Comparing speech environments of children with cochlear implants and typically-hearing children

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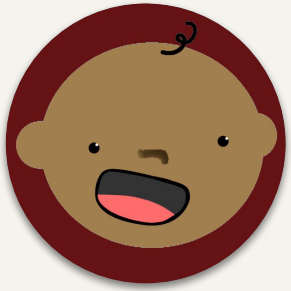
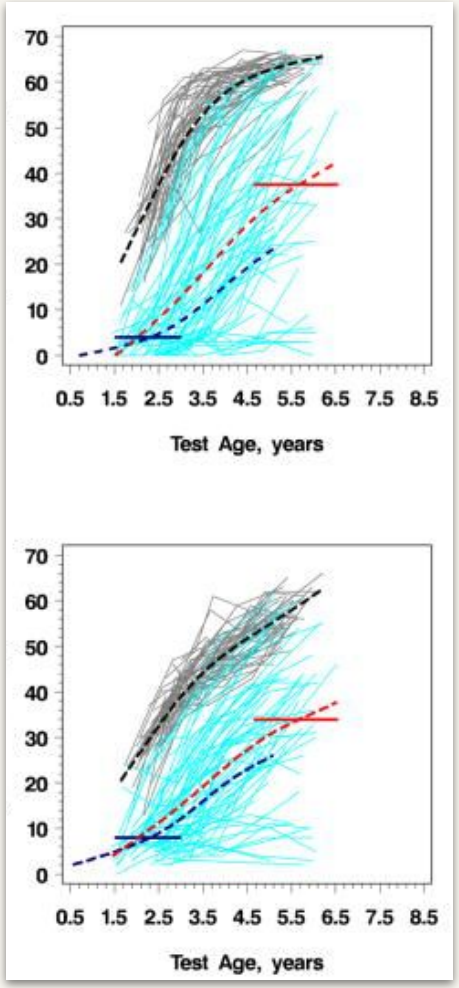


Introduction

- In U.S., ~2/1000 children born with severe-to-profound deafness (CDC).
  - Of these, >90% born to hearing parents (Mitchell & Karchmer 2004).
- ~80% of deaf/hard-of-hearing (DHH) children globally receive cochlear implants (CIs)
- First CIs at 9mos - several years old: often their first exposure to language (Levine et al. 2016)
  - High risk of language deprivation
- Acoustic signal is degraded (Houston, 2005; Valimaa et al., 2002)
- *Much* higher variability in spoken language outcomes, often substantial delays (Duchesne, Sutton, & Bergeron, 2009; Lund, 2016; Niparko et al., 2010; Warner-Czyz et al., 2024; Werfel, 2018).

High variability in DHH language outcomes



Niparko et al., 2010

Comprehension

Hearing scores

Deaf w/ CI scores

Production

Potential drivers of variability in CI speech outcomes

- Delayed access to input (Nittrouer, Lowenstein & Holloman 2016; Kirk et al. 2002; Hall et al., 2017)
- Variation in device efficacy (Houston & Miyamoto 2010; Kutlu, Ozkan & Yucel 2021)
- Frequency and comfort of device use; listening fatigue
  (Park et al. 2019; Haukedal, Lyxell, & Wie 2020; Phillips et al., 2023)
- Listening environment (Eisenberg et al., 2016; Majorano et al., 2021; Percy-Smith et al., 2013; Poupore et al., 2024)
- Access to sign language input (Delcenserie et al., 2024; Pontecorvo et al. 2023)

But input also drives variation

- Input features drive variation in typically hearing (TH) kids

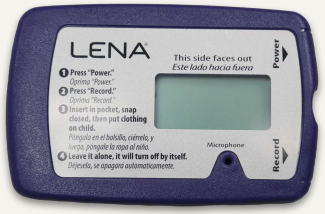
  (Anderson et al., 2021; Bergelson et al., 2023; Demir et al., 2015; Gilkerson et al., 2018; Hsu et al., 2017; Huttenlocher et al., 1991, Rowe, 2012; Watkins et al., 1998; Weisleder & Fernald, 2013; *inter alia*)

- Input differs in other populations of kids with disabilities (Dirks et al., 2020; Lorang et al., 2020; Odijk & Gillis, 2021; Snow, 1972)

…Could this be a driver of variation for CI users too?

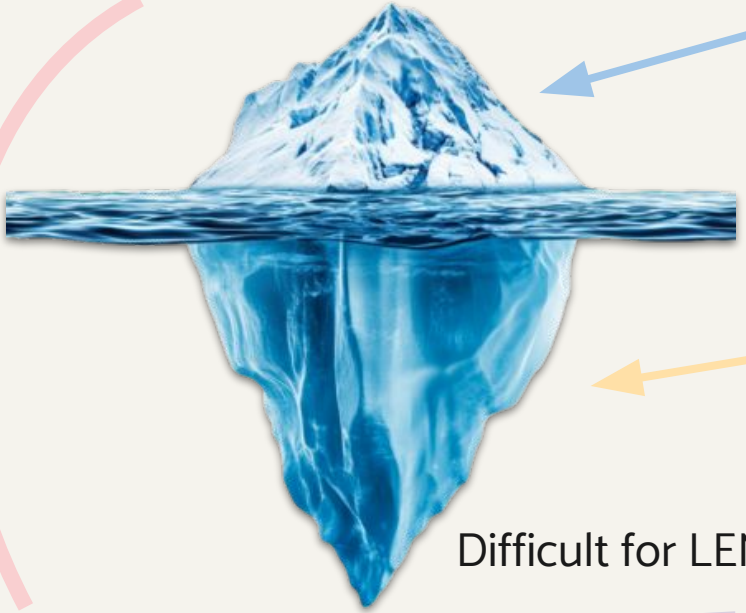
Prior work examining input to kids with CIs

- Past studies have found...
  - Broadly similar input regardless of hearing status (Aragon & Yoshinaga-Itano, 2012; Cychosz et al. 2024; Sultana et al. 2024; VanDam et al., 2012; Wang et al. 2022)
  - Weaker input-output relationship for kids with CIs (Cychosz et al. 2024)
  - Less TV/electronic noise in the environment for DHH kids (Wang et al. 2022)



Analyses conducted using LENA's automated analysis (E.g: Adult Word Count)

Characterizing the input with automated vs. manual measures



What LENA alone can tell us

Content of the input

Features of the environment that might impact language development

Difficult for LENA 🤝 Difficult for CI processing

Ambrose et al., 2014; Cristia et al., 2020, 2024; Ferjan Ramírez et al., 2021; Grieco-Calub et al., 2009

Present Study

1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

2. Does **children's language production** differ based on their hearing status and/or hearing age?

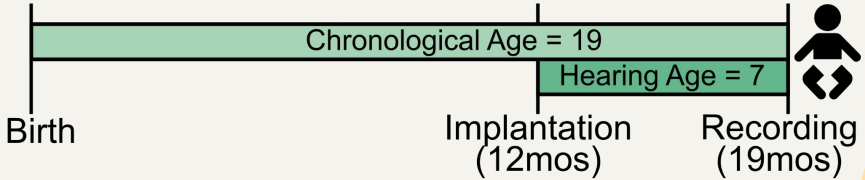
3. What **input variables** are related to each group of children's language outcomes?

Methods: Participants

Subset of recordings collected at OSU by Houston lab, used in Wang et al. (2022)

16 bilateral, severe to profoundly deaf toddlers (16-30 mo.) with CIs, monolingual English learners (no significant exposure to a sign language)

- Two control groups:
  - 16 same age (16-30 mo.) hearing toddlers
  - 16 same hearing age-matched (time since first CI activation) hearing infants (6.9-12mo)



Methods: Transcription

Daylong recordings hand-transcribed, 48 recordings at 40mins/recording

- 15x 2-min **random** intervals
- 5x 2-min **high-talk** intervals selected using VTC (Lavechin et al., 2020)

1920 total minutes

ACLEW & MinCHAT style (MacWhinney, 2019; Soderstrom et al., 2021)

- What was said?
- Who said it?
- To whom?
- When?

