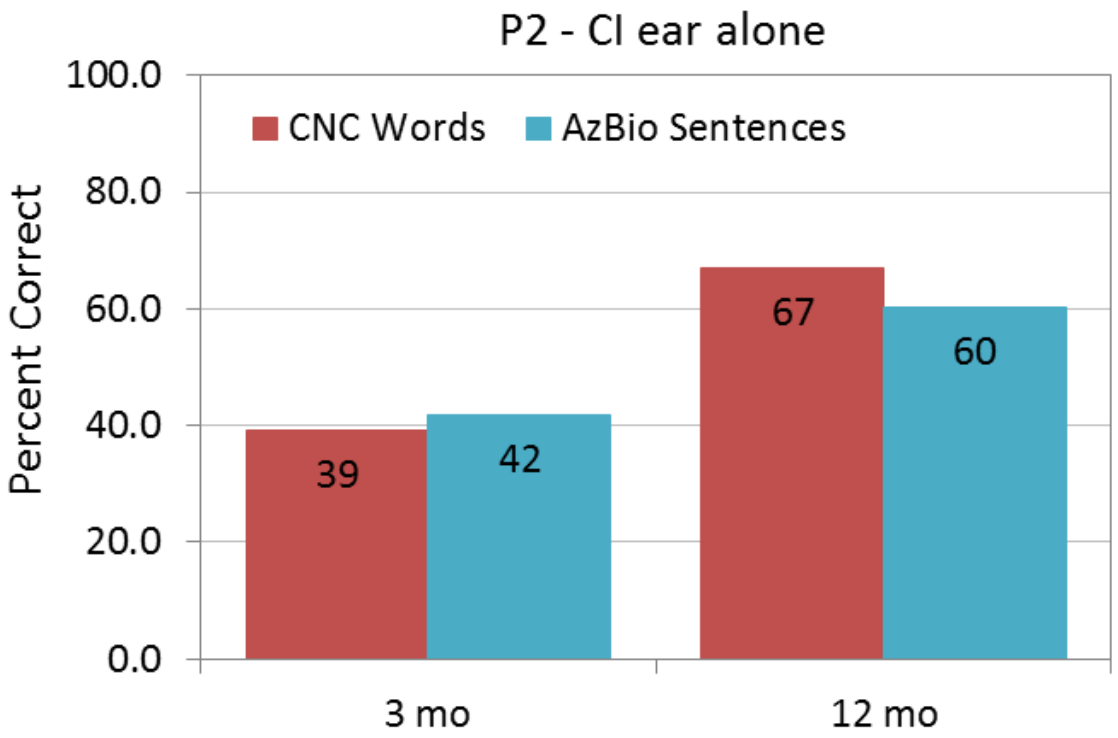
Very poor speech discrim in LE,
NU6 word score of 8% at 100 dB HL

