

Factors Supporting Growth Trajectories in Auditory, Language, and Reading Skills for Adolescents with Hearing Loss

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OSSPEAC, 2026

Financial Disclosures

- I am an employee of the University of Iowa Department of Communication Sciences and Disorders.
- I receive funding from the National Institutes of Health and U.S. Department of Education
- I have no non-financial disclosures

My history

- Master's degree in Communication Disorders from University of Minnesota-Twin Cities
- CFYs in SLP and Aud, Riley Children's Hospital
- PhD in Speech and Hearing Science from University of Iowa
- Professor and Director of Pediatric Audiology and Language Lab, University of Iowa

IOWA



Today's Topics

How can we promote outcomes?

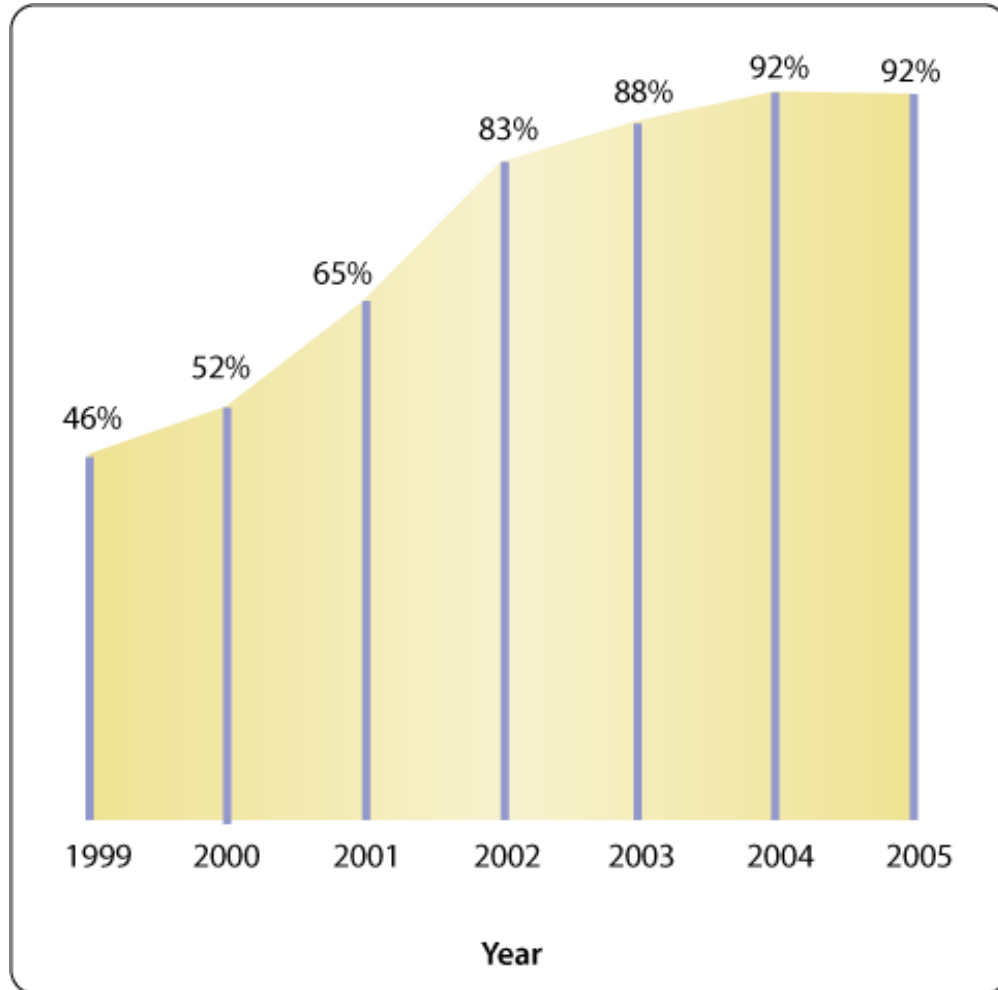


Cumulative auditory experience

Aided
audibility

Device
use

Since 2000, there has been a sharp increase in early identification of hearing loss...



Across all states, increase in newborn hearing screening from 3% of infants in 1993 to 98% in 2009 (White et al., 2010)

Since early 2000s, new practices →

Screening
by 1 month



Diagnostic
test by 3
months



HA fitting
within 1
month of
Dx



Early
intervention
by 6
months

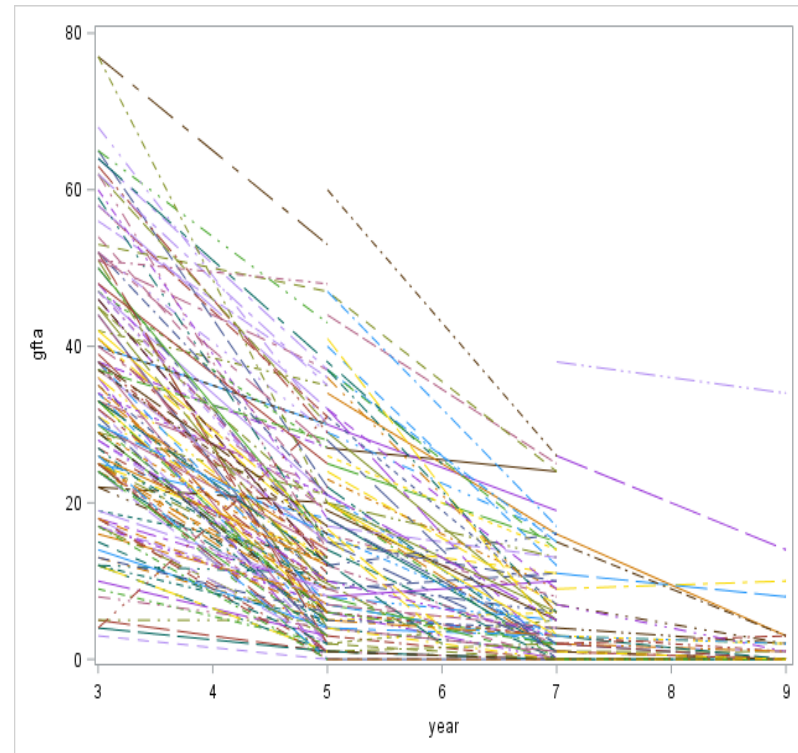


What is driving long-term outcomes?

Why do children who are deaf or hard of hearing show so much variability?



Degree of
HL
(PTA)



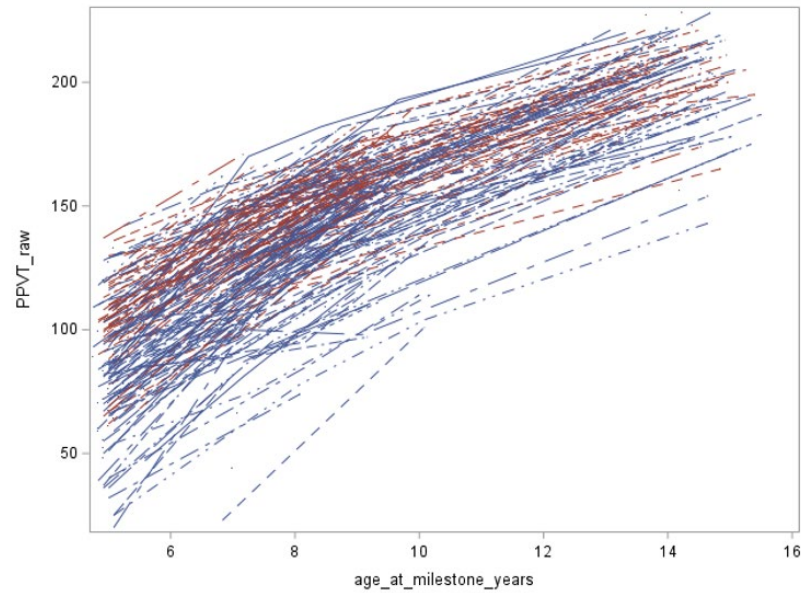
Historical Perspectives about risk pos hearing loss

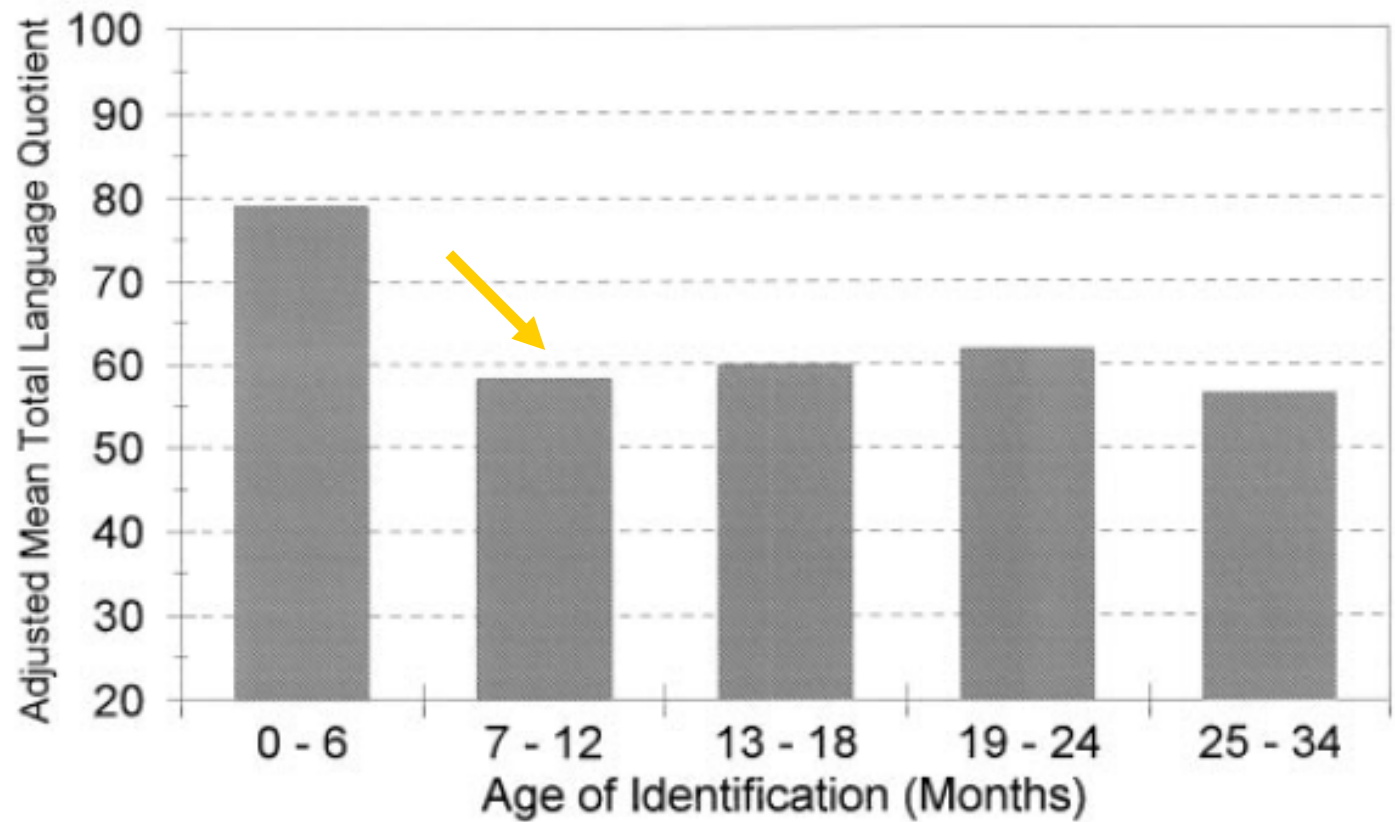
Note:

- Small sample sizes
- Focus on degree of HL
- Little consideration of “malleable factors” in clinical intervention

Delayed relative to peers	<i>n</i>	Age (yr)	Like typical peers	<i>n</i>	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

Age at
identification





Pure Tone Average:
Cognitive Quotient:

