Influence of Auditory Experience on the Outcomes of Children with Hearing Aids: Auditory Access Matters

Elizabeth Walker, PhD, CCC-SLP/A
Assistant Professor
University of Iowa, Iowa City, IA

Supported by NIDCD R01 DC009560

CANADIAN ACADEMY OF AUDIOLOGY
OCT 28, 2019

Iowa City, IA


WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VA
PENNSYLVANIA
NEW YORK
NEW HAMPSHIRE
VERMONT
MAINE
MASSACHUSETTS
RHODE ISLAND
CONNECTICUT
NEW JERSEY
DELAWARE
MARYLAND
WASHINGTON, D.C.
ALASKA
HAWAII
N
W
E
S

Acknowledgements

Research reported in this presentation was supported by the **National Institute On Deafness And Other Communication Disorders** of the National Institutes of Health under Award Numbers R01DC009560, DC013591, and R21DC015832. The content is solely the responsibility of the author and does not necessarily represent the official views of the National Institutes of Health.

Acknowledgements

Mary Pat Moeller, PhD

Ryan McCreery, PhD

Bruce Tomblin, PhD

Meredith Spratford, AuD

My history

- Master's degree in Communication Disorders from University of Minnesota-Twin Cities
- PhD in Speech and Hearing Science from University of Iowa
- Assistant professor and director of Pediatric Audiology Laboratory, University of Iowa

- Intro to OCHL
- Preschool-age CHH
  - Auditory access
    - Aided audibility
      - ANSD
    - HA use
      - Mild bilateral hearing loss
- School-age CHH
  - Academic and language outcomes

Why study children who are hard of hearing?

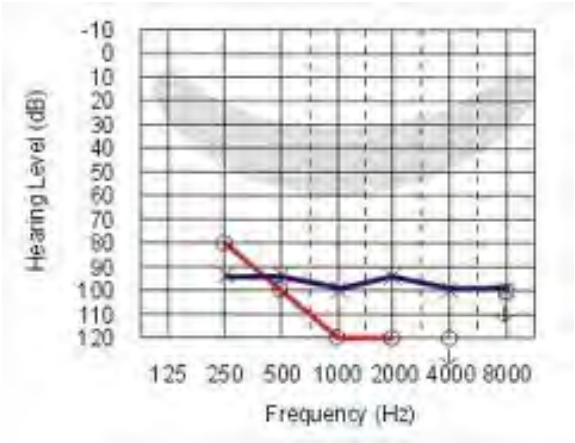
"Research on hard-of-hearing children…is rare. The greatest amount of research has been conducted on deaf children…although the results of such studies are useful for understanding the effects of profound hearing loss, they are not applicable to hard-of-hearing children."

Julia M. Davis
"Our Forgotten Children"
1977

There are many challenges with past research on children who are hard of hearing

Small sample sizes

Children who are deaf or HH combined into one group

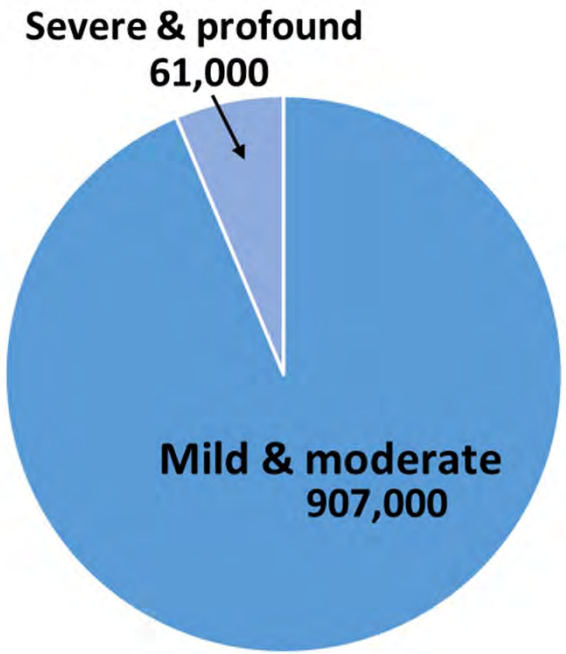


Did not take hearing aids or HATs into account

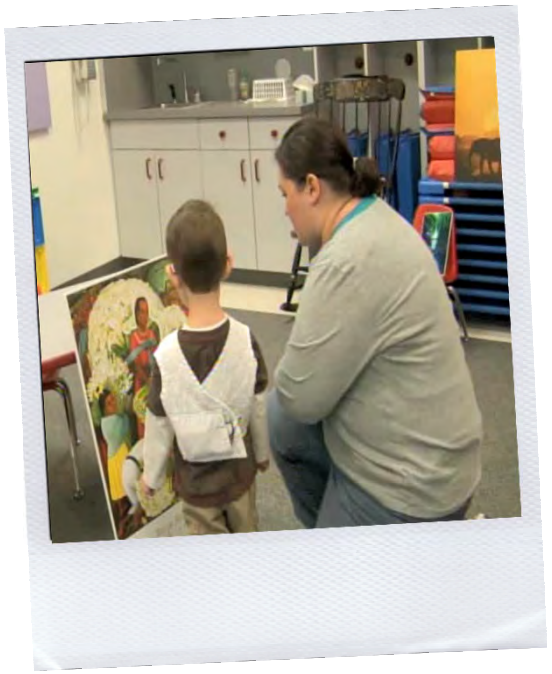
Lack of prospective studies

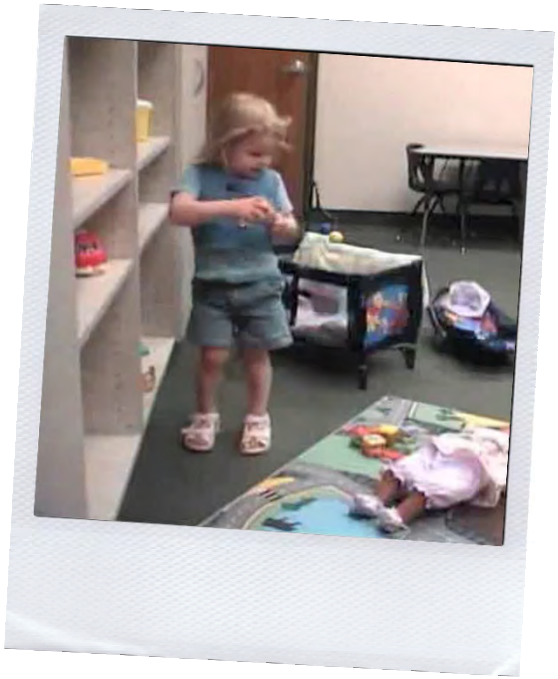
~15% of children ages 6-19 years have a significant hearing loss

NHANES II & III
(Niskar et al., 1998)



Goal: Explain individual variability





Previous outcomes research

Historical Perspective: Ambiguity about risk posed by mild to severe hearing loss

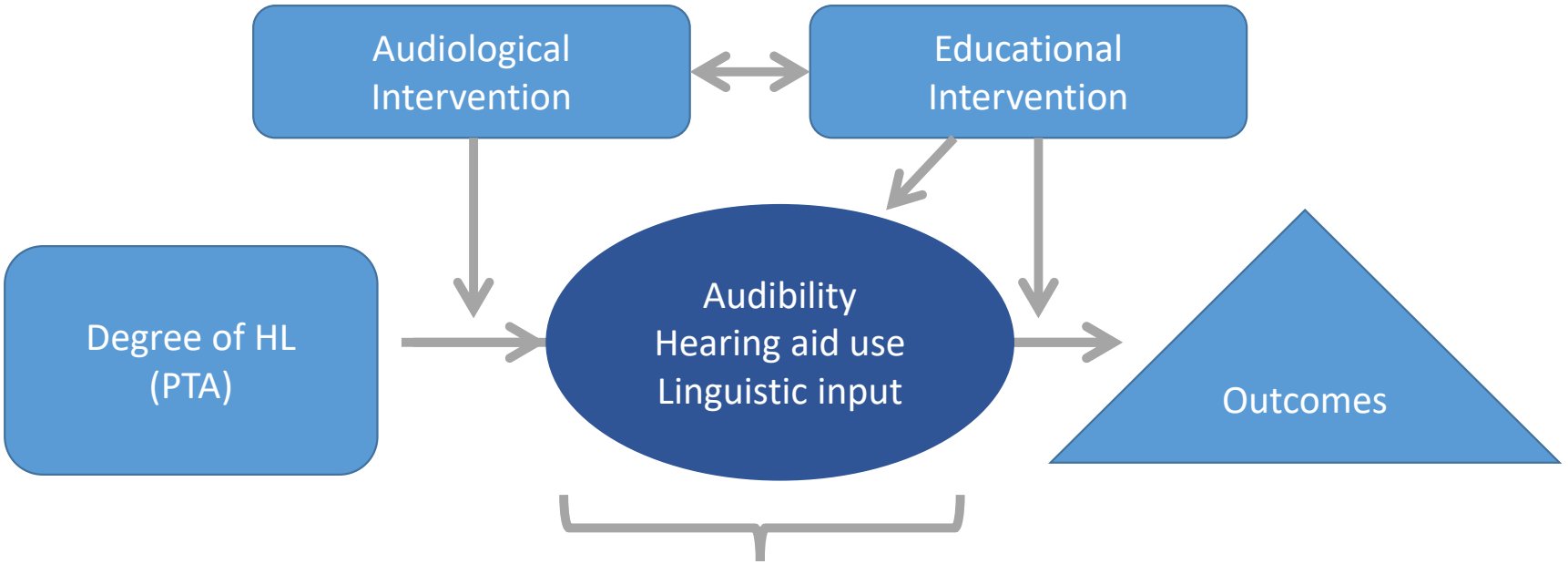
Note:
- Small sample sizes
- School age children
- Focus on degree of HL and timing of intervention
- Little consideration of "malleable factors" in clinical intervention

Delayed relative to peers	*n*	Age (yr)	Like typical peers	*n*	Age (yr)
Davis et al. (1986)	40	5-18	Briscoe et al. (2001)	19	5-10
Elfenbein et al. (1994)	40	5-18	Gilberston & Kamhi (1995)	20	7-10
Blair et al. (1985)	24	7-10	Norbury et al. (2001)	19	5-10
Delage & Tuller (2007)	19	11-15	Wolgemuth et al. (1998)	13	10-15

Even mild HL has consequences
Persistent risks in speech, grammar

Many = hearing peers and > Language Disorders
Selected children impaired

OCHL outcomes model: auditory-linguistic access



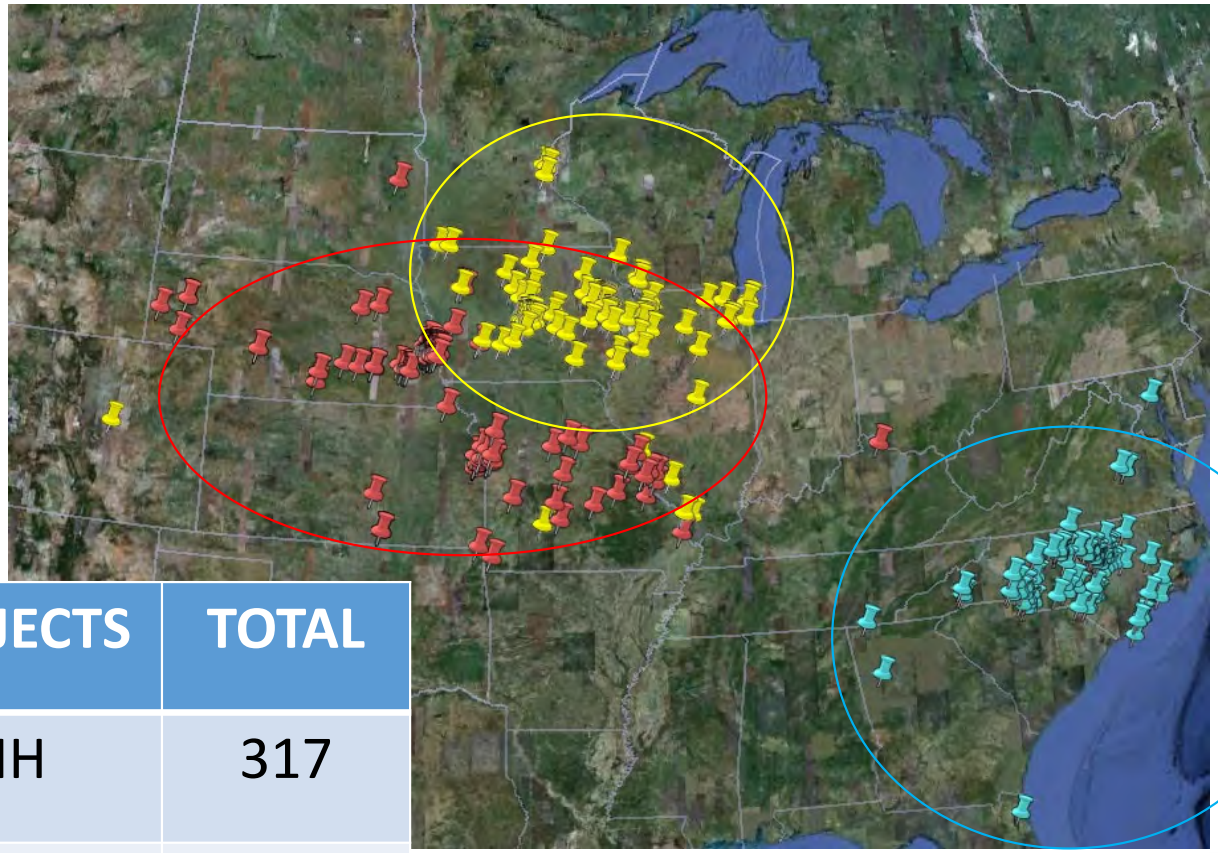
Factors that influence relationship between PTA and outcomes.

Null hypotheses

Auditory experience is **invariant**.

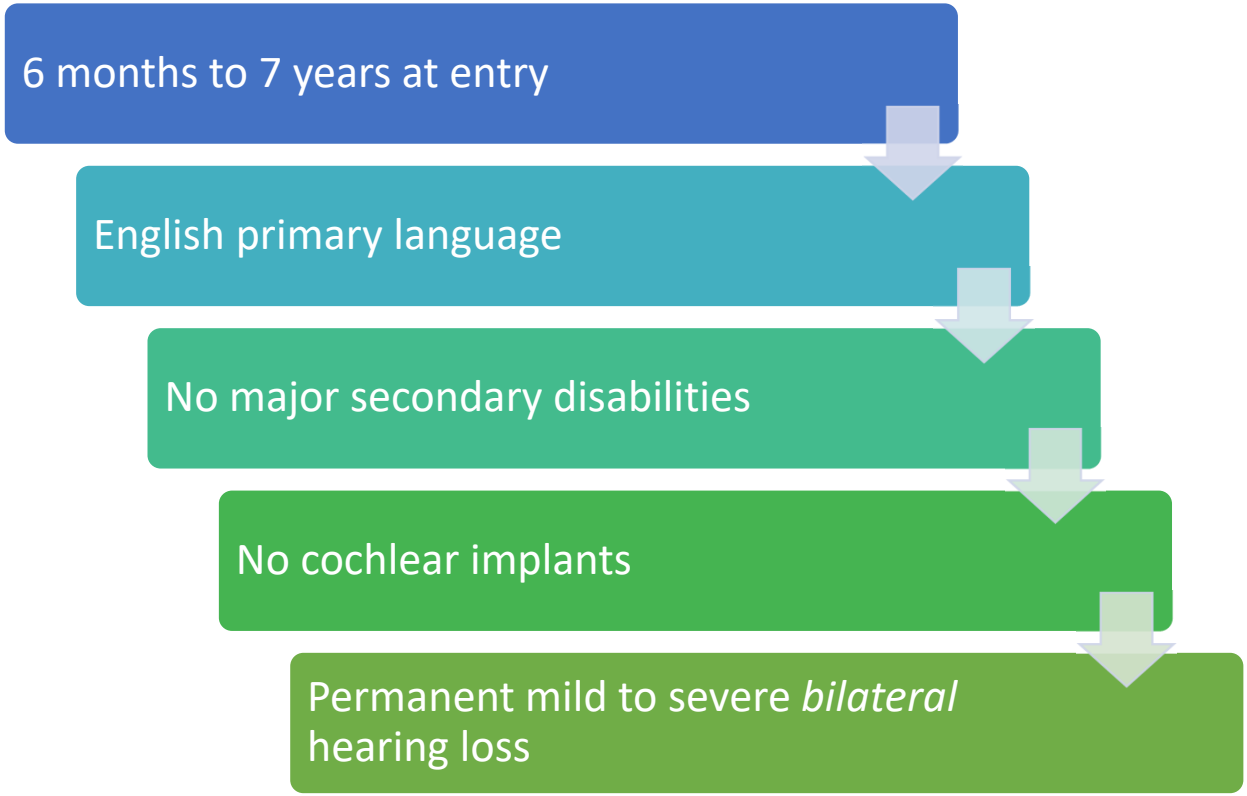
- Infants and children wear their hearing aids all the time.
- Hearing aids provide consistent audibility.
- Demographic factors will predict outcomes

The OCHL study is a multicenter, longitudinal study focusing on outcomes of children with mild-severe hearing loss



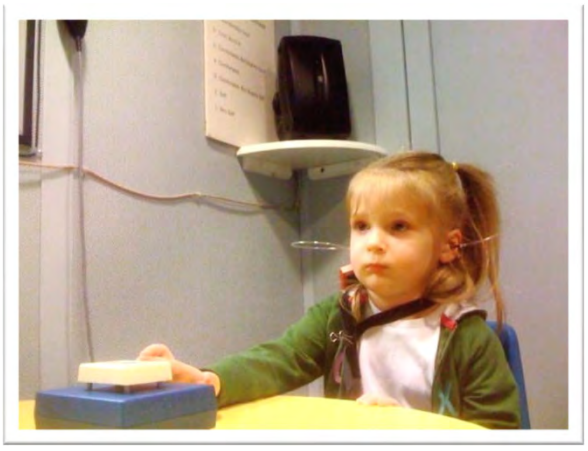
SUBJECTS	TOTAL
HH	317
NH	117

Study participants: Inclusion criteria



Study participants

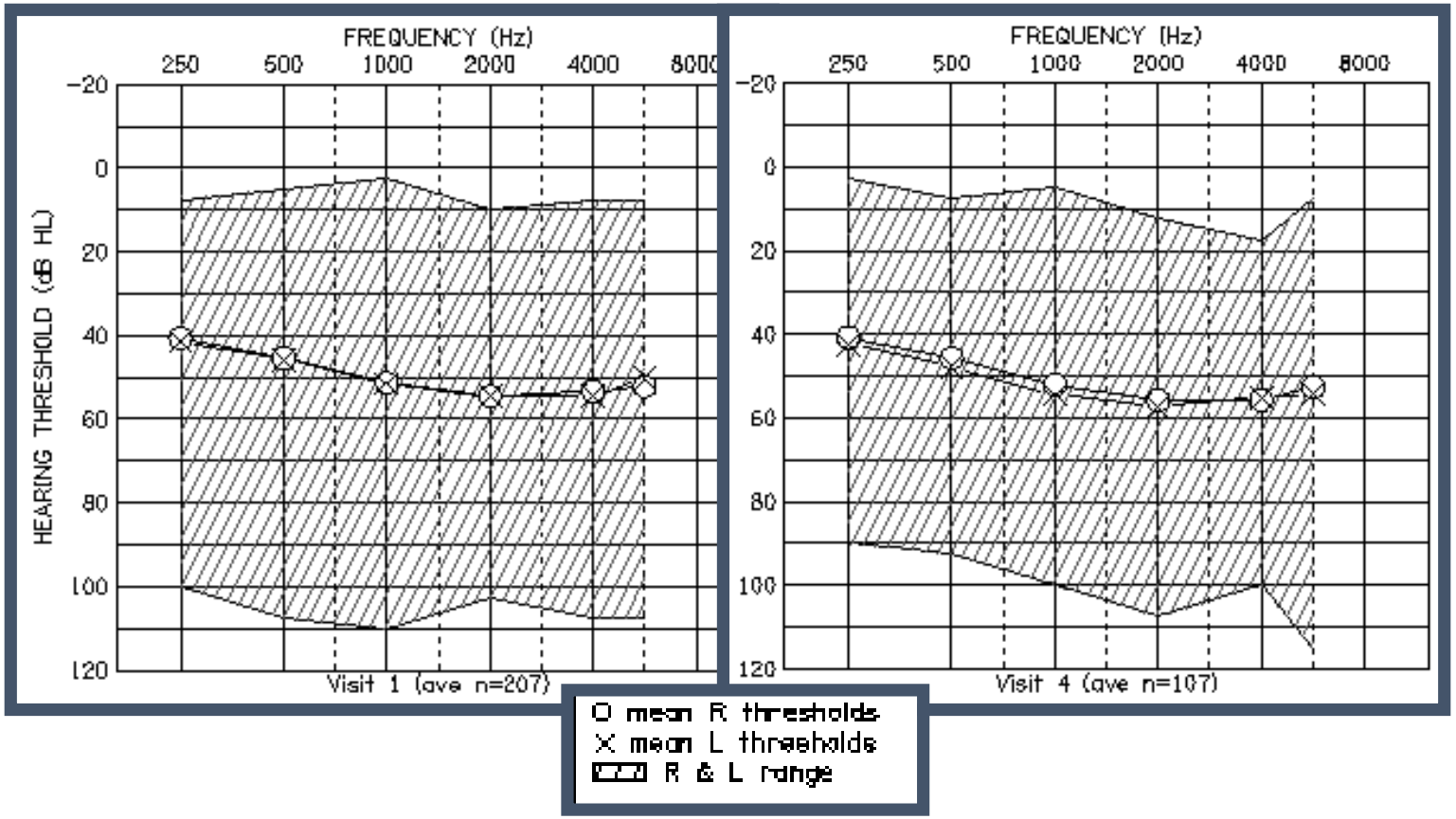
	CHH	CNH	Both Groups
Number	317	117	Matched on income & maternal education Higher than typical US sample
Gender	173 male; 144 female	54 male; 63 female	
Hearing	*M*= 48.88 dB HL 7 without amplification 76% identified from NHS Age of ID = 7.32 mos	< 20 dB HL	