CI only Perception in Quiet



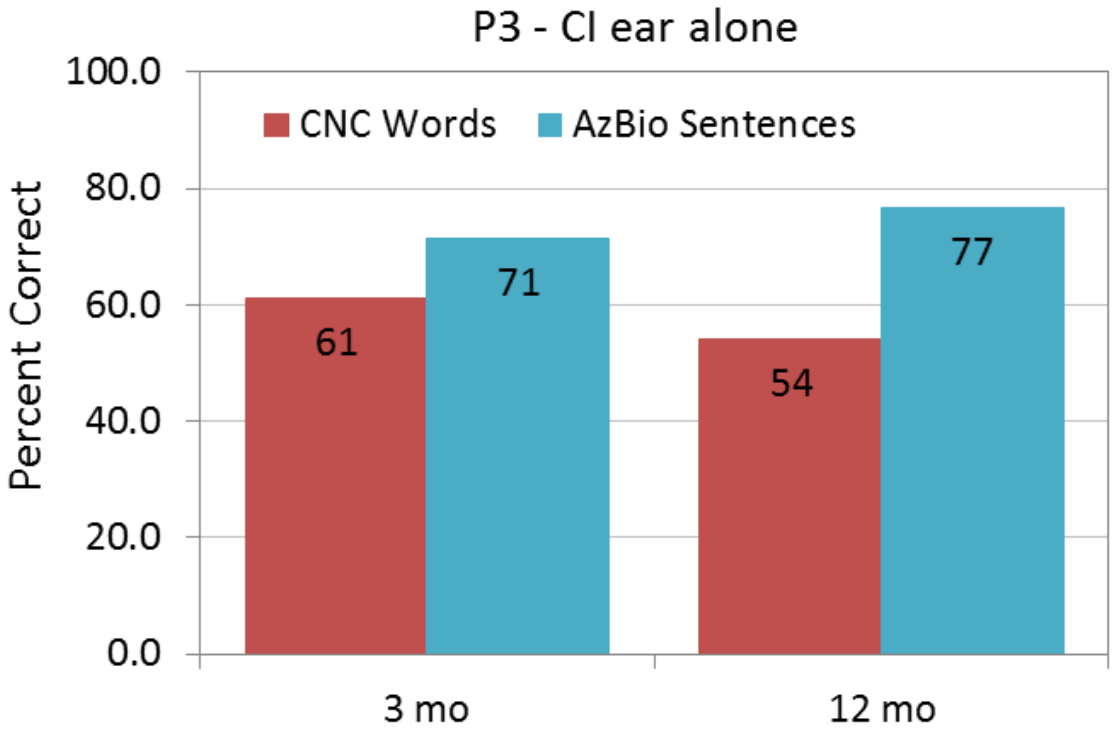
Scores with CI only. Better ear plugged and muffed.

CI only Perception in Quiet



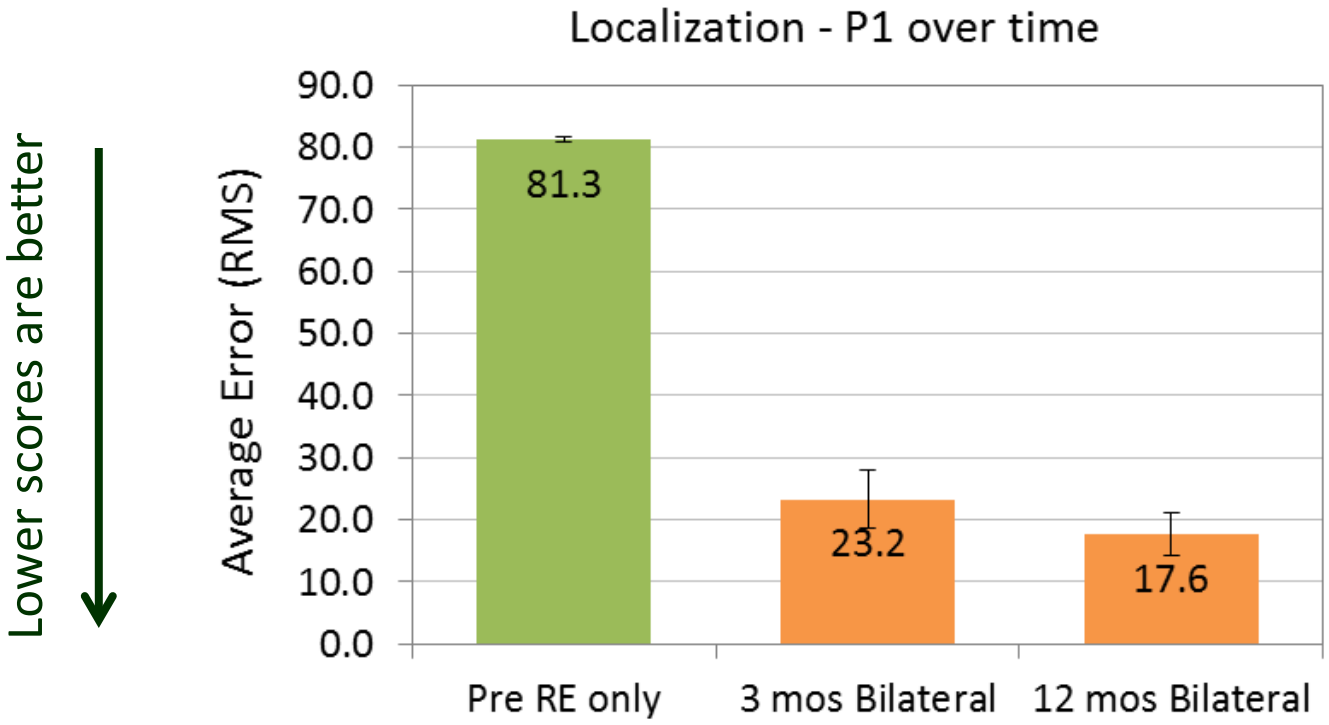
Scores with CI only. Better ear plugged and muffed.