63
88

62
74

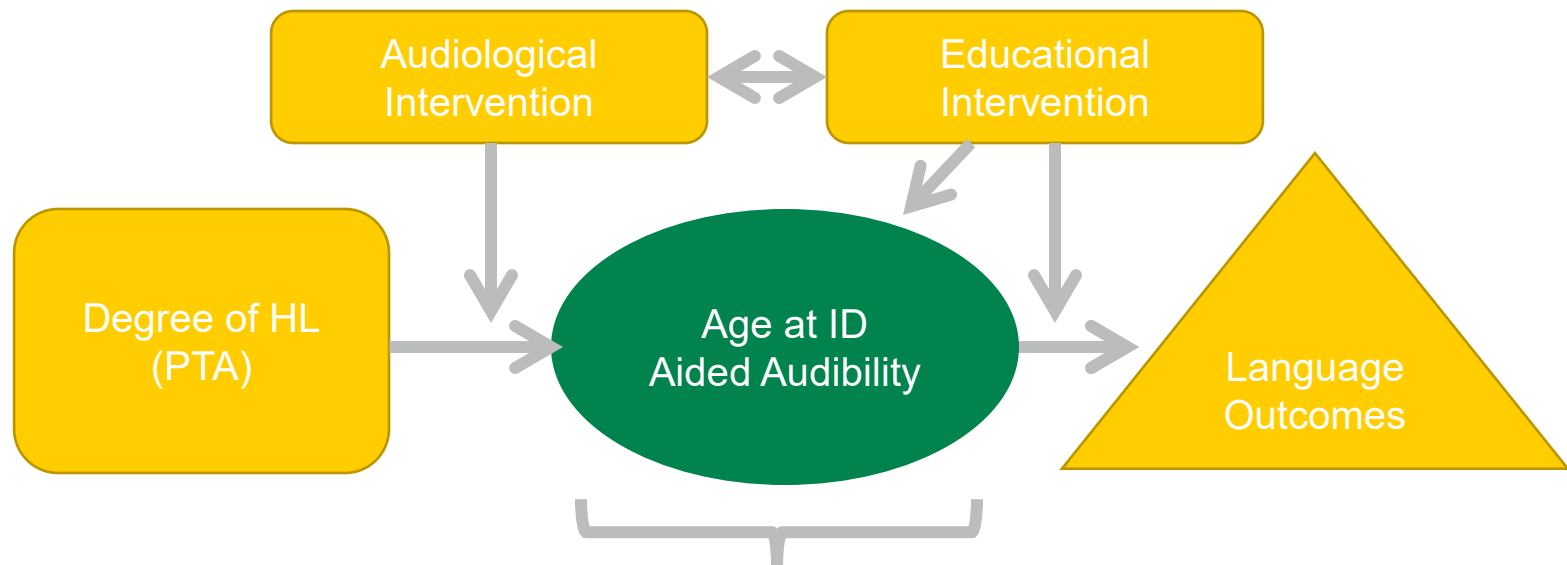
80
82

72
76

64
71

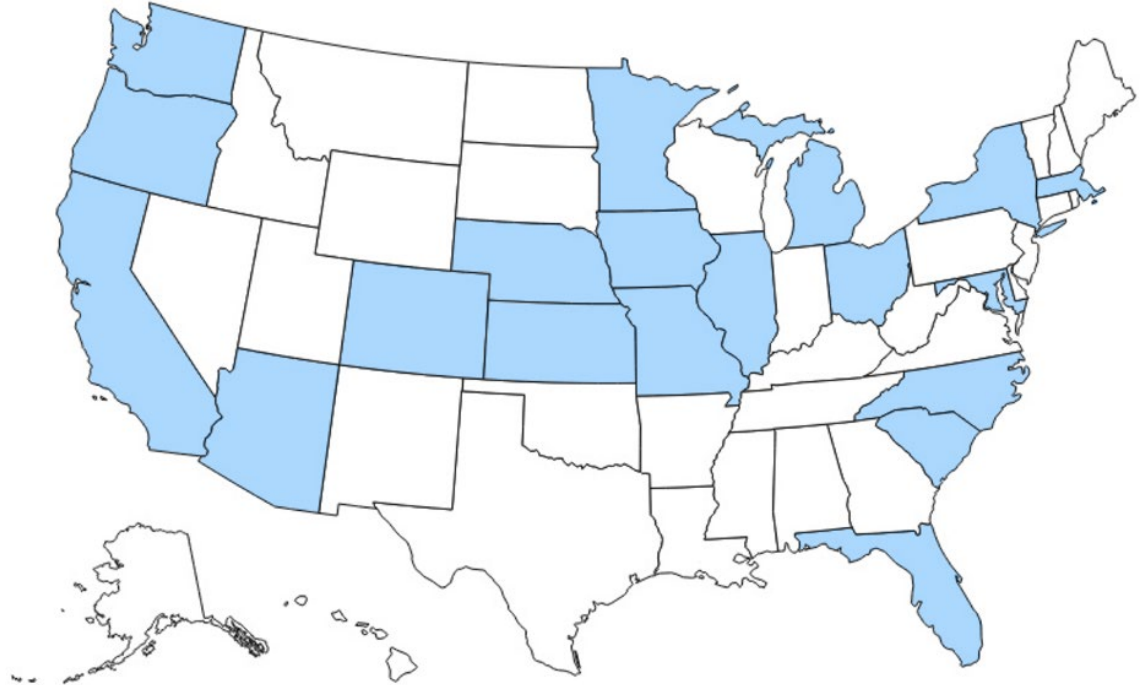
Yoshinaga-Itano et al. 1998

What is the role of intervention on outcomes?



**Cumulative Auditory Experience:
Modifiable factors in intervention**

Outcomes of Children with Hearing Loss Consortium (OCHLCON)



SUBJECTS	TOTAL
HH	317
TH	117

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

Outcomes of Children with Hearing Loss Consortium (OCHLCON) is a multicenter, longitudinal study focused on new generation of children with HL



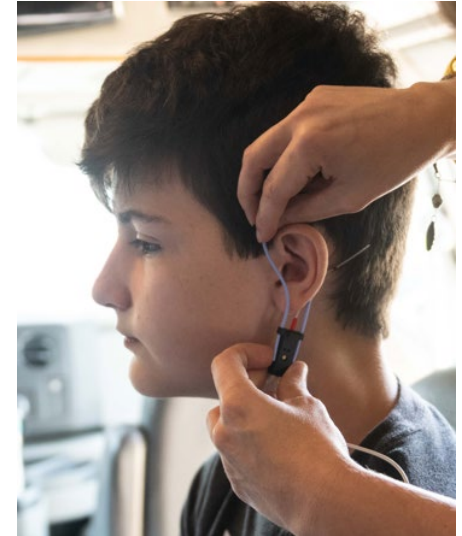
Outcomes of Children with Hearing Loss

6 mos – 9 years
2009-2013



Outcomes of School Age Children
who are Hard of Hearing

1st - 4th grade
2013-2018



Longitudinal Outcomes of Literacy in Adolescents
who are Hard of Hearing

Junior high and high school
2021-2026

Study participants: Inclusion criteria

6 months to 7 years at entry between 2009-2013



Spoken English primary language



No major secondary disabilities



Permanent mild to severe *bilateral* hearing loss

Today's talk: What factors predict long-term outcomes in vocabulary, morphosyntax, and phonological awareness?



Predictors: maternal education level, auditory access, and age at confirmation of hearing loss



172 adolescents with HL and 82 adolescents with typical hearing (control group)



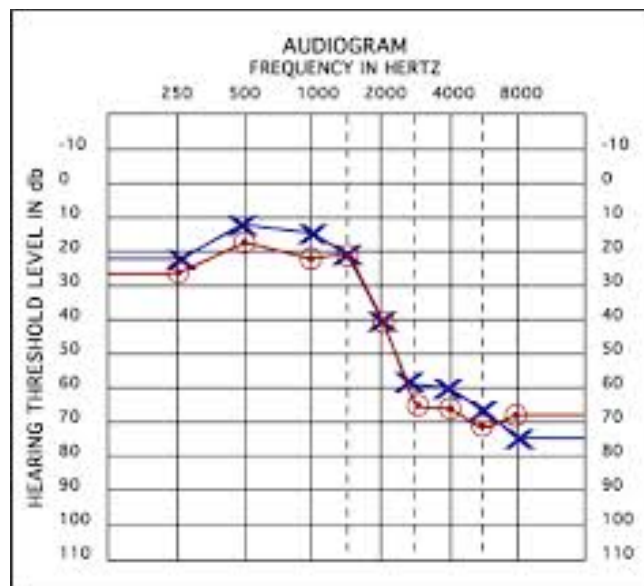
Outcomes: Junior high and high school language scores

HOW CAN WE PROMOTE OPTIMAL OUTCOMES FOR CHL?



- Provide consistent auditory input that will improve speech perception, speech production, language
- Therefore, access to the speech spectrum (i.e., audibility) is crucial

How can we determine amount of access to the speech spectrum?



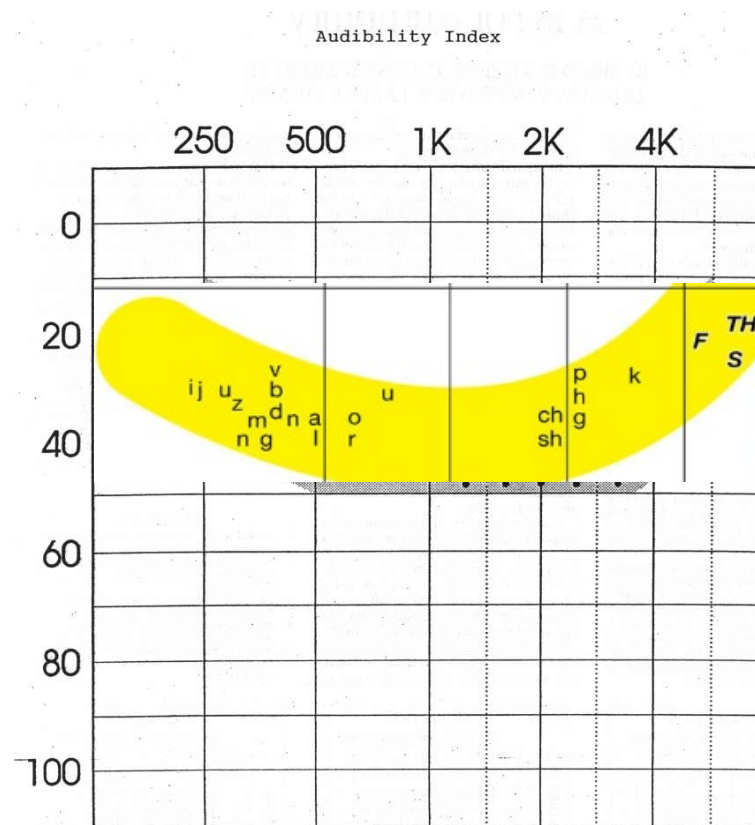
Unaided or aided
audiometric
thresholds (i.e.,
PTA)?



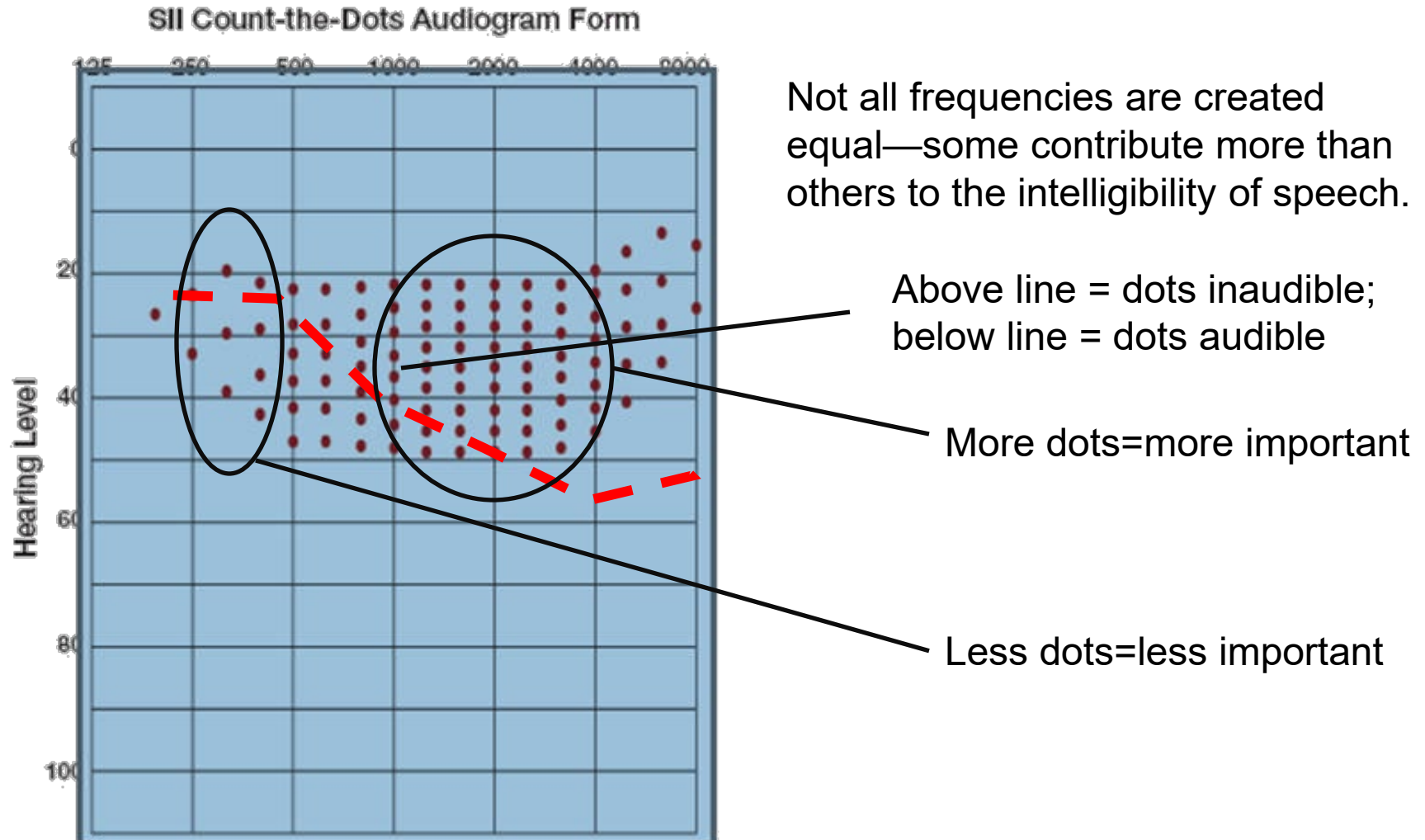
Or by
quantifying
audibility?