Audiograms from visit 1-4

First visit

Fourth visit



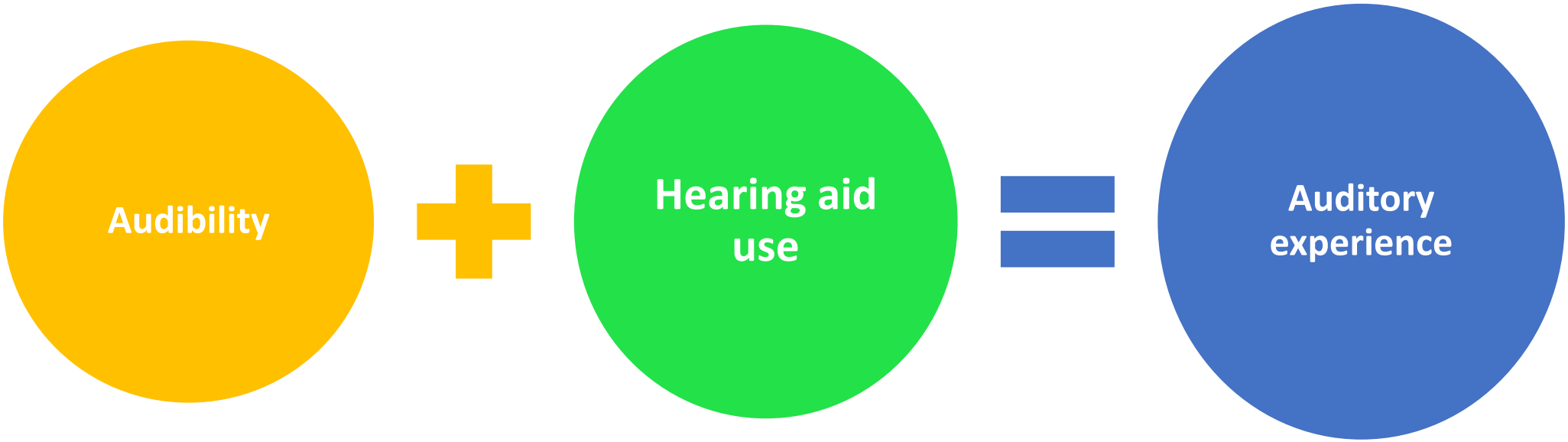
Caveats for OCHL

- Socioeconor
- Language ba
- Additional d
- Cochlear im

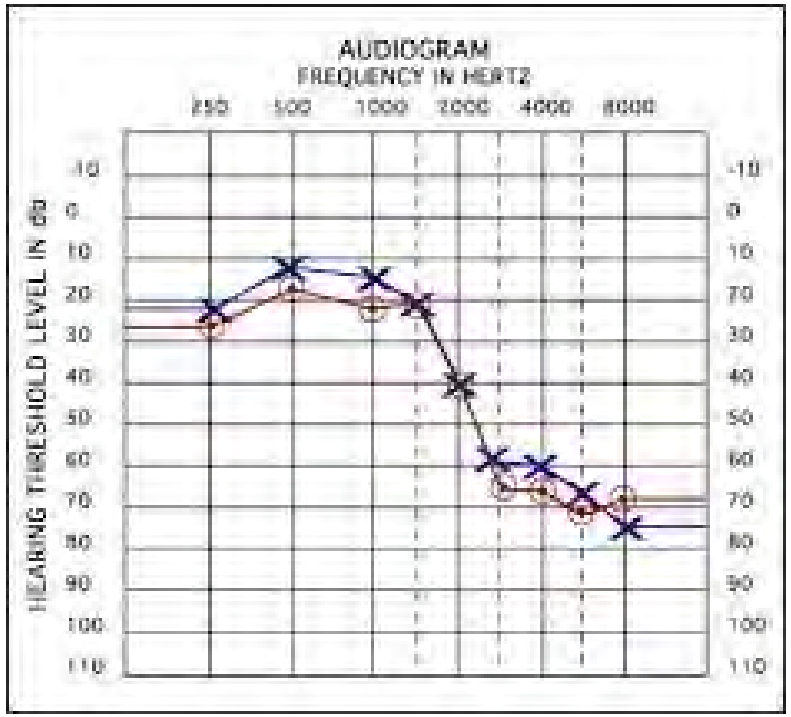
Outcomes may appear better than they would be in the general population

- Intro to OCHL
- Preschool-age CHH
  - Auditory access
    - Aided audibility
      - ANSD
    - HA use
      - Mild bilateral hearing loss
- School-age CHH
  - Academic and language outcomes

What about the influence of auditory access?

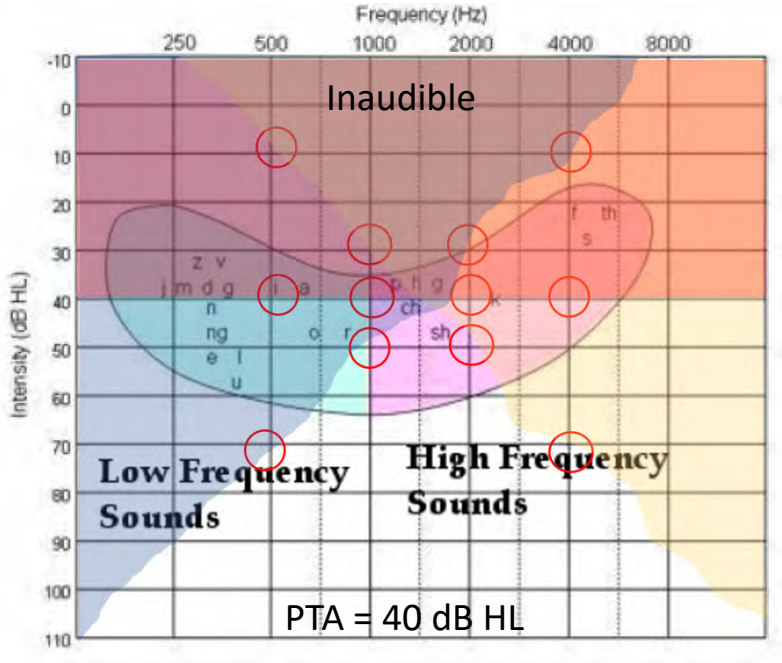


We hypothesize that access to speech will predict success for children who are HH



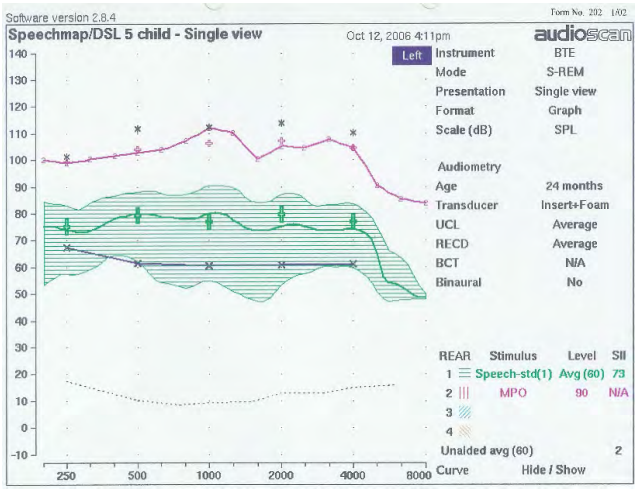
Most previous research looked at audiometric thresholds (i.e., PTA) as a predictor of success

What does PTA not tell us?



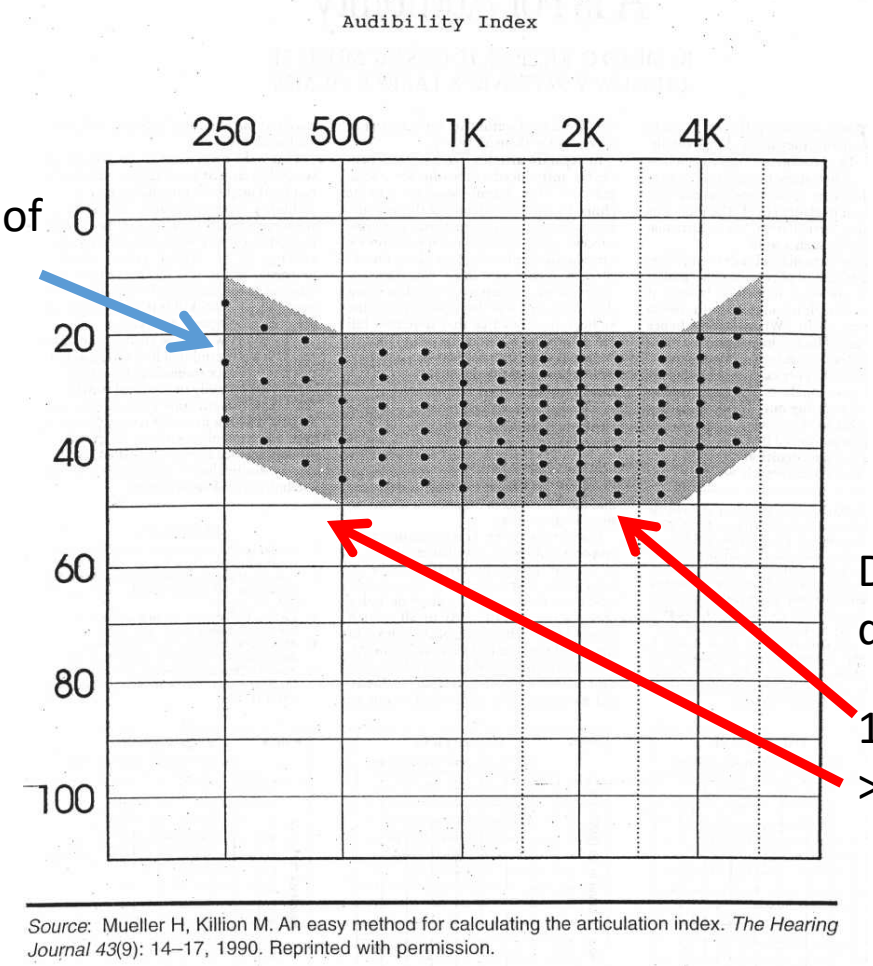
How different configurations may impact speech perception

How child will perceive speech with hearing aids (aided audibility)



How do we quantify aided audibility?....Speech Intelligibility Index (SII) (or “count the dots”)

Each dot represents ~1% of information contributing to speech clarity



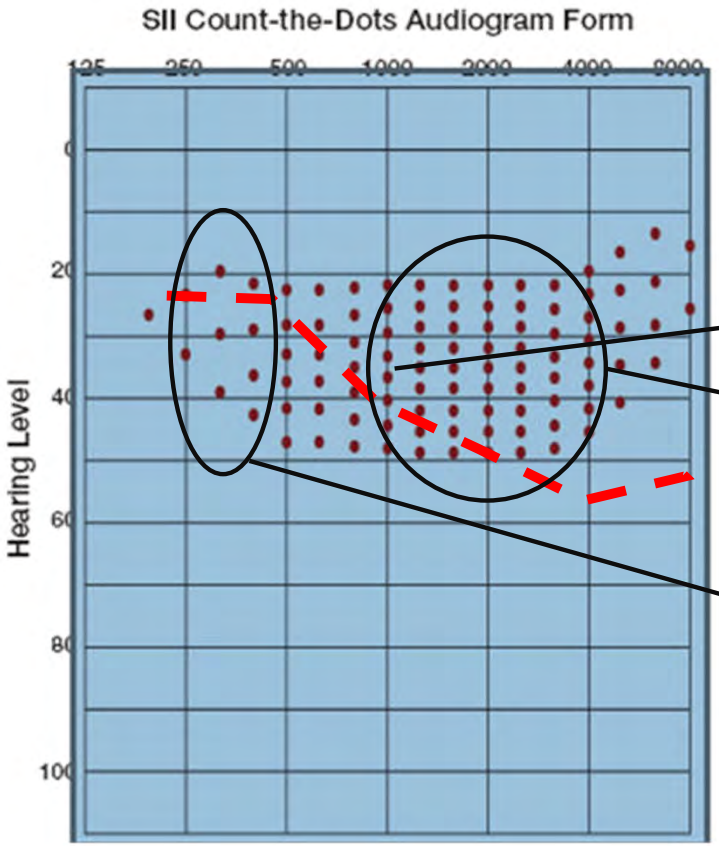
Source: Mueller H, Killion M. An easy method for calculating the articulation index. *The Hearing Journal 43*(9): 14–17, 1990. Reprinted with permission.

Number of dots that are audible predict how well one understands quiet speech from a six foot distance

Dots are unevenly distributed:

1000 and 3000 Hz > 250 to 500 Hz

How do we quantify audibility?....Speech Intelligibility Index (SII)



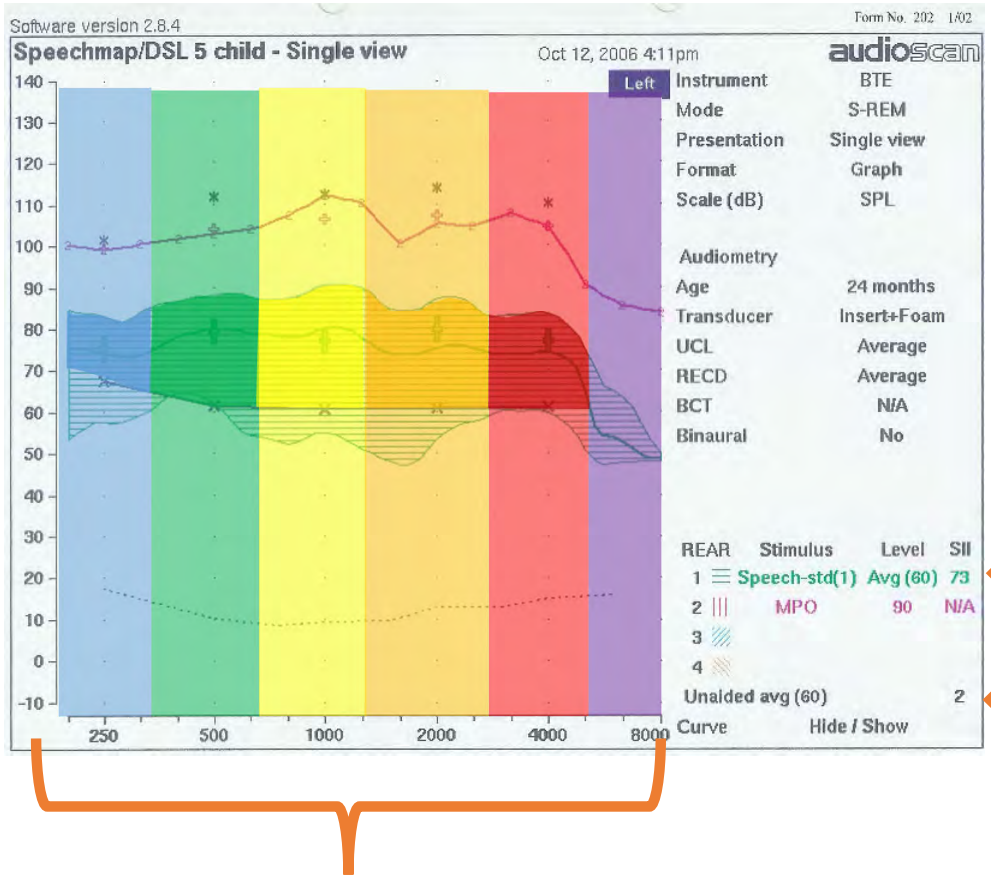
Not all frequencies are created equal—some contribute more than others to the intelligibility of speech.

Above line = dots inaudible; below line = dots audible

More dots=more important

Less dots=less important

Speech intelligibility index (SII)



For each band:
Audibility x FIW = weighted audibility

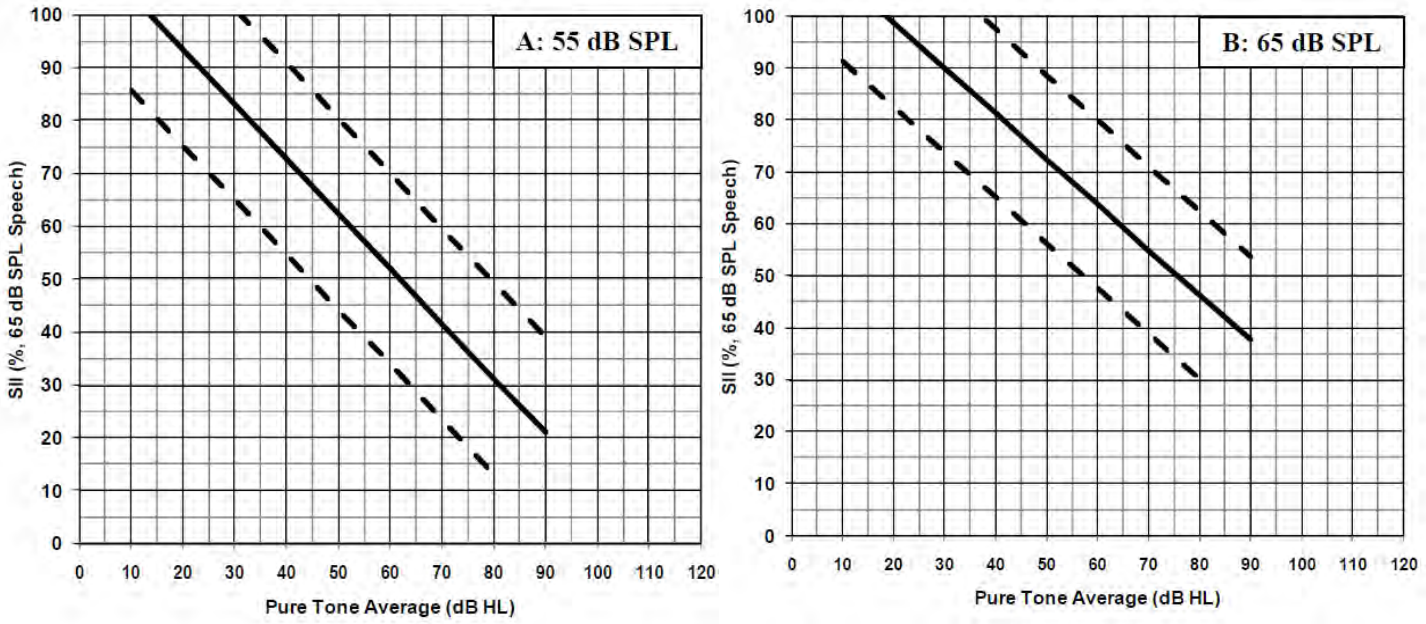
Aided SII

Unaided SII

SII = Sum of weighted audibility of all frequency bands

How much SII is enough?

