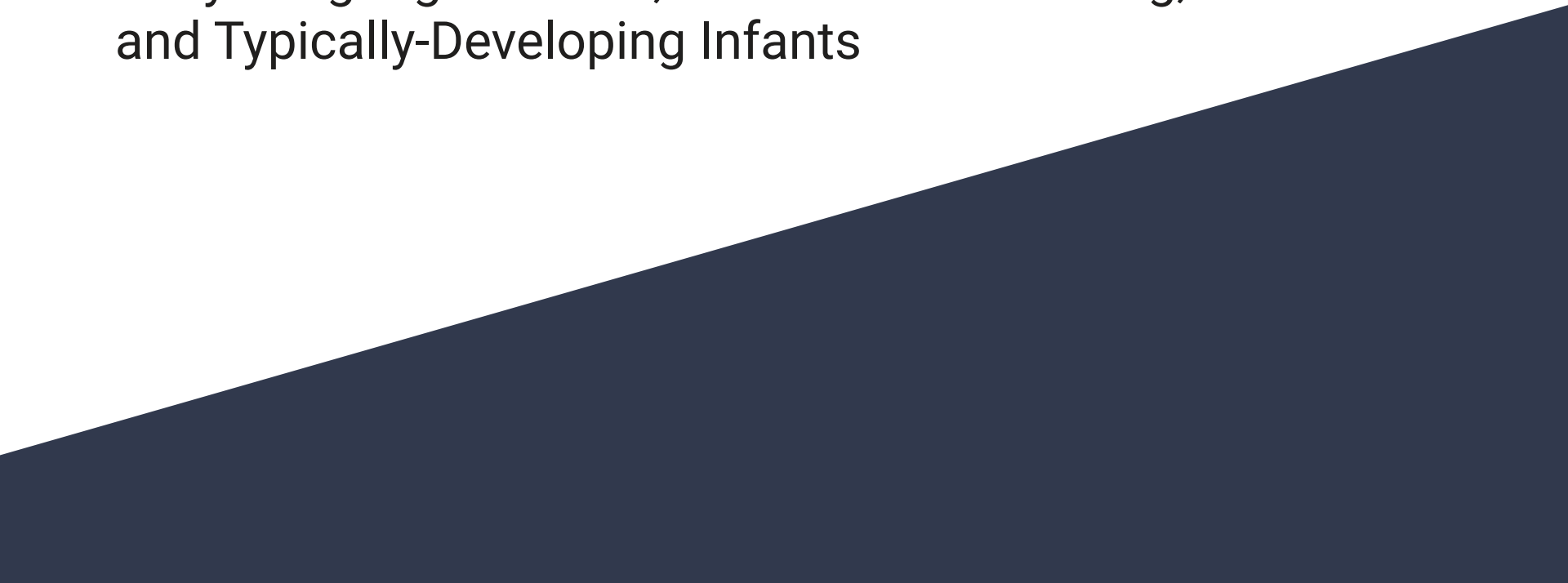


# Early Language in Blind, Deaf/Hard-of-Hearing, and Typically-Developing Infants

A dark blue diagonal gradient bar that starts from the bottom left and extends towards the top right, covering the lower half of the slide.

# Introduction

- Children learn about the world through language and direct perceptual experience
- We can talk about the senses through language → redundant sensory information
- Individuals with congenital sensory impairments know a lot about the senses!

**How does language act as a source of sensory information?**

# Participant Groups

## Deaf / Hard-of-Hearing (DHH)

- >40 dB hearing loss
  - Amplification: delayed and degraded auditory signal
- Prevalence: ~10/10,000
- Language: similar input, but spoken language delays
- Age range: 9-31 months

## Blind

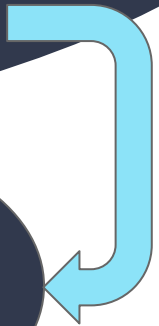
- No more than minimal light perception
- Prevalence: ~3/10,000
- Language: less known
- Age range: 6-31 months

**Typically-Developing (TD)** participants: matched on age (and when possible, gender, mat ed, vocab)

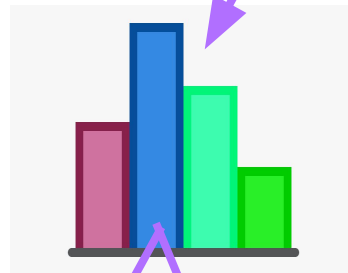
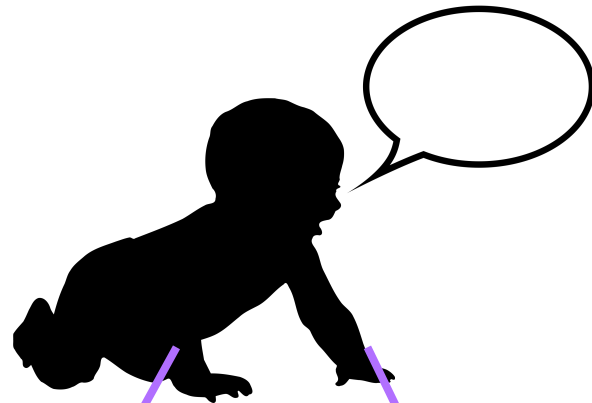
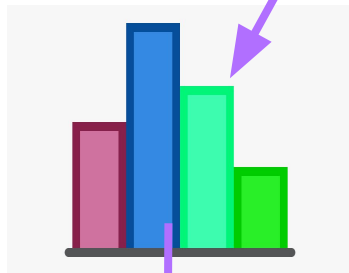
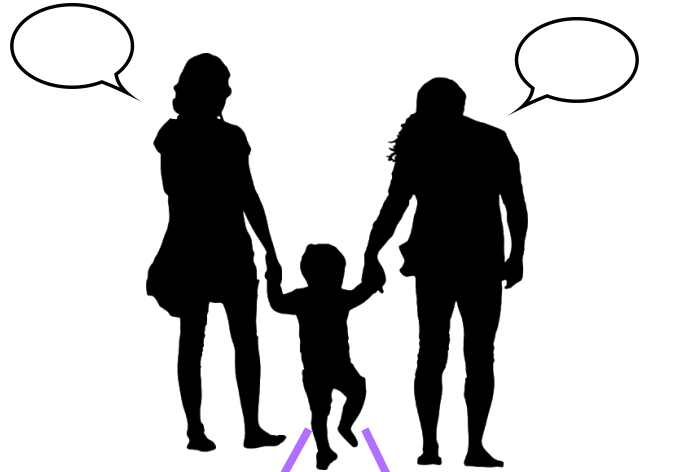
Is the early input and speech production of  
DHH and Blind children different from their  
typically-developing peers?