How do we quantify audibility?

→ Speech Intelligibility Index (i.e., “count the dots”)



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



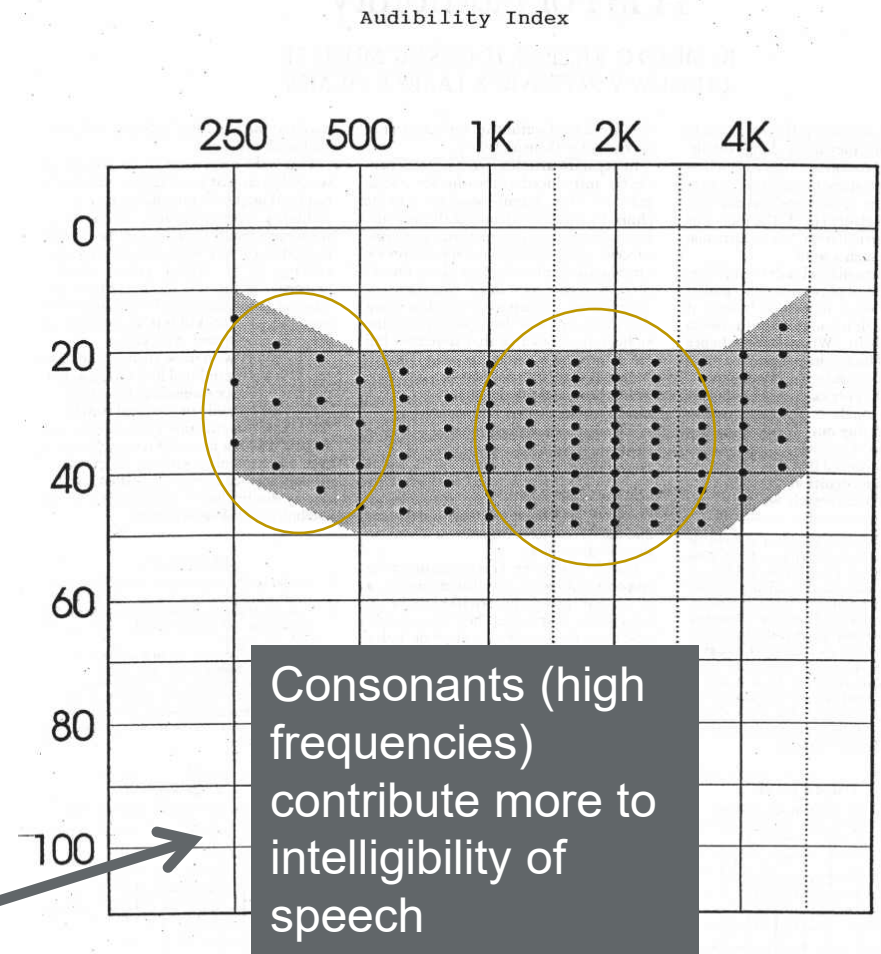
Quantifying audibility: Speech Intelligibility Index

Each dot = ~1% of the information contributing to speech clarity.

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

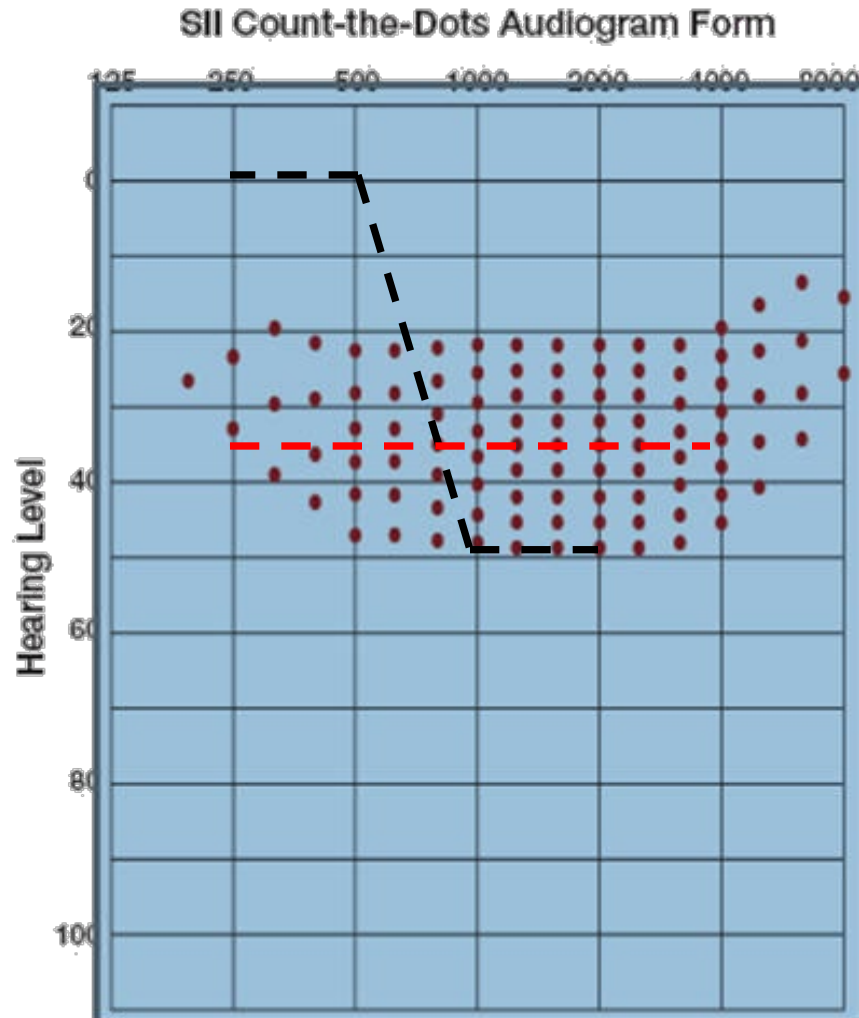
Dots unevenly distributed - more between 1000 and 3000 Hz than 250 to 500 Hz.

Why?



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

PTA does not always = SII



SII takes configuration and importance of speech cues into account

3F PTA = 33.33 dB HL
SII = .25

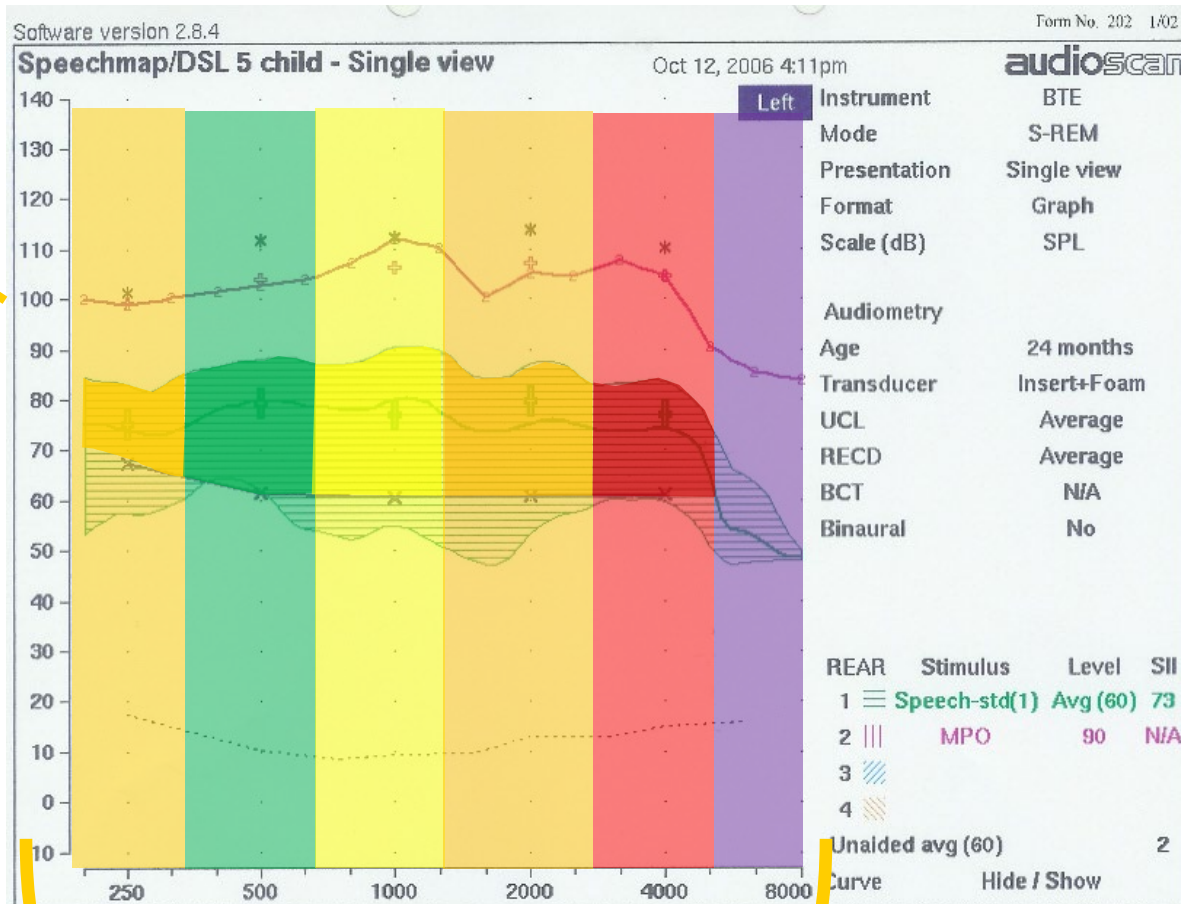
3F PTA = 35 dB HL
SII = .40

Speech intelligibility index (SII)

For each band:
Audibility x FIW
=
weighted
audibility

SII = Sum of
weighted
audibility of all
frequency
bands

Accounts for
ear canal
acoustics

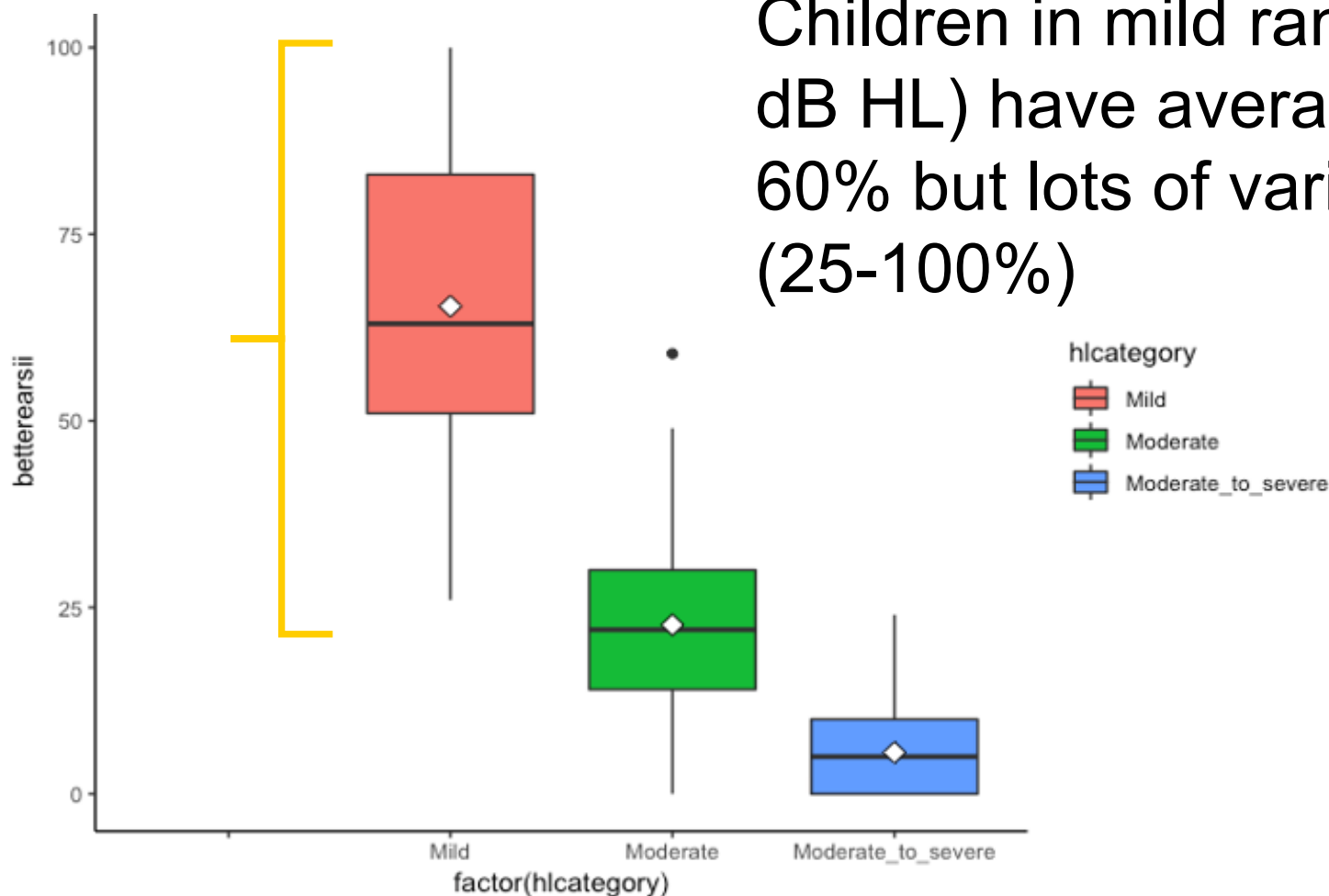


Aided SII

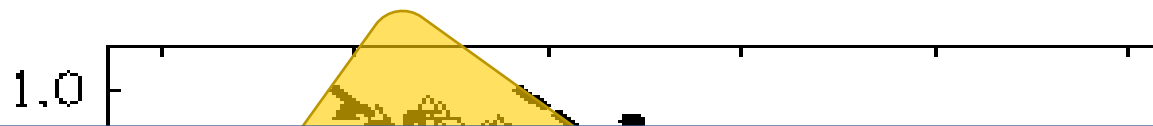
Unaided
SII

Range of SII across hearing loss categories

Children in mild range (20-40 dB HL) have average SII = 60% but lots of variability (25-100%)