- Depends on degree of loss and input level

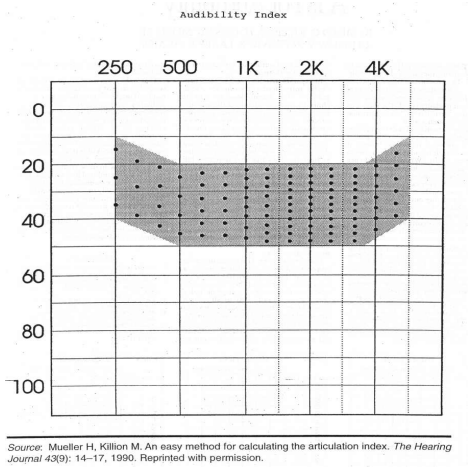


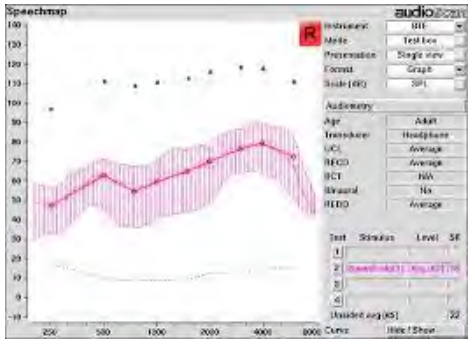
UWO PedAMP Protocol, 2010

Determining how close HA fittings are to target

"The characteristics of hearing aid fittings in infants and young children" (McCreery, Bentler, & Roush, 2013)

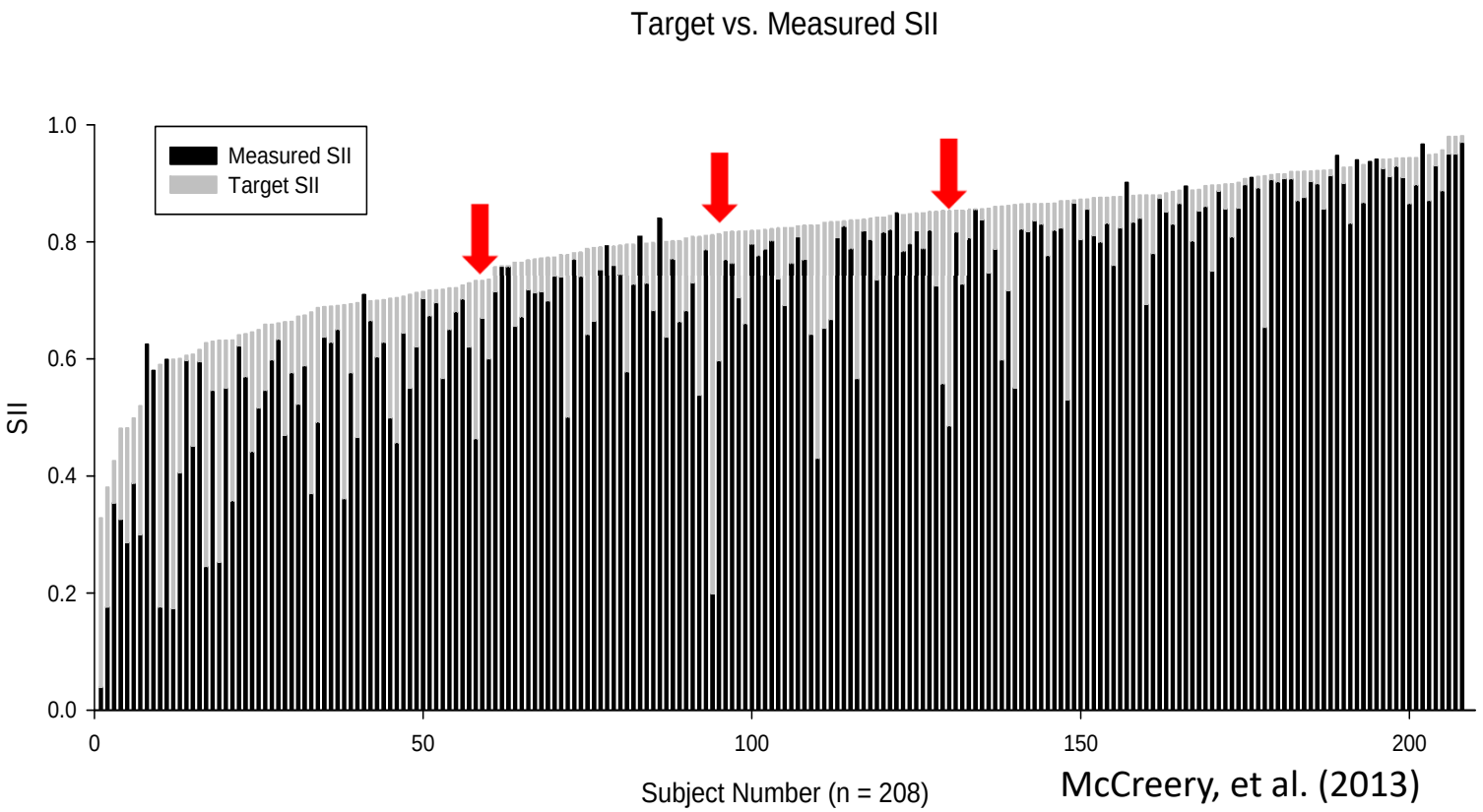
RMS = root-mean-square





Compare DSL target SII to **measured SII**	**RMS error** to DSL target at 4 frequencies
• 0-1, with 1 = completely audible	• RMS error < 5 dB = optimal HA fitting

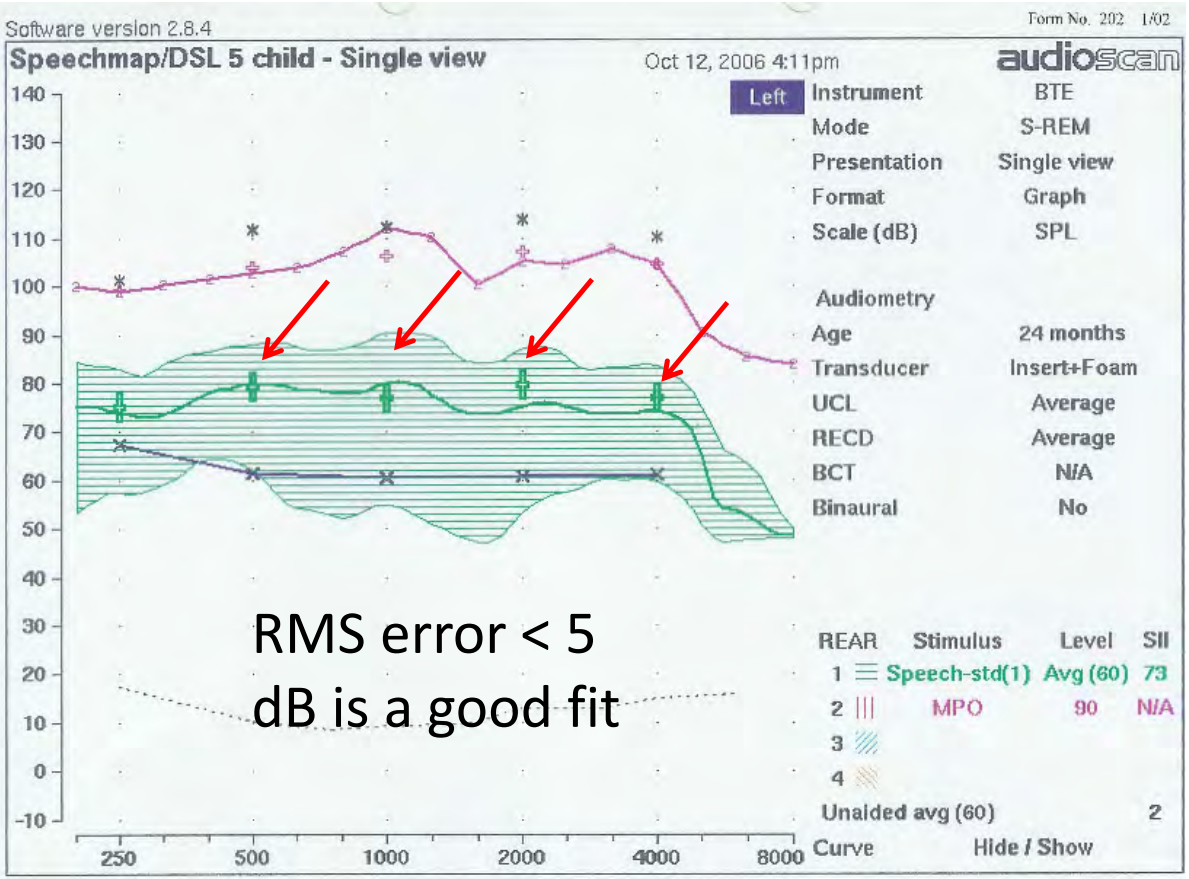
Can we assume children are fit to target?



McCreery, et al. (2013)

Conclusion: Substantial number of HA's could be fit better. Best practice in HA fitting matters for children's outcomes.

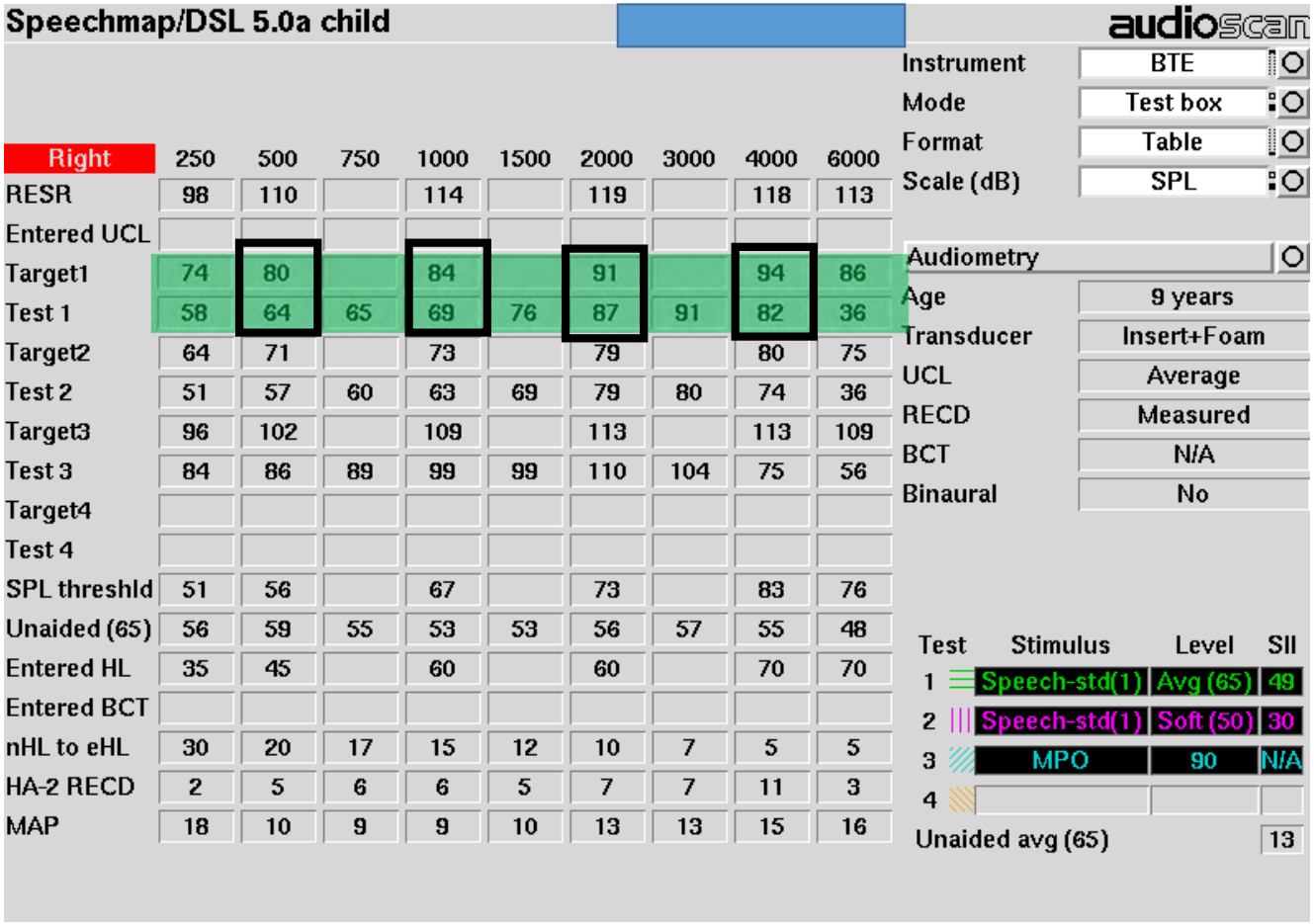
Target vs. Actual (RMS error)



Fitting data compared to DSL targets

Calculate RMS error of deviations from target at 5., 1, 2, and 4 kHz

How can you measure RMS error?



Speechmap/DSL 5.0a child

audioscan

Right	250	500	750	1000	1500	2000	3000	4000	6000
RESR	98	110		114		119		118	113
Entered UCL									
Target1	74	80		84		91		94	86
Test 1	58	64	65	69	76	87	91	82	36
Target2	64	71		73		79		80	75
Test 2	51	57	60	63	69	79	80	74	36
Target3	96	102		109		113		113	109
Test 3	84	86	89	99	99	110	104	75	56
Target4									
Test 4									
SPL threshld	51	56		67		73		83	76
Unaided (65)	56	59	55	53	53	56	57	55	48
Entered HL	35	45		60		60		70	70
Entered BCT									
nHL to eHL	30	20	17	15	12	10	7	5	5
HA-2 RECD	2	5	6	6	5	7	7	11	3
MAP	18	10	9	9	10	13	13	15	16

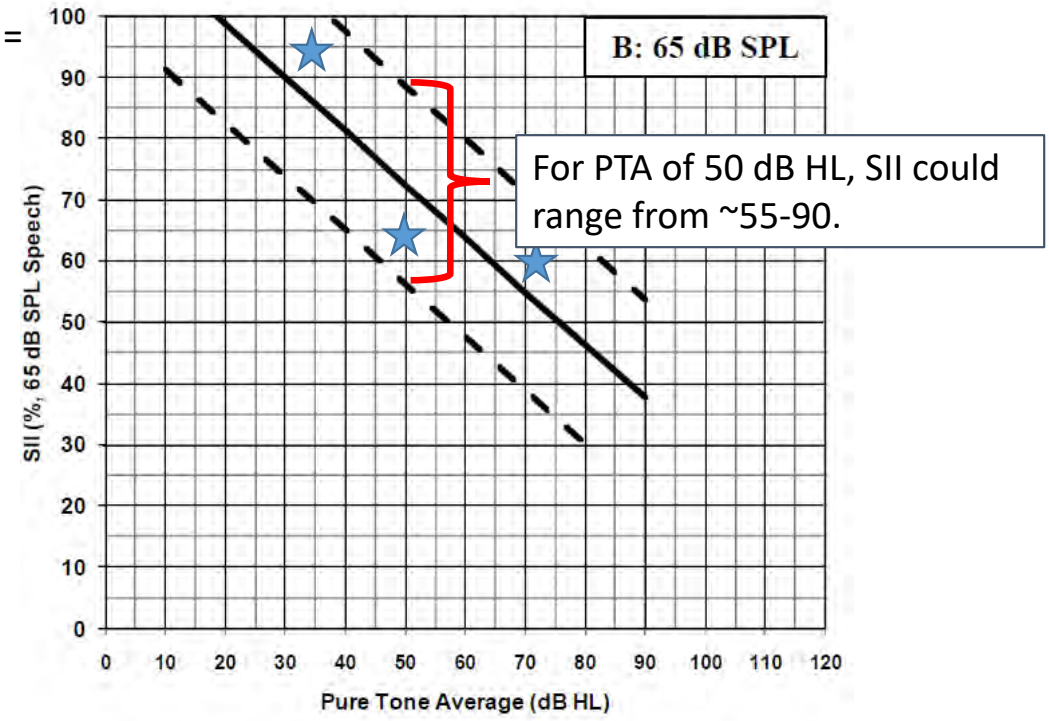
Instrument	BTE
Mode	Test box
Format	Table
Scale (dB)	SPL
Audiometry	
Age	9 years
Transducer	Insert+Foam
UCL	Average
RECD	Measured
BCT	N/A
Binaural	No

Test	Stimulus	Level	SII
1	Speech-std(1)	Avg (65)	49
2	Speech-std(1)	Soft (50)	30
3	MPO	90	N/A
4			

Unaided avg (65) 13

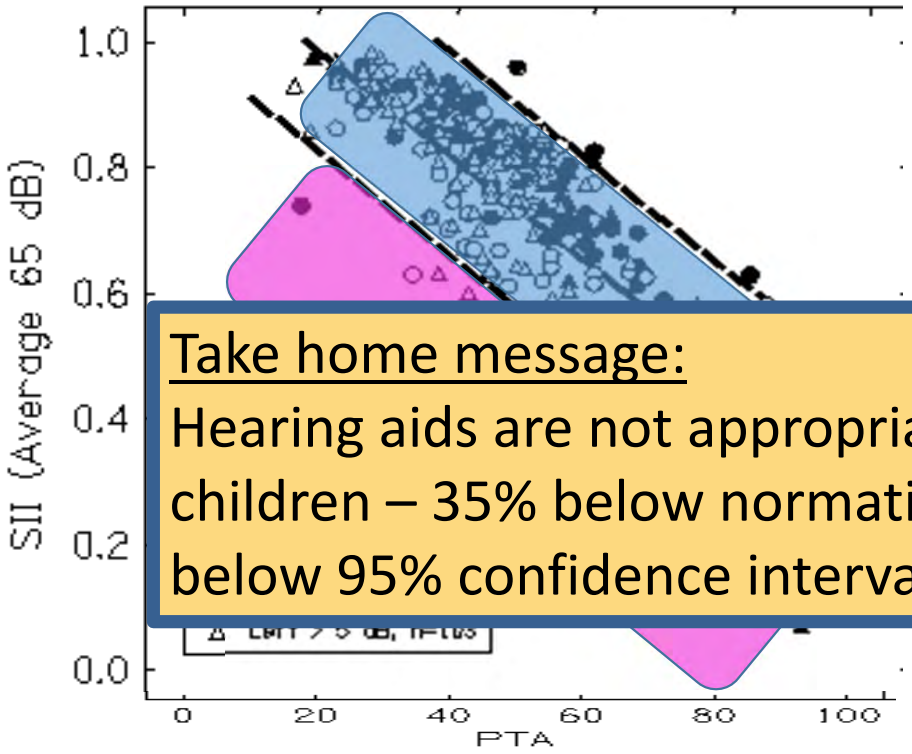
Confidence intervals for SII when hearing aids are fit appropriately

Below dashed line = poor fit



Bagatto, et al., 2011

Hearing aids are <u>not</u> optimally fit for all children

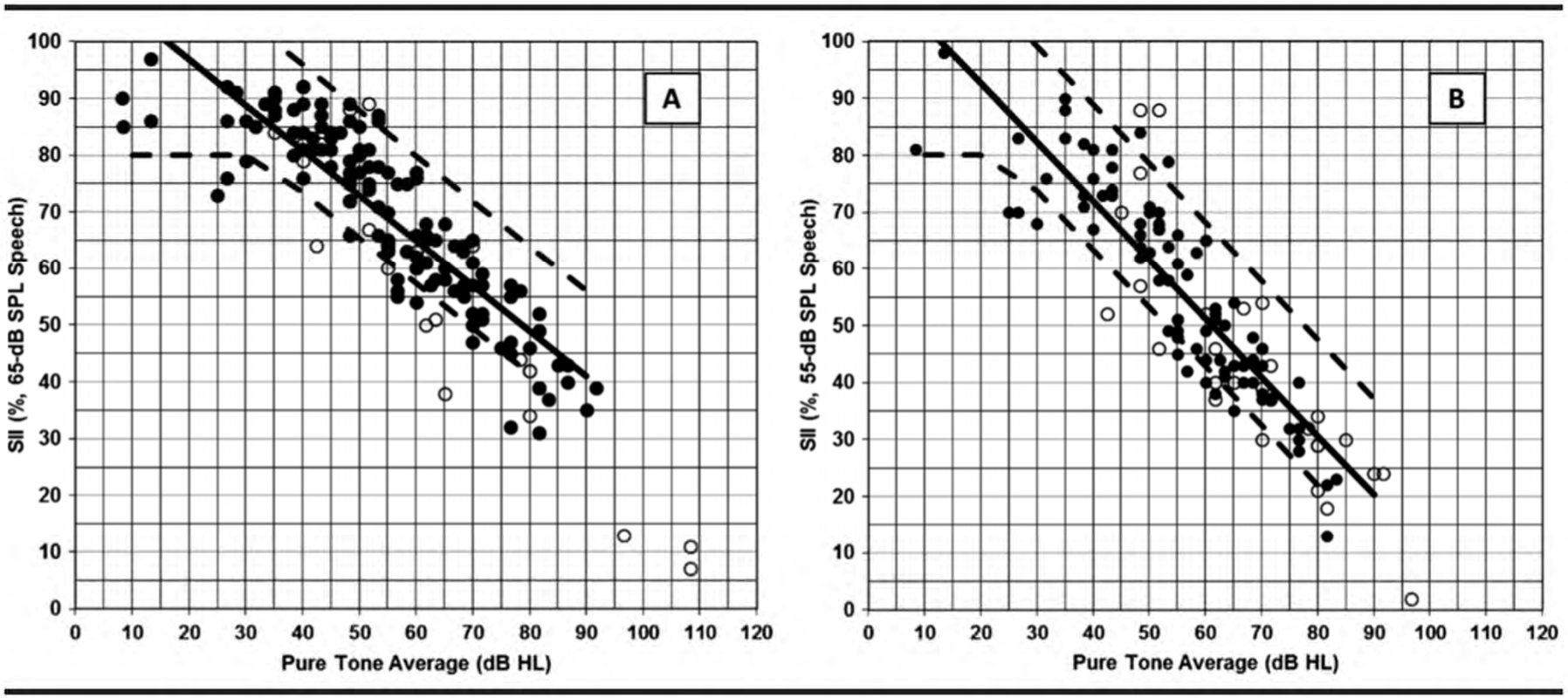


Below dashed line

<u>Take home message:</u>
Hearing aids are not appropriately fit for all children – 35% below normative mean, 10% below 95% confidence intervals

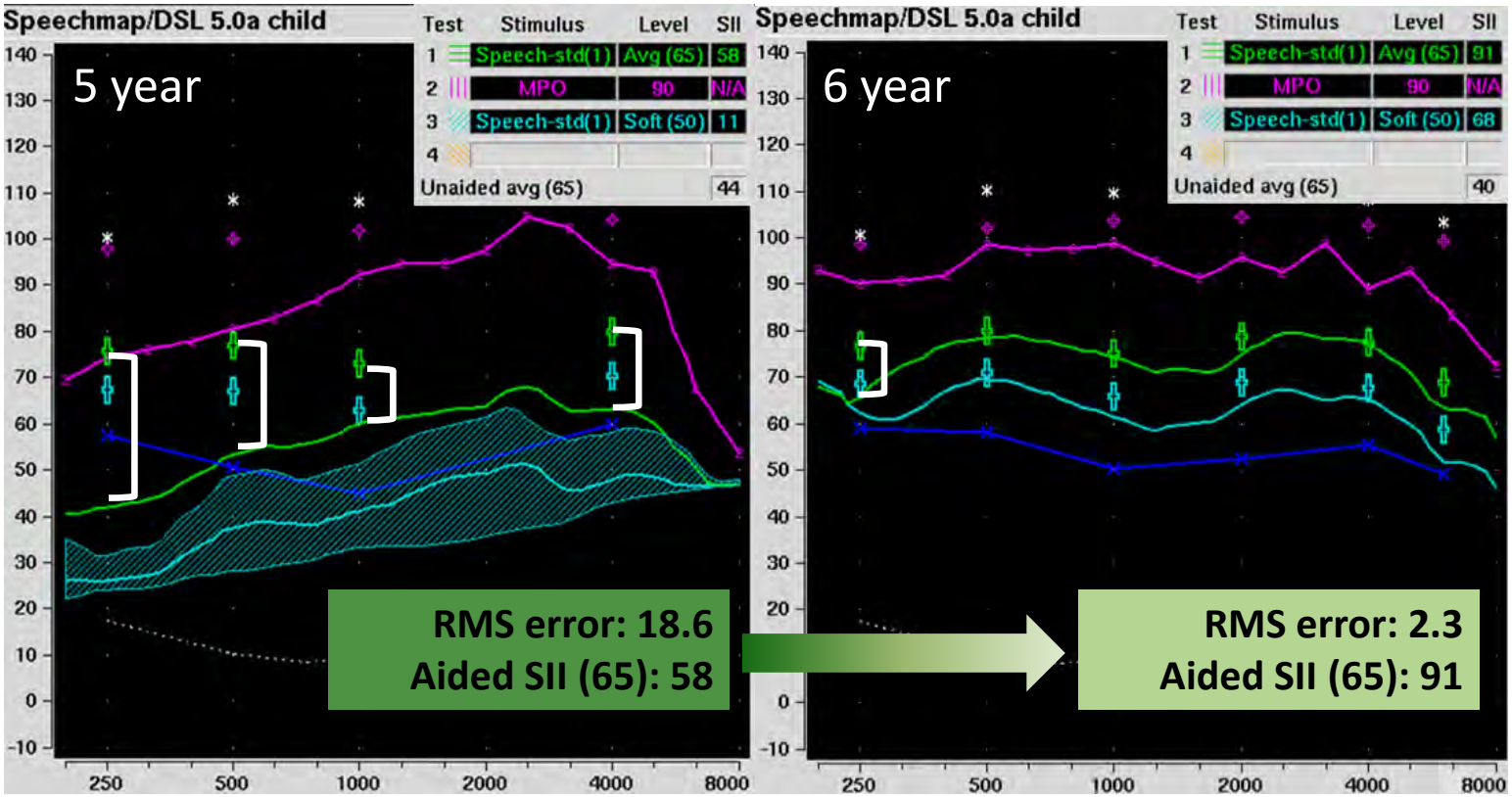
McCreery et al., *2015*

Evidence that optimal HA fittings can be achieved…



Moodie et al., 2017, AJA

Better match to targets → Better SII



What impacts quality of fitting?