Research Questions

1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

2. Does **children's language production** differ based on their hearing status and/or hearing age?

3. What **input variables** are related to each group of children's language outcomes?

Input Variables

Input Variable	Scope
Adult Word Count (LENA)	🤖
Total Word Count	✏️
Prop. Child-Directed Speech	✏️
Prop. Overlapping Speech	🤖 & ✏️
Nonspeech and Electronic noise	🤖
Prop. Unintelligible	✏️
Words per Second	✏️
Mean Length of Utterance	✏️
Type-Token Ratio	✏️
Prop. Decontextualized Utterances	✏️
Prop. Auditory Words	✏️

Quantity

Audibility

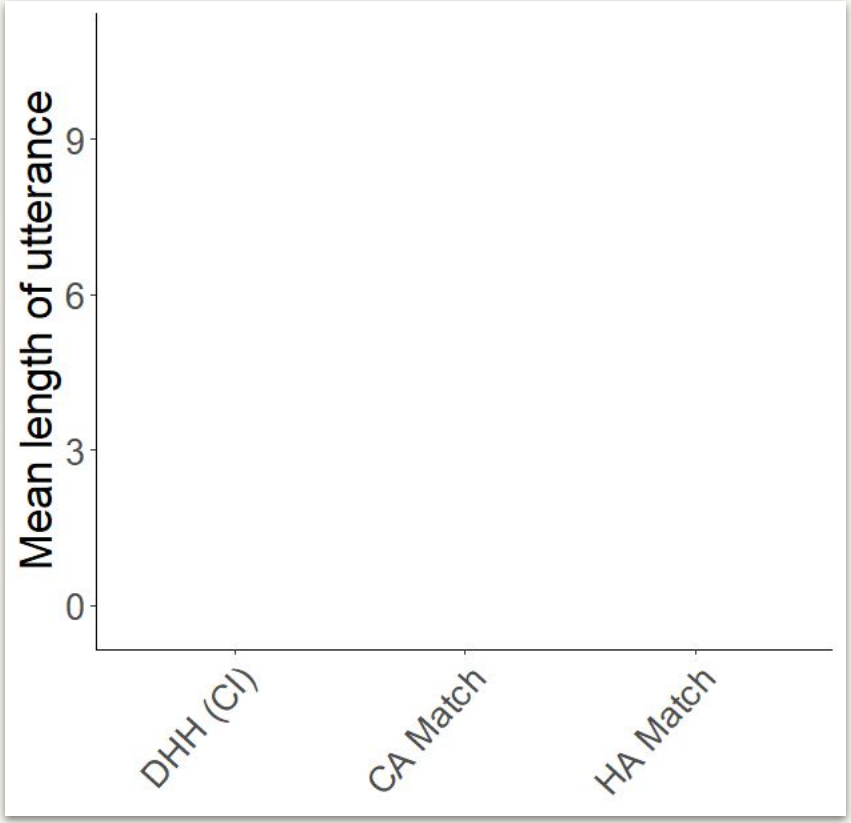
Complexity

Conceptual

Results: Input Complexity

MLU: Number of morphemes per utterance, by all speakers

Hearing age matches hear **longer** utterances in the input than **DHH CI users**



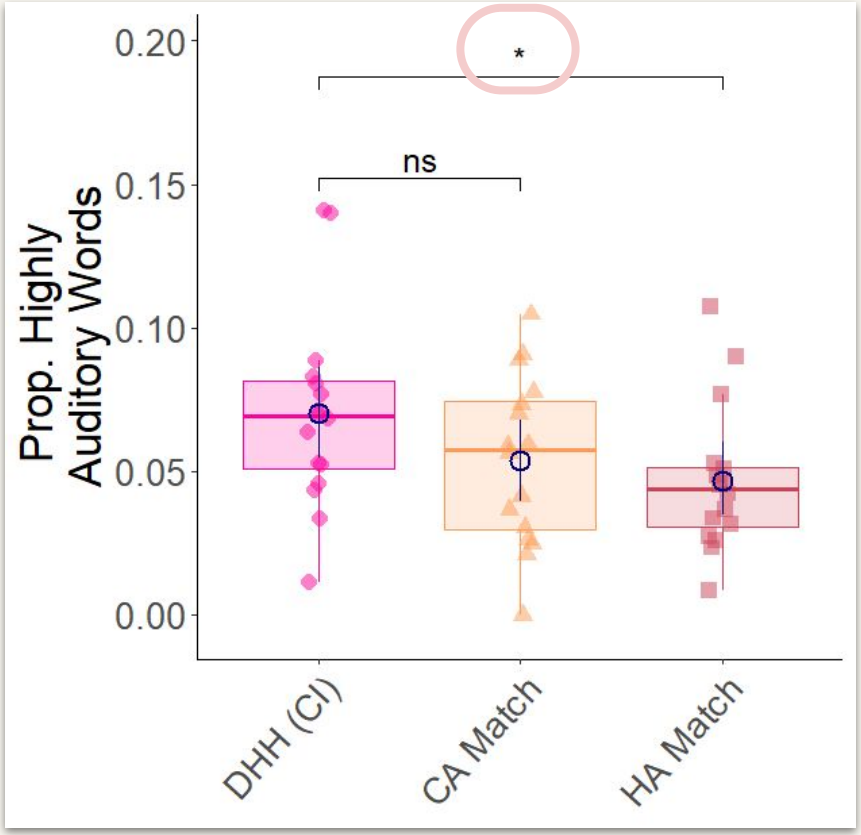
Results: Conceptual Properties of Input

- Each content word has sensory association scores out of 5—Lancaster Sensorimotor norms (Lynott et al., 2020)

- Proportion of words that are highly auditory + low rated for other senses
  - E.g., *Loud*

DHH kids hear **more** auditory words than **hearing age matches**

- Potential explanation: clinician guidance and/or common topics with older vs. younger kids



Research Questions

1

Does the **spoken language environment** differ based on children's hearing status and/or hearing experience?

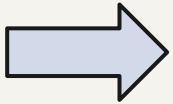
Largely no:

- No differences between **DHH** and **chronological age matches**
- **Hearing-age matches** hear longer utterances & fewer highly auditory words than **DHH group**
- No differences across quantity and audibility variables

Research Questions

1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

   Largely no, *but hearing-age matches hear longer utterances & fewer highly auditory words*



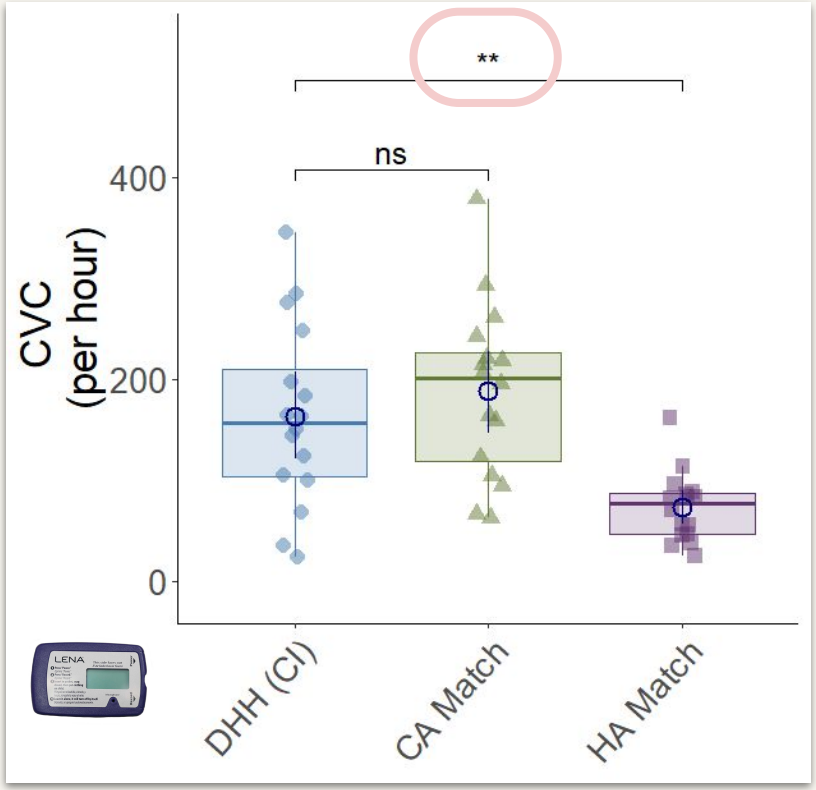
2. Does **children's language production** differ based on their hearing status and/or hearing age?

3. What **input variables** are related to each group of children's language outcomes?

Results: Children's Production

Child vocalization count: LENA-generated count of utterances by target child over full recording

- **DHH kids** vocalize **more** than (younger) **hearing age matches**
- Same **amount** as **chronological age matches**