Auditory



Visual



# Methods



## Daylong audio recordings (LENA)

- 16-hour home audio recordings → ~25,000 minutes
- **Automated metrics: Adult Word Count & Child Vocalization Count**



## Play sessions

- 30-minute in-lab video play sessions → ~1,000 minutes
- Dense recording of parent-child interaction
- **Full transcripts & analysis of parent speech via sensory norms**



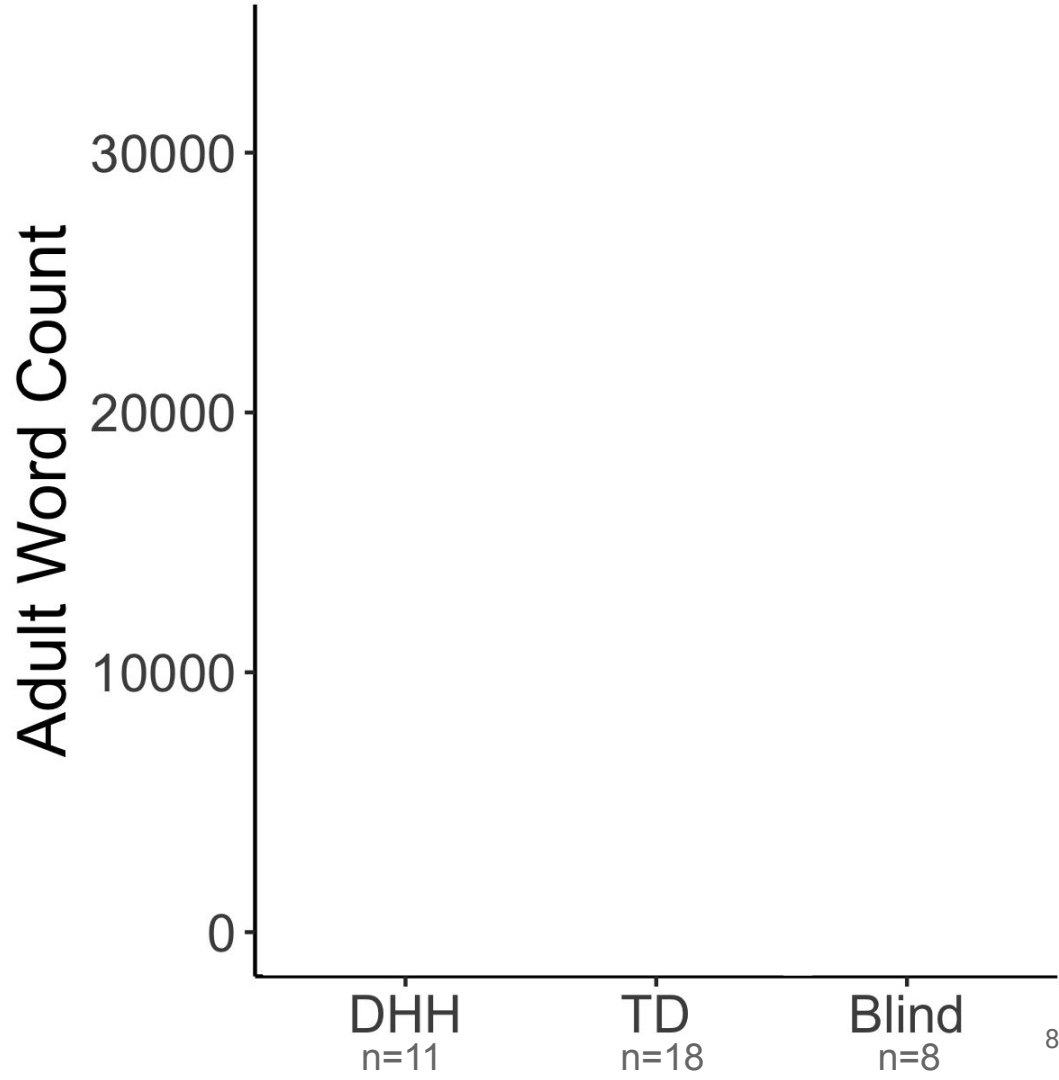
## Communicative Development Inventory (CDI) scores

- Parent-report vocabulary checklist
- **Number of words produced by child**

1. # of adult words in input in daylong LENA recordings
2. Proportion of auditory/visual words in input in 30-min language samples