Online survey

Audiologist's degree

Level of specialization with children

Techniques for HA verification

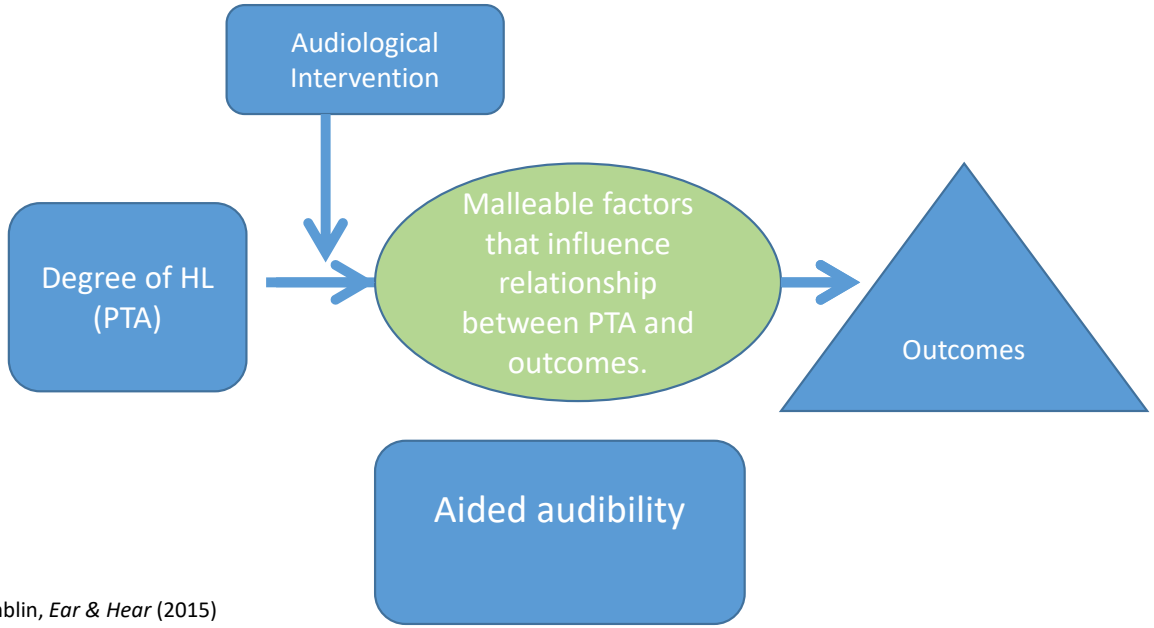
Accuracy of Verification methods

Probe microphone real ear measures
RMS error= 5.67 dB (SD = 3.95 dB)

Functional gain (aided soundfield)
RMS error=7.92 dB (SD = 4.67 dB)

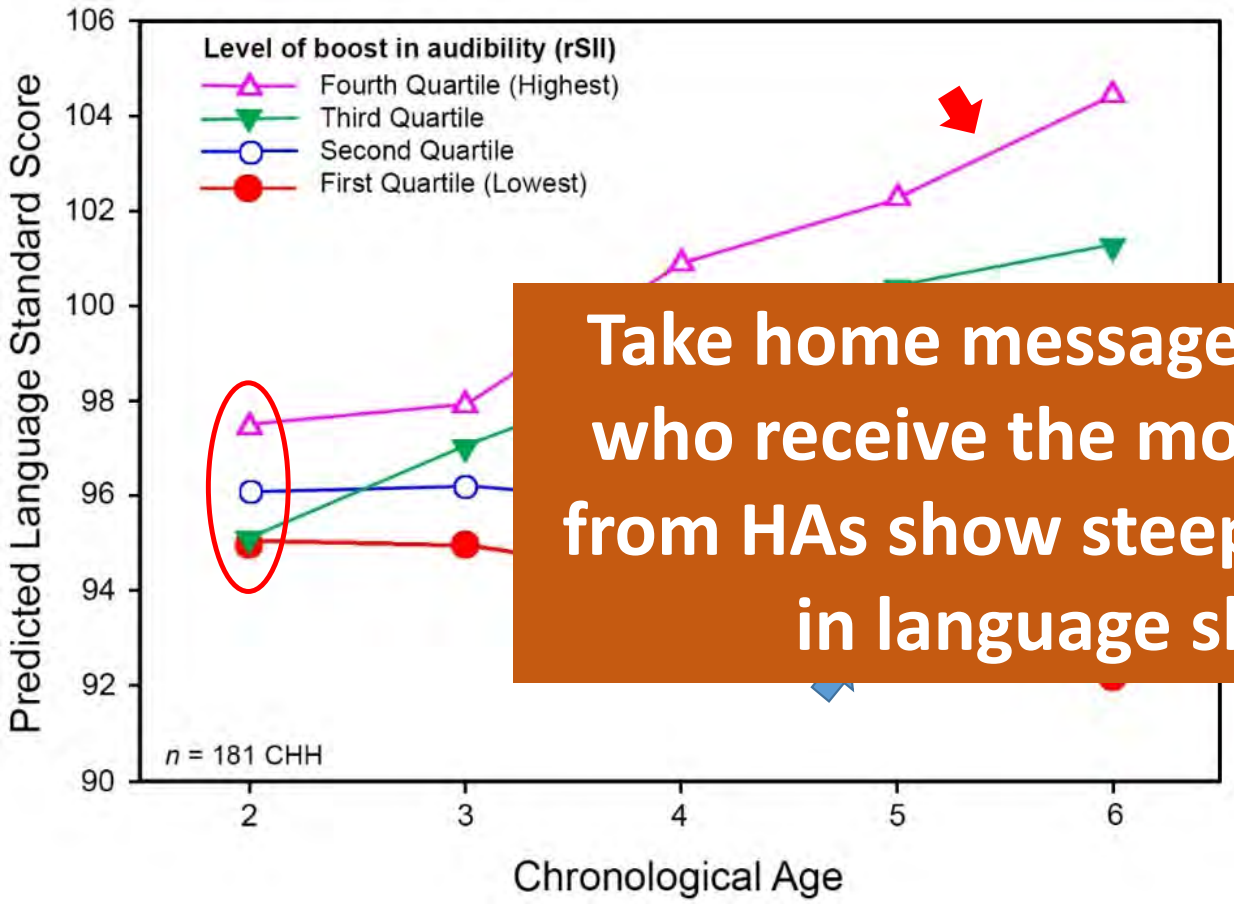
McCreery, Bentler, Roush, 2013

Does it matter if hearing aids are optimally fit?



Moeller & Tomblin, *Ear & Hear* (2015)

Aided Audibility Contributes to Language GROWTH



- **Quartiles of Aided Benefit**, after controlling for degree of loss

Take home message: Children who receive the most benefit from HAs show steeper growth in language skills

Tomblin, Harrison, Ambrose, Walker, Oleson, & Moeller, *E&H* (2015); McCreery et al., *E &H* (2015)

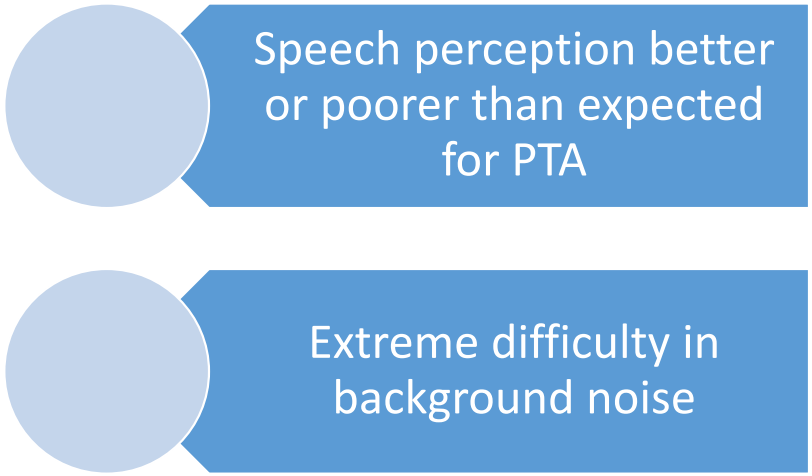
Clinical implications: Audibility

- Can't:
  - Control threshold change
  - Alter child's middle ear status
- Can:
  - Monitor threshold changes
  - Verify with real-ear probe mic measures
    - Measure RECD when not possible to do REAR on ear.
  - Adjust gain to match prescriptive targets

Fittings that are consistently matched to target are more likely to have high audibility over time!

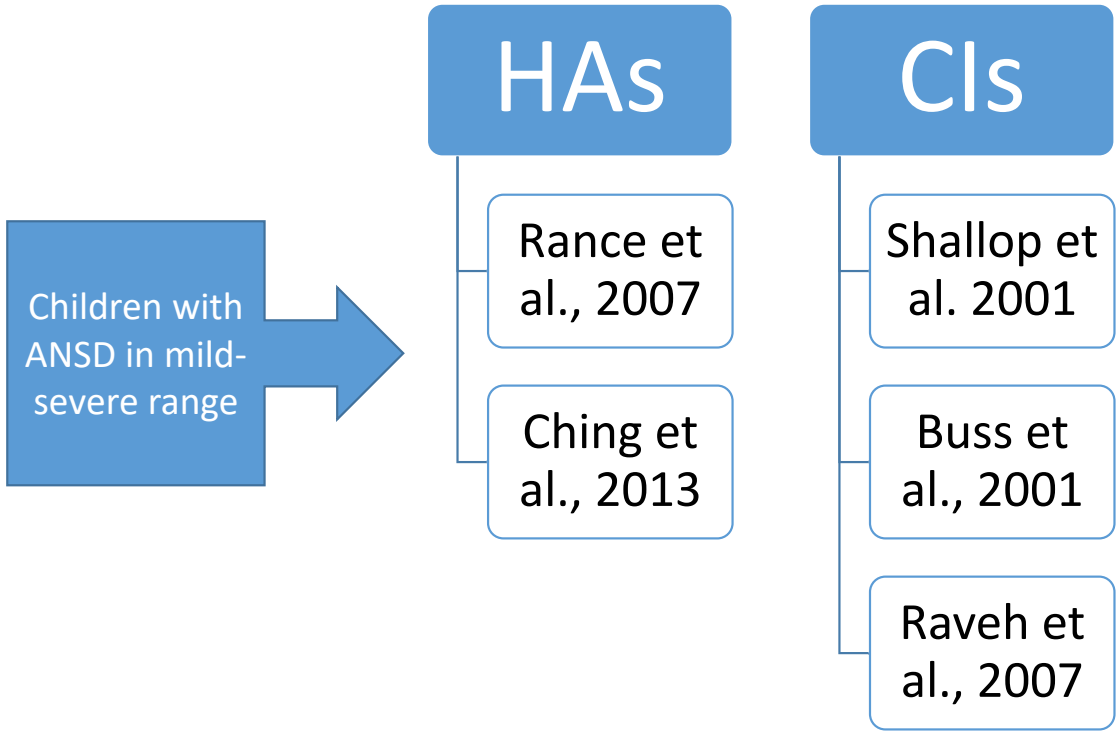
Special Populations: ANSD

- Abnormal neural response, but normal pre-neural cochlear response



https://www.youtube.com/watch?v=IY5YIiu_4t4

Ambiguity regarding clinical management for ANSD



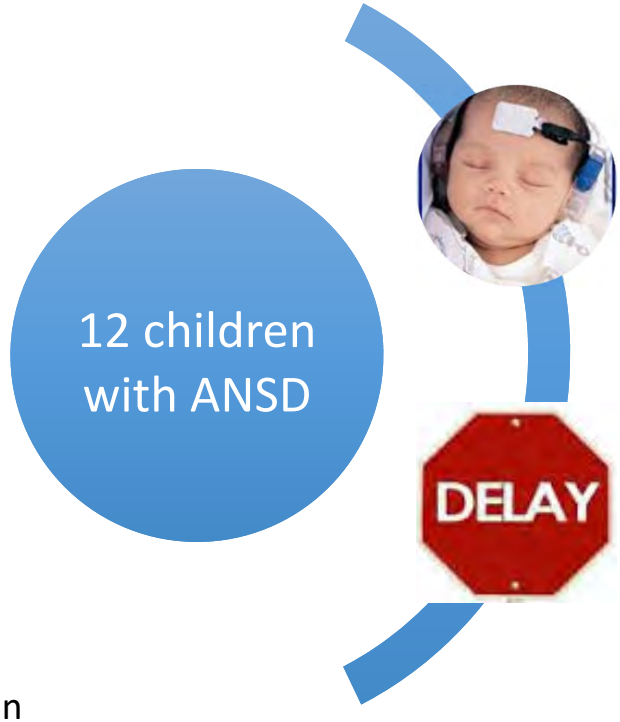
American Academy of Audiology Clinical Practice Guidelines

Pediatric Amplification

June 2013

Children with Auditory Neuropathy Spectrum Disorder (ANSD) should have a trial with amplification as soon as it can be established that hearing sensitivity is sufficiently poor that speech at conversational levels will not be easily audible. Because neither the auditory brainstem response (ABR) in children with ANSD, nor the presence or absence of otoacoustic emissions provides a valid estimate of behavior threshold, amplification should only be provided based on behavioral observations (by the clinician and by parents) until reliable behavioral thresholds can be established. Children with ANSD may or may not demonstrate improvements in speech understanding with the provision of amplification. Based on the potential for improved speech recognition and the difficulty in predicting hearing aid benefit from audiological characteristics, a trial with appropriately fit amplification for children with ANSD is recommended prior to candidacy evaluation for cochlear implantation. Until hearing thresholds can reliably be established, careful observation of the responsiveness of the child to sounds while wearing hearing aids is essential, with adjustments to the degree of amplification as necessary. Alternatively, information about the audibility of speech with and without hearing aids can be obtained from assessment of cortical responses evoked by speech sounds.

Children with ANSD fitted with hearing aids applying the AAA Pediatric Amplification Guideline: Current Practice and Outcomes



How do children with ANSD compare to children with SNHL in terms of characteristics of amplification?

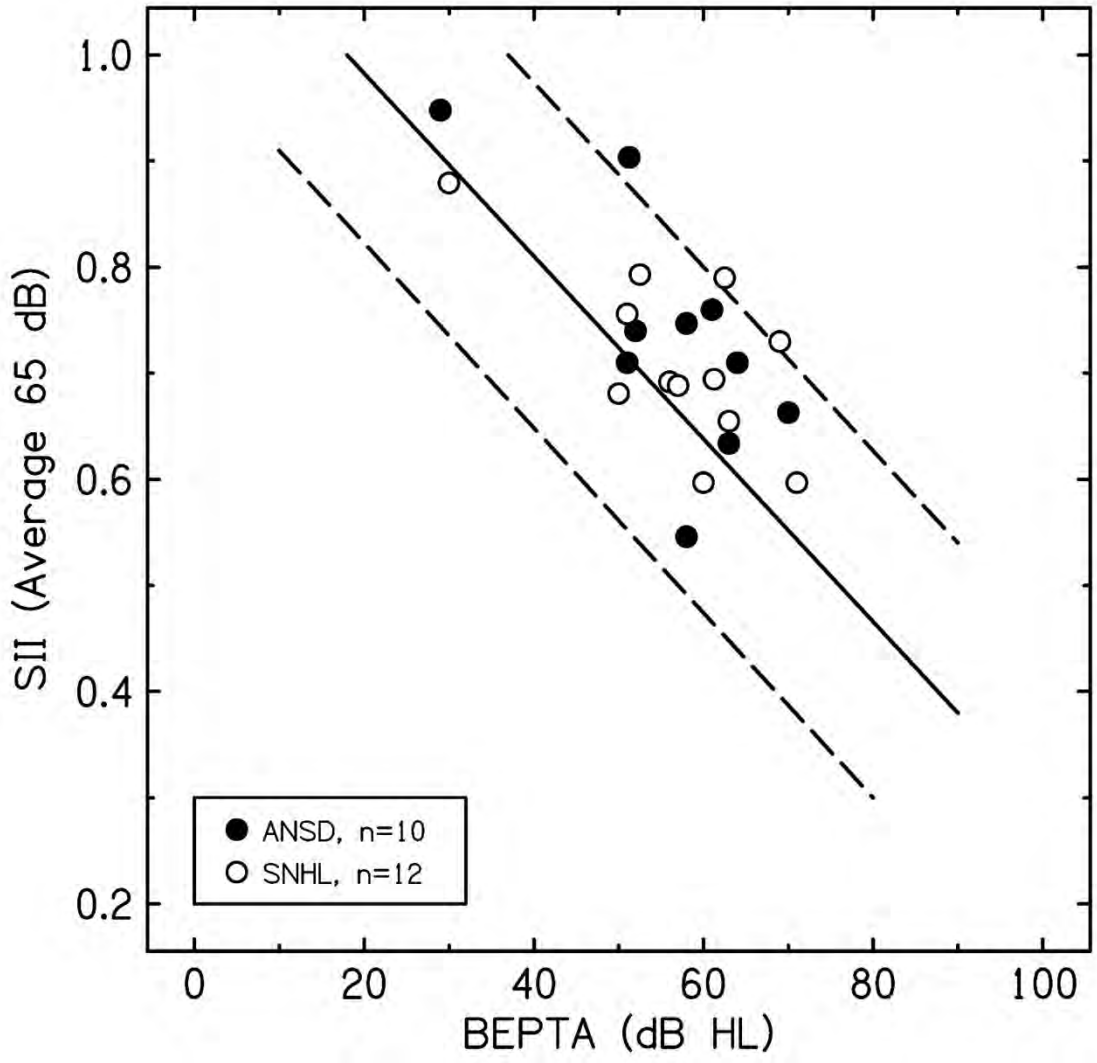
How do children with ANSD compare to children with SNHL on outcomes?