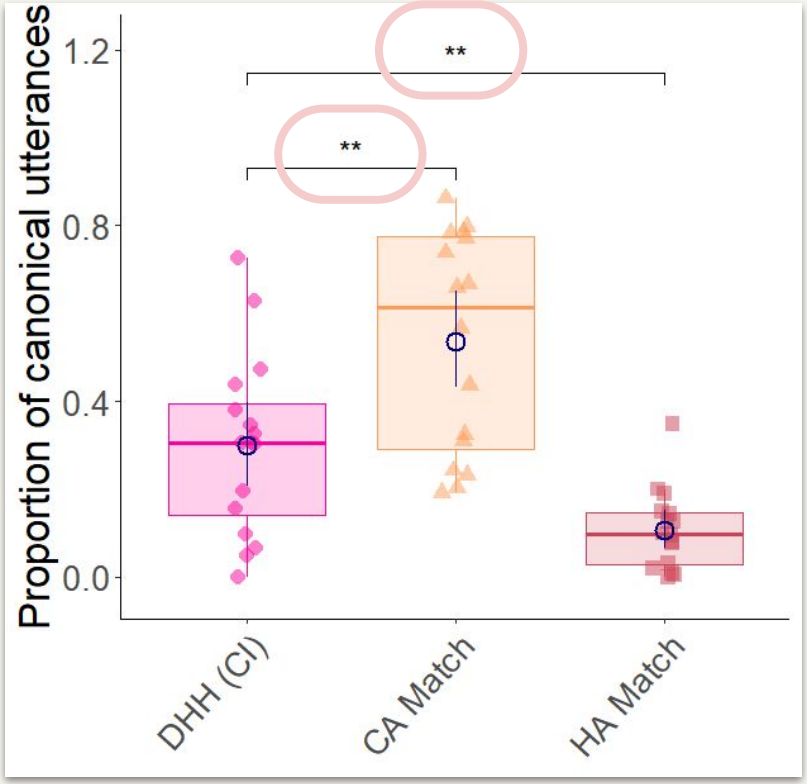


Results: Children's Production

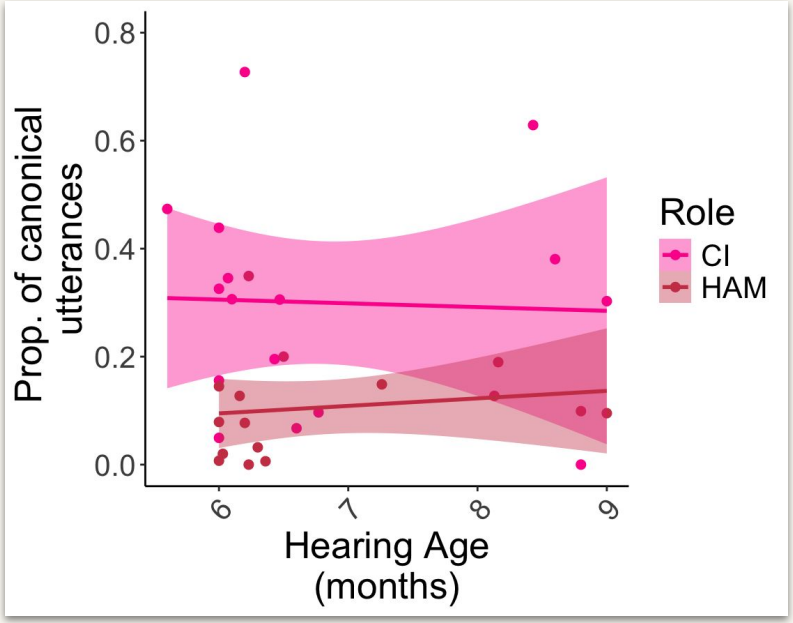
- Canonical babble indexes ***maturity:***
- Contains at least a **CV syllable** sequence
- **Includes lexical** utterances

Children produce more canonical utterances over development

- **DHH kids** produce **more mature** vocalizations than **hearing age matches**
- BUT **less mature** vocalizations than **chronological age matches**



Results: Speech Production

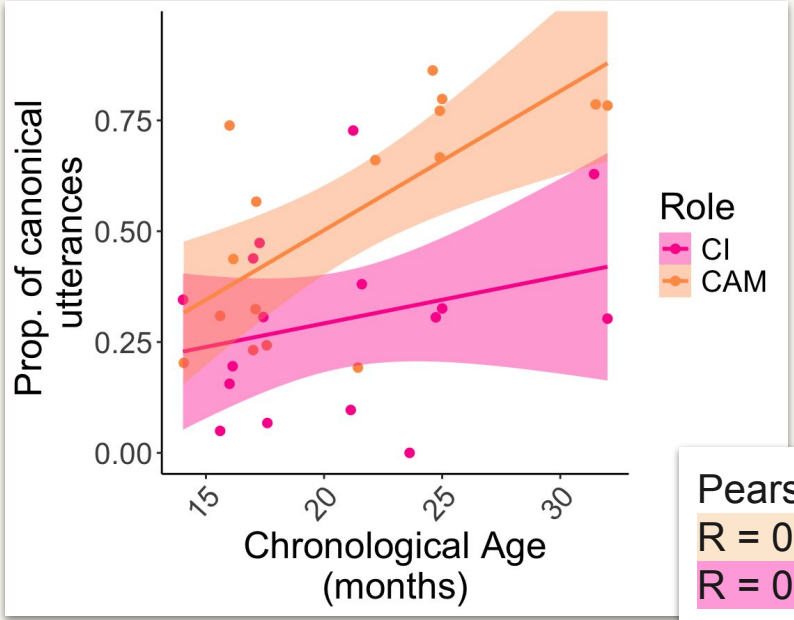


Proportion of canonical utterances over hearing age

No effect of hearing age on vocal maturity;

DHH group produces **more mature** utterances than younger **hearing age matches**

Results: Speech Production



Proportion of canonical utterances over chronological age

Vocal maturity **increases** with age for **chronological age matches**

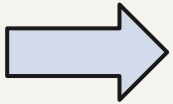
Vocal maturity **does not increase** with age for **DHH group**

Pearson's
R = 0.7, **p < .005*;**
R = 0.28, p = .287

Research Questions

1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

   Largely no, but hearing-age matches hear longer utterances & fewer highly auditory words



2. Does **children's language production** differ based on their hearing status and/or hearing age?

Yes!

- **DHH children** produce more vocalizations than younger **hearing age matches**
- With manual annotations, enough sensitivity to see higher variability and less mature vocalizations from **DHH children** than **same age matches**
- **Chronological age matches** show growth with age, **DHH group** does not

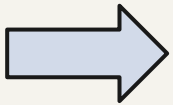
Research Questions

1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

   Largely no, but hearing-age matches hear longer utterances & fewer highly auditory words

2. Does **children's language production** differ based on their hearing status and/or hearing age

   Yes!



3. What **input variables** are related to each group of children's language outcomes?

What best predicts child vocalizations?

Stepwise regression with 4 sets of models:

- 2 control group matchups
- 2 dependent variables

Outcome Variables (DVs)	DHH & Hearing Age matches	DHH & Chronological Age matches
Child Vocalization Count	1	2
Proportion of Canonical Utterances	3	4

No input variables predict outcomes, only group does

Possible predictors

Input features

Adult Word Count (LENA)
Total Word Count (Manual)
Proportion Child Directed Speech
Type-Token Ratio
Mean Length of Utterance
Proportion Displaced Verbs
Proportion Highly Auditory Words
Chronological Age
Group (DHH vs. Hearing)

Chronological Age Matches & Deaf/Hard of Hearing children with Cochlear Implants

→ Proportion of Canonical babble

Possible predictors

Input features

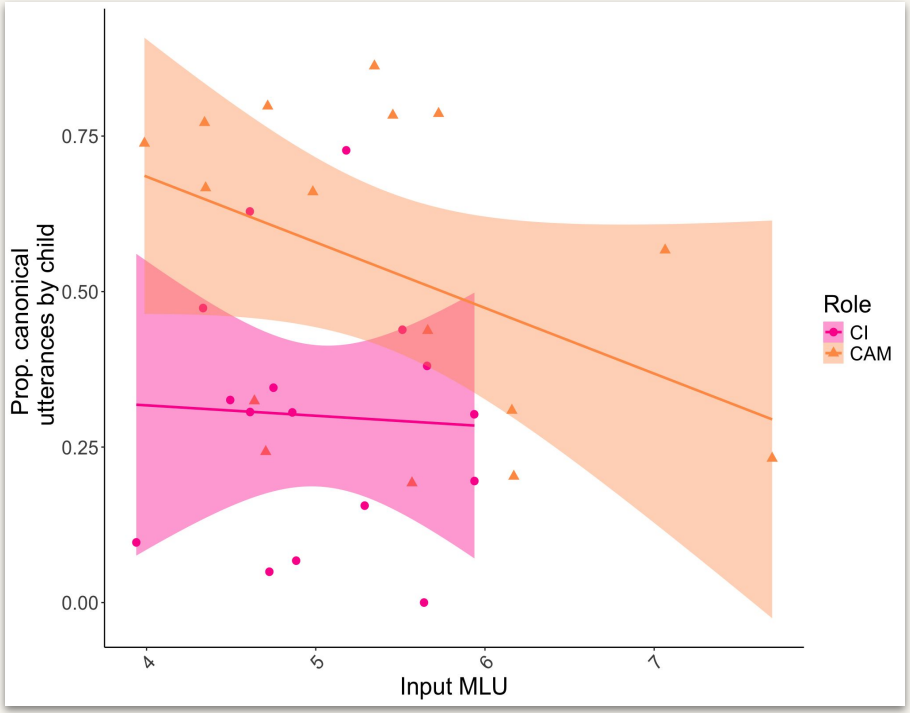
- Adult Word Count (LENA)
- **Total Word Count (Manual)** +
- Proportion Child Directed Speech
- Type-Token Ratio
- **Mean Length of Utterance** −
- Proportion Displaced Verbs
- Proportion Highly Auditory Words
- **Chronological Age** +
- **Group** **(CAM > HAM)**

Chronological Age Matches & Deaf/Hard of Hearing children with Cochlear Implants

→ Proportion of Canonical babble

$R^2_{adjusted}$=0.47, p < .001

MLU in input negatively predicts vocal maturity



Potential driver: MLU gets shorter *because* kids are talking back, not the other way around

Research Questions

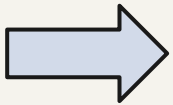
1. Does the **spoken language environment** differ based on children's hearing status and/or hearing age?