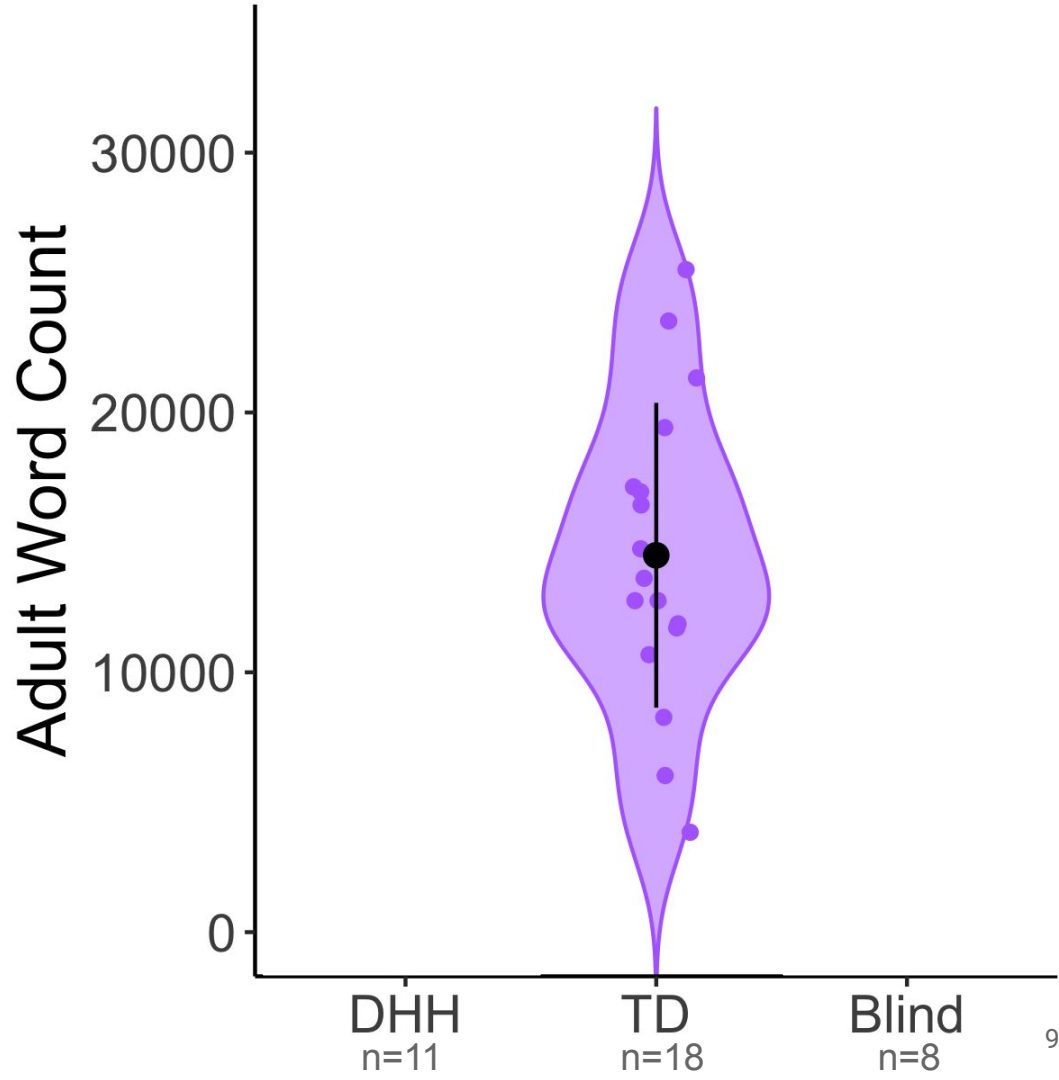
# Input

Do blind and DHH children receive a different amount of language input?



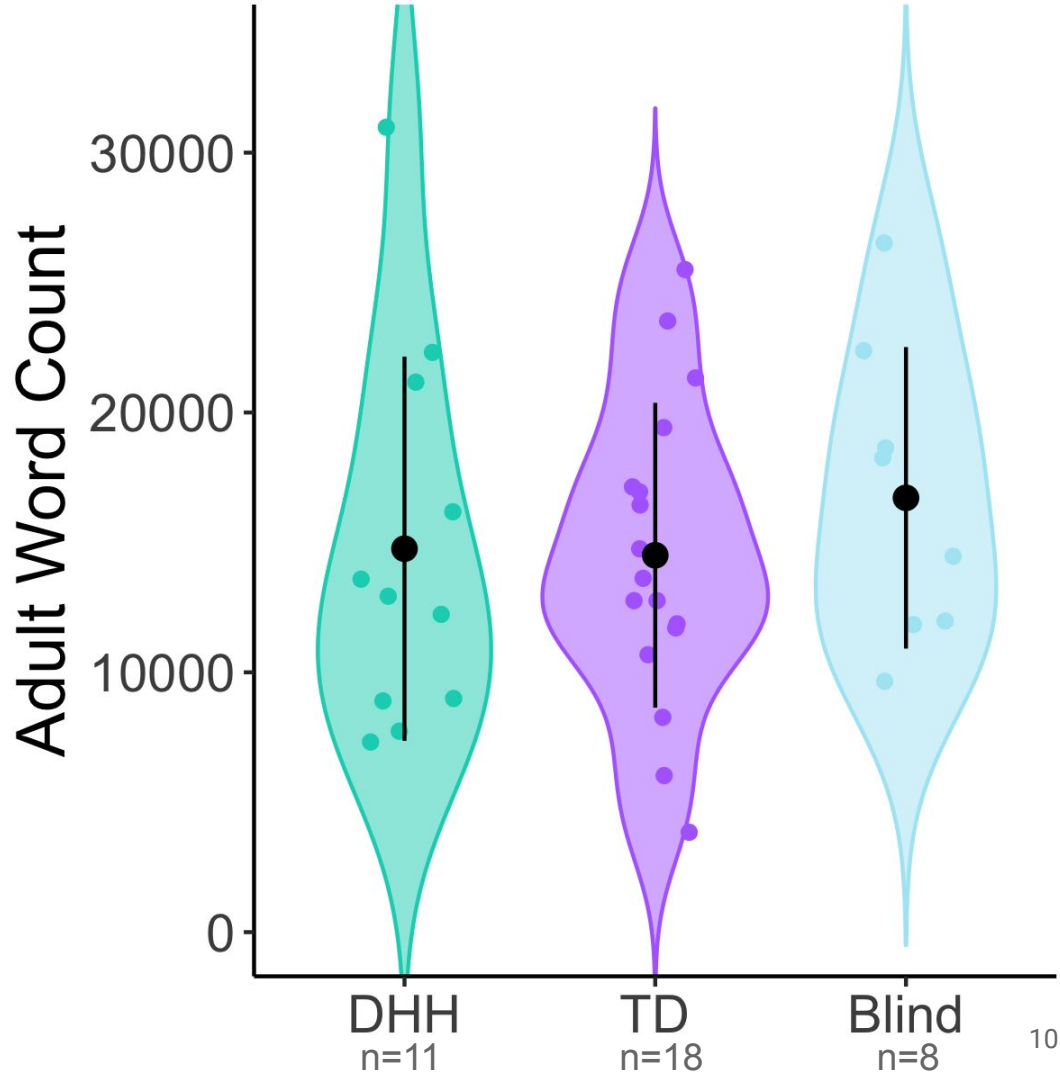


Do blind and DHH children receive a different amount of language input?



Do blind and DHH children receive a different amount of language input?

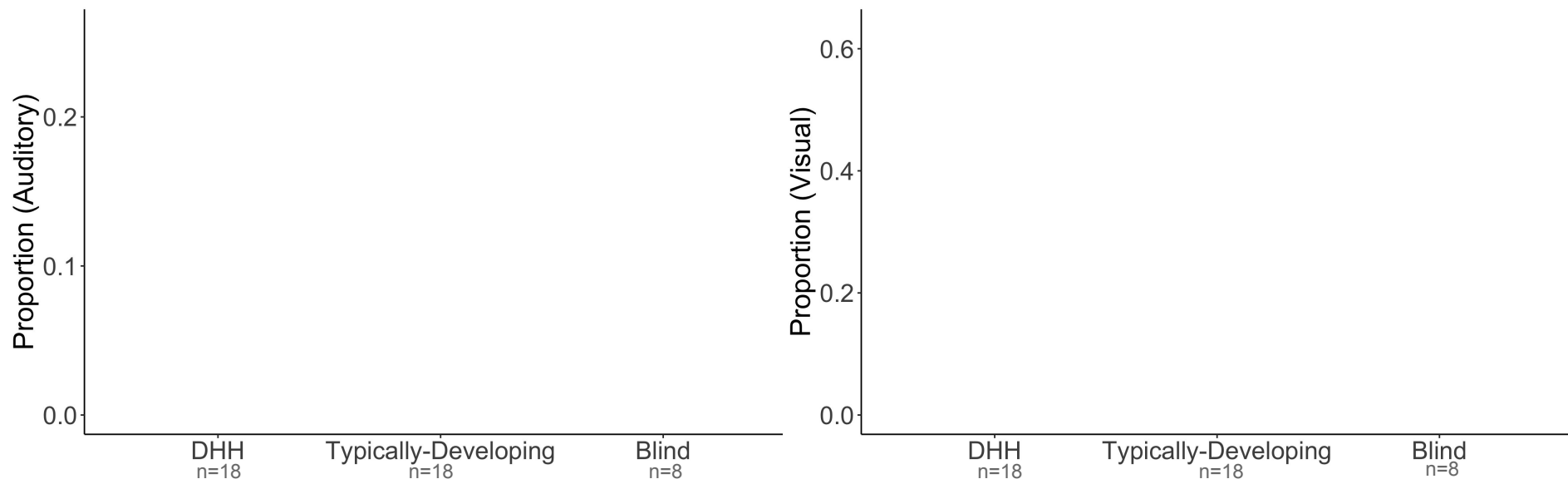
No. Adult word count looks the same across groups.



# How much auditory & visual information is there in language?

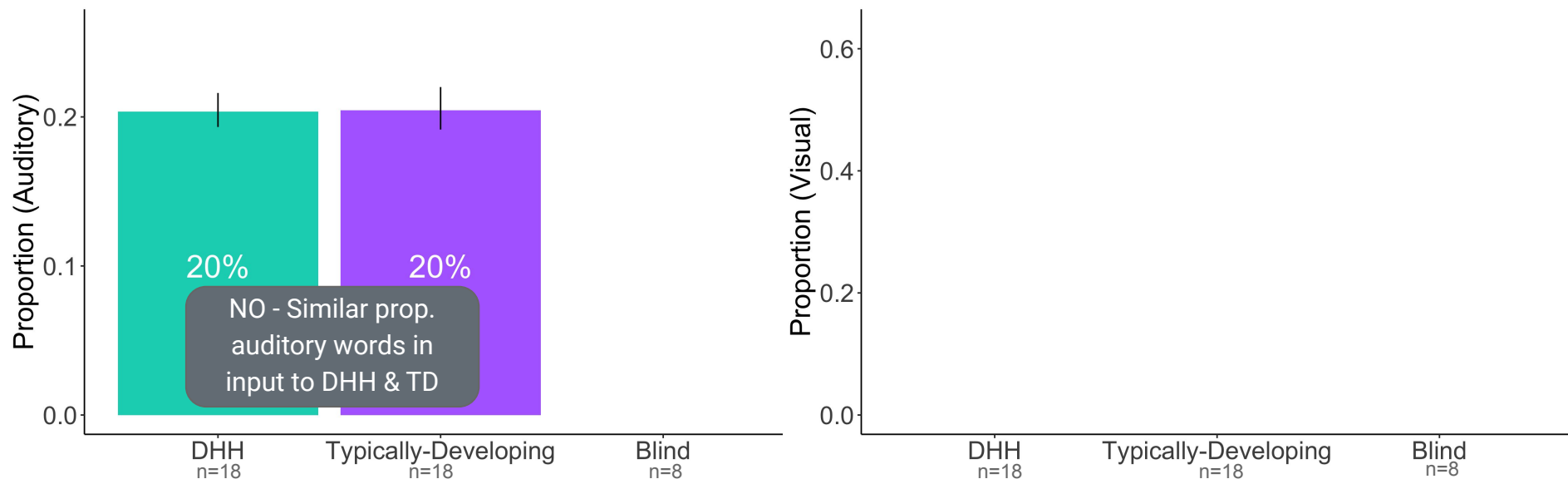
- This is hard to quantify. We're using sensorimotor norms as a first step.
- **Lancaster Sensorimotor Norms**
  - Typically developing english-speaking adults rated ~40,000 words
  - Each word rated 1-5 for how strongly associated it was with 6 senses:
    - Visual, Auditory, Gustatory, Olfactory, Haptic, & Interoceptive
- These norms:
  - Predict adult word recognition, lexical decision performance
  - Predict age of acquisition
  - Describe sensory characteristics of English
- Our analysis:
  - What proportion of the words in the input and early vocabulary were rated as predominantly visual or auditory?

# Does sensory language input differ?



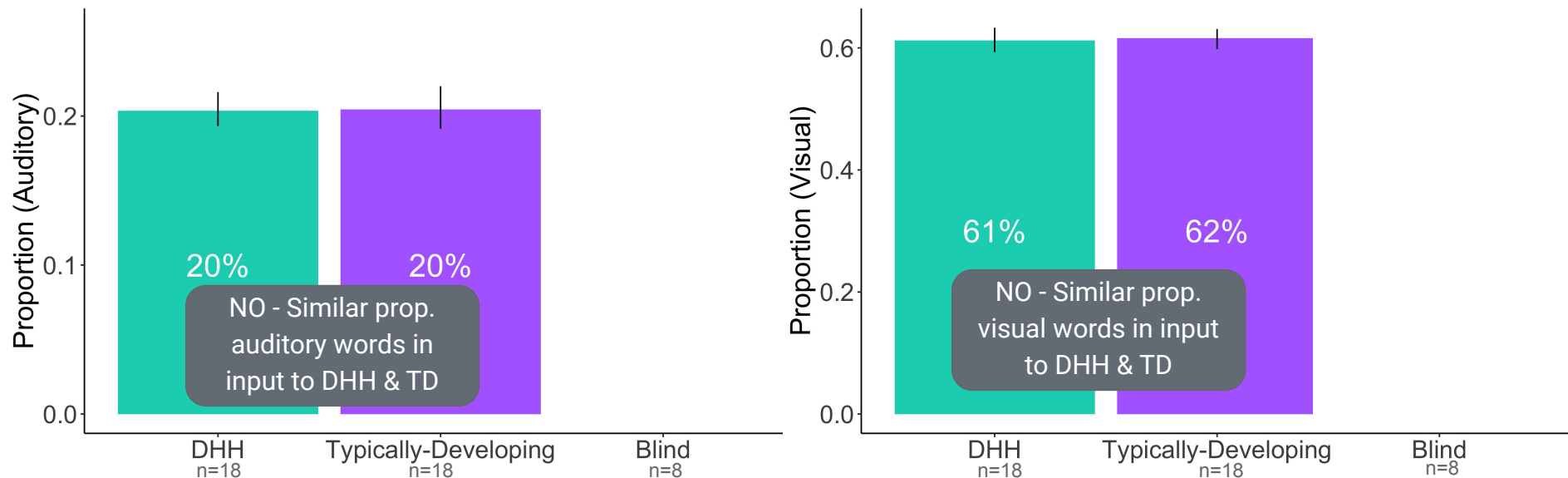
*\*  $p < .05$  on Kruskal- Wallis & follow-up Dunn test*

# Does sensory language input differ?



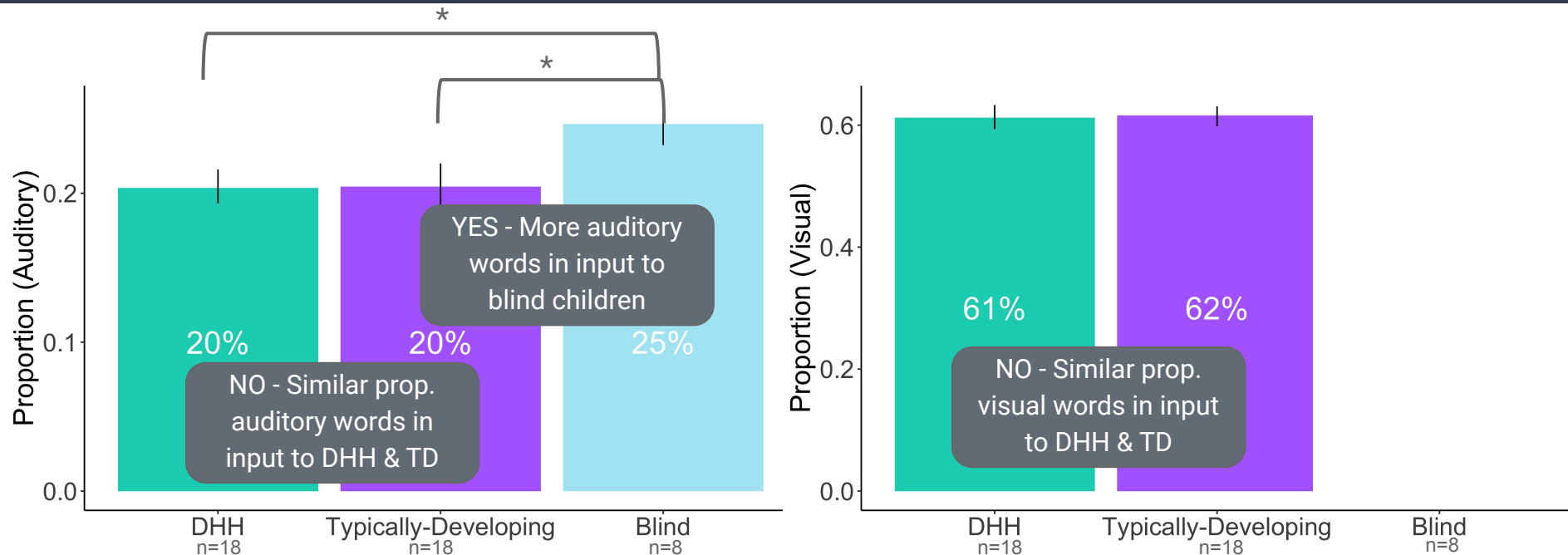
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# Does sensory language input differ?