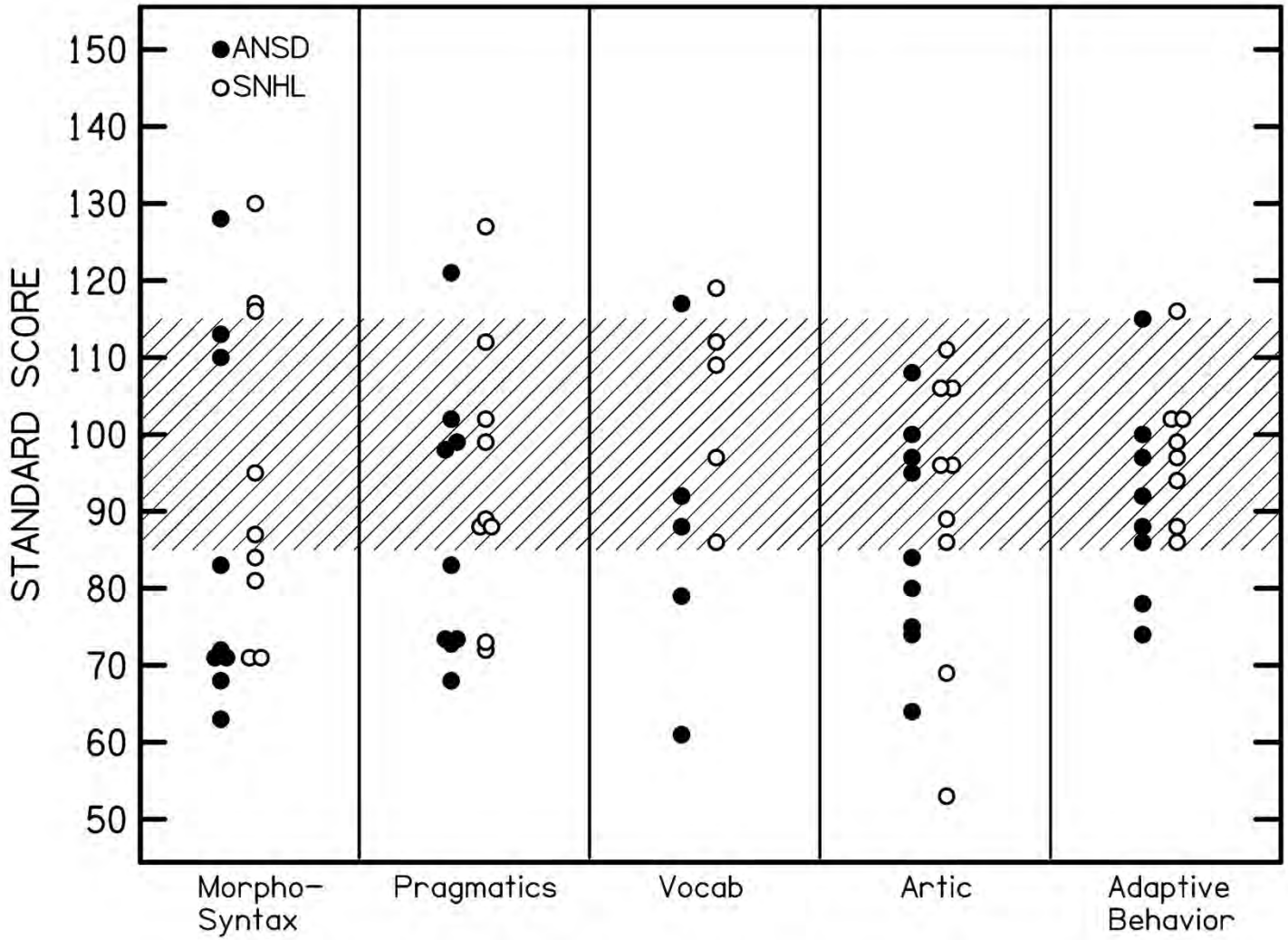
Walker et al., in press, JAAA

ANSD group and SNHL matched on…

- Gender
- Maternal education level
- Chronological age
- Better ear PTA
- Better ear SII
- NHS status (IDed or not ID-ed)
- All participants (ANSD and SNHL) fit according to best-practice guidelines (AAA, 2013)

	ANSD (n=12)				SNHL (n=12)				p-value
Test variable	**Mean**	**Med**	**SD**	**range**	**Mean**	**Med**	**SD**	**range**	
Better Ear PTA (dB HL)	56.96	58	11.11	29-71.25	56.88	58.13	10.74	30-71	.90
Better Ear SII	.74	.73	.12	.55-.95	.72	.69	.08	.60-.88	.58
Amount of daily HA use (parent report in hours)	11.46	12	2.11	6.71-15	12.33	12.25	1.78	9-15	.31
Age at Service Delivery (months)									
First evaluation[a]	8.42	4	10.64	1-36	6.25	2	8.74	.5-25	.17
Confirmation[b]	8.95	5.25	10.67	1-36	7.3	2	9.80	.5-25	.31
HA fitting[c]	13.73	12	9.48	4-38	8.18	4	9.48	1.5-27	.005*
Entry into early intervention[d]	10.73	6	11.22	3-41	7.05	3.5	7.04	1-24	.25

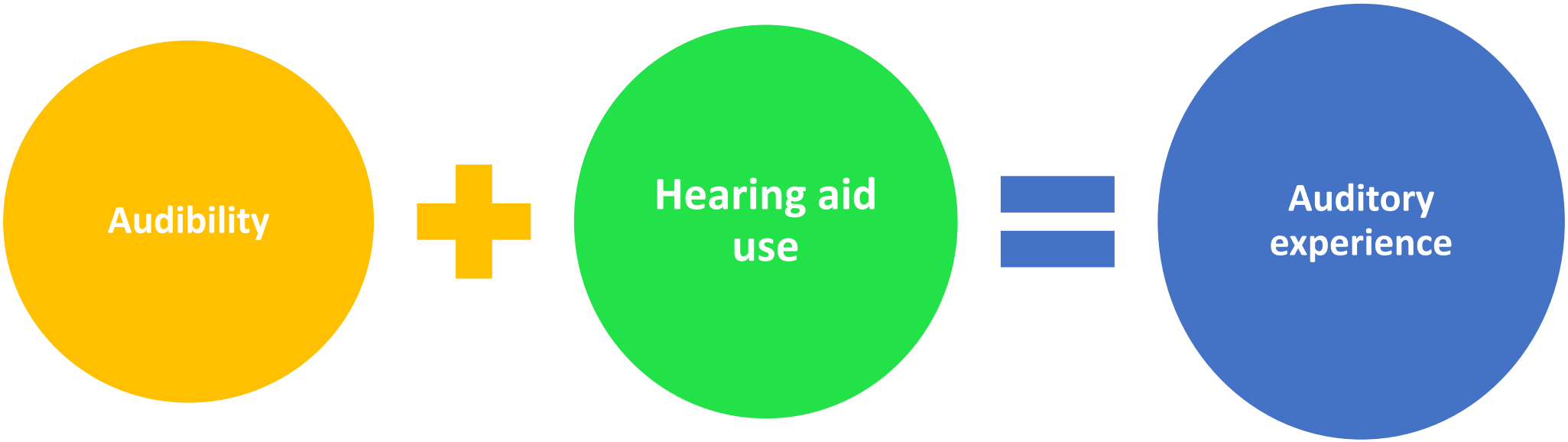

1.0
0.8
0.6
0.4
0.2
SII (Average 65 dB)
0
20
40
60
80
100
BEPTA (dB HL)
ANSD, n=10
SNHL, n=12


ANSD
SNHL
STANDARD SCORE
150
140
130
120
110
100
90
80
70
60
50
Morpho-
Syntax
Pragmatics
Vocab
Artic
Adaptive
Behavior

ANSD: Summary

- No significant differences between groups on speech, language, auditory skills
- For children with ANSD in the mild to severe hearing loss range, the current results appear to support the AAA Pediatric Amplification Guidelines.
- Caveat: selective group of children with ANSD, no major secondary disabilities, who did not qualify for cochlear implantation

What about the influence of auditory access?



How often do CHH wear their HAs?

272 children with hearing aids

Which factors predict HA use time in children who are hard of hearing?

How consistently do children wear HAs in different settings?

Walker et al., 2013

How did we measure amount of daily HA use?

Subjective

Objective

Hearing aid questionnaire

average # of hours per day

Hearing aid data logging

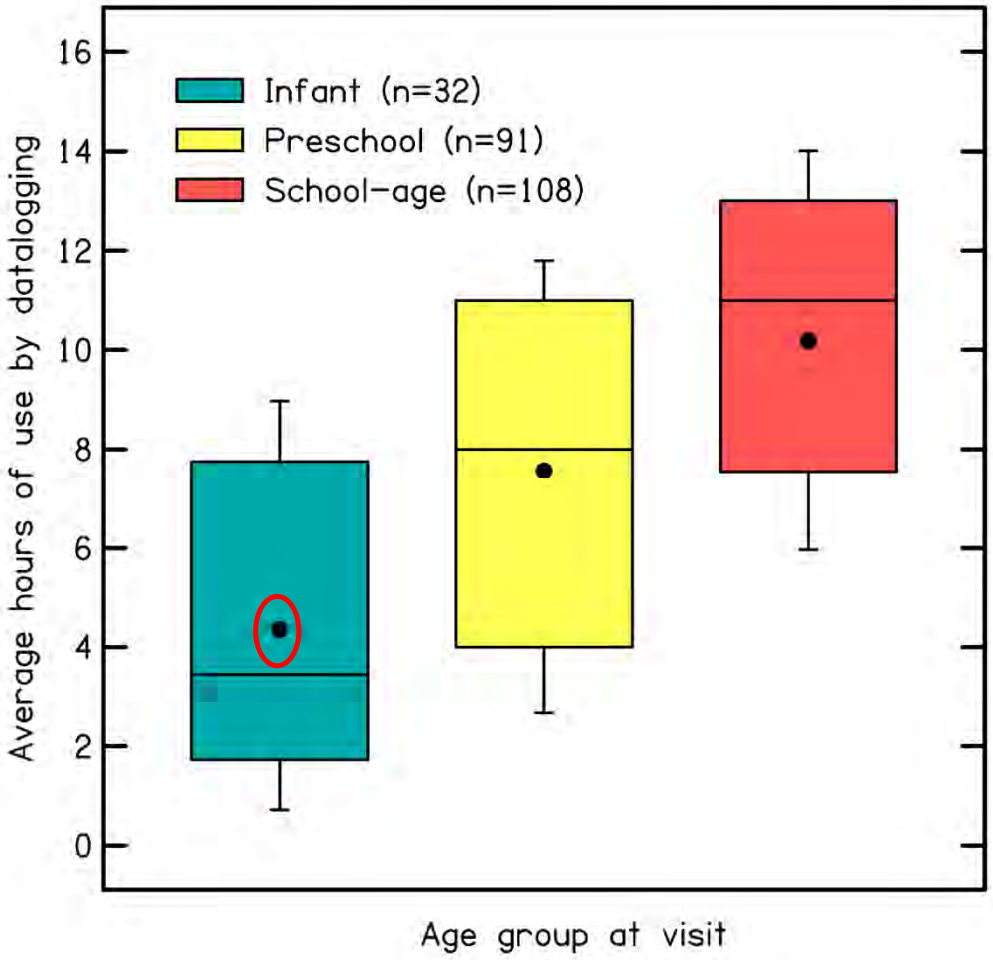
Measuring hearing aid use consistency

Put an X in the boxes below to indicate how consistently your child uses HAs in the situations listed:

Situation	Never (0)	Rare (1)	Sometimes (2)	Often (3)	Always (4)	N/A
Car						
Pre-School/School						
Day Care						
Meal Time						
Playing Alone						
Book Sharing						
Playground						
Public (store, zoo)						

Walker et al., 2013
www.ochlstudy.org

What we know about HA use



- At-risk for low use:
  - Younger age
  - Mild HL
  - Low SES

Walker, et al., 2013

Parental “disconnect” with mild HL

7. Current use time: @ School

8. How many **hours a day** does your child currently wear the aid(s)?

Monday-Friday 7

Saturday-Sunday 0

Put an X in the boxes below to indicate how consistently your child uses HAs in the situations listed:

Situation	Never (0)	Rare (1)	Sometimes (2)	Often (3)	Always (4)	N/A
10. Car	X					
11.PreSchool/School					X	
12.Day Care	X					
13.Meal Time	X					
14.Playing Alone	X					
15.Book Sharing	X					
16.Playground	X					
17.Public (store, zoo, restaurant)	X					

18. Describe any other situations when the child does not typically wear the hearing aid (not covered above). @ home

20. Has your child been without her/his hearing aid(s) for an extended period of time (>7 days) in the past year? X Yes ___No

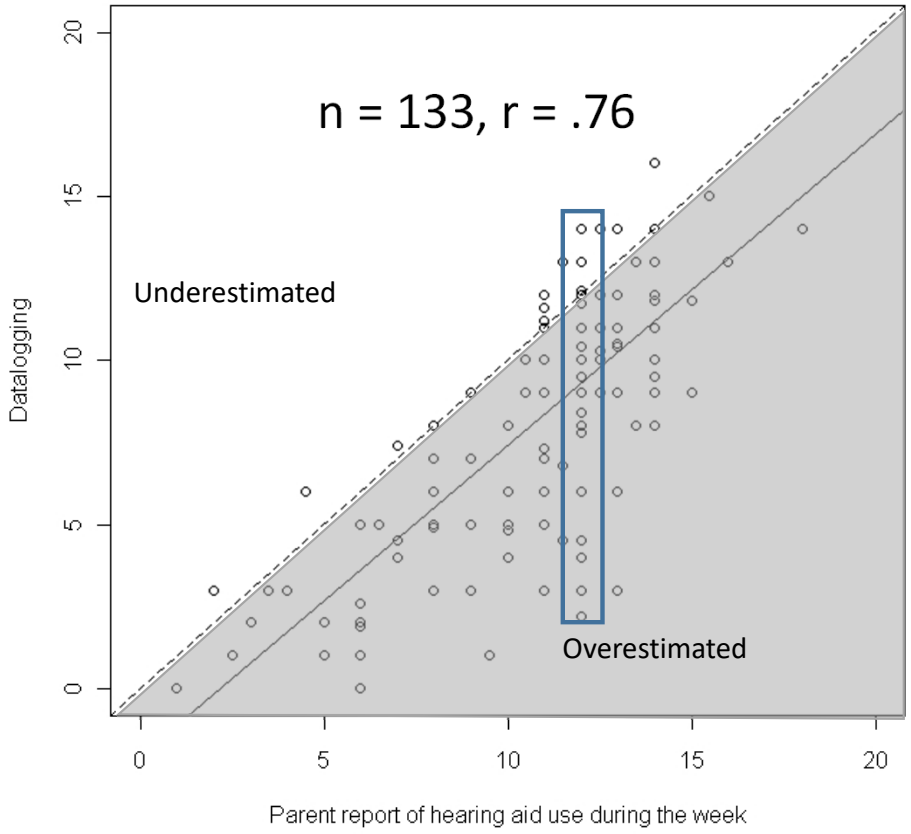
21. If yes, please estimate how long your child was without hearing aid(s)

___8-14 days ___15-21 days ___22-30 days ___1-2 months

X 2-3months ___3-6 months ___6-12 months ___>12 months

22. Were one or both ears affected? ___One ear X Both ears

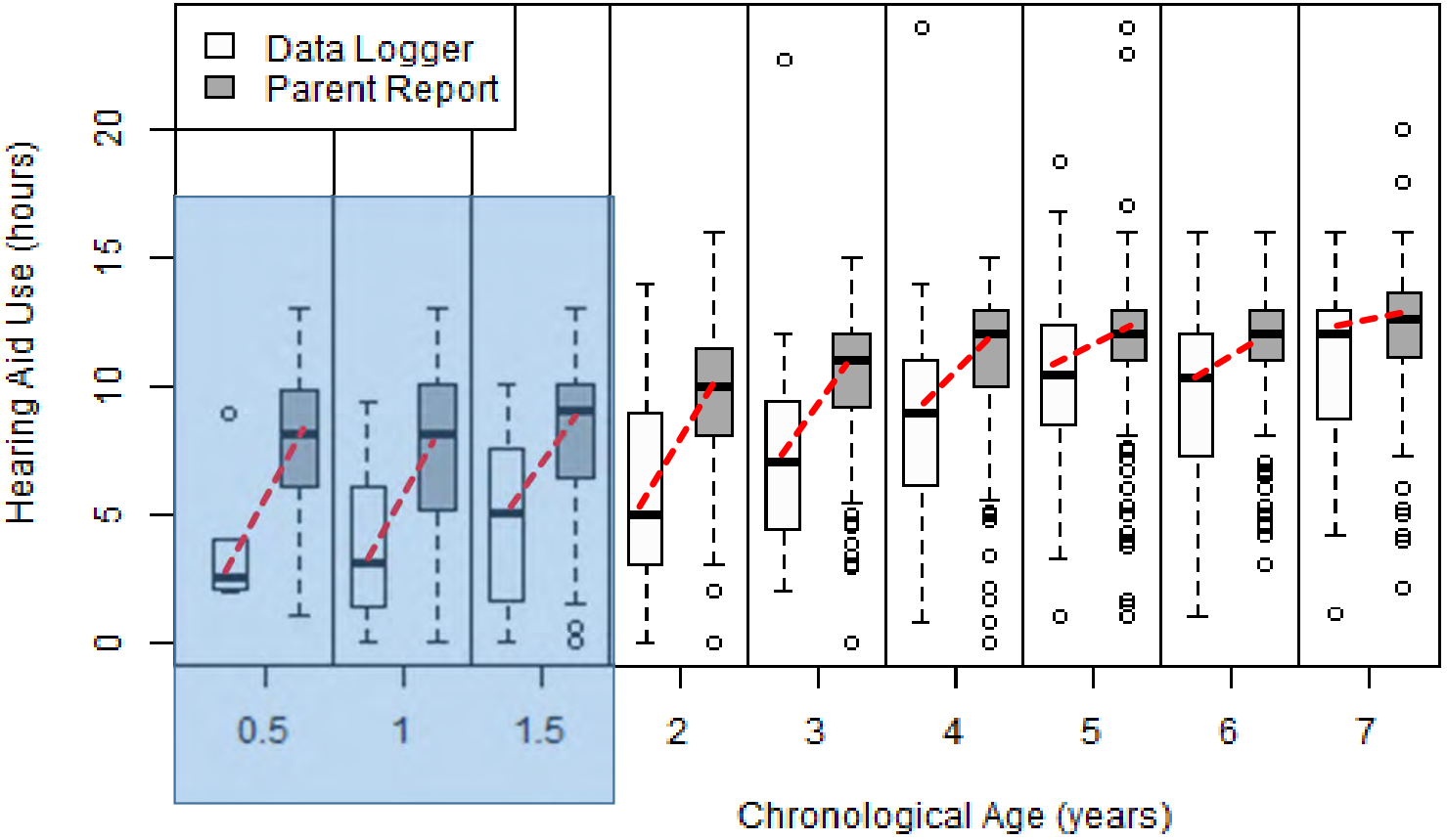
Are parents accurate at estimating daily hearing aid use time?



- Parent report = 10.84 hours
- Data logging = 8.3 hours
- Average difference = 2.6 hours
- As children get older, parents become more accurate reporters

Walker et al, 2013

As children get older, parents become more accurate reporters

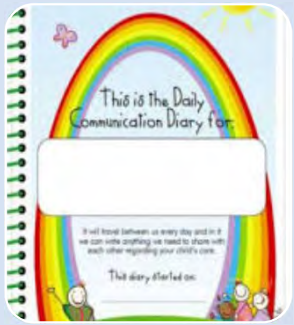


Walker et al., 2015

How can we help with consistency of use?

Find times when initial use is most practical

Give parents retention options (Karen Anderson's webpage)

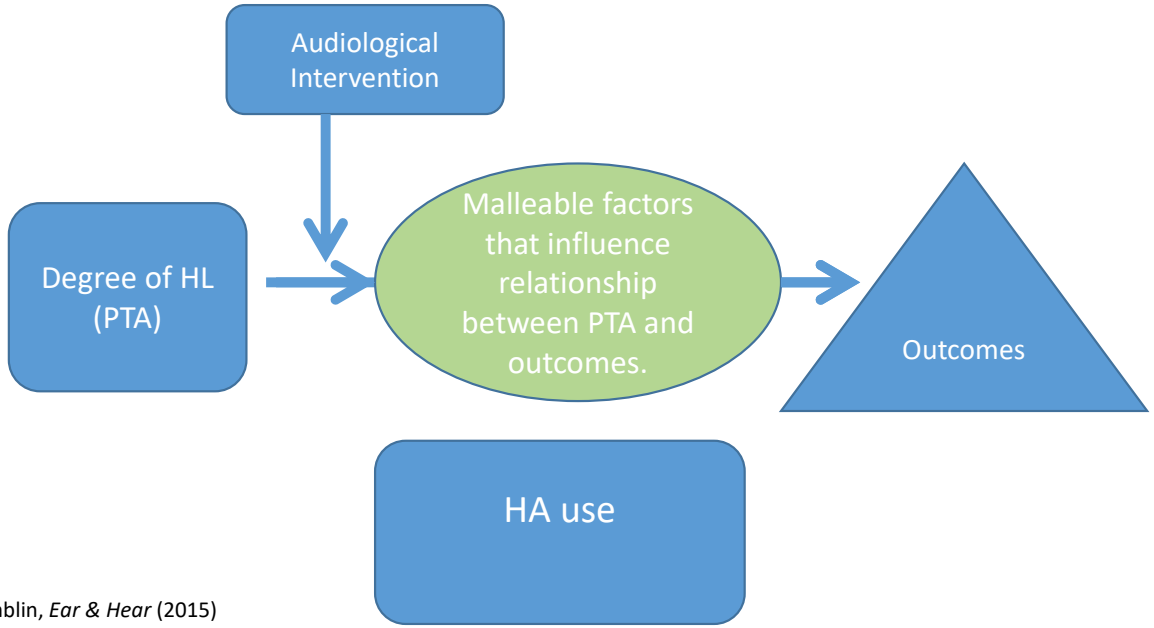


Communication diary

Datalogging

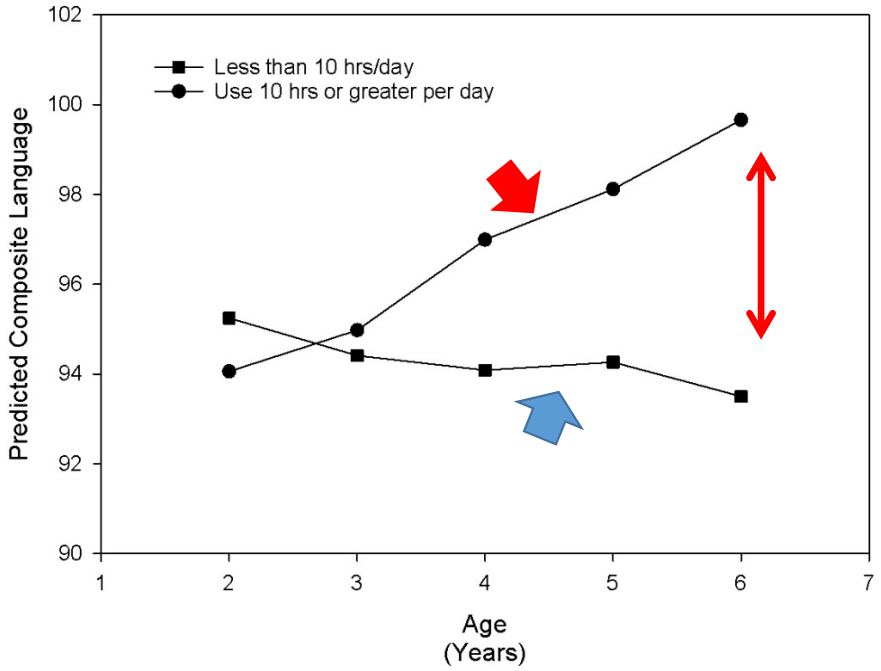
Emphasize link between auditory stimulation and later language and reading skills

Does it matter if hearing aids are worn consistently?