   Largely no, but hearing-age matches hear longer utterances & fewer highly auditory words

2. Does **children's language production** differ based on their hearing status and/or hearing age?

   Yes!

3. What **input variables** are related to each group of children's language outcomes?



- With **hearing-age-matched** children: **none** (only group)
- With **chronological-age-matched children**: MLU and # of words in the input (alongside hearing status and age)

Discussion & Conclusions

Do systematic input differences drive the variation in language outcomes for children with CIs?

Probably not!

- Persistent **outcome differences** despite broadly **similar input**
- **Age matters:**
  - For how people talk to children: we found *no* input differences between the **DHH group** and their **chronological age matches;** only with younger **hearing age matches**
  - For children's early production abilities:
    - **DHH group** systematically produced more mature vocalizations than younger **hearing age matches**
    - Age was a significant predictor for variation in outcomes for **DHH group** and **chronological age matches** (along with input variables)

Discussion & Conclusions

Do systematic input differences drive the variation in language outcomes for children with CIs?

Probably not!

- Due to noisy signal from CI, input DHH children *can access* through a CI will be lower in quantity than they are exposed to, and less regular/reliable (e.g. Houston 2022)
- Language produced in environment ≠ language children can access

Access, not input modifications

Sign language input

Comfort of use

Device efficacy

Early assessment and intervention

De-noising environment

Increasing input quantity

(Campbell & Bergelson, 2022; Delcenserie et al., 2024; Hall et al., 2017; Hardman et al., 2022; Kirk et al., 2002; Kutlu et al., 2021; Niparko et al., 2010; Nittrouer et al., 2016; Park et al., 2019; Peters et al., 2010; Pontecorvo et al., 2023; Snow & Ertmer, 2009)

Thank you!

NSF CAREER Award 2337766 to EB

NSF GRFP 2019274952 to EC

Transcription team, participants, and families!

BUCLD Organizing Team & our interpreter!

Input Variables

Input Variable	Description	Scope
Adult Word Count (LENA)	Est. # of nearby adult utts./hour	LENA auto, full day
Total Word Count	# words by any speaker	Manual annotations, 30 randomly sampled minutes
Prop. Child-Directed Speech	# of child-directed utterances/all utterances	Manual, 40 minutes
Prop. Overlapping Speech	Total time with overlapping utterances/rec. length	LENA and manual
Nonspeech and Electronic noise	Duration marked as TVN or OLN/recording length	LENA auto, full day
Prop. Unintelligible	# utterances w/unintelligible segments/ all utterances	Manual, 40 minutes
Words per Second	# words / speech duration	Manual, 40 minutes
Mean Length of Utterance	Average # of morphemes/utterance	
Type-Token Ratio	# unique words/total words	Manual, 40 minutes
Prop. Decontextualized Utterances	utterances that refer to past, future, or hypothetical events/all utterances	Manual, 40 minutes
Prop. Auditory Words	Content words with high auditory association ratings, low ratings for other perceptual modalities/ all words	Manual, 40 minutes