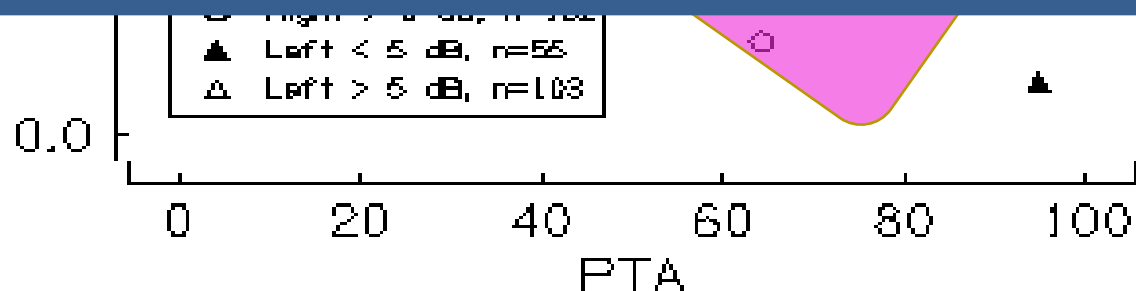


Hearing aids are not optimally fit for all children



Take home message:

Hearing aids are not appropriately fit for all children – 35% below normative mean, 10% below 95% confidence intervals

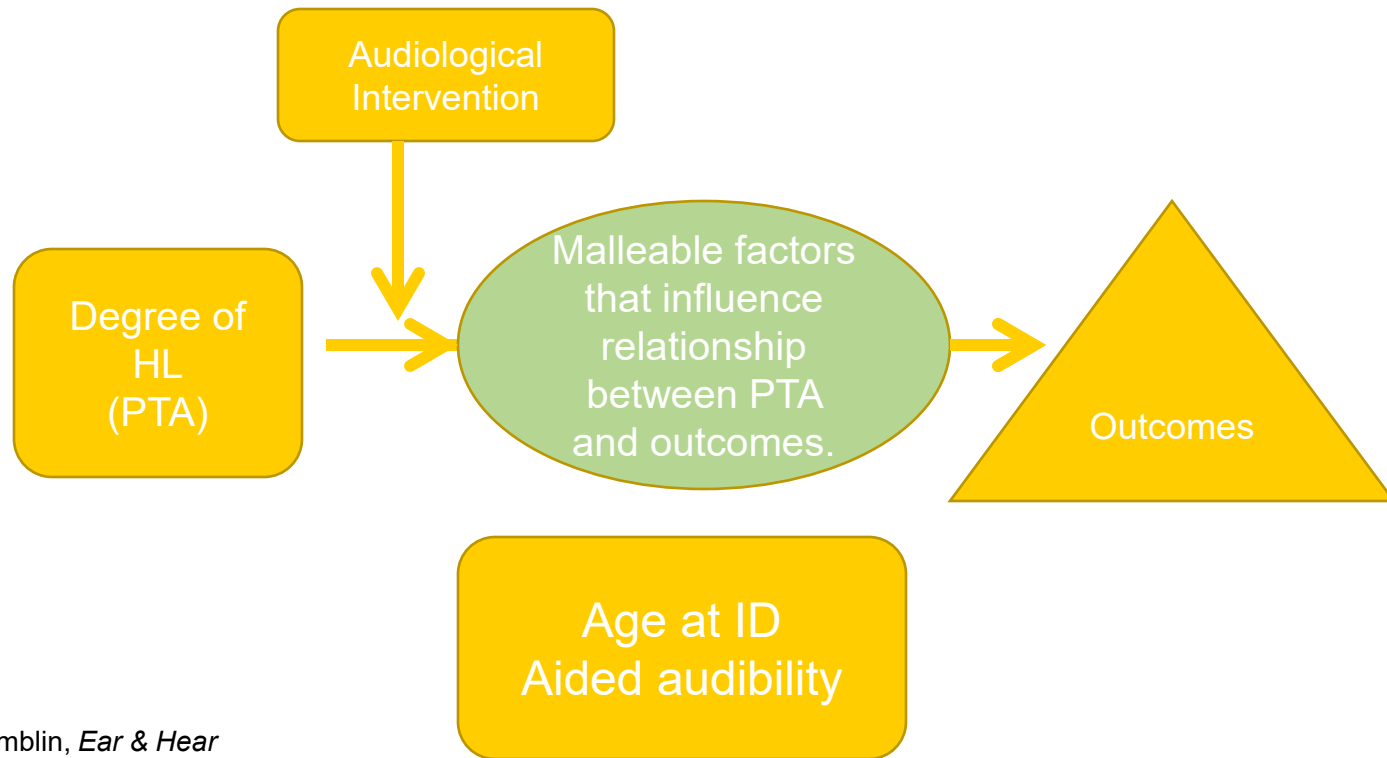


McCreery et al., 2015

Why so much variability? Audibility is affected by hearing thresholds, configuration, and ear canal acoustics

- Poorer thresholds = more limited audibility
- Sloping configuration = more limited audibility (especially in 2-6k range)

Does it matter when intervention starts and if hearing aids are optimally fit?



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

Hearing aids
before 6 months of
age results in less
delays relative to
typical hearing
children, on
average

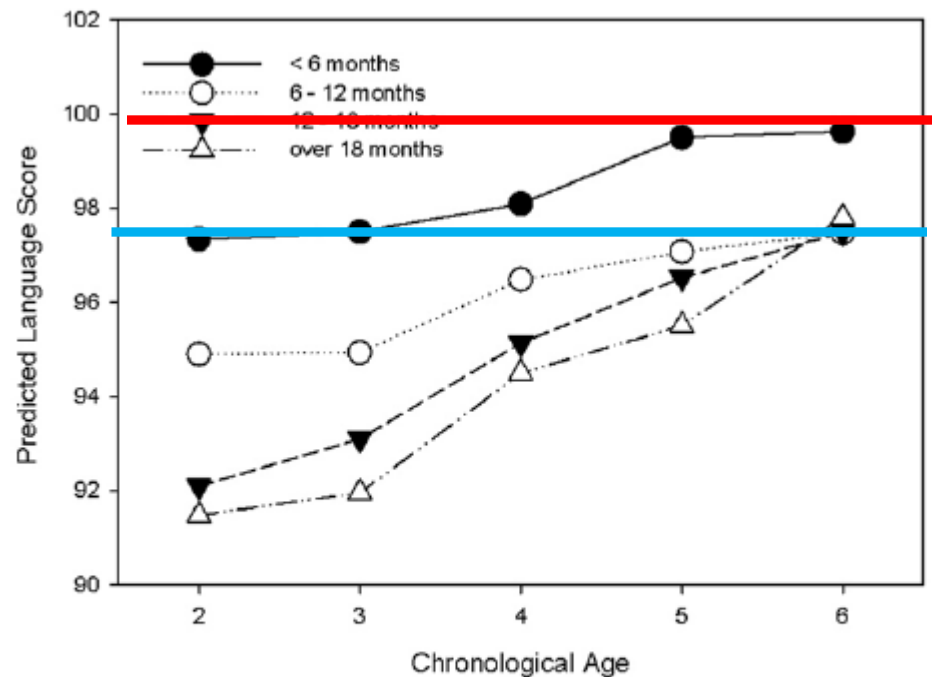
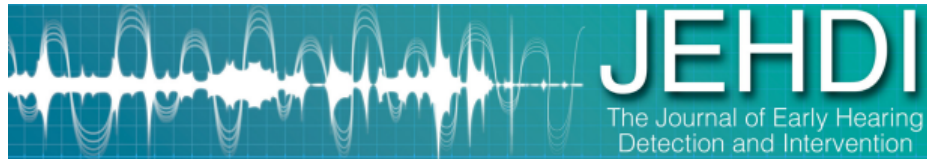


Fig. 5. Average predicted language scores based on mixed model across the ages of 2 to 6 years for children receiving hearing aids at 0–6, 6–12, 12–18, and over 18 months.

Tomblin et al., 2015, Ear and
Hearing

EHDI “1-3-6” benchmarks vs “1-2-3”?



2022; 7(1): 1–10

Language Growth in Children with Mild to Severe Hearing Loss who Received Early Intervention by 3 Months or 6 Months of Age

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1 month of age
Hearing screen