CI only Perception in Quiet



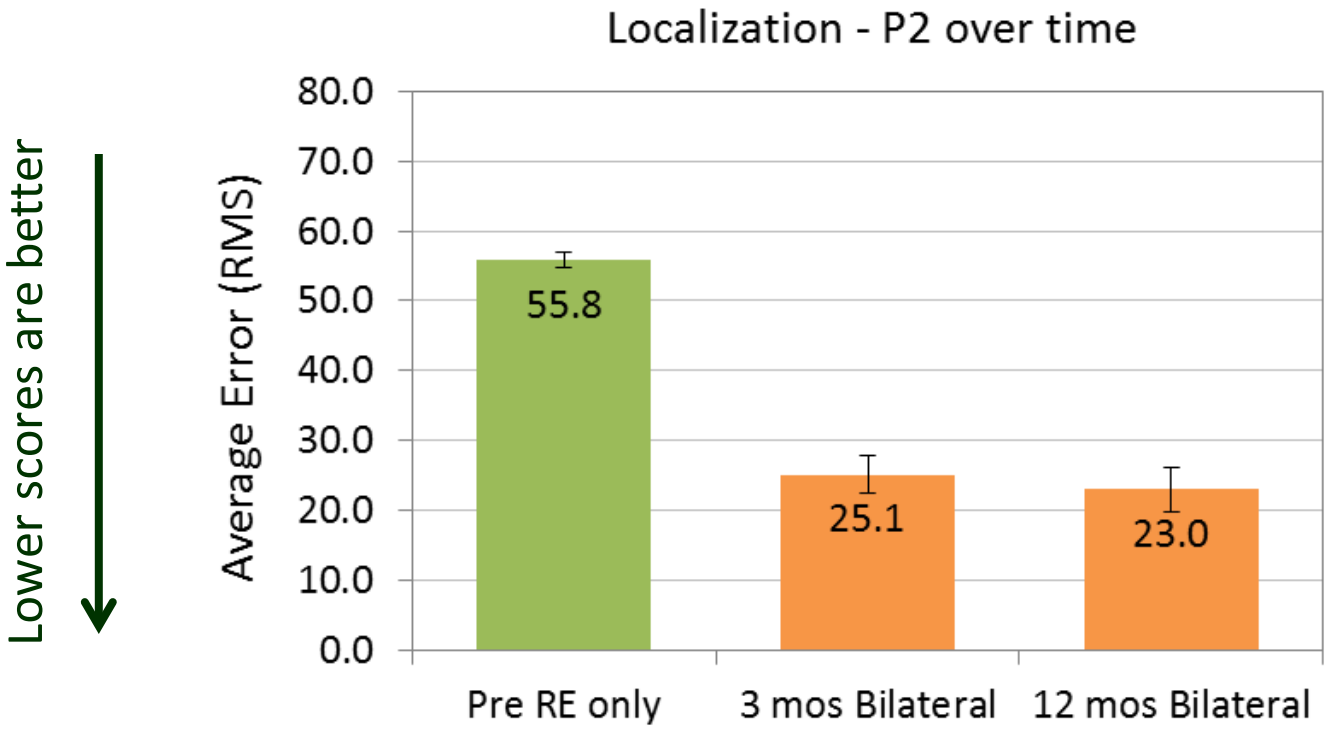
CI only scores. Better ear plugged and muffed for testing.