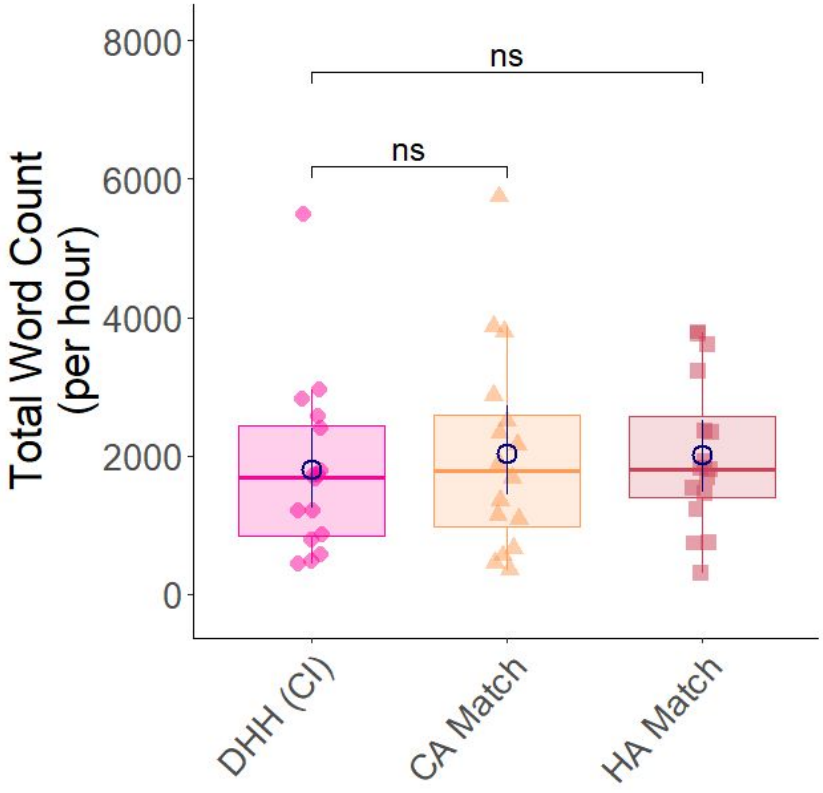
Quantity

Audibility

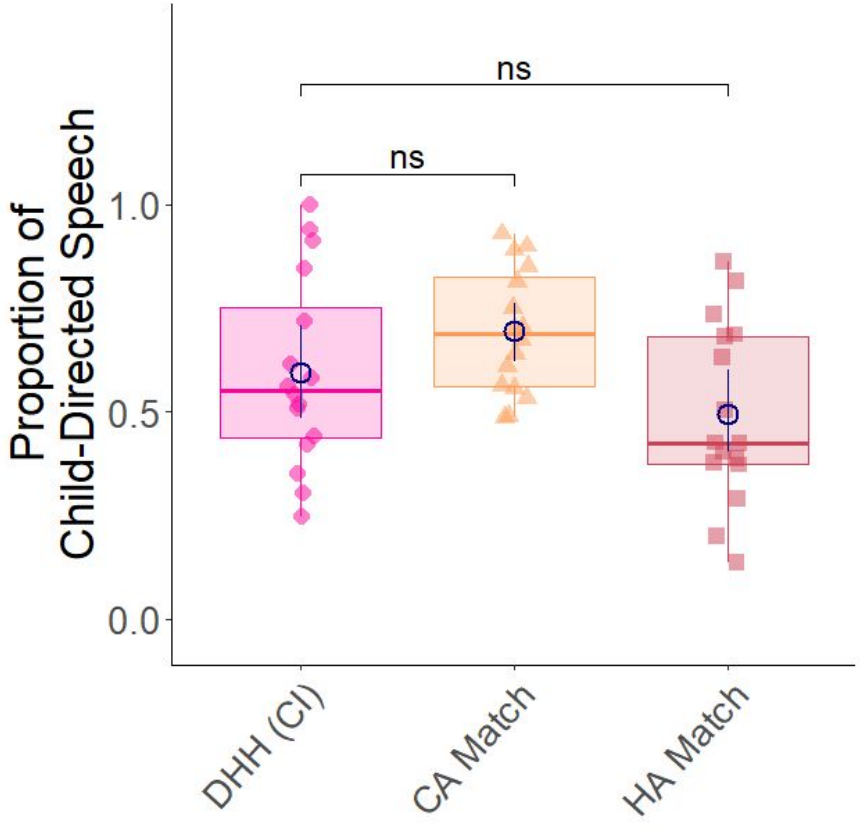
Complexity

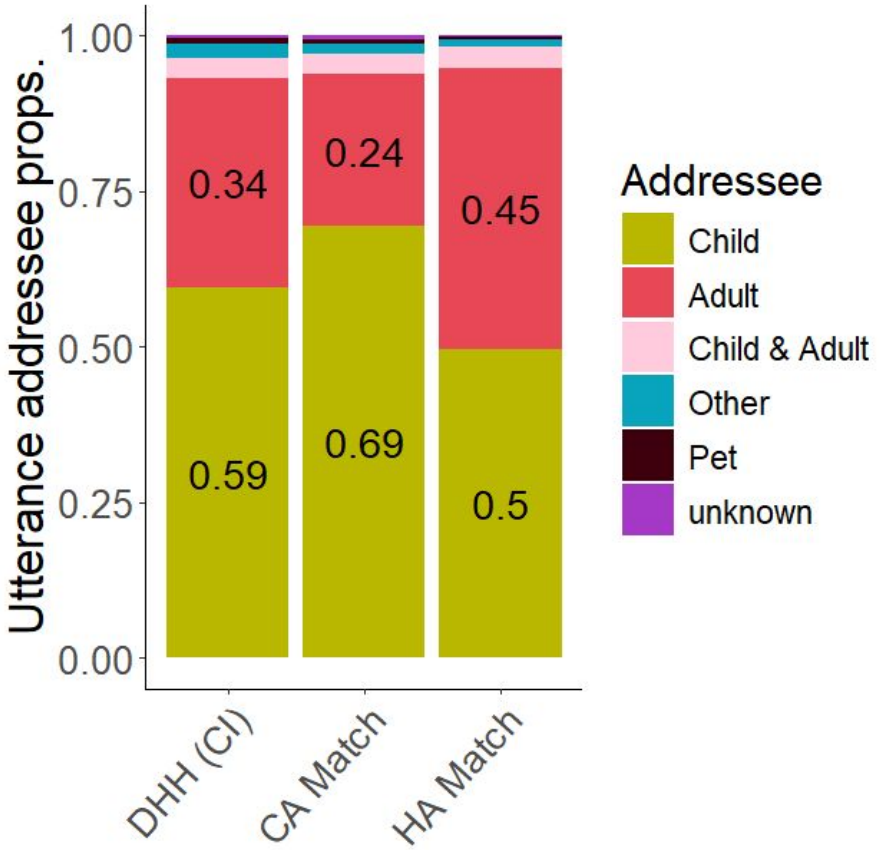
Conceptual

Results: Input quantity

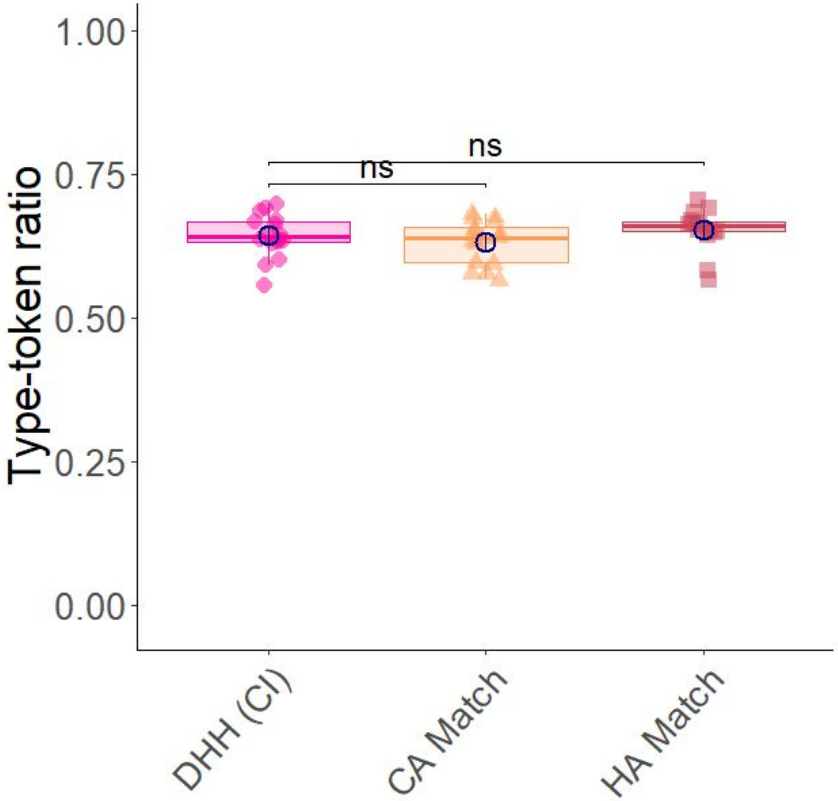


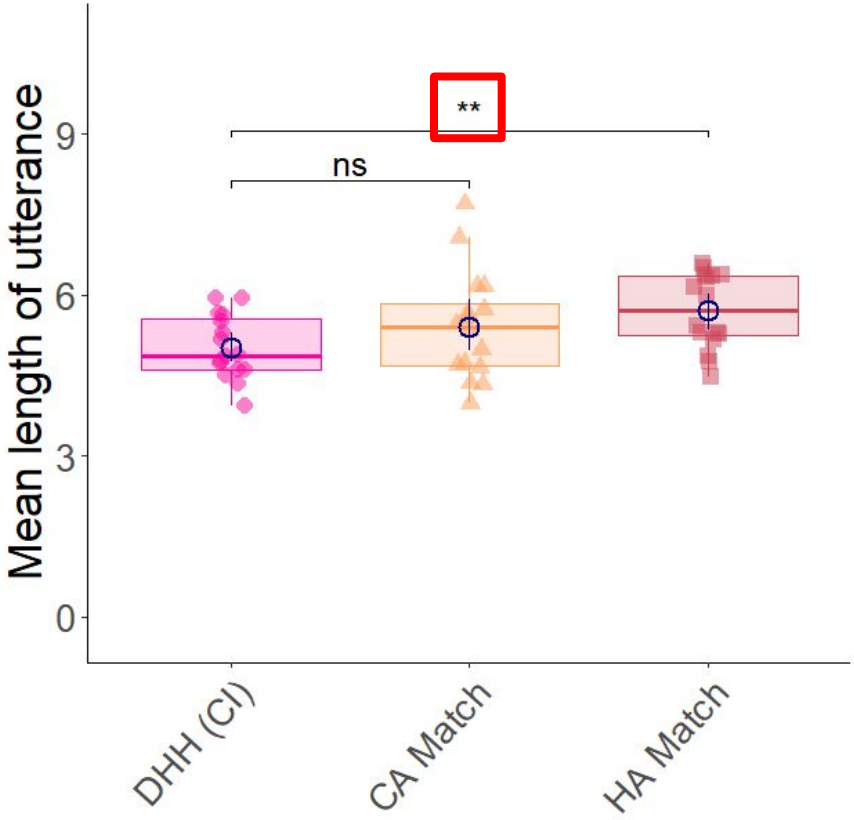