3 months of age
Confirmation of HL



6 months of age
Early intervention

1 month of age
Hearing screen

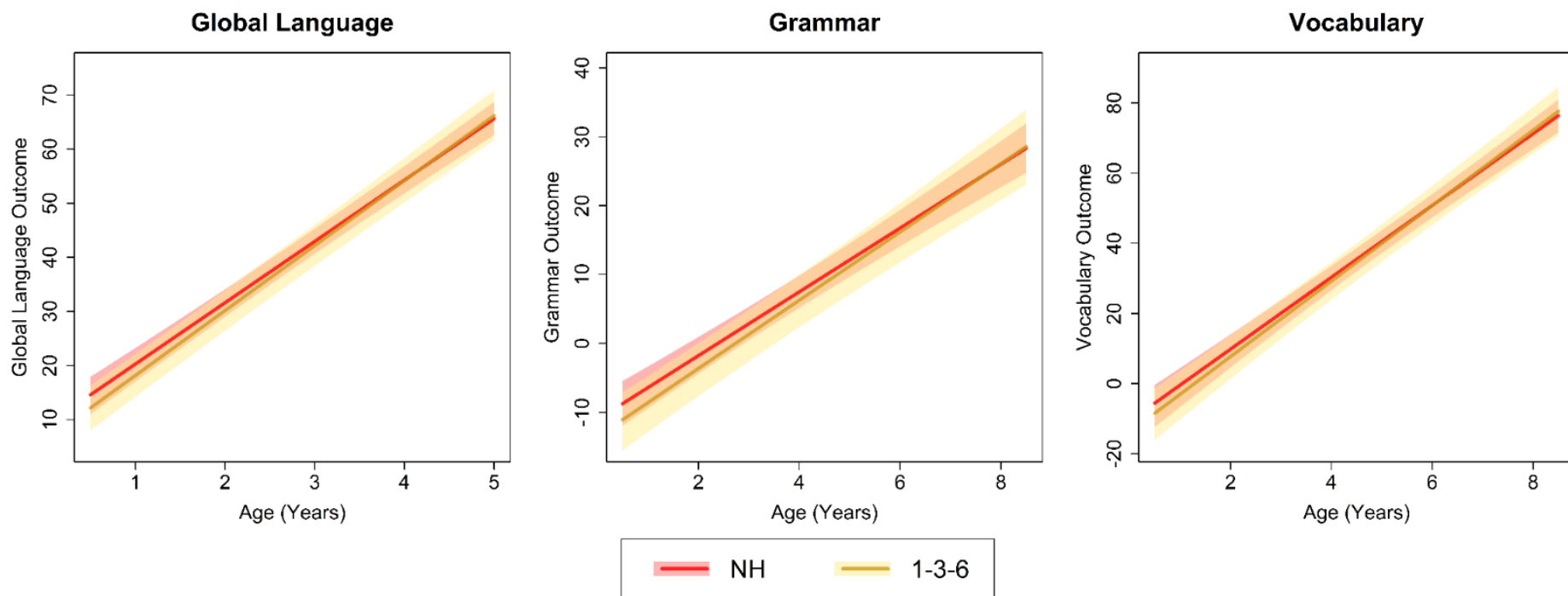


2 months of age
Confirmation of HL



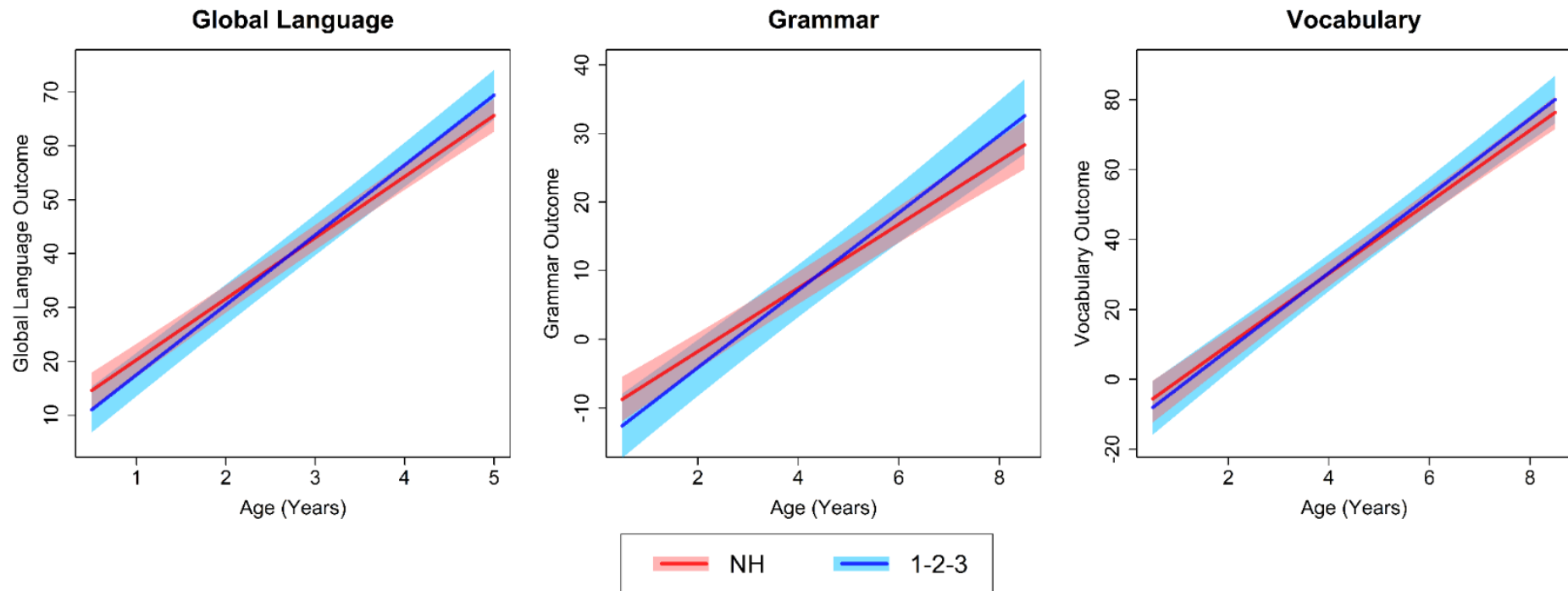
3 months of age
Early intervention

No difference in language growth trajectories between “1-3-6” and NH children



“1-2-3” group show steeper growth in global language and grammar

Population Curves and 95% Credible Intervals over Time
1-2-3 vs NH





**Take
home message*

- Enrollment in early intervention by 6 months of age results in age-appropriate language growth trajectories out to 8 years of age
- Children in EI by 3 months show faster language growth – preliminary evidence to support very early intervention for children who have early confirmation

Vocabulary Breadth and Depth

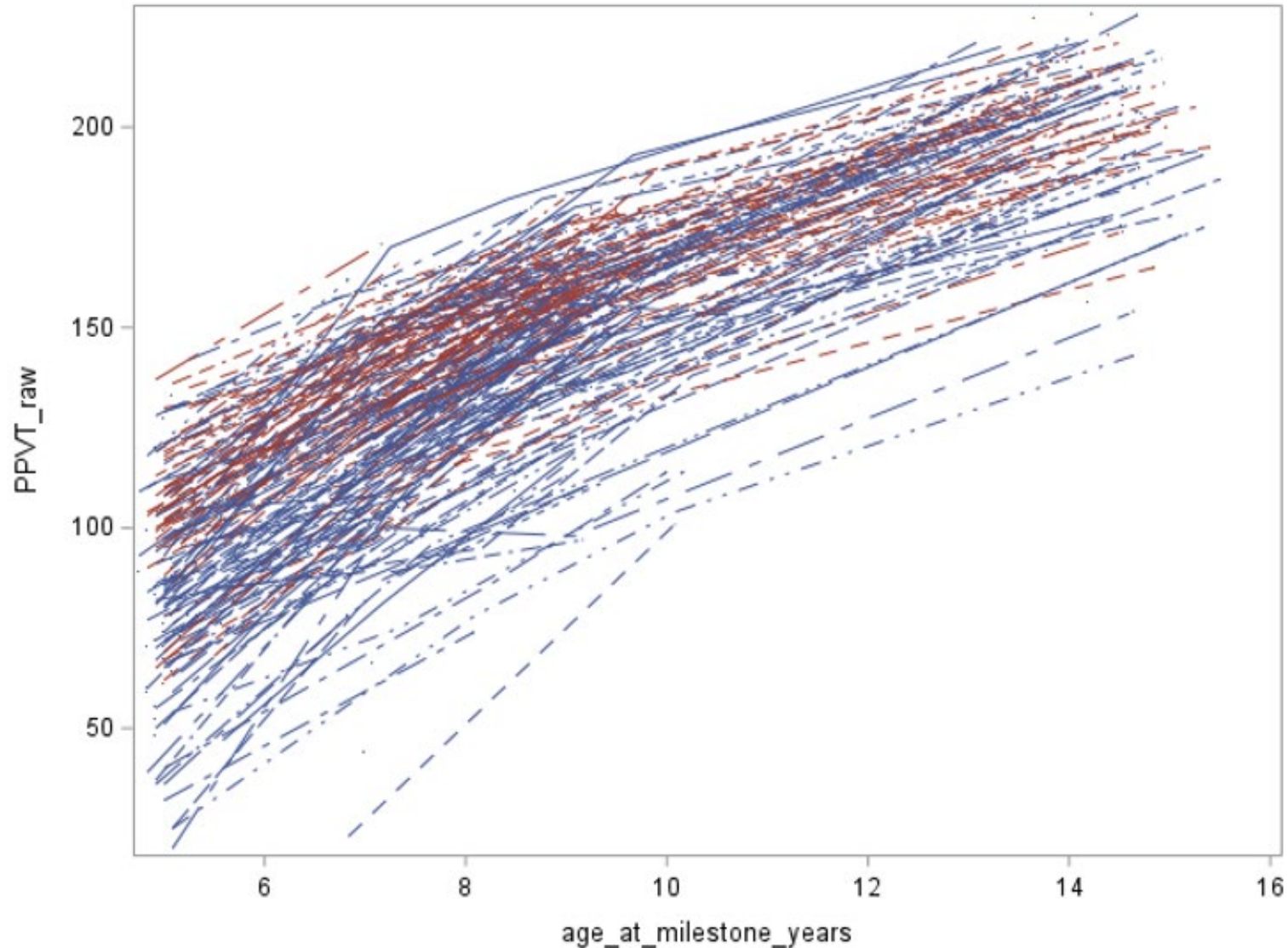


PPVT-5 at kindergarten, first grade, third grade, 7th or 8th grade, 11th or 12th grade

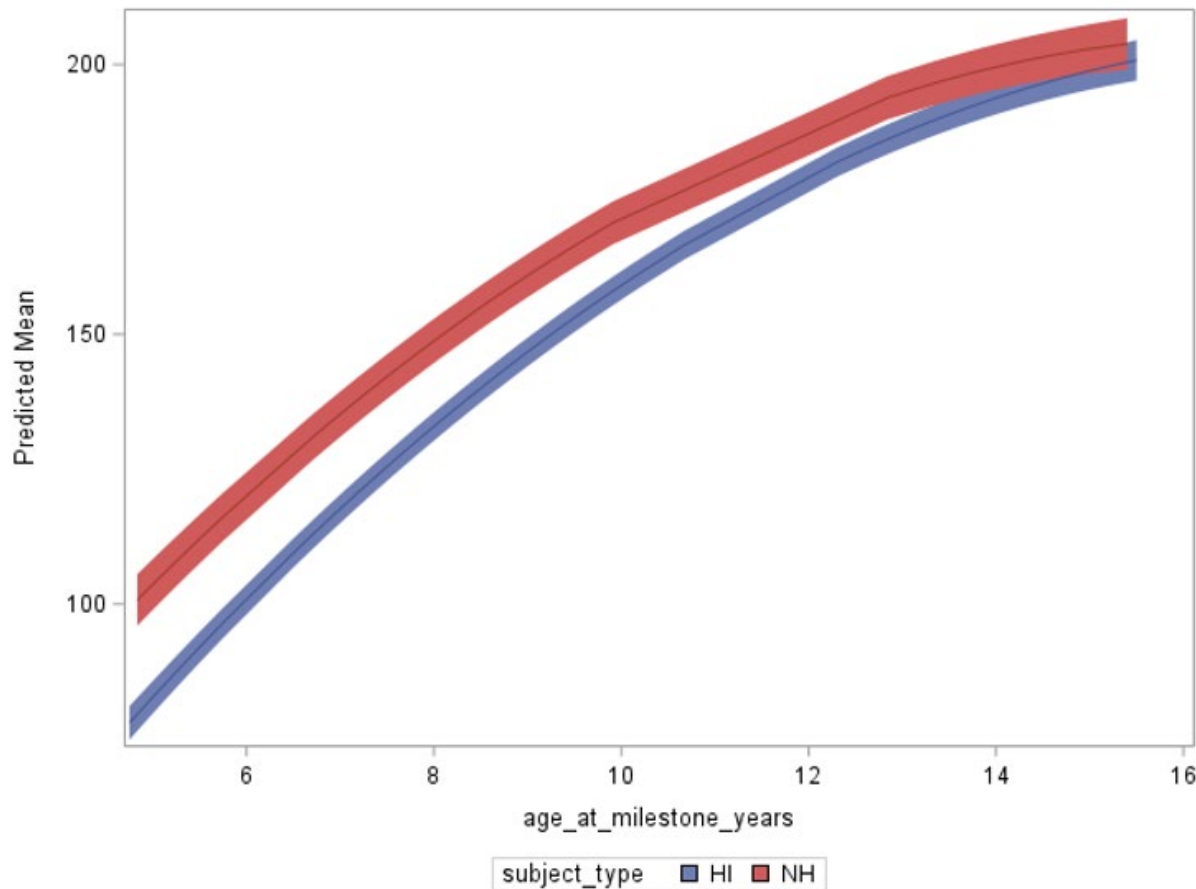
WASI-2 Word Definitions		
Word	Semantic Elements	Elaborative Details
Shirt	• Clothing • Worn • Upper body • Covers you	• Sleeves, collar • Buttons, zipper • Types of shirt • Put on/goes on
Reveal	• To uncover • Remove barrier • Show/tell, make known • Can see now	• Surprise • Makeovers • examples

WASI vocabulary definitions task at first grade, third grade, fourth grade, 7th or 8th grade, 11th or 12th grade

Vocabulary growth from age 5 to 16 years

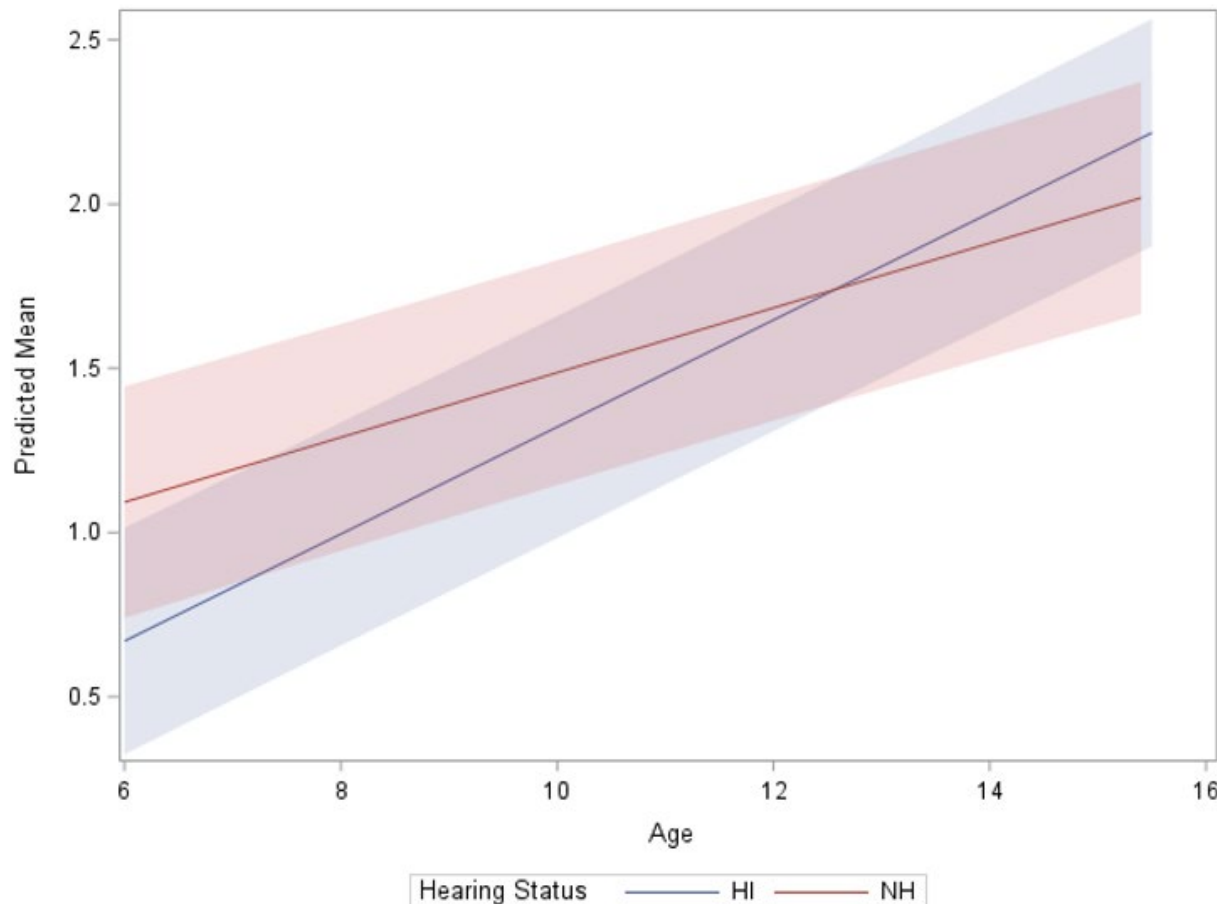


Results: Vocabulary Breadth



- Significant main effect of hearing status (NH > HL)
- Significant main effect of age
- Significant age x hearing status interaction – HL group starts off lower but shows faster growth than NH group. No difference between groups by older ages.