Localization



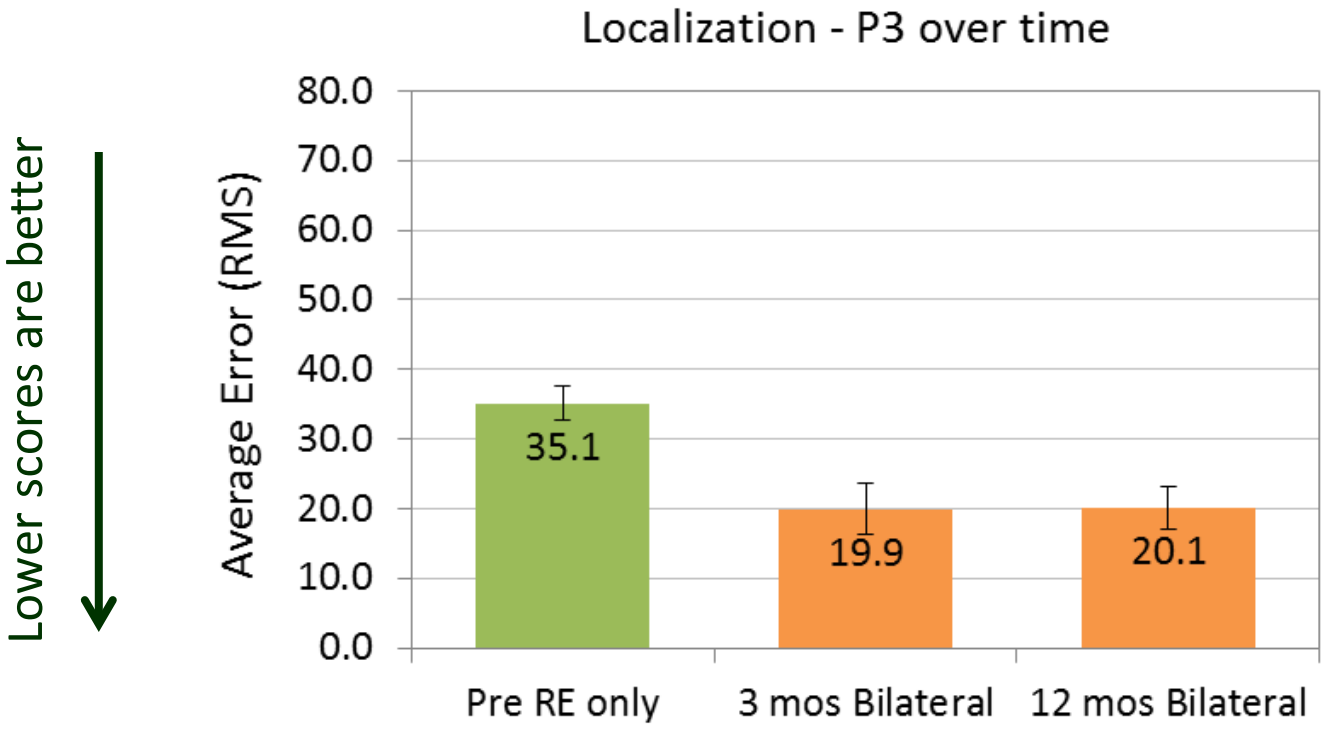
Large improvement at 3 and 12 months post-op in the bilateral condition (using good ear and CI) over his pre-op condition.

Localization



Better localization scores with CI and good ear (3 and 12 mos post-op) than with good ear alone (pre-op).

Localization



Better localization scores with CI and good ear (3 and 12 months post-op) than pre-op condition.