Results: Child-directed speech



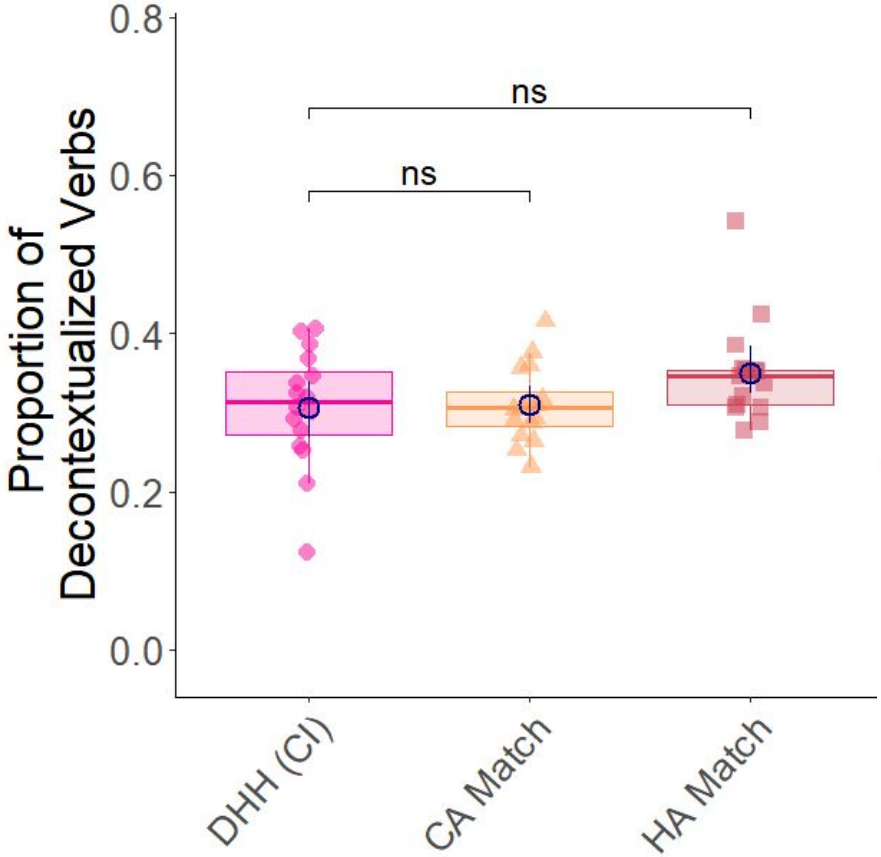


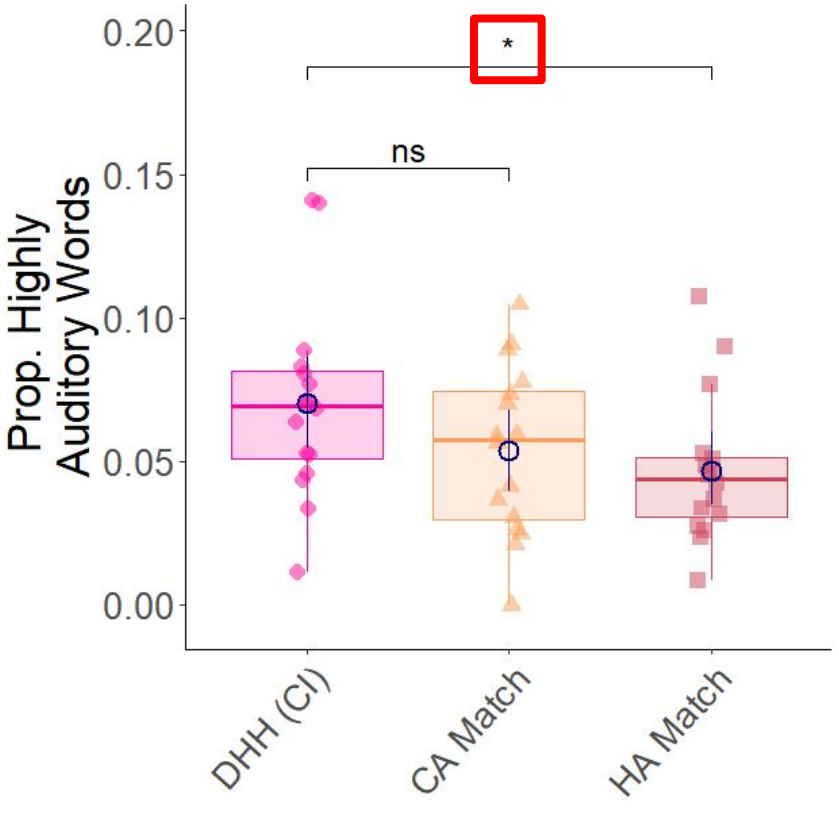
Results: Input Complexity

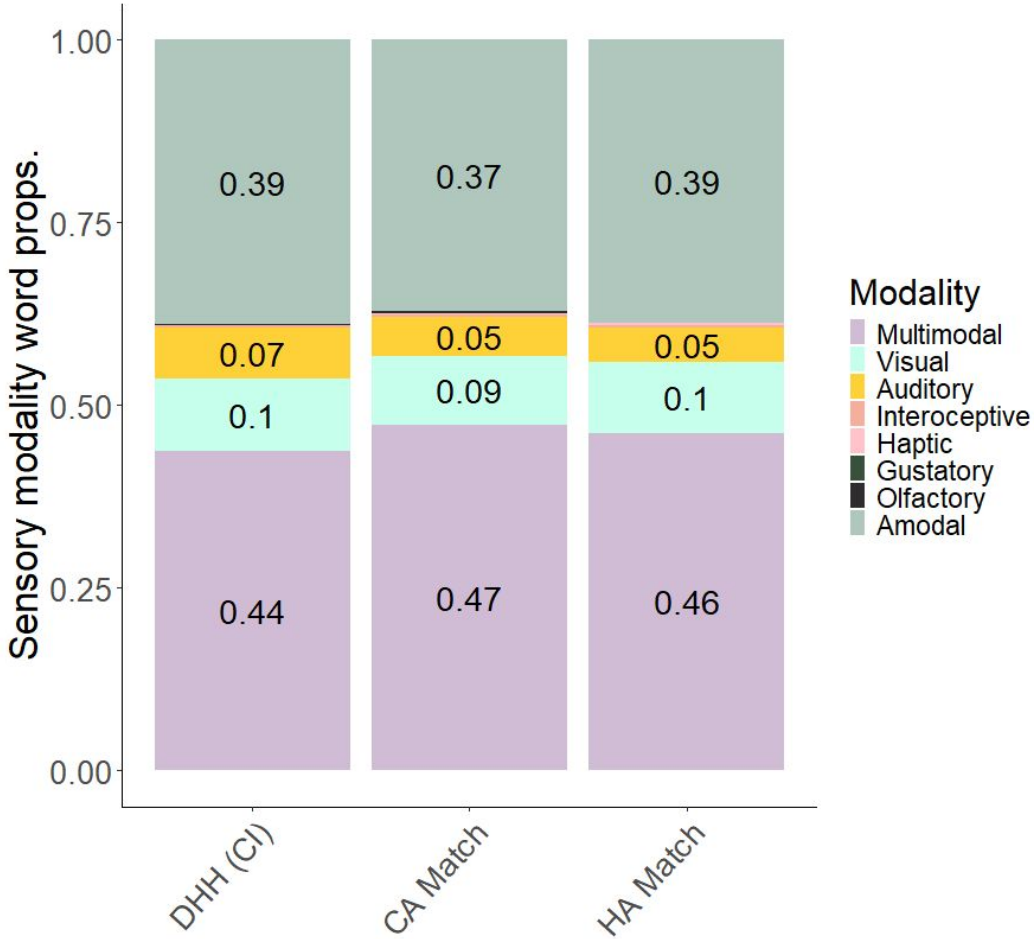




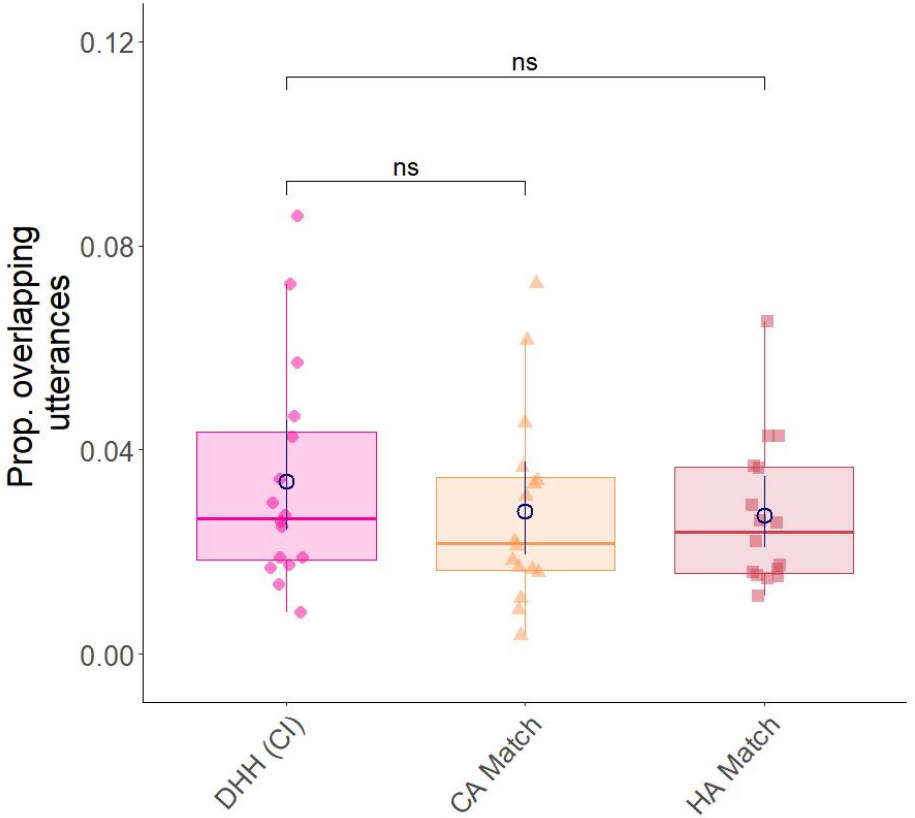
Results: Conceptual Properties of Input



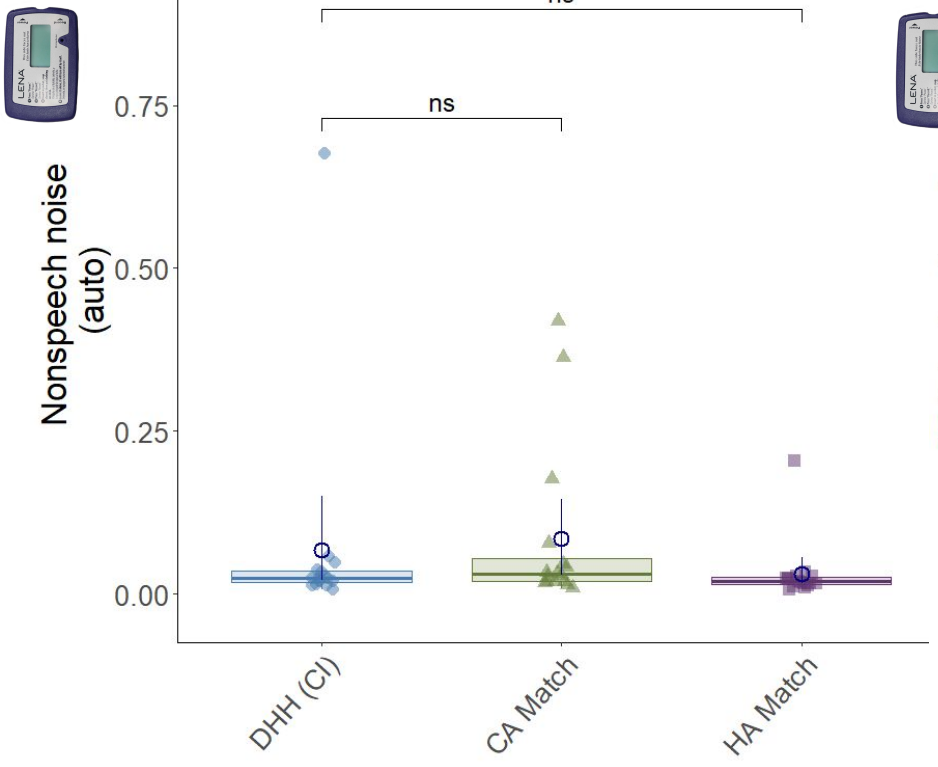