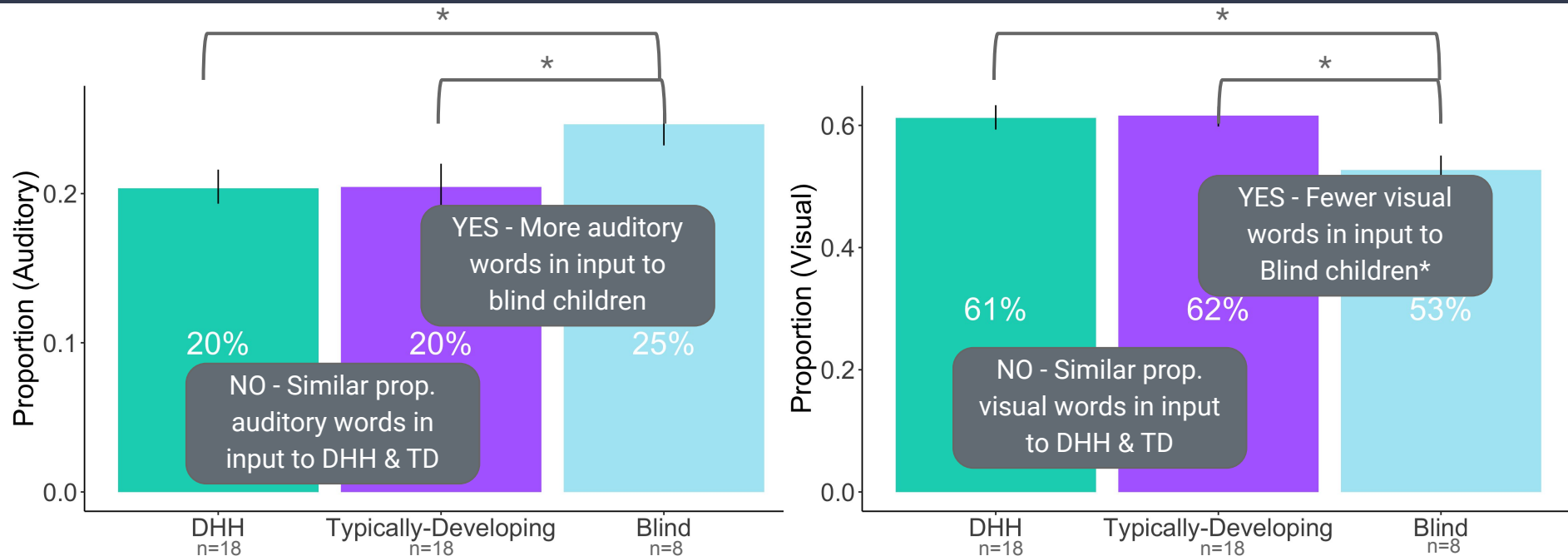
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# Does sensory language input differ?



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\*  $p < .05$  on Kruskal- Wallis & follow-up Dunn test



# Input Results Summary

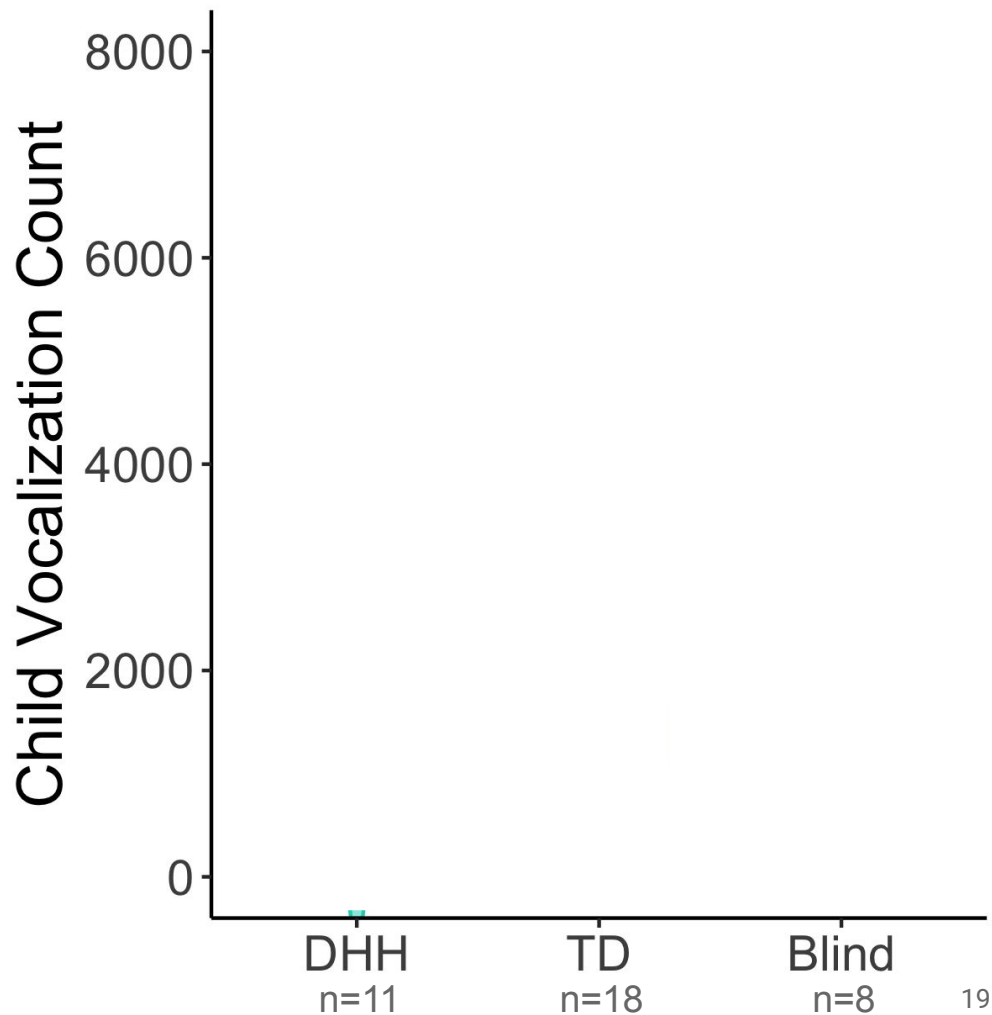
- Overall: similar adult word counts across Blind, DHH, and TD
  - High variability *within* each group
- Sensory language in the input:
  - DHH vs. TD: No differences in proportion of predominantly auditory & visual words
  - Blind vs. TD: +5% auditory & -11% visual words