Participant Comments

- Examples of when CI is most helpful
  - Localization
  - Hearing and understanding family
  - Understanding in everyday situations
  - Hearing environmental sounds
- Examples of when CI is least helpful
  - Movie theatres too loud; Some restaurants
- I wear the processor all day, everyday. I hate taking it off. It's like taking off an ear. I feel lost. (P1)
- I don't feel that there is a situation in which the implant is detrimental. (P2)
- The CI has opened up a whole new world for me. (P3)

Counseling Recommendations

Based on results and discussions with participants, pre-implant counseling important:

- Improvements may be realized in some but not all listening environments
- Sound quality from CI will differ from acoustic hearing; may need additional time to adjust
- CI alone practice is essential to maximize CI benefit (direct connect to CI or better ear plugged)

All patients commit to post-op rehabilitation for 8-10 weeks—emphasis on programming optimization of CI ear and training

Programming Comments

- Protocol—similar to traditional CI users
  - —Plug the better ear, especially for balancing and Ts
- Loudness—difficulty determining volume
  - —Set CI volume with BE plugged, may be too loud with BE + CI. When evaluating CI alone and BE ear plugged, CI volume may be too soft
- Subjective feedback—some have more difficulty giving feedback re programming changes, small differences not as apparent (better ear dominant)
- Acclimatization—can take longer to adjust, longer to reach maximum performance

Patient Selection Recommendations

- Hearing history
  - Any unaided thresholds in poor ear
  - Age at onset (sudden vs congenital)
  - Cochlear anatomy
  - Previous trials with other devices
- Communication needs
  - Work environment
  - Family and Social environment
- Motivation and realistic expectations
- Commitment to rehab process

Careful selection is needed to avoid non-use in the future

Overall Summary

- UHL poorer than NH-Adults and children
- Tremendous variability, some score within the NH range
- Experience helps with localization but not listening in noise
  - Adults with acute UHL vs UHL; UHL Adults Young AAO vs Recent AAO, Older UHL children
  - Others have reported similar *(Slattery & Middlebrooks, 1994)*
  - Different mechanisms involved

Overall Summary

- Length of deafness is a significant factor in traditional CI performance
  - For bilateral SPHL *(Lazard et al., 2012; Blamey et al., 2013; Holden et al., 2013; Geers et al., 2003; Nicholas & Geers, 2013)*
  - For 2nd ear of sequential bilateral recipients *(Gordon et al., 2009, 2010, 2013; Ramsden et al., 2005; Reeder et al., 2014; 2016)*
- Length of deafness is not associated in the same manner for those with AHL
- Age at onset is a critical factor, even w/one opposite good hearing ear

Issues to Consider

- If we assume UHL deprives binaural processes, and we need bilateral input…
  - We do recommend bilateral HAs, bilateral CIs, and bimodal (HA+CI) at young ages
- We know from sequential CIs, bilateral input is needed in a timely manner—can't wait too long
- If younger is better, how do we identify deficits early? How do we determine recommendations for treatment? And how do we measure benefit?

Issues to Consider

- If not all children have a deficit, how to identify those that do
- Maybe all children have a deficit and we need different measures
- Those with performance comparable to NH peers, how are they doing it? Using other resources? Greater cognitive load? Some other work around?

Issues to Consider

- There will still be deficits with a CI
- Is there the potential to decrease performance?
- If so, who is at risk for poorer performance?
- Does etiology play a bigger role? Children with UHL have higher risk of cochlear anomalies
- Many unanswered questions…

Future Directions

- Studies of asymmetric hearing loss in children
- NIH funded clinical trial (U01) of adults with asymmetric hearing loss
  - Multi-center, four sites
  - Clinically feasible protocol, FDA approved
  - Including Quality of Life measures

Future Considerations: Raise the Bar for Bilateral Input

- We should consider treatment for each ear with hearing loss, be it acoustic or electric
- The auditory system is designed to be binaural. We should treat the system by treating each ear
- CI Candidacy requirements should be modified to allow treatment to each ear rather than requiring bilateral hearing loss for cochlear implantation

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