Results: Vocabulary Depth



- Significant main effect of hearing status (NH > HL)
- Significant main effect of age
- Significant interaction between age and hearing status – HL group starts off lower but shows faster growth than NH group. No difference between groups by older ages.

Statistical Analysis: Individual differences in vocabulary growth rates

→ Outcome: raw scores on PPVT and WASI vocab

→ Predictors:

- chronological age
- maternal education level
- age at confirmation of hearing loss
- amount of access to speech spectrum via hearing aids (better-ear aided Speech Intelligibility Index)

Results

- Amount of access to speech via hearing aids (aided SII) was a significant predictor of vocabulary breadth and depth, with a large effect size.
- Age at confirmation of hearing loss was a significant predictor for breadth, but it had a small effect size. It was not significant for depth.
- Maternal education level was significant for breadth and depth, with larger effect sizes in breadth than depth.

Parameter	Breadth		Depth	
	P Value	Effect Size	P Value	Effect Size
Age at testing	<0.0001	.04	<0.0001	.20
Average aided SII	<0.0001	1.55	0.0390	.44
Age at confirmation	0.0048	.01	0.1493	.003
Maternal Education	<0.0001		<0.0001	
HS vs some College	0.2012	0.34	0.1334	.26
HS vs College	0.0584	.48	0.9985	.02
HS vs grad school	0.0076	.62	0.9472	.07
Some college vs college	<0.0001	.82	0.0332	.28
Some college vs grad	<0.0001	.97	0.0133	.33
College vs grad	.7535	.14	0.9682	.05

Phonological Awareness in Middle School

Directions: Say, OK, now let's try some more where we say even smaller parts of words, one part at a time. I want you to listen carefully and then put these parts together to make a whole word. Ready? Let's try one. (Continue the recorded items below, pausing after each item.) Items may be repeated once.

Item	Word	Correct Response	Score (1 or 0)	Track #
9.	s-ŭ n	sun	☐	(9)
10.	t-ā k	take	☐	(10)
11.	n-ō	no	☐	(11)
12.	m-ă -d	mad	☐	(12)

CTOPP-2 Blending Words

11. Say "meet." Now say "meet" without saying /t/. me

12. Say "farm." Now say "farm" without saying /f/. arm

13. Say "mat." Now say "mat" without saying /m/. at

14. Say "bold." Now say "bold" without saying /b/. old

CTOPP-2 Elision

18. The word find has four sounds, /f/-/i/-/n/-/d/. What is the second sound in the word find? /long i/

19. What is the second sound in the word toast?..... /long o/

20. The word frog also has four sounds, /f/-/r/-/o/-/g/. What is the third sound in the word frog? /au/

21. What is the second sound in the word flat? /l/

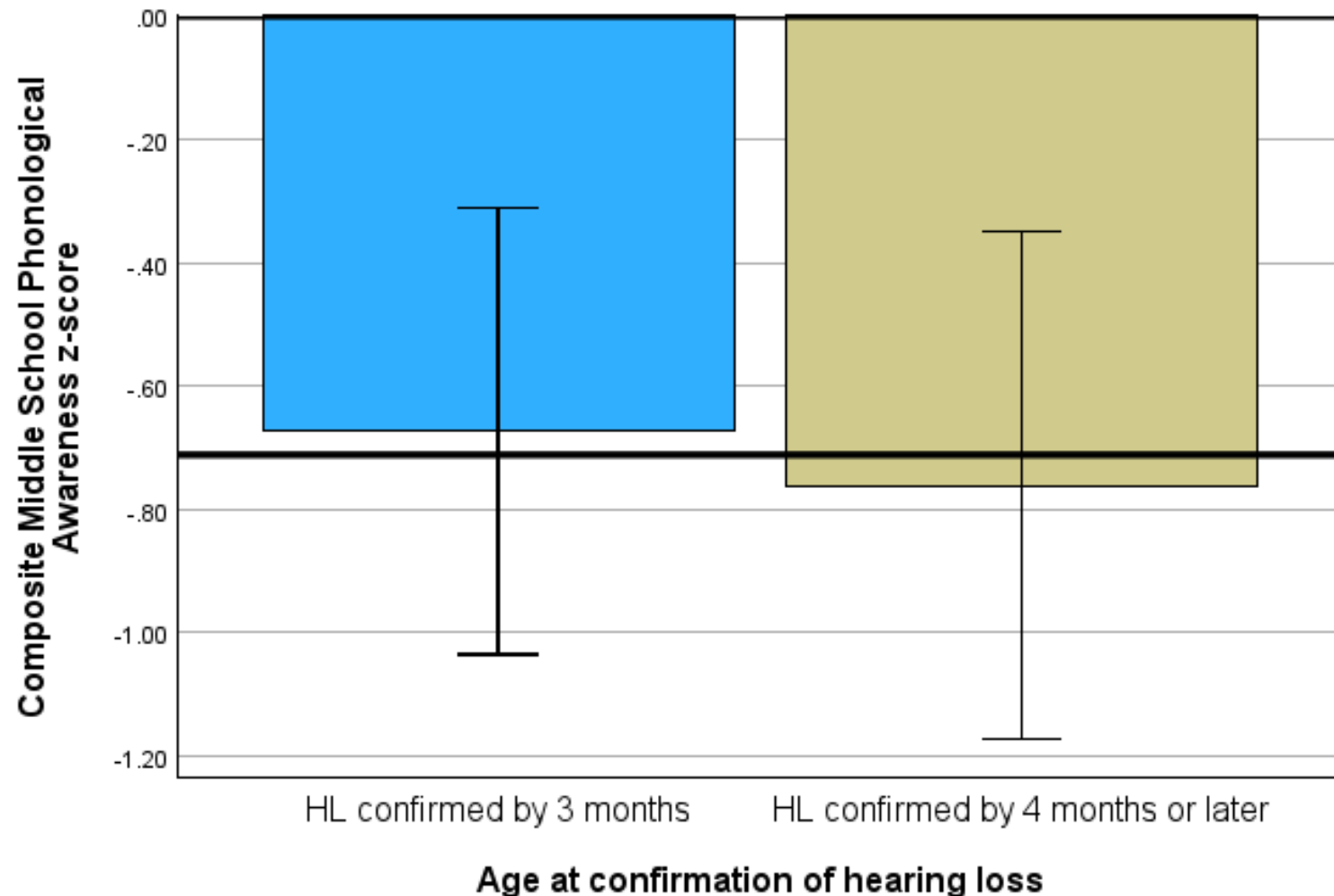
CTOPP-2 Phoneme Isolation

Statistical analysis



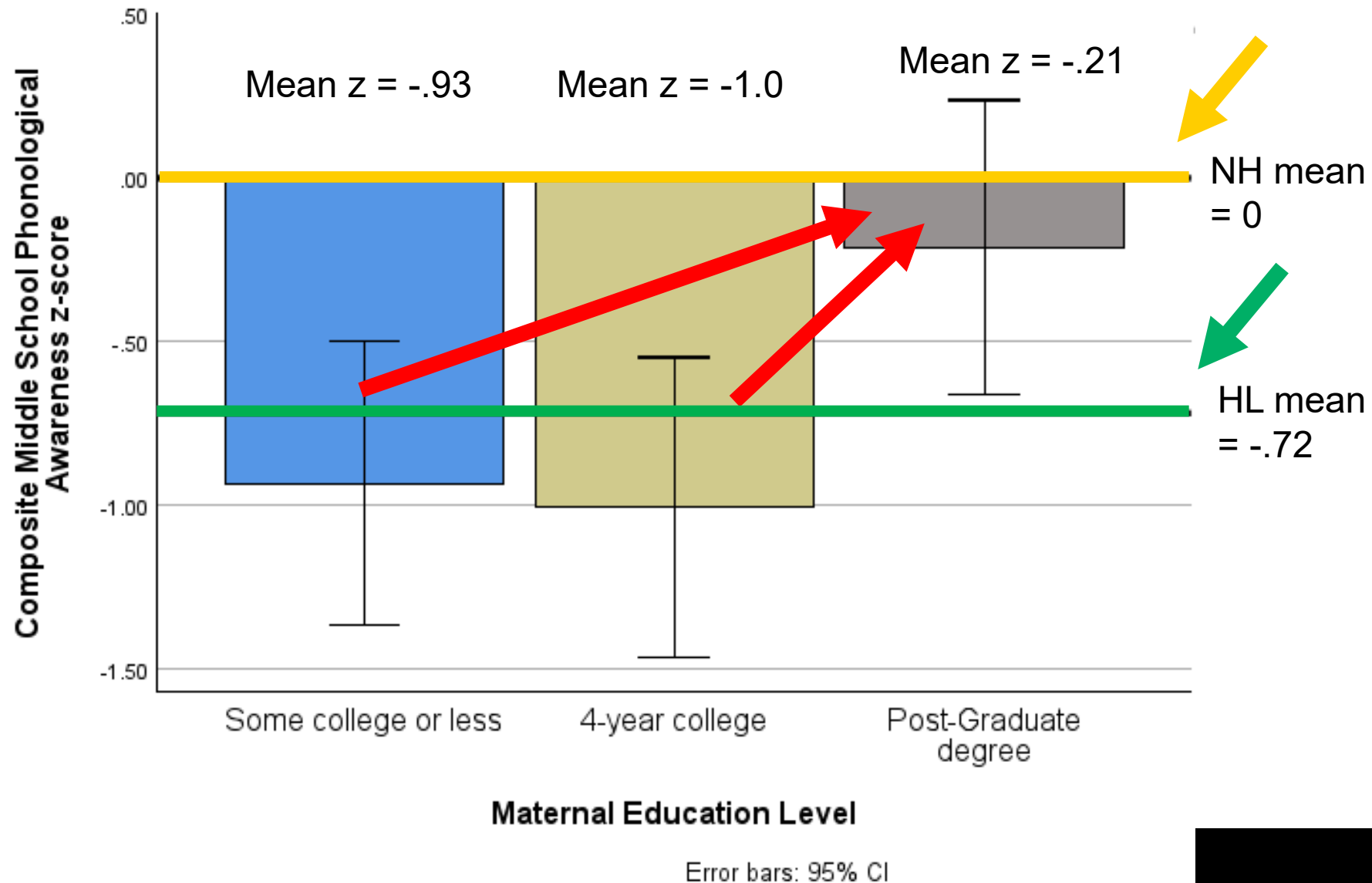
- Did not administer same phonological awareness tests at multiple visits so we can't look at growth trajectories
- Outcomes:
 - Raw scores from CTOPP-2 Blending Words, Elision, and Phoneme Isolation converted into z-scores relative to NH sample and averaged together for phonological awareness composite score in Middle School
- Predictors:
 - Age at HL confirmation (dichotomized as HL loss confirmed by 3 months vs 4 months or later)
 - Maternal education level (some college or less, 4-year college, post-grad degree)
 - Better-ear SII in second grade
 - Better-ear PTA in second grade