**What about children's own speech production?**

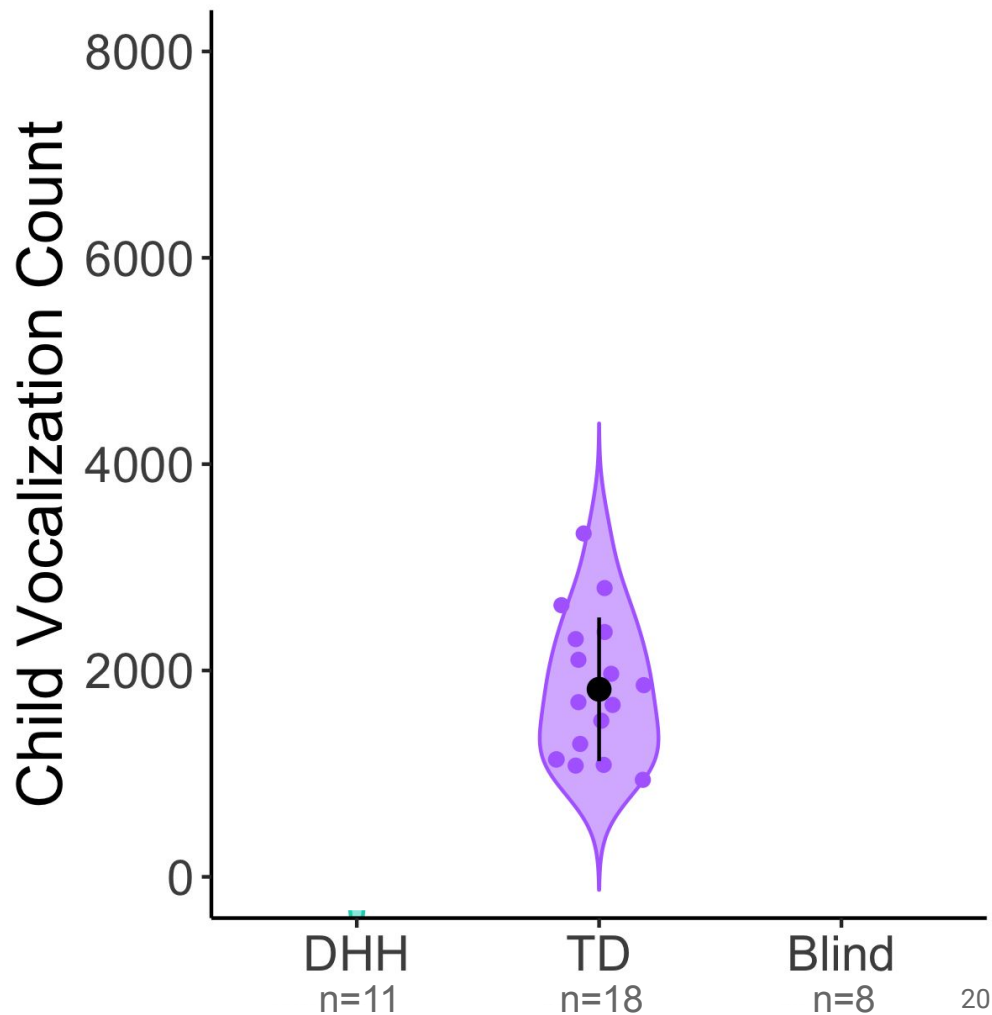
1. # of child vocalizations in daylong LENA recordings
2. # of words produced on CDI
3. Proportion of auditory/visual words produced on CDI

# Production

Do DHH/blind children vocalize at similar rates to typically-developing peers?

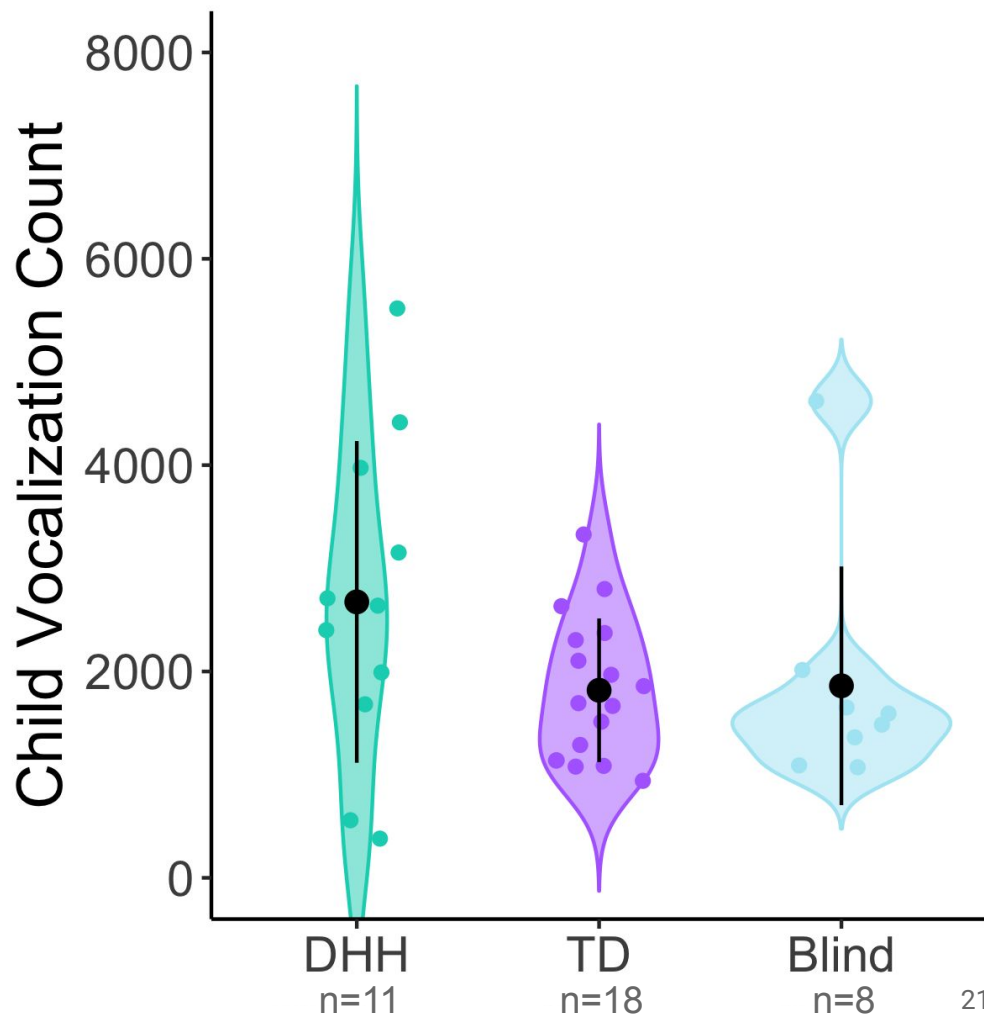


Do DHH/blind children vocalize at similar rates to typically-developing peers?