Moeller & Tomblin, *Ear & Hear* (2015)

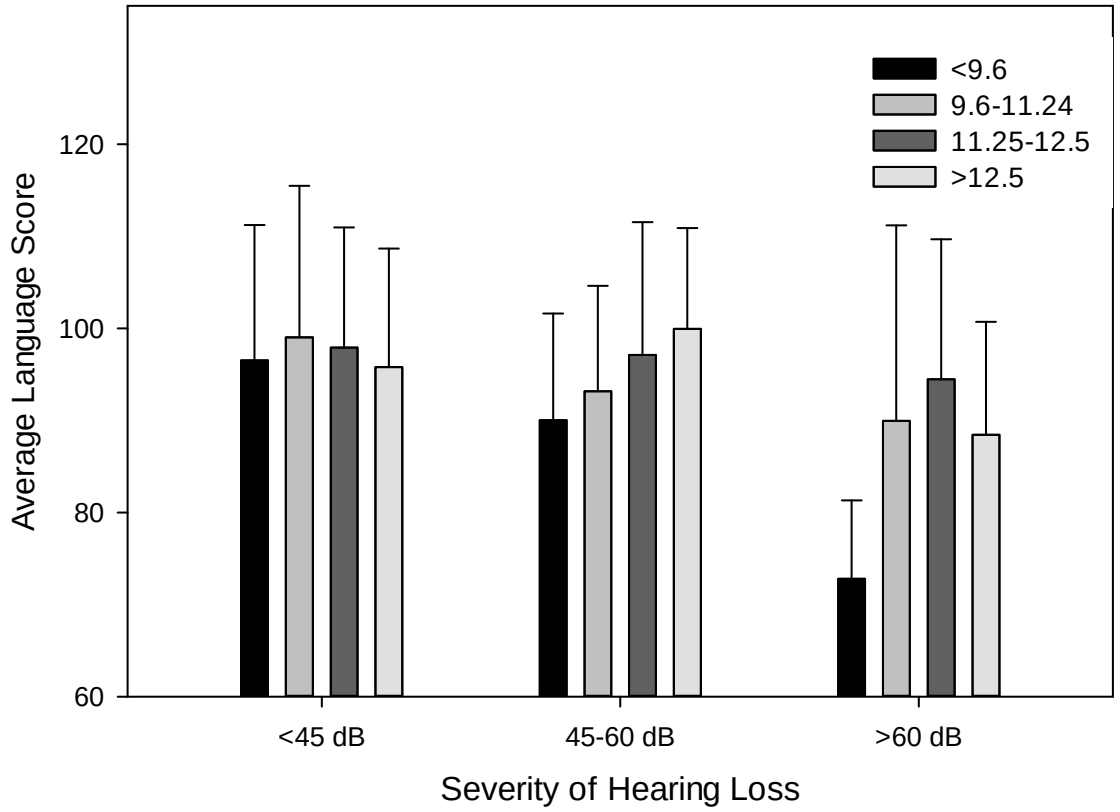
Consistent HA Use Benefits Growth



Conclusion: Children who wear HAs more than 10 hours/day show steeper growth in language skills than children wearing HAs less than 10 hours/day

Tomblin et al., *E&H* (2015)

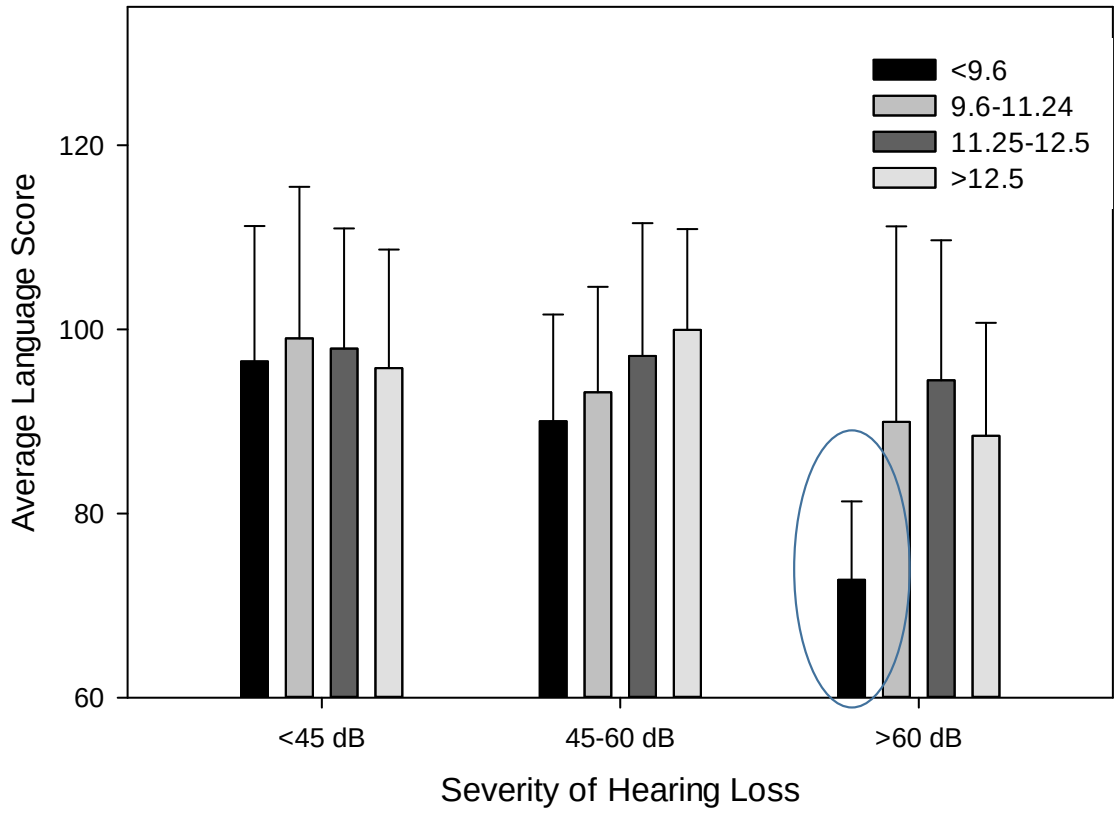
Language scores as a function of degree of HL and amount of HA use



For every hour of HA use, language scores improve by .5 point

Tomblin et al., 2015

Language scores as a function of degree of HL and amount of HA use



Average language standard scores for low users with severe HL = 73

Clinical implications: HA use

- May not see immediate results from wearing HA
  - Counsel on realistic expectations & stress importance of auditory access in the long run.
- Support and teach families to regularly wear devices & check audibility to ensure good access to speech.
  - Target situations of low use.
  - Emphasize quality over quantity.

Special populations: Are there differences in outcomes for children with mild hearing loss, as a function of amount of hearing aid use?

- Vocabulary
- Articulation
- Grammar
- Phonological processing
- Speech recognition in noise

Situation of “clinical equipoise” regarding benefits of HAs for children with mild hearing loss

Current evidence base

- Chi
  are
  (Bess
  Davis
  al., 20
- Oth
  min
  mild HL on outcomes, with ambiguity re. HA benefit (Porter et al., 2014; Wake et al., 2006)

Limitations of past studies

- Mild
- R
- scribe
- f
  daily HA use on outcomes
- However, >33% of children with mild HL do not wear HAs consistently (Fitzpatrick et al., 2010)

Can hearing aids make a difference?

HA use groups	n=	Average HA use (hrs)
Full-time (>8.7 hrs)	14	10.99
Part-time (2-8.3 hrs)	15	5.58
Nonusers (<2 hrs)	9	0.11

Significant differences:

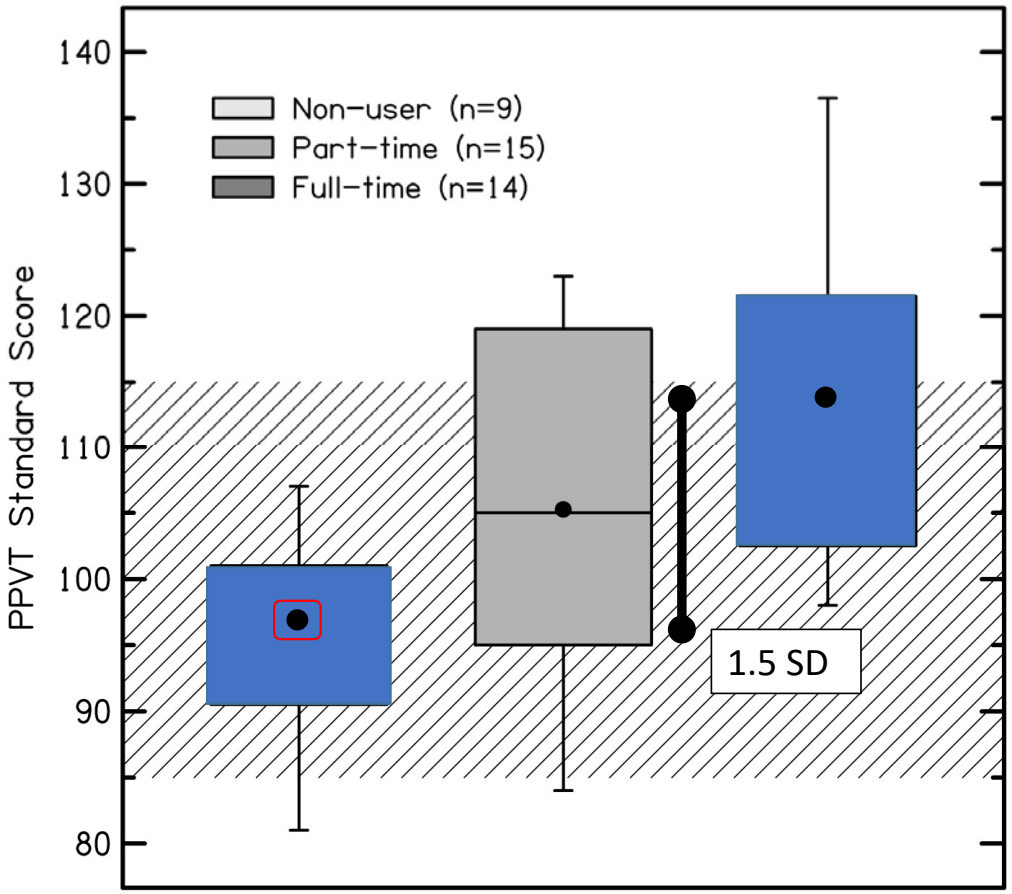
- **Better ear pure tone average (nonusers > part-time, full-time)**

No significant differences between the three groups:

- **maternal education levels**
- **nonverbal IQ**
- **level of audibility**

Full-time HA users had better vocabulary skills than non-users

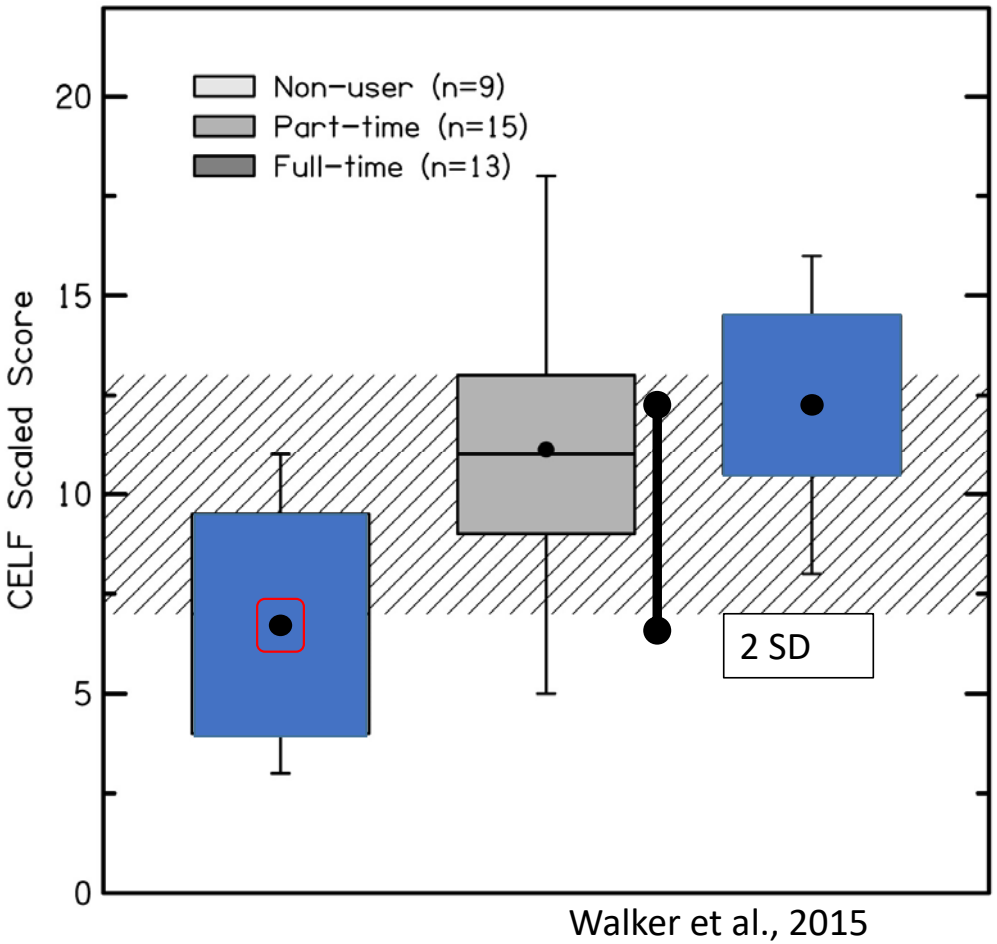
Full-time > non-users



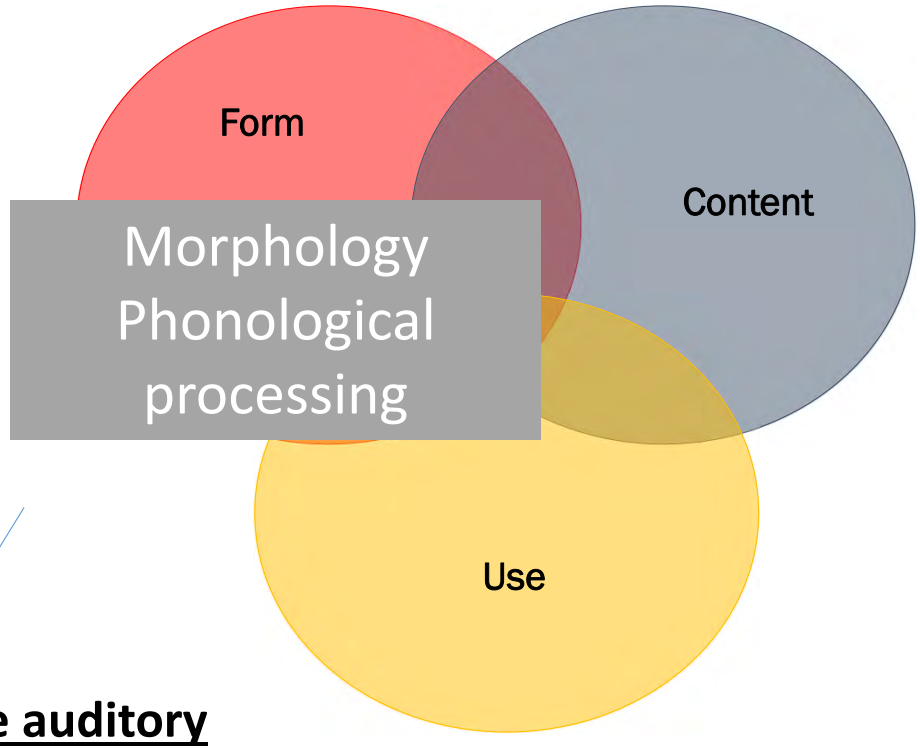
Walker et al., 2015

Full-time HA users had better morphosyntactic skills than non-users

Full-time, part-time > non-users

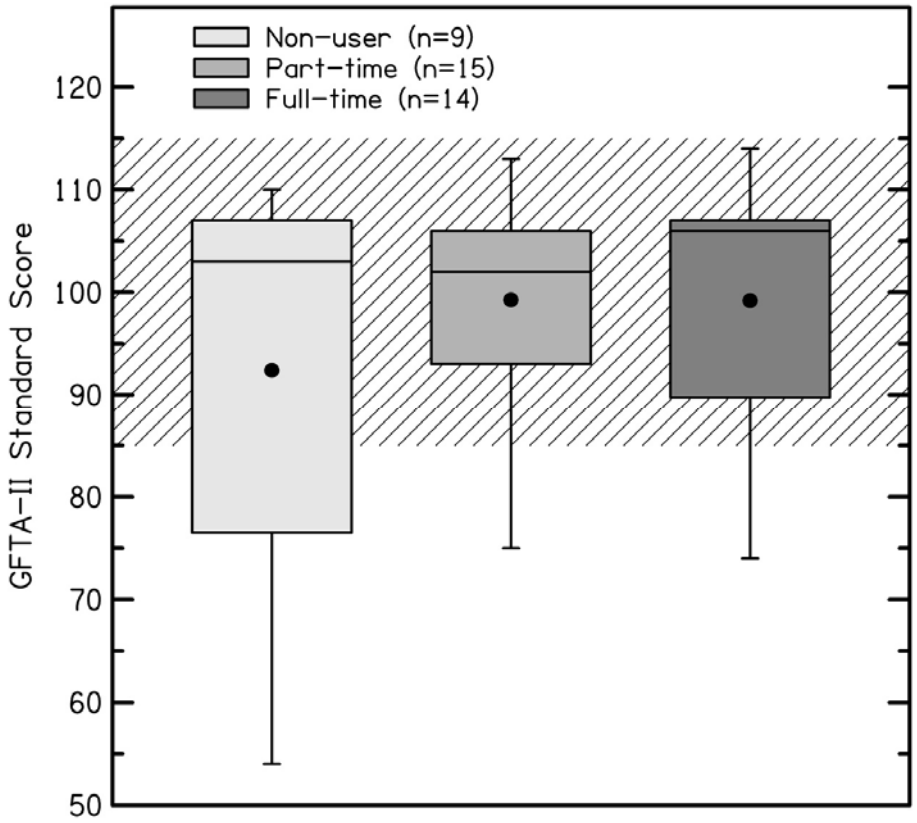


Walker et al., 2015



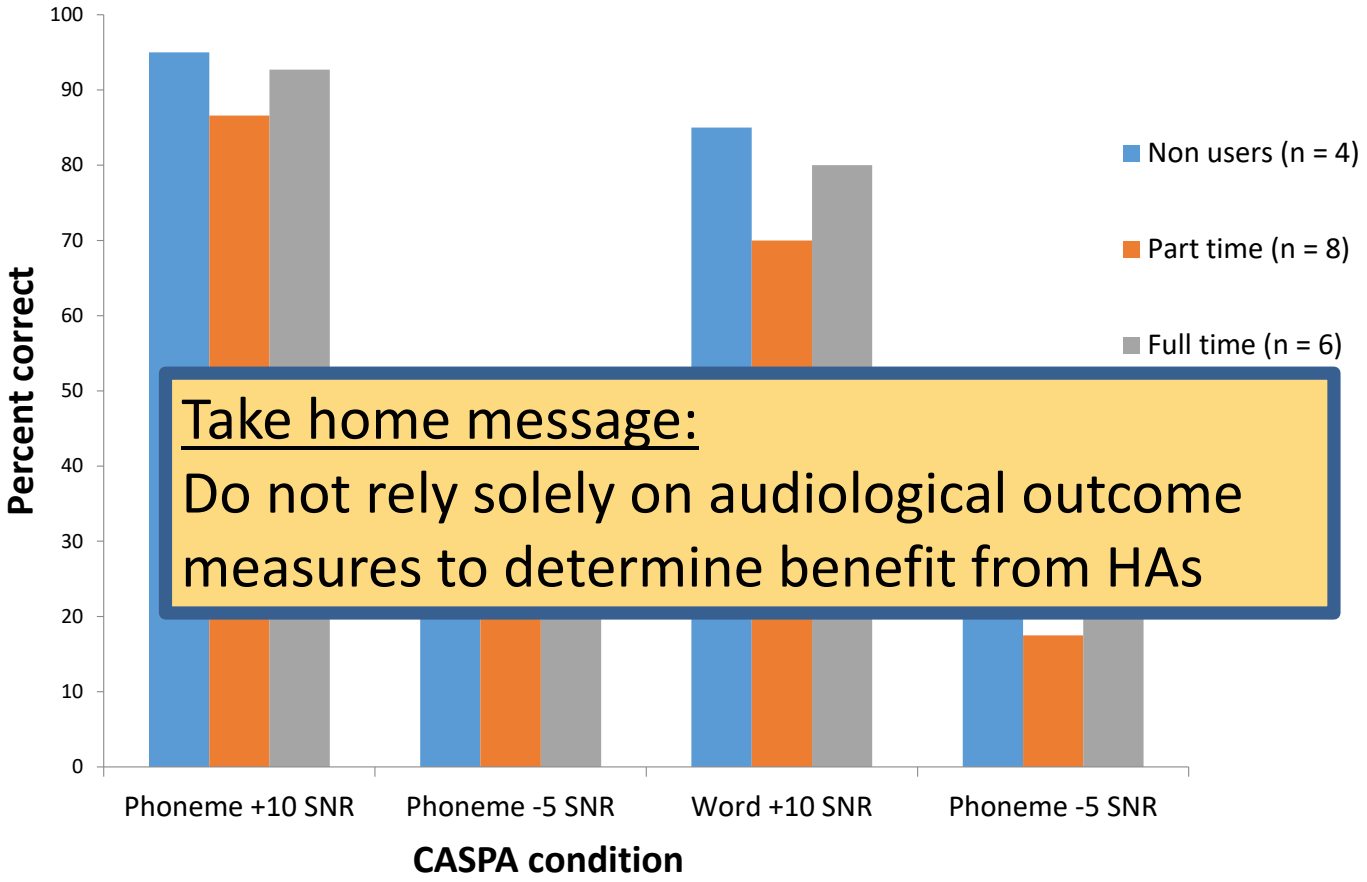
Cumulative auditory experience affects structural aspects of language development

There were no significant differences between groups for articulation



Walker et al., 2015

There were no differences between groups for speech recognition in noise



Take home message:

Do not rely solely on audiological outcome measures to determine benefit from HAs

What are the implications?