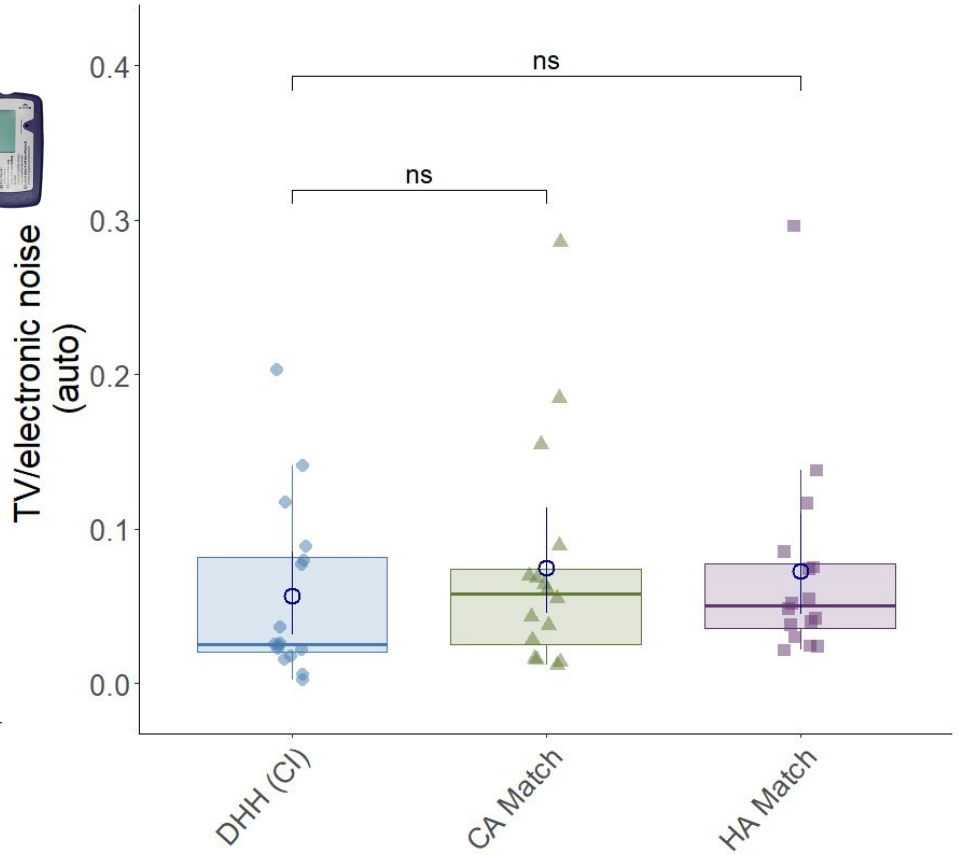

Sensory modality word props.
1.00
0.75
0.50
0.25
0.00
0.39
0.37
0.39
0.07
0.05
0.05
0.1
0.09
0.1
0.44
0.47
0.46
DHH (CI)
CA Match
HA Match
Modality
Multimodal
Visual
Auditory
Interoceptive
Haptic
Gustatory
Olfactory
Amodal