Age at HL confirmation had no effect on phonological awareness

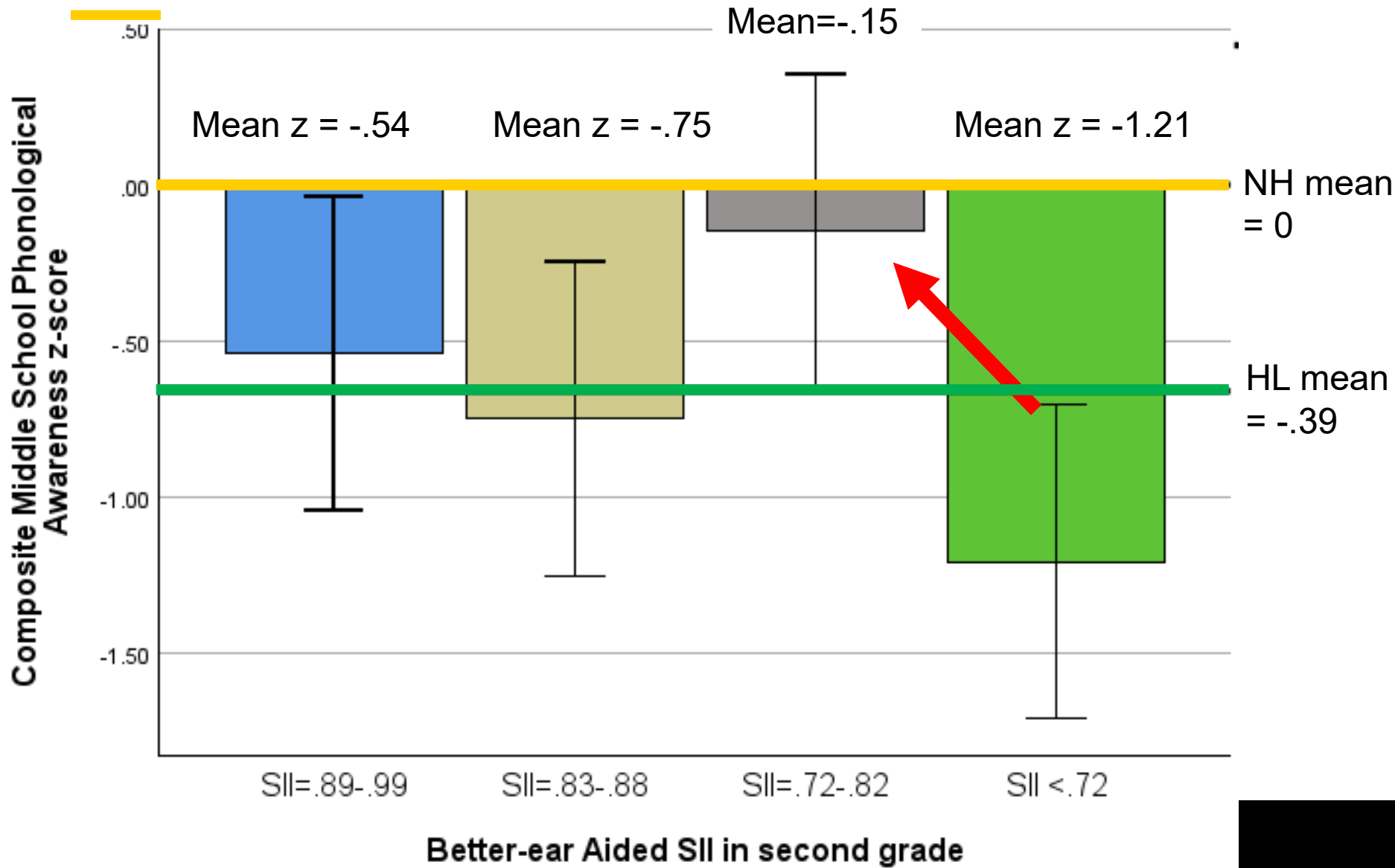


Error bars: 95% CI

Maternal Education Level associated with phonological awareness



2nd grade better-ear aided SII associated with later phonological awareness



3. Morphosyntax in High School (11th or 12th grade)

GRAMMATICAL MORPHEMES			
Item	Correct	Alternative Dialect Response	Skill Measured
35. Say: <i>He is to him as they is to ____.</i>	them		Function: pronoun (<i>them</i>)
36. Say: <i>Talk is to talks as pitch is to ____.</i>	itches		Inflection: present verb tense, plural (-es)
37. Say: <i>Walked is to will walk as sat is to ____.</i>	will sit	will sat	Inflection: future verb tense (<i>will sit</i>)
38. Say: <i>Can is to could as will is to ____.</i>	would		Function: auxiliary (<i>would</i>) Inflection: past verb tense
39. Say: <i>She is to hers as they is to ____.</i>	theirs	them	Function: possessive pronoun (<i>theirs</i>)
40. Say: <i>Would eat is to would have eaten as would be is to ____.</i>	would have been	would of been	Inflection: conditional perfect verb tense (<i>would have been</i>)
41. Say: <i>Higher is to highest as more is to ____.</i>	most	mostest	Inflection: irregular superlative (<i>most</i>)
42. Say: <i>Tall is to taller as good is to ____.</i>	better	gooder	Inflection: irregular comparative (<i>better</i>)
43. Say: <i>I is to my as he is to ____.</i>	his	him	Function: possessive pronoun (<i>his</i>)
44. Say: <i>Him is to himself as our is to ____.</i>	ourselves	ourself	Function: pronoun (<i>ourselves</i>)
45. Say: <i>Pull is to pulled as sing is to ____.</i>	sang		Inflection: irregular past verb tense (<i>sang</i>)

CASL-2 Grammatical Morphemes Items 35-45 205

GRAMMATICALITY JUDGMENT SENTENCE COMPREHENSION

1	0	1. Jeremy wants football for his birthday. (I)
1	0	2. I think me heard my mom calling. (I)
1	0	3. My school is very difference from yours. (I)
Foil		4. Sarah is running up the hill. (C)
1	0	5. That one is yours, this one is mines. (I)
1	0	6. Whitney needs eggs so she can made her cake. (I)
1	0	7. The presentation was fantastible. (I)
1	0	8. You ain't the best student in the class. (I)
1	0	9. Them boys run really fast. (I)
1	0	10. The cat drink milk. (I)

Comprehensive Assessment of
Spoken Language (CASL-2)
Grammatical Morphemes

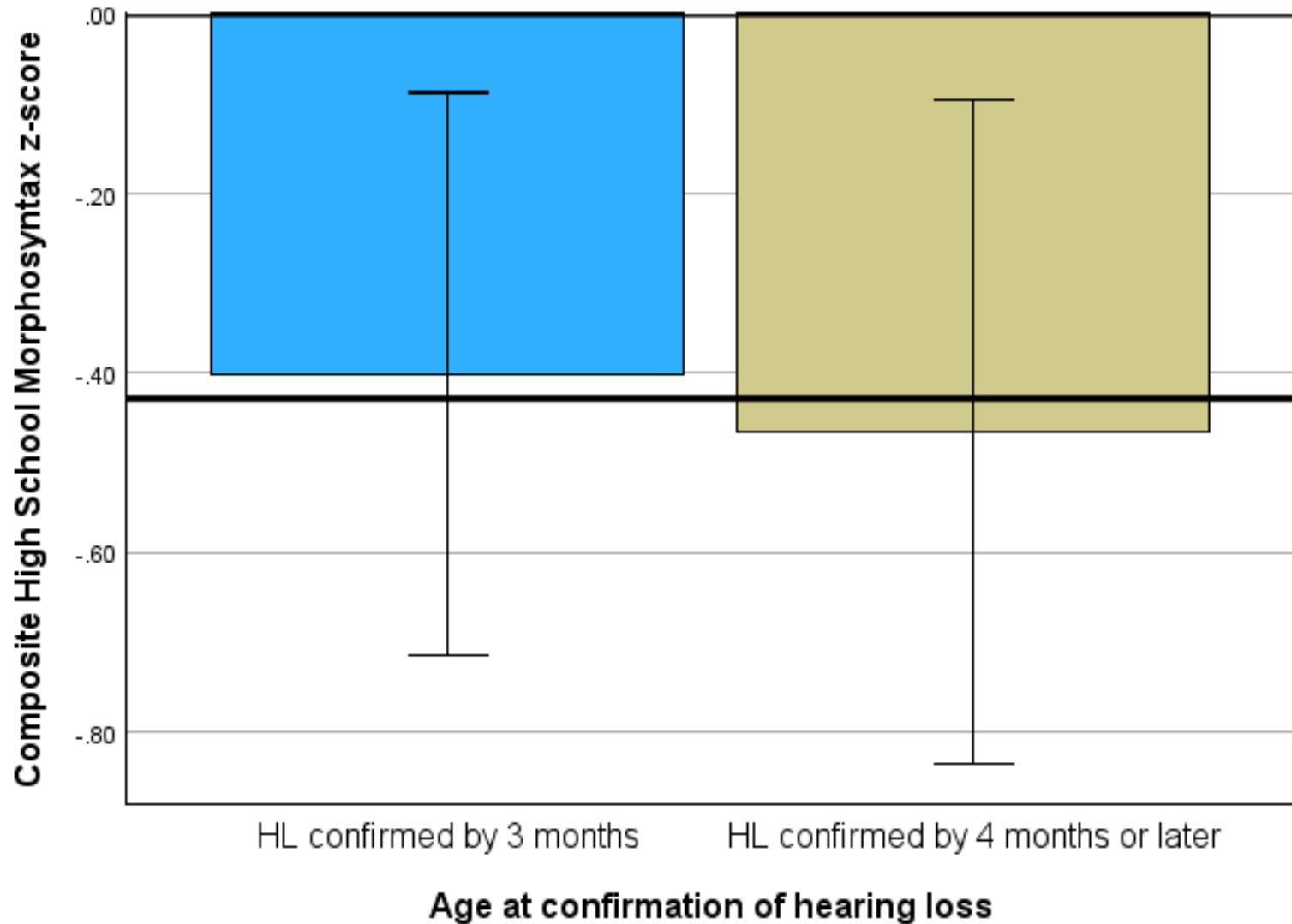
Test of Expressive and Receptive
Morphology (TERM)

Statistical analysis



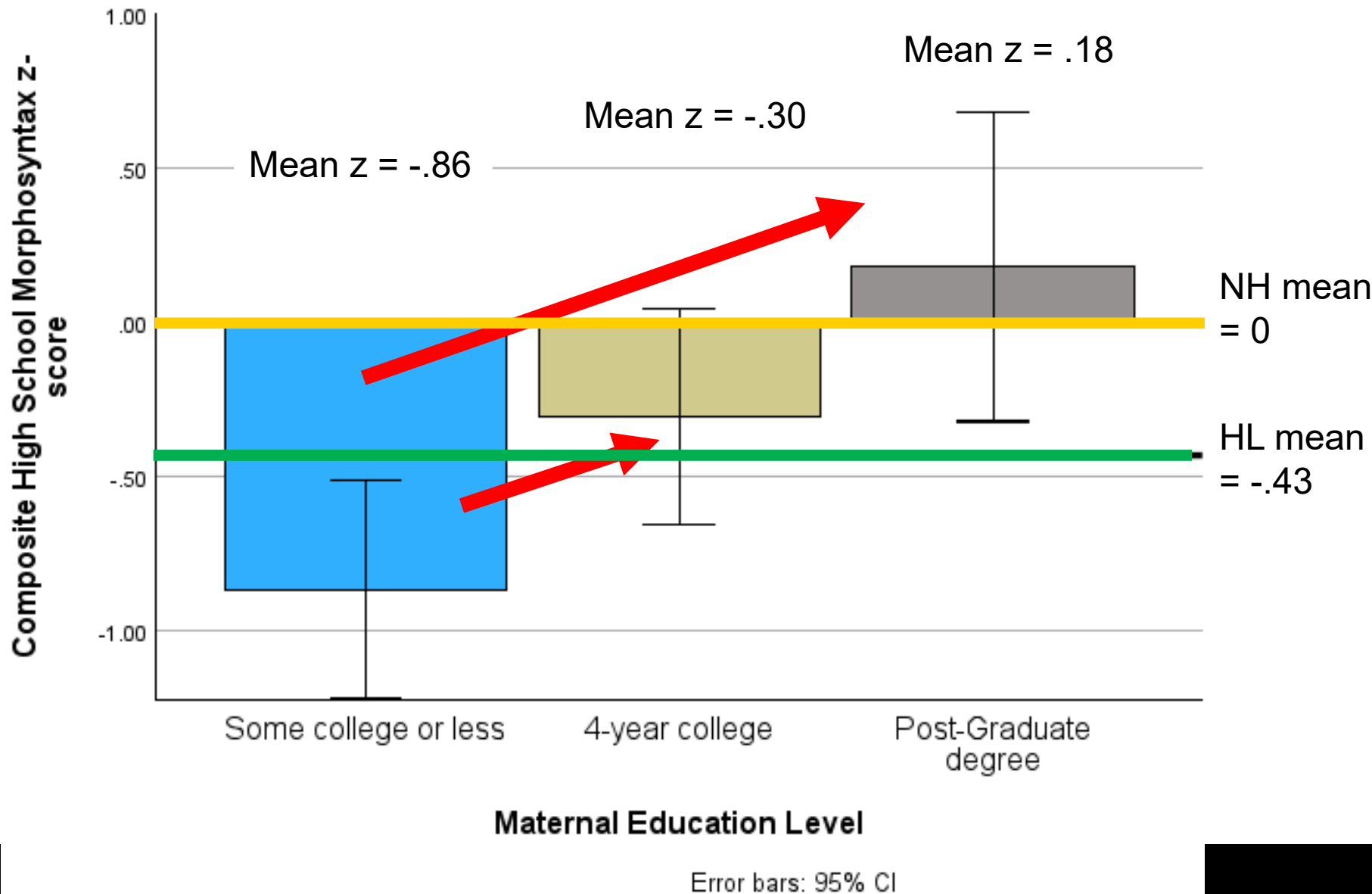
- Did not administer same morphological tests at multiple visits so we can't look at growth trajectories
- Outcomes:
 - Raw scores from the CASL-2 Grammatical Morphemes and Test of Expressive and Receptive Morphology (TERM) converted into z-scores relative to NH sample and averaged together for morphosyntax composite score in High School
- Predictors:
 - Age at HL confirmation (dichotomized as HL loss confirmed by 3 months vs 4 months or later)
 - Maternal education level (some college or less, 4-year college, post-grad degree)
 - Better-ear SII in second grade
 - Better-ear PTA in second grade

Age at HL confirmation had no effect on morphosyntax

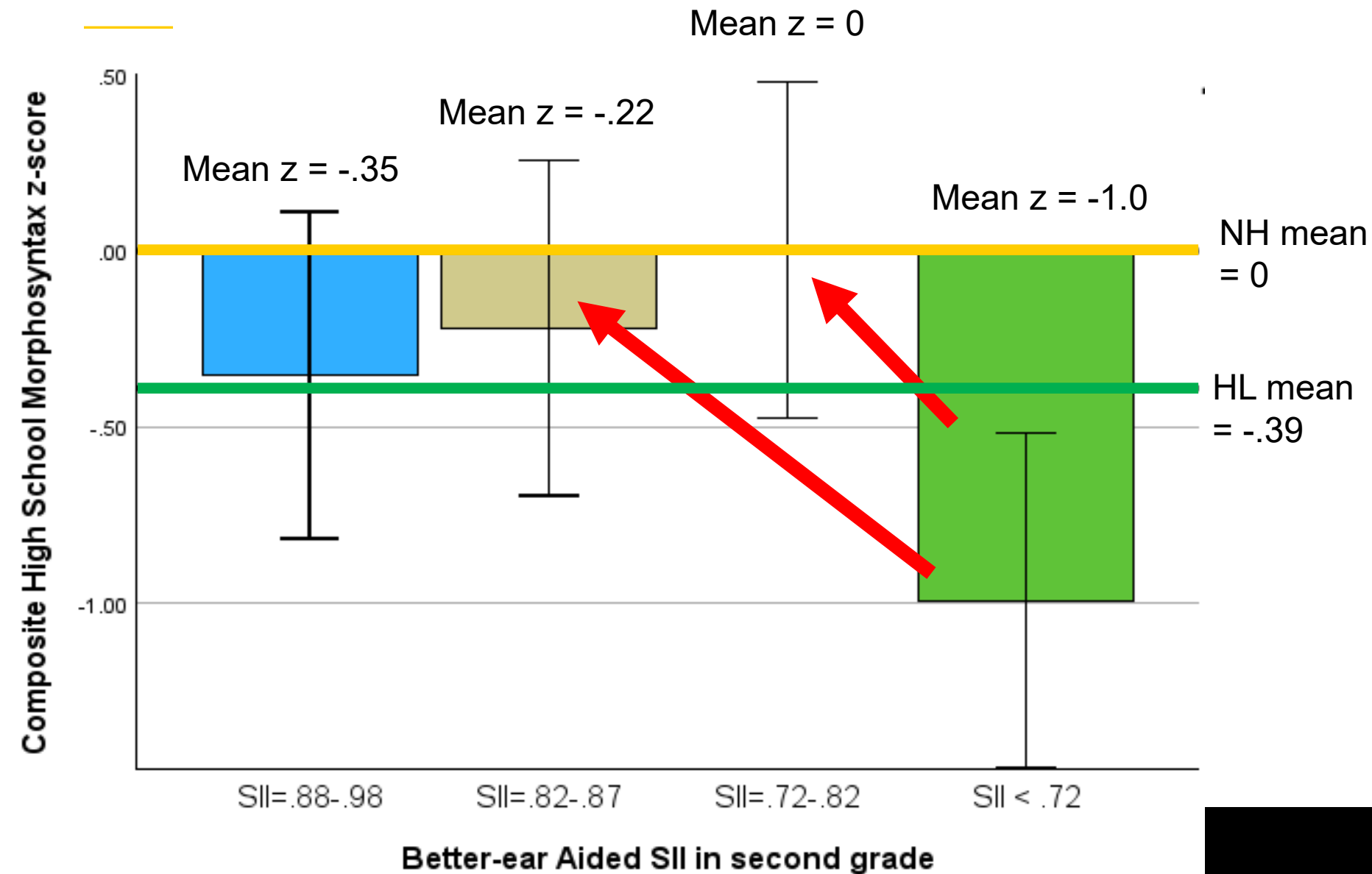


Error bars: +/- 2 SE

Maternal Education Level associated with morphosyntax



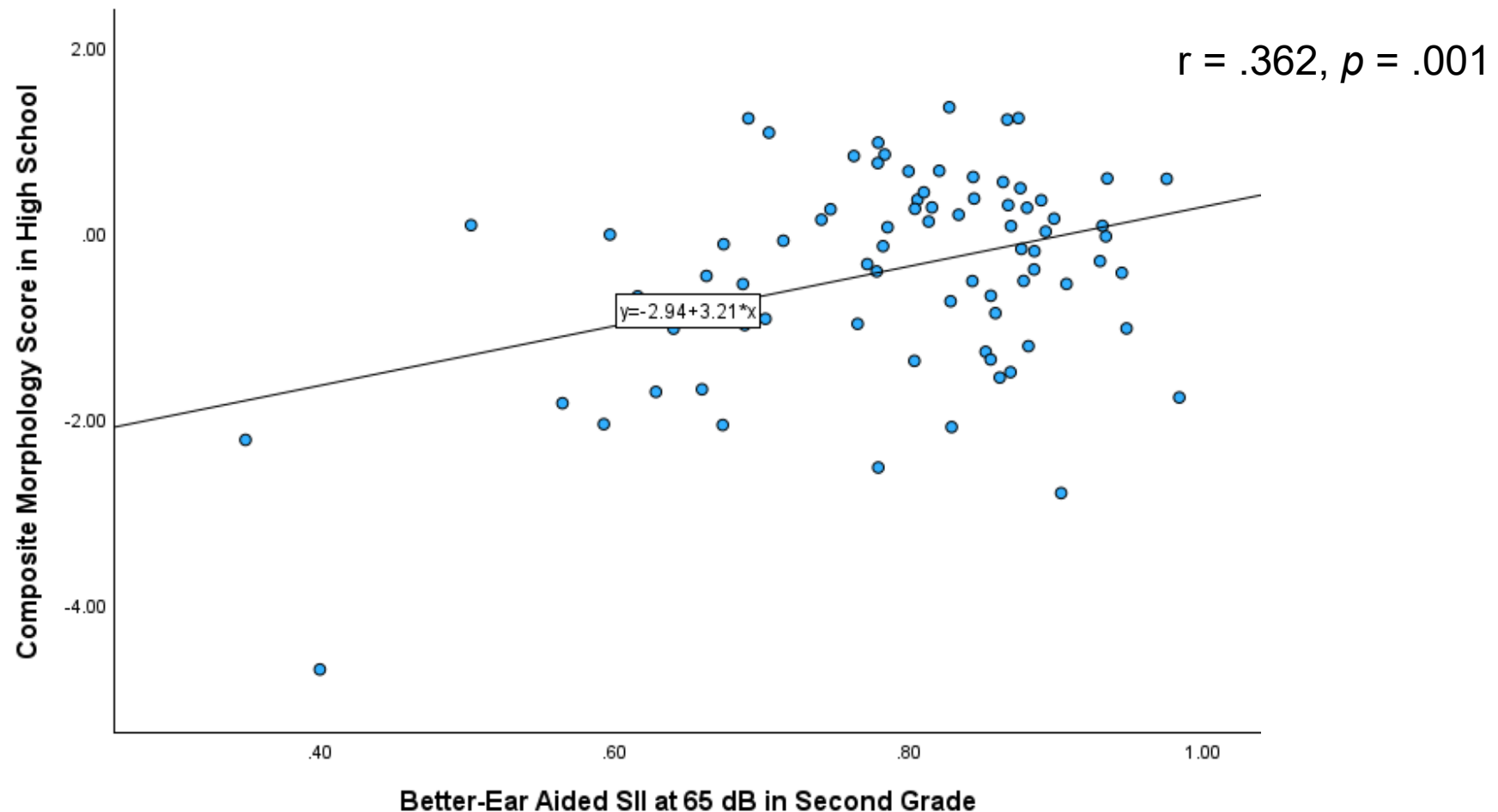
2nd grade better-ear aided SII associated with later morphosyntax



Multiple regression analyses with morphosyntax and phonological awareness as outcomes

- Entered maternal education level, age at hearing loss confirmation, better-ear PTA and better-ear SII at second grade
- Model accounted for 27% of the variance in morphosyntax in high school
 - Maternal education level ($\beta = .374$, $p < .001$) and Better-ear SII ($\beta = .441$, $p = .024$) are the only variables to contribute unique variance
- Model accounted for 18% of the variance in phonological awareness scores in middle school
 - No variables contributed to unique variance

2nd grade BE SII predicts morphosyntax in high school (but age at ID, BE-PTA in 2nd grade/high school and SII in high school does not).



Summary of findings

- Age at confirmation of hearing loss impacts growth in vocabulary breadth but not depth. It was not a predictor of later phonological awareness or morphological skills.
- Early aided audibility is a significant factor driving variation in growth rates for vocabulary breadth and depth and long-term morphosyntax and phonological awareness skills. Children with greater audibility via hearing aids show steeper growth and better outcomes than children with poorer audibility.
- Social drivers of health (e.g., maternal education level) also contribute to variability in language outcomes. Higher maternal education levels serve as a protective factor for limited auditory access.

Final Take-Home Points

- Early identification has transformed outcomes for children who are deaf or hard of hearing but access to intervention is still uneven
 - Universal newborn hearing screening has created a new generation of children identified at very young ages
 - Early access to technology and intervention provides a strong foundation, but large variability in outcomes persists
- Audibility drives developmental outcomes
 - PTA alone does not predict how children function in the real world
 - Even children with milder hearing loss may have limited access to language input without amplification

Final Take-Home Points

- Auditory access is a malleable, powerful intervention factor
 - Children who are deaf or hard of hearing can achieve age-appropriate language outcomes when provided with:
 - Early identification
 - Well-fit amplification
 - Consistent device use
 - Individualized educational and clinical support
- We can't change degree of hearing loss, but we *can* change access! Improving cumulative auditory experience transforms developmental trajectories.

Best Practice Goals

A

All families receive timely follow up

C

There is reason for optimism, but not complacency!

SS

Set the bar high and Super-size services!

Consistent audibility appears to be a key construct tied to positive outcomes among children whose families choose spoken language.

Across type and level of HL

Tomblin et al., 2015
Walker et al., 2016
Walker et al., 2017
McCreery et al., 2020

Adequacy of amplification

Tomblin et al., 2015
McCreery et al., 2017
Walker et al., 2017

Stiles et al., 2012

Davidson et al., 2014

Consistency of access

Tomblin et al., 2015
Walker et al., 2015
Walker et al., 2017
Walker et al., 2019
Tomblin et al., 2020
Walker et al., 2020

Park et al., 2019

Where are we now?



Outcomes of Children with Hearing Loss



Outcomes of School Age Children
who are Hard of Hearing



Complex Listening Skills in
School-Age Hard of Hearing Children



Longitudinal Outcomes of Literacy in Adolescents
who are Hard of Hearing

Help Researchers

Learn How Children
with Unilateral Hearing
Loss Locate Sounds,
Develop Language Skills
and Succeed Academically



Researchers at the University of Iowa invite children with hearing loss in one ear or children with normal hearing, ages 6 to 16 years old, to join a longitudinal research project studying auditory experience.

What will participants do?

Participants will complete:

- 🕒 A hearing test and brain imaging
- 🕒 Speech, language, attention and memory measures
- 🕒 Listening to sounds and words in quiet and in background noise

Ideally, participants will be involved longitudinally over the course of several years.

Who can participate?

- 🕒 Children ages 6 to 16 with unilateral mild to profound hearing loss **OR** children ages 6 to 16 with normal hearing
- 🕒 Children who use no amplification or use a hearing aid

Compensation

Participants will be compensated **\$25 per hour**.

Where does the study take place?

- 📍 **University of Iowa**
302 S. Grand Avenue
Iowa City, IA 52242

Questions?

Contact the Pediatric Audiology and Language Lab at:
wjshc-pedaud@uiowa.edu

Characterizing the Impact of Hearing Loss on Cognitive and Neural Function in Children and Adolescents

This project, which is a collaboration between the CASI Lab, the Audibility, Perception and Cognition Lab at Boys Town National Research Hospital and the Pediatric Audiology Lab at the University of Iowa, seeks to provide new data on the impact of hearing loss and hearing aid measures on cognitive, language and neural function in children ages 7-15.

We are currently enrolling children with hearing loss (7-15 years old) to undergo functional and structural brain imaging, as well as tests of auditory, cognitive and language function. We hope that data from this study will shed light on what combination of factors puts some children with hearing loss at risk for learning delays and what we can do to modify those factors.

Participate

- **Who:** children with bilateral hearing loss
- **Age:** between 7 and 15 years old
- **Time:** 3-4 visits of 1-3 hours each
- **Compensation:** \$50 per visit at the lab, \$20 at the audiology visit, \$170 total
- **Additional information:** for participants traveling from over 50 miles away from Boys Town, we will compensate for your mileage and other potential expenses, please reach out to us for more information

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Contact

For more information, call or text [\(402\) 249-9503](tel:402-249-9503) (cell), call [\(531\) 355-8937](tel:531-355-8937) (landline), or email casi.lab@boystown.org.

Pediatric Audiology and Language Lab



- Research Associates
 - Wendy Fick
 - Nonalee Gardner
 - Emma Rose
- Graduate students
 - Caroline Henning
 - Olivia Goodyear
 - Maddie Williams-Kane
 - Brandon Alpers
 - Katie Pribyl
 - Katie Kingsbury
- Undergraduates
 - Ava Van Voorst
 - Keegan Nissen
 - Annika Cheadle
 - Kelsey Eichbauer
 - Haley Richter
 - Ella McCann
 - Lauren Rymer
 - Audrey Uptegraph
 - Allie Zabel

Supported by NIH NIDCD R01 DC019081 (PI: Elizabeth Walker), R01 DC013591 and DC018330 (PI: Ryan McCreery)



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Thank you!