Traditional word recognition tests may not be sensitive to individual differences for children with mild hearing loss

Language, Speech, and Hearing Services in Schools

Editor-in-Chief: Holly Storkel

Impact Factor: 1.538 (2018) 2.074 (5-year)

LSHSS LANGUAGE, SPEECH, AND HEARING SERVICES IN SCHOOLS | HOME | ISSUES | NEWLY PUBLISHED | SUBSCRIBE | RECOMMEND TO A LIBRARIAN | Search

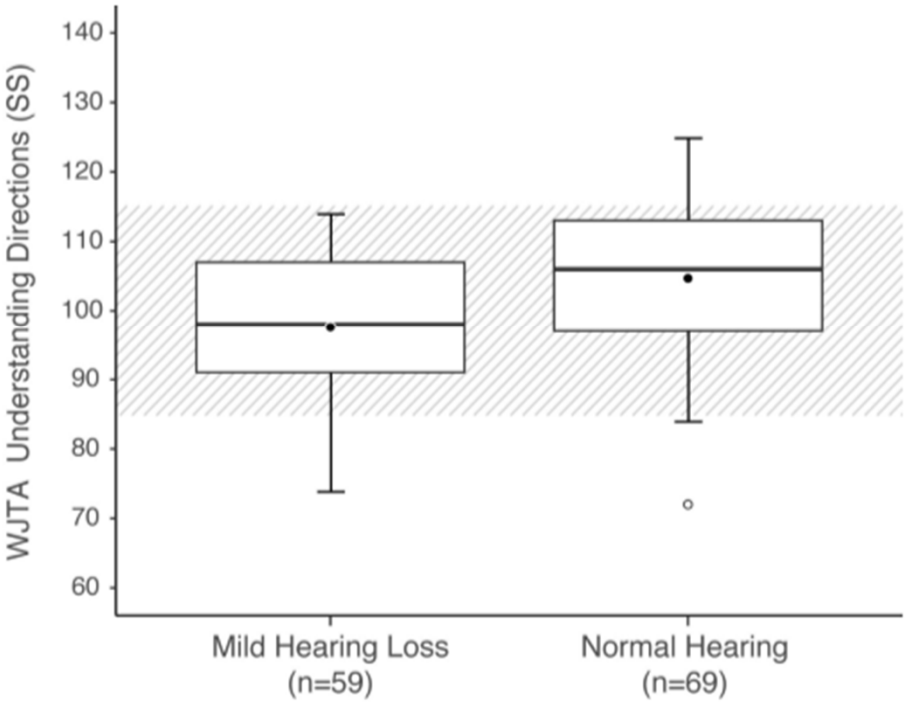
Coming soon…

Special forum on Mild bilateral and Unilateral Hearing Loss in School-age Children

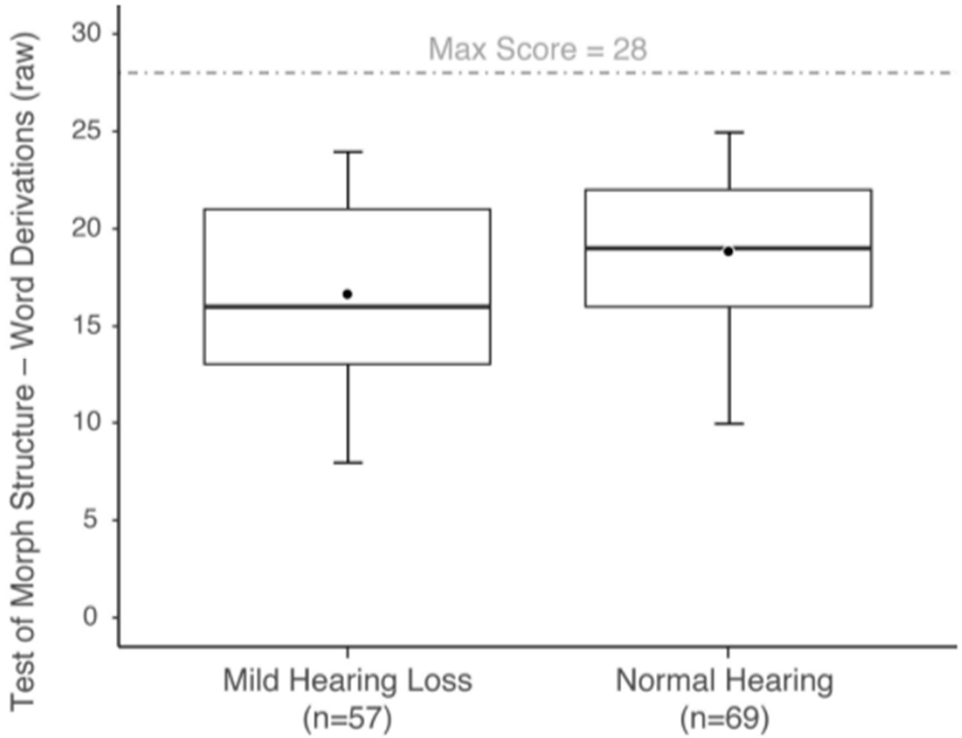
LSHSS LANGUAGE, SPEECH, AND HEARING SERVICES IN SCHOOLS

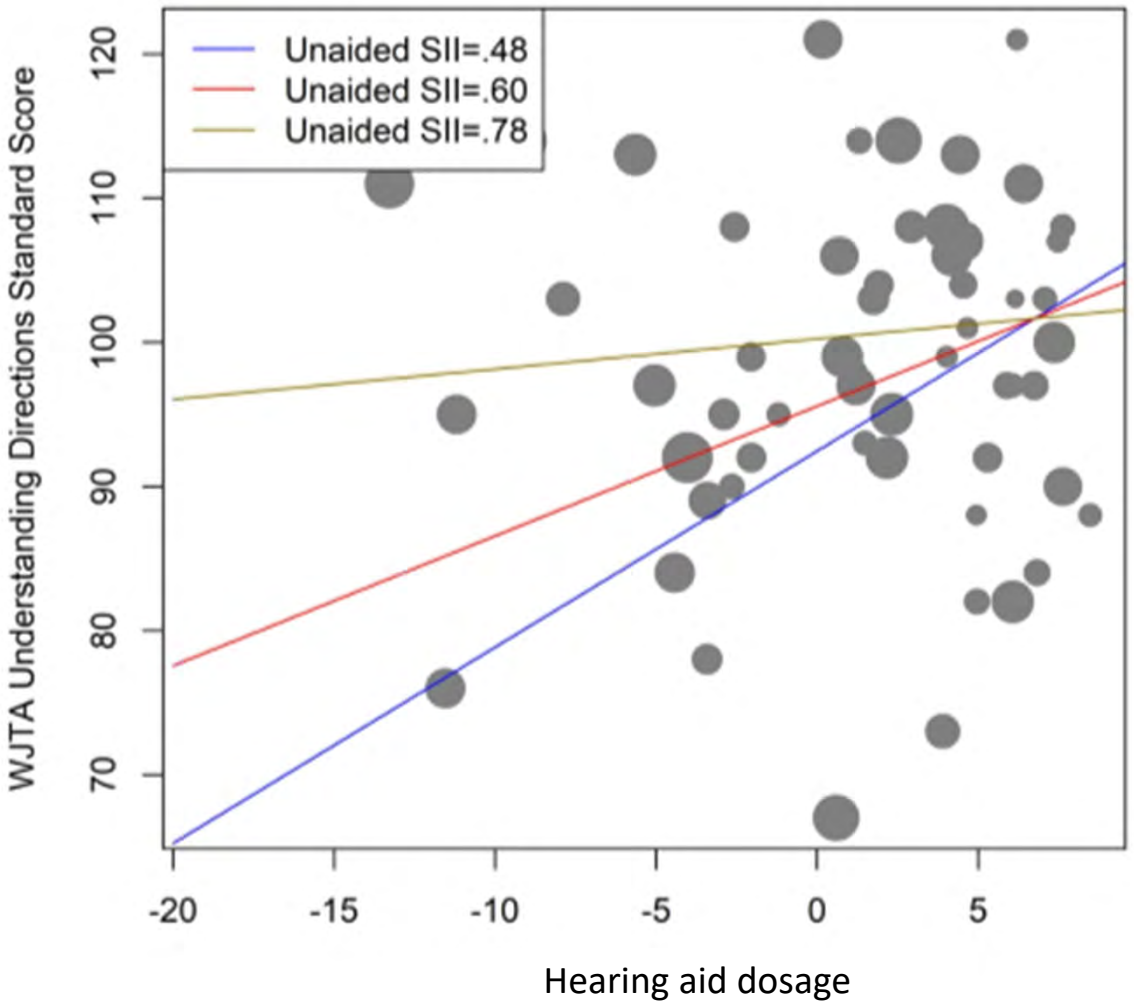
Language and Reading Outcomes in Fourth-Grade Children with Mild Hearing Loss Compared to Age-Matched Hearing Peers

Journal:	*Language, Speech, and Hearing Services in Schools*
Manuscript ID	LSHSS-OCHL-19-0015.R1
Manuscript Type:	Research Article
Date Submitted by the Author:	12-Apr-2019
Complete List of Authors:	Walker, Elizabeth; University of Iowa, Communication Disorders and Sciences Sapp, Caitlin; University of Iowa, Communication Disorders and Sciences Dallapiazza, Margaret; University of Iowa, Communication Disorders and Sciences Spratford, Meredith; Boys Town National Research Hospital, Center for Childhood Deafness McCreery, Ryan; Boys Town National Research Hospital, Research Oleson, Jacob; University of Iowa, Biostatistics
Keywords:	Auditory rehabilitation, Children, Hearing loss, Language, Literacy, Morphology



Walker et al., in press





Walker et al., in press

LSHSS LANGUAGE, SPEECH, AND HEARING SERVICES IN SCHOOLS

Audibility-based hearing aid fitting criteria for children with mild bilateral hearing loss

Journal:	*Language, Speech, and Hearing Services in Schools*
Manuscript ID	LSHSS-OCHL-19-0021.R1
Manuscript Type:	Research Article
Date Submitted by the Author:	n/a
Complete List of Authors:	McCreery, Ryan; Boys Town National Research Hospital, Research Walker, Elizabeth; University of Iowa, Communication Disorders and Sciences Stiles, Derek; Boston Children's Hospital, Audiology Spratford, Meredith; Boys Town National Research Hospital, Center for Childhood Deafness Oleson, Jacob; University of Iowa, Biostatistics Lewis, Dawna; Boys Town National Research Hospital, Hearing Research
Keywords:	Hearing, Amplification or hearing aids, Hearing loss, Children

Results: The level of unaided audibility for children with hearing loss that was associated with differences in language development from children with typical hearing or based on the modelling approach varied across outcomes and criteria but converged at an unaided speech intelligibility index of 80.

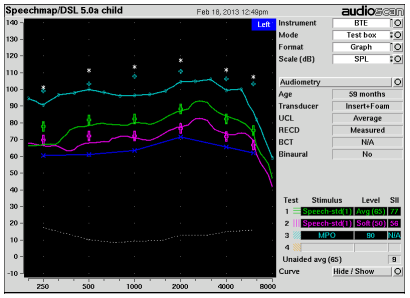
Conclusions: Children with hearing loss who have unaided speech intelligibility index values less than 80 may be at risk for delays in language development without hearing aids. The unaided speech intelligibility index potentially could be used as a clinical criterion for hearing aid fitting candidacy for children with hearing loss.

What is the take-home message?

Children with mild hearing loss **(especially with unaided SII <.80)** are at risk for delays in language acquisition.

Protective factors include:

timely detection and intervention services



Hearing aids that are fit to prescriptive targets

early and consistent auditory access

Pediatric & Educational Audiologists: AKA-Freakin' Miracle Workers

Closed group

About

Discussion

Mentorship

Announcements

Members

Events

Joined · Notifications · Share · ··· More

[redacted]

Wondering if you'd fit amplification for a 3 month old with slight/mild high-frequency hearing loss only at 4000 Hz? We have had two ABRs with consistent findings (below). I did not test below 20 dBeHL as that is considered normal with our ABR equipment. DPOAEs were absent 3-8kHz bilaterally. I was thinking about waiting until we could get behavioral testing at 6 mos to obtain ear-specific high-frequency thresholds above 4000 Hz, then decide? What would you do?

[redacted] I would take an RECD and run an SII on the verifit at average and soft to see how much is audible before proceeding with amplification .

Like · Reply · 16h · 8

[redacted]! We're fitting kids under 0.8 SII values.

Like · Reply · 16h · 3

[redacted] A co-worker also suggested that and I found the "how-to" guide for that in the Ontario amplification protocol! I was just going to ask what your cutoff was. I can't remember the numbers exactly but the unaided SII for soft speech was about 40% and for average speech about 70%. This was with an average RECD though, so I'll have to get a measured RECD at his follow-up appt.

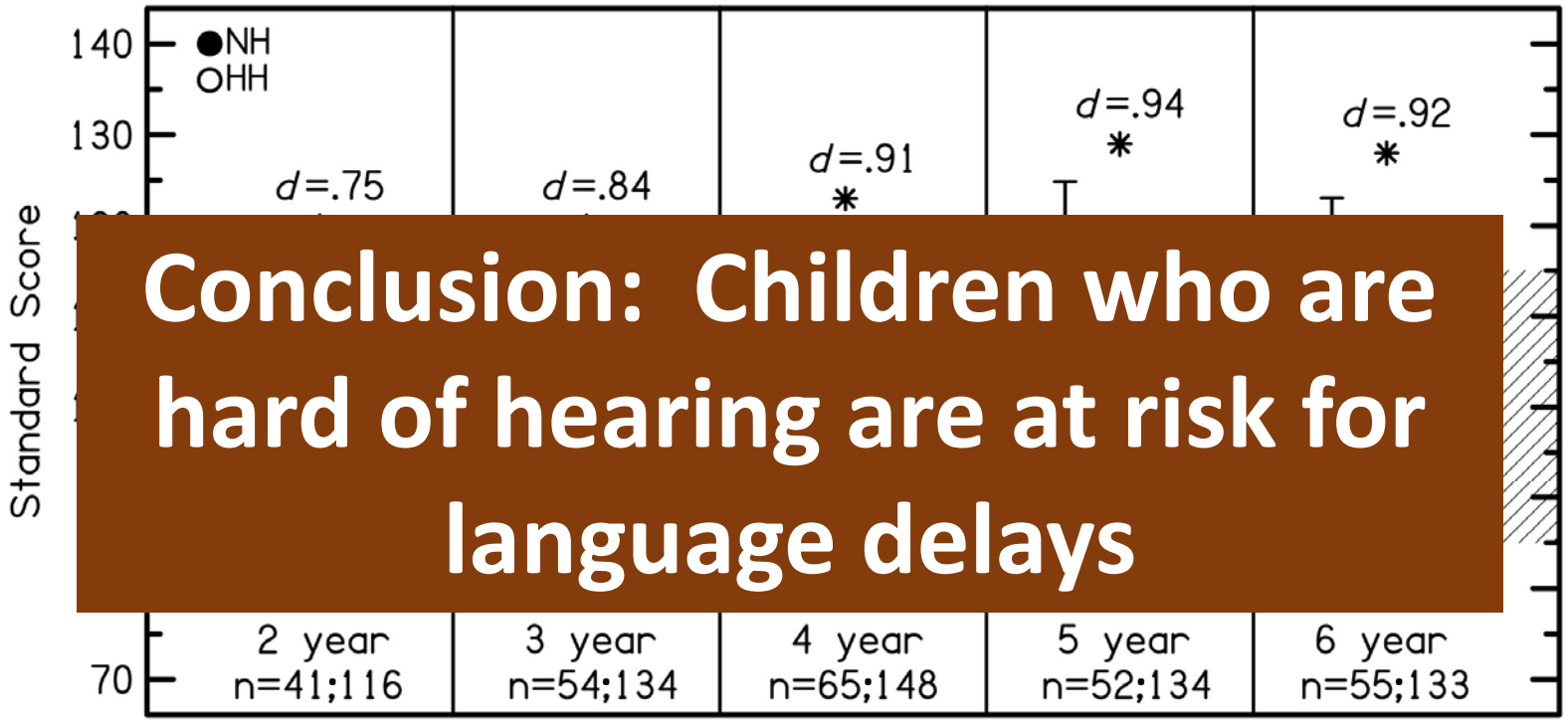
Like · Reply · 16h · 2

[redacted] You might want to measure RECD and check the SII. If it is better than 80 I would hold on amplification but counsel heavily that we need to monitor and hearing aid may be recommended in the future

Like · Reply · 5h

- Intro to OCHL
- Preschool-age CHH
  - Auditory access
    - Aided audibility
      - ANSD
    - HA use
      - Mild bilateral hearing loss
- School-age CHH
  - Academic and language outcomes

How do young children who are hard of hearing compare to children with normal hearing?