Results: Overlapping speech

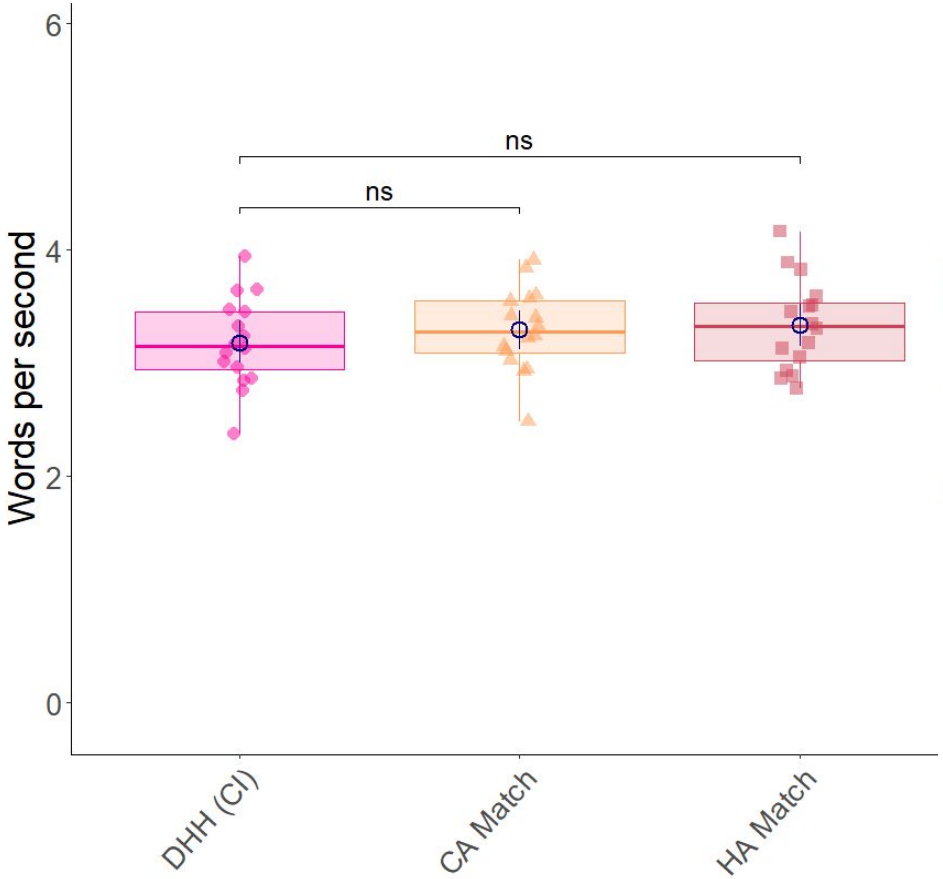


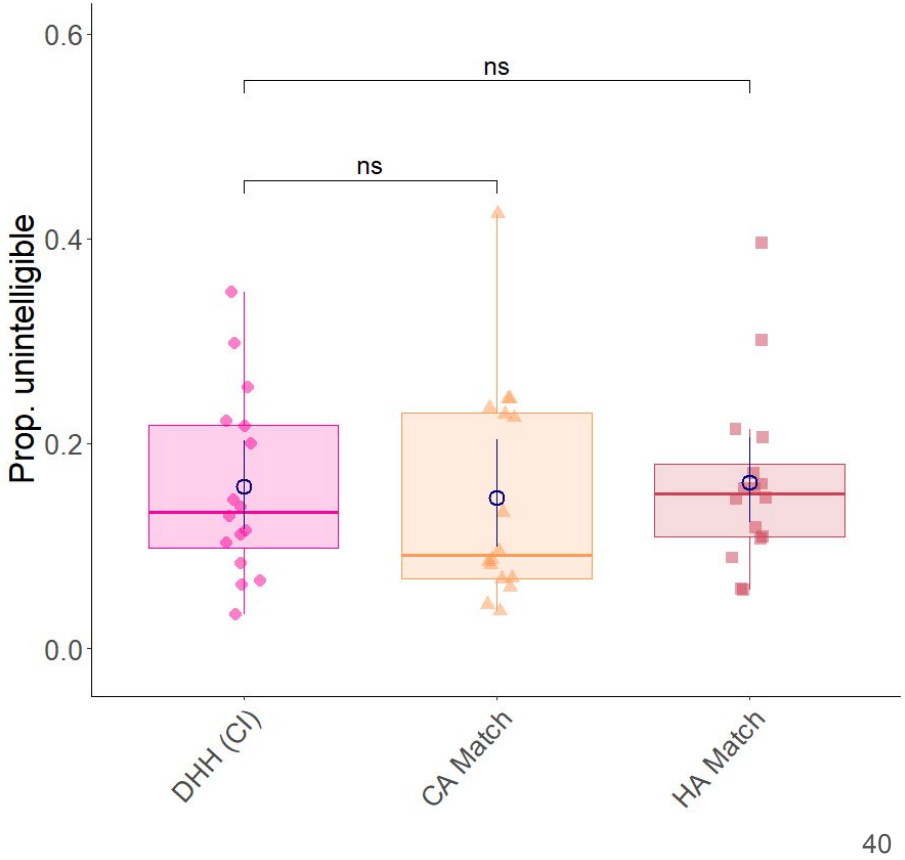
Results: Nonspeech noise



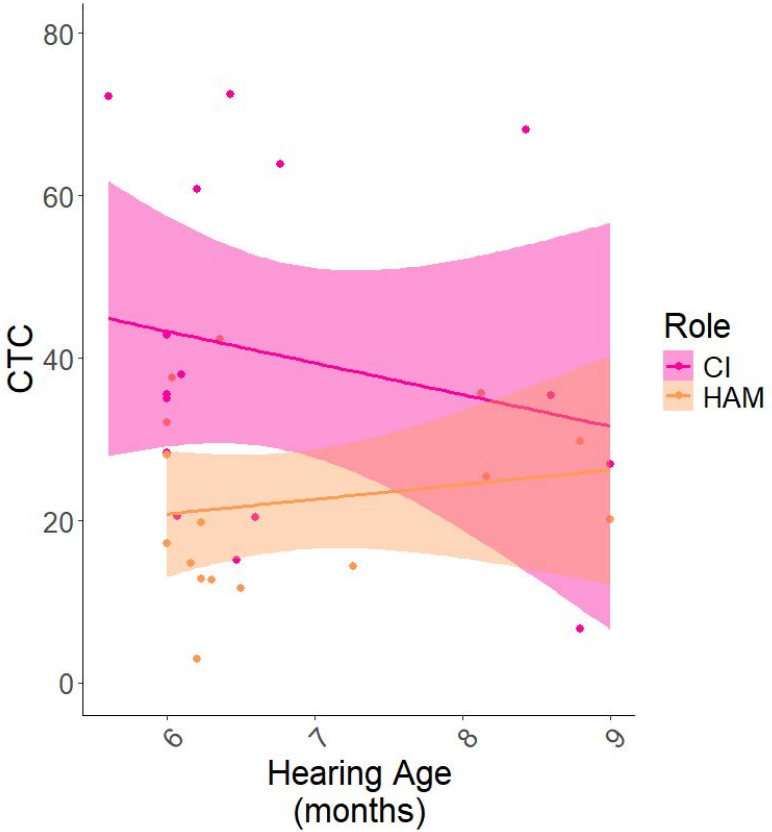


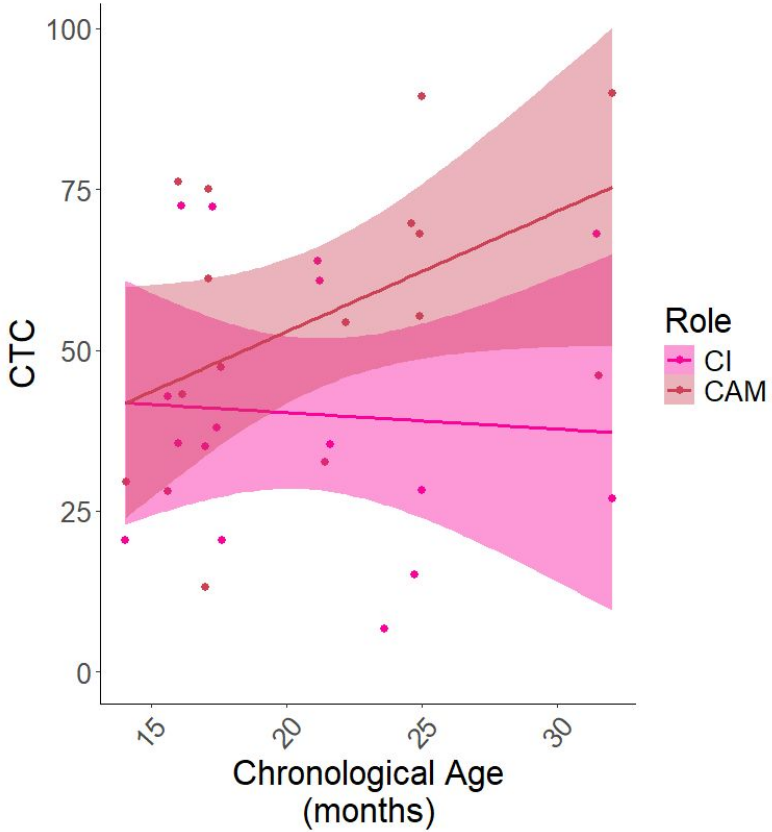
Speech rate and unintelligible speech



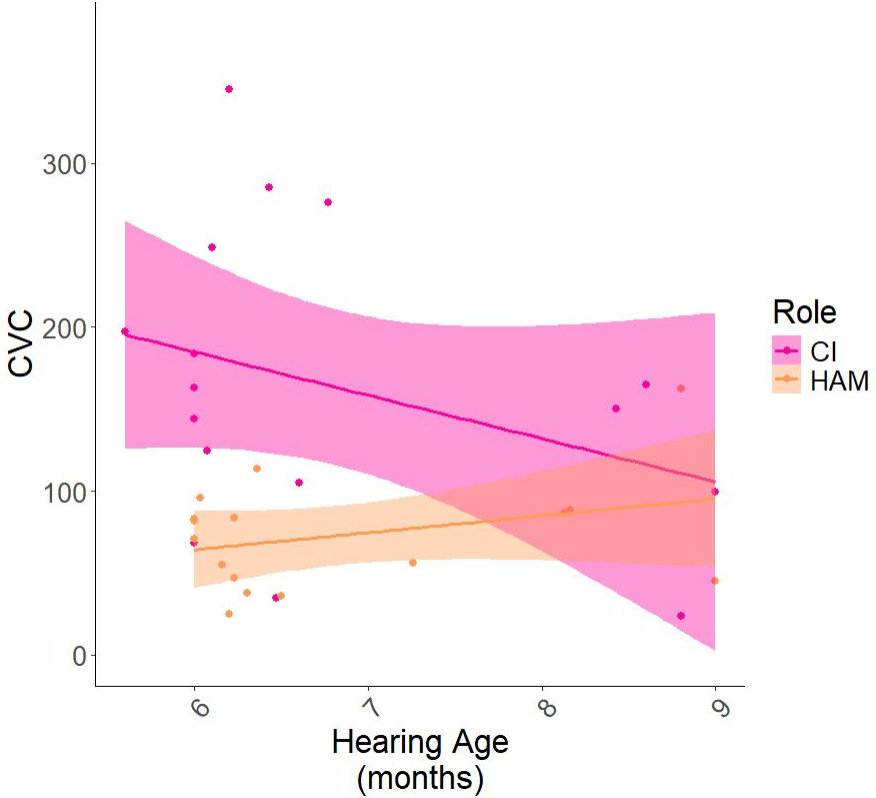


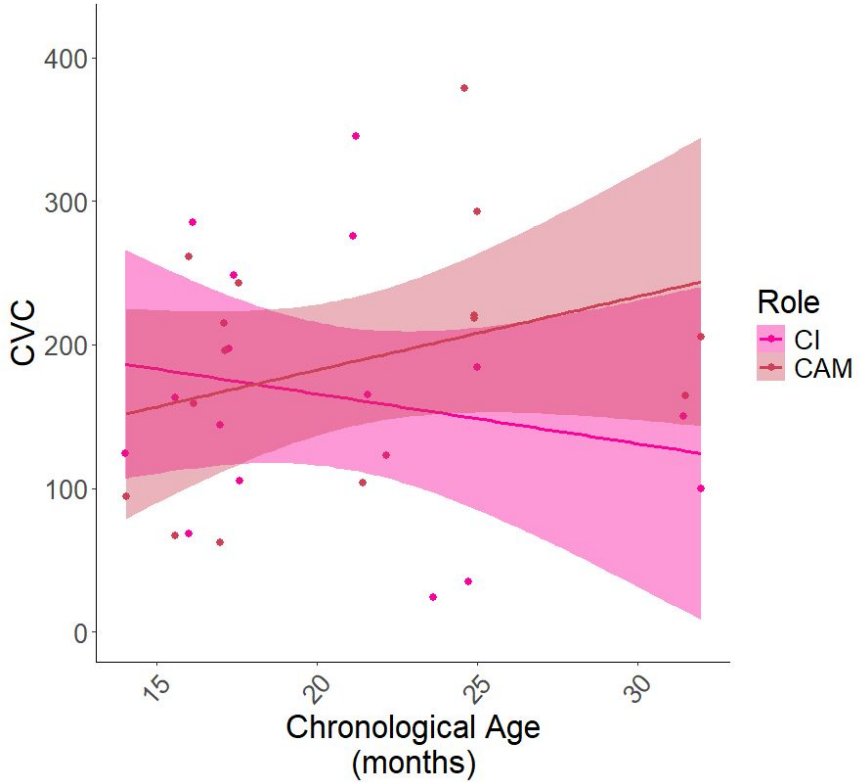
Backup slide: CTC over developmental time





Backup slide: CVC over developmental time





Possible predictors

HAM & DHH → CVC

Adult Word Count (LENA)
Total Word Count (Manual)
Proportion CDS
Type-Token Ratio
MLU
Proportion Displaced Verbs
Proportion Highly Auditory Words
Hearing Age
Group

Possible predictors

HAM & DHH → CVC

Adult Word Count (LENA)
Total Word Count (Manual)
Proportion CDS
Type-Token Ratio
MLU
Proportion Displaced Verbs
Proportion Highly Auditory Words
Hearing Age
Group

Possible predictors

HAM & DHH → Canonical babble

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Possible predictors

CAM & DHH → CVC

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MLU
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Chronological Age
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Possible predictors

CAM & DHH → CVC

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