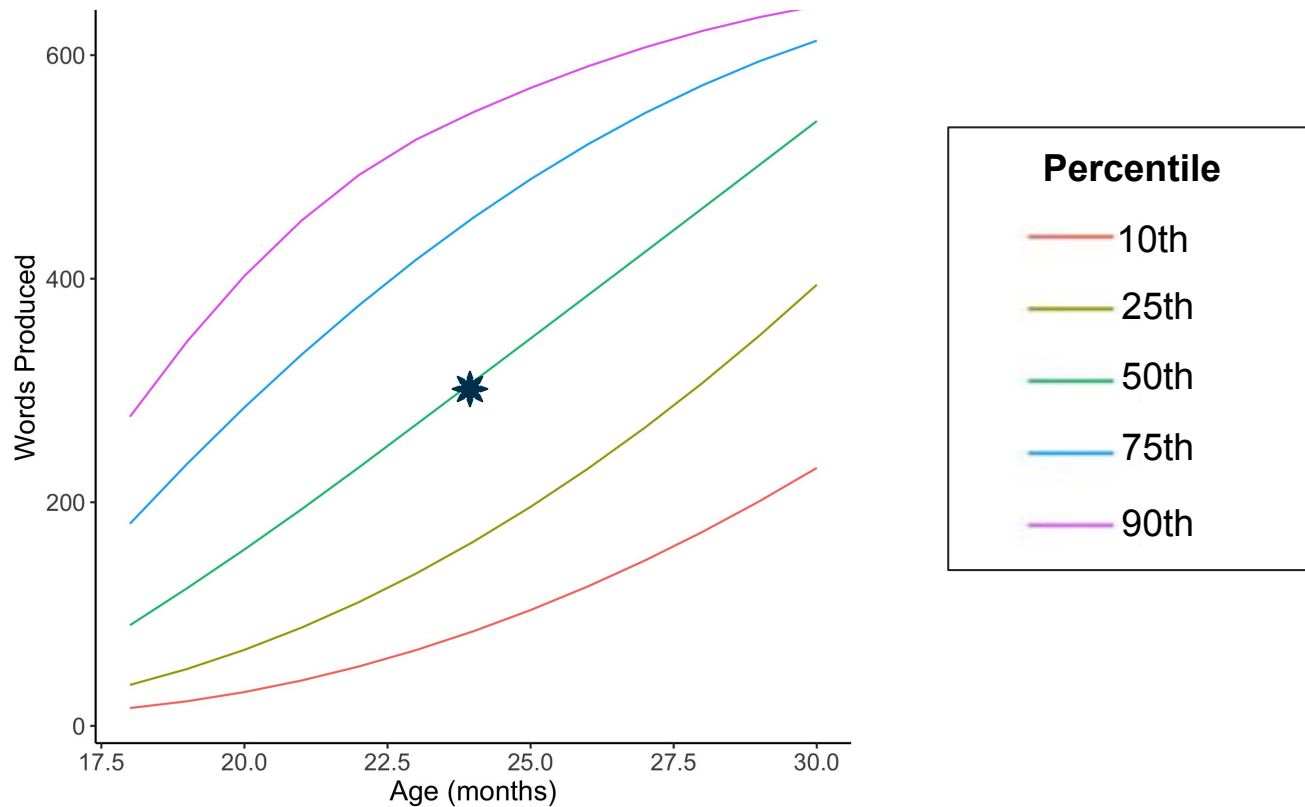


Do DHH/blind children vocalize at similar rates to typically-developing peers?

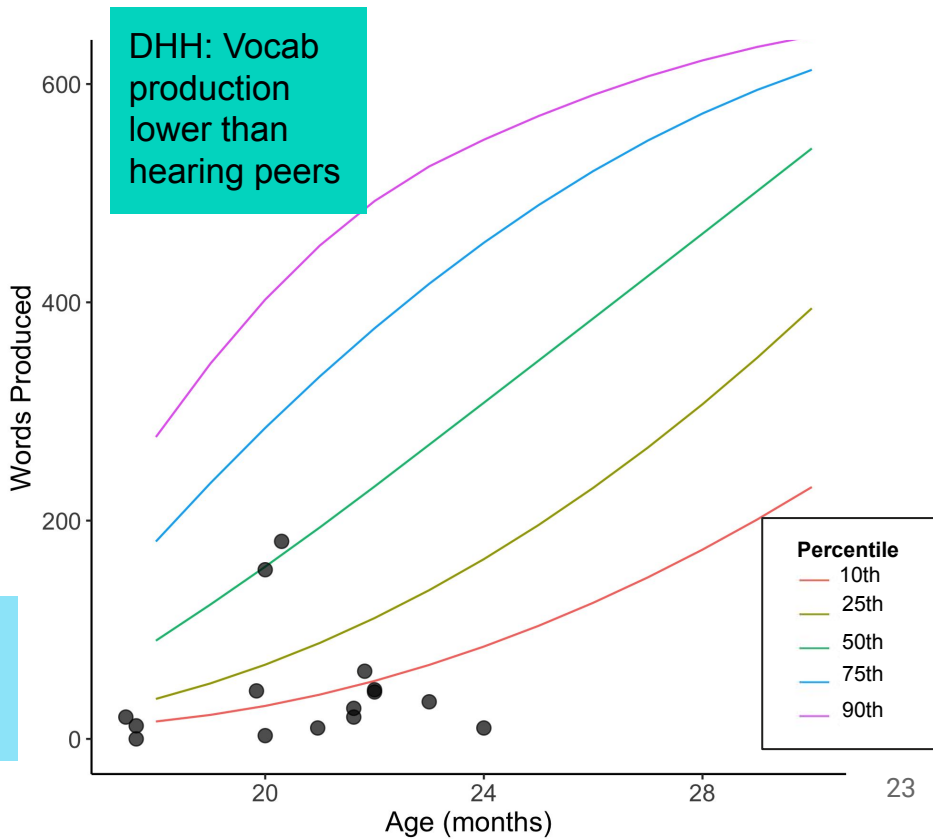