Conclusion: Children who are hard of hearing are at risk for language delays

* $p < .0001$

Tomblin et al., *Ear & Hearing*, 2015

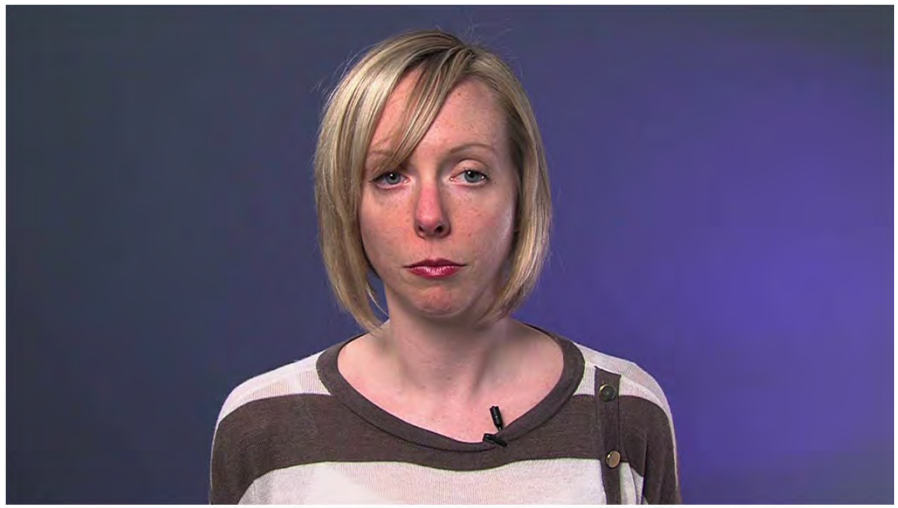
Social cognition, language and literacy outcomes

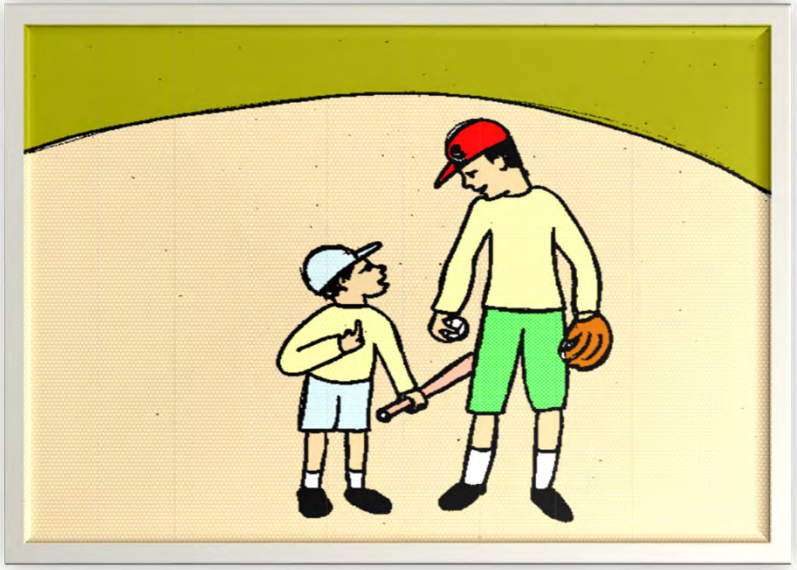
Outcomes of School Age Children who are Hard of Hearing

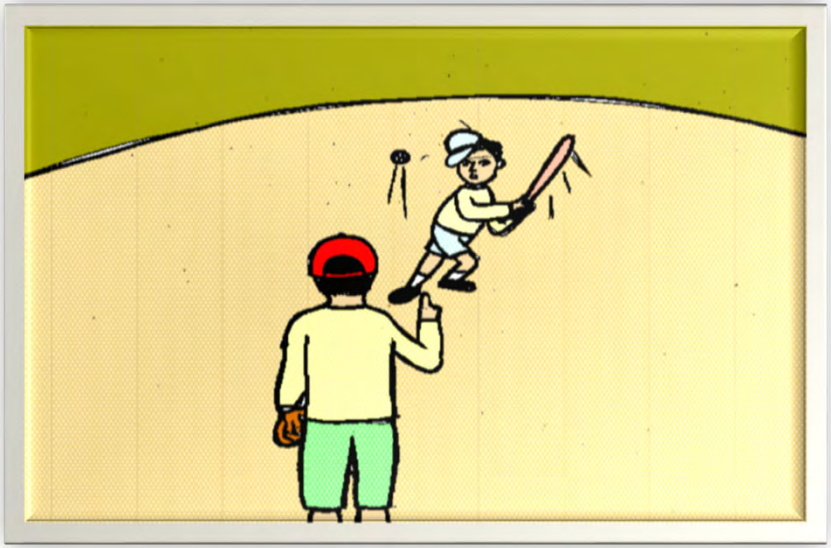
Higher-level social cognition: IRONY

Method

- 9 Picture-Supported Stories
  - de Villiers & de Villiers
- Presented in standard audio-visual format
- Child answered questions requiring interpretation or reasoning







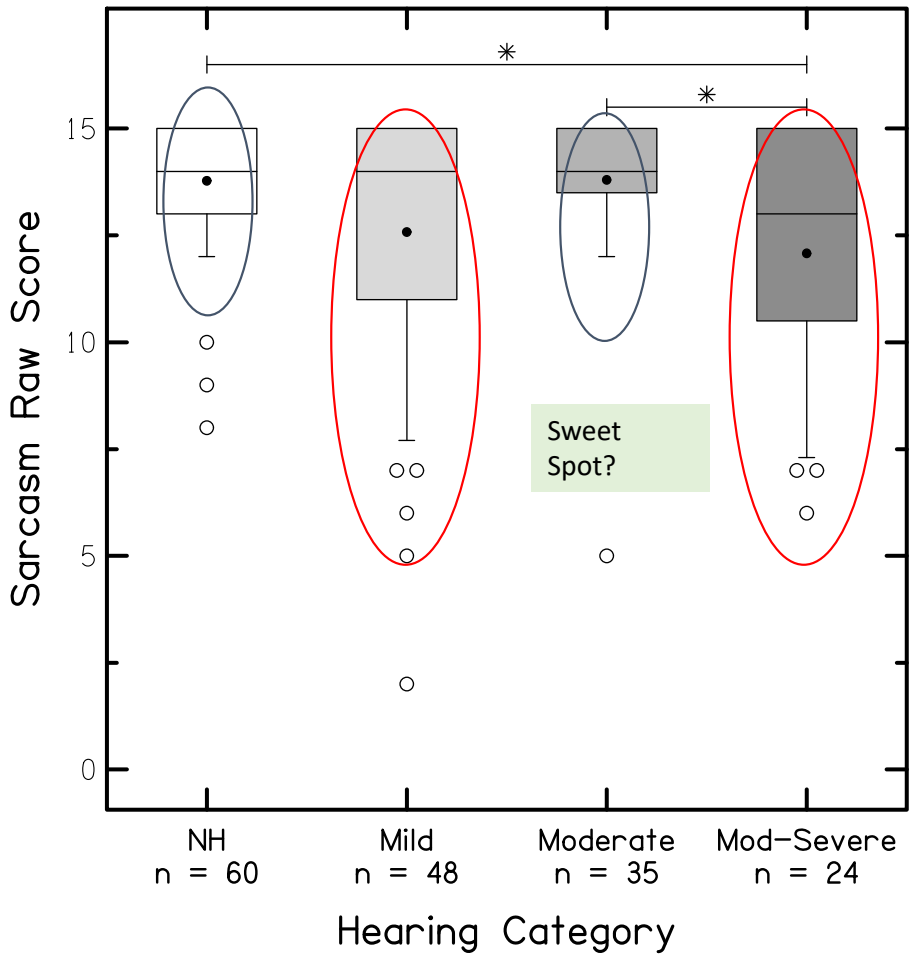
1. What did the big brother mean when he said that?

2. Did the brother think that the little boy was a bad hitter or a good hitter?

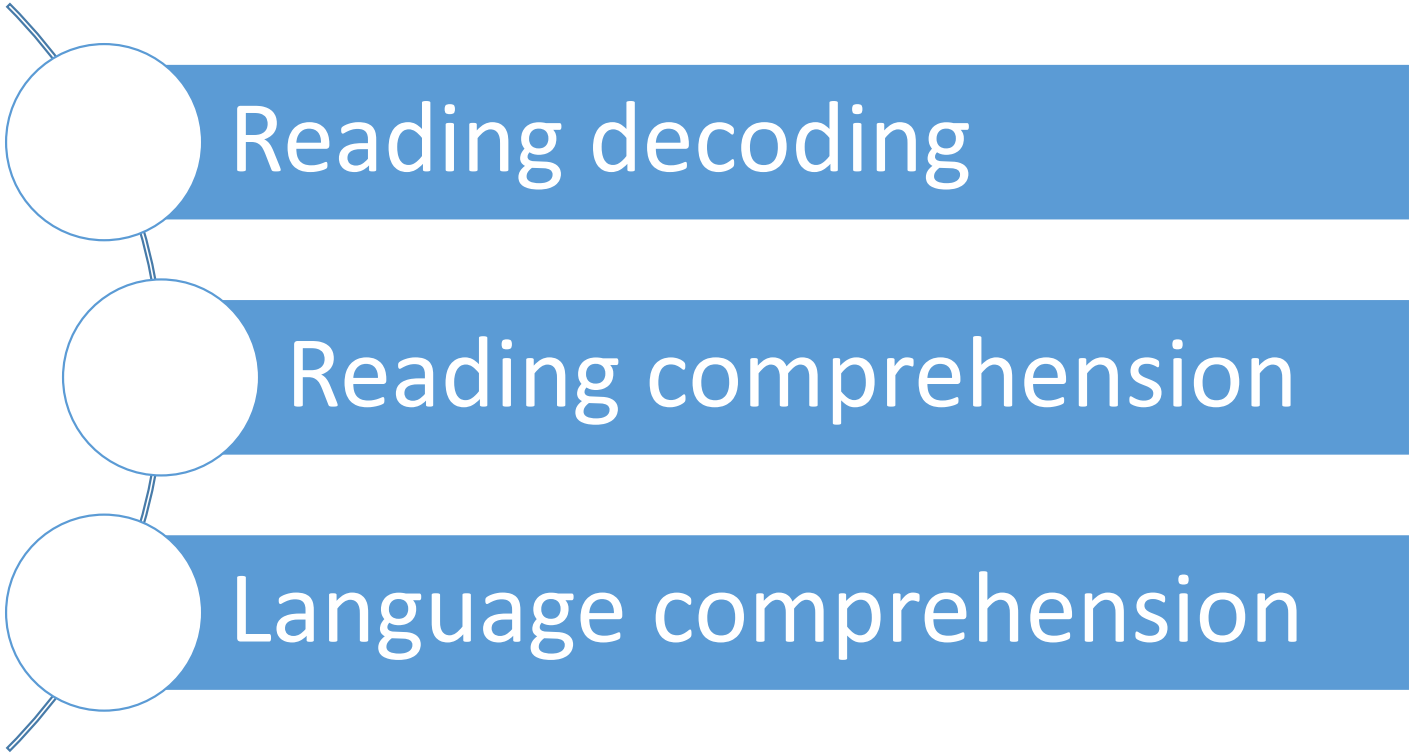
   Bad _____ Good _____

Results – Under

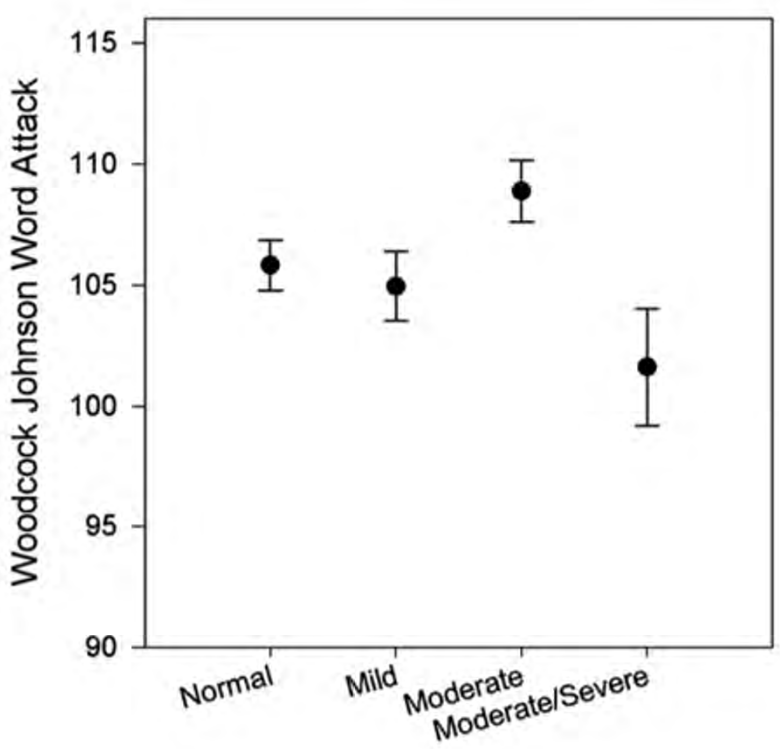
Main effect of hearing category p = .004

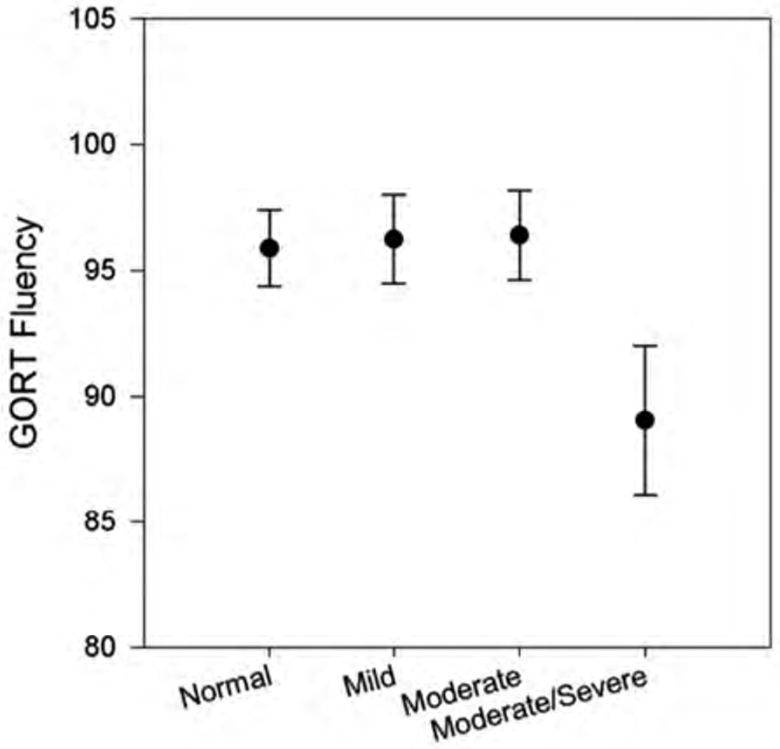


Language and Literacy Outcomes at age 8



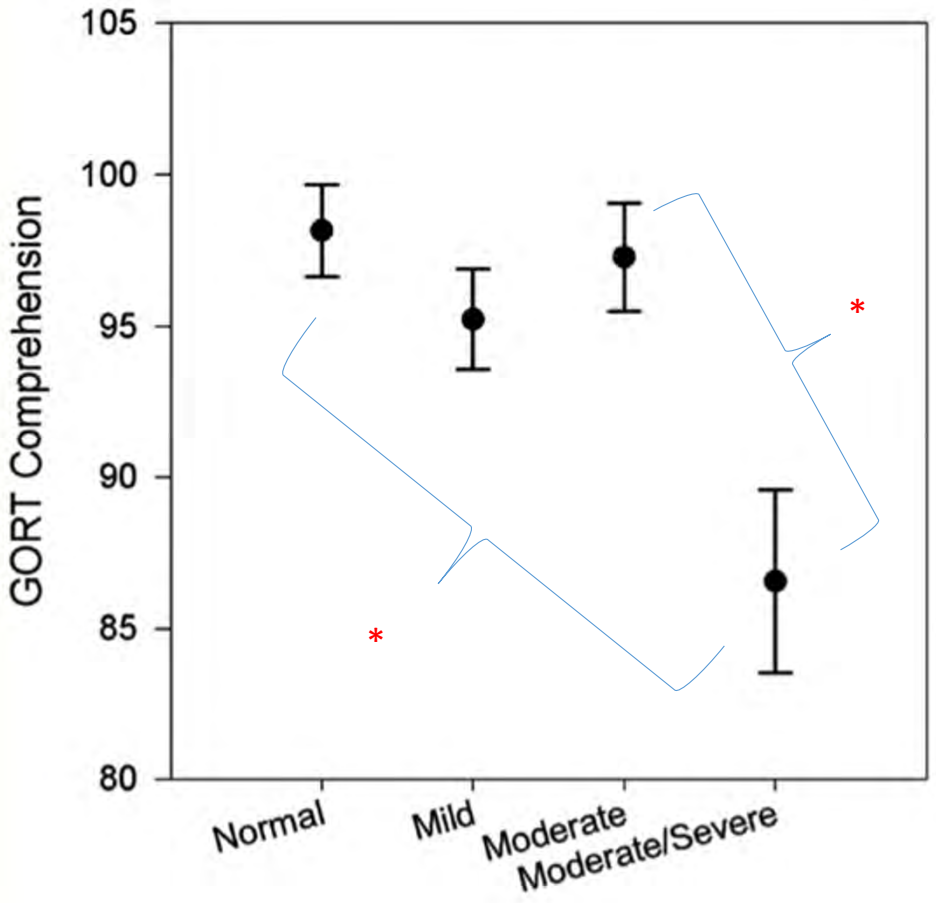
Results: Literacy at 8 years





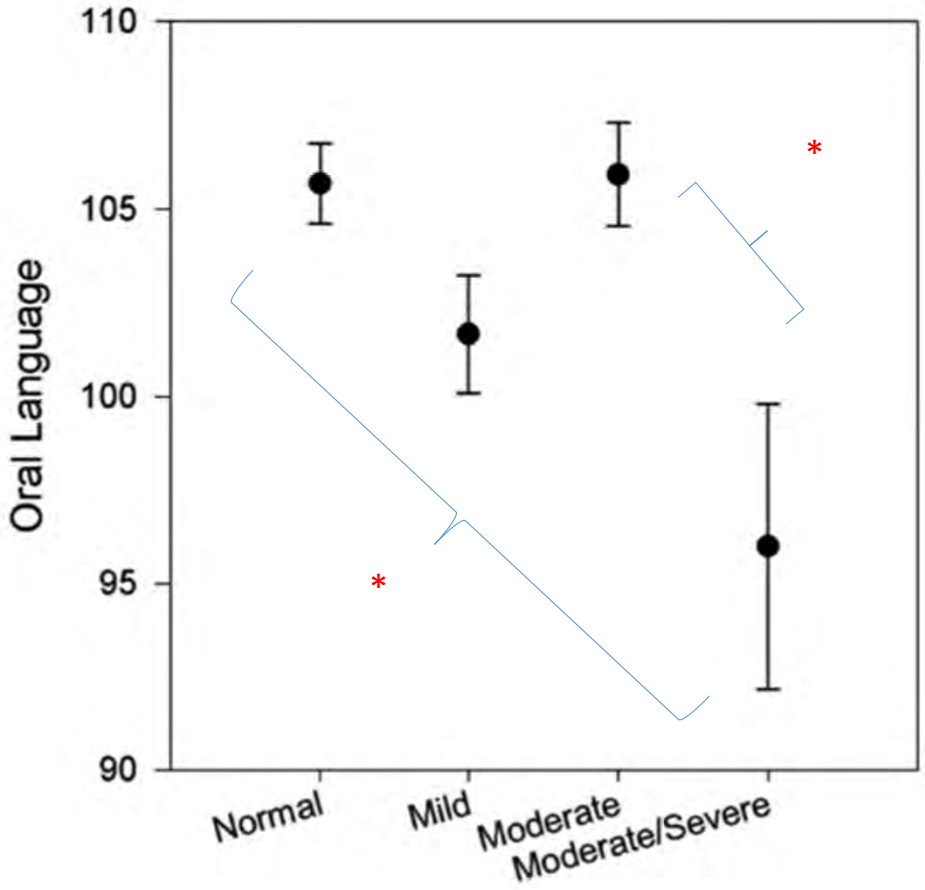
Decoding skills (reading words) similar in children with and without hearing loss

Results: Literacy and Language at 8 years



- Children with Moderate-severe HL poorer than children with normal hearing and children with moderate HL in reading comprehension.

Results: Literacy and Language at 8 years

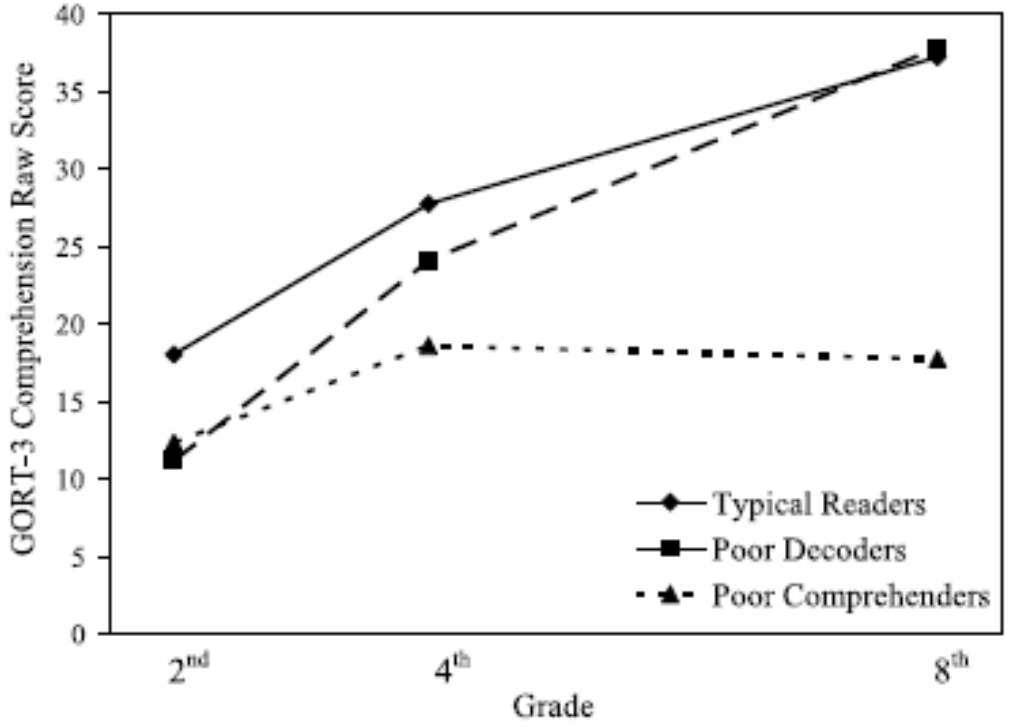


- Oral language outcomes are similar to reading comprehension.
- Children with Mild and Moderate hearing loss show resilience in reading and oral language (but note “sweet spot”).

Clinical Implications

- The resilience of the children with moderate hearing loss relative to the mild and moderate/severe…
  - Is this a “sweet spot” where the interventions (hearing aids and aural rehab.) are effective and/or better utilized?
- Children with moderate-severe hearing loss show persistent delays, suggesting need for improvements in interventions.

- The profile of poor comprehension in reading and language is especially concerning
- Among hearing children, we know that children with low reading and language comprehension are often not identified as being delayed until after age 10 (Catts et al. 2012)
- Where will these children who are hard of hearing be by 8th grade?



Time for a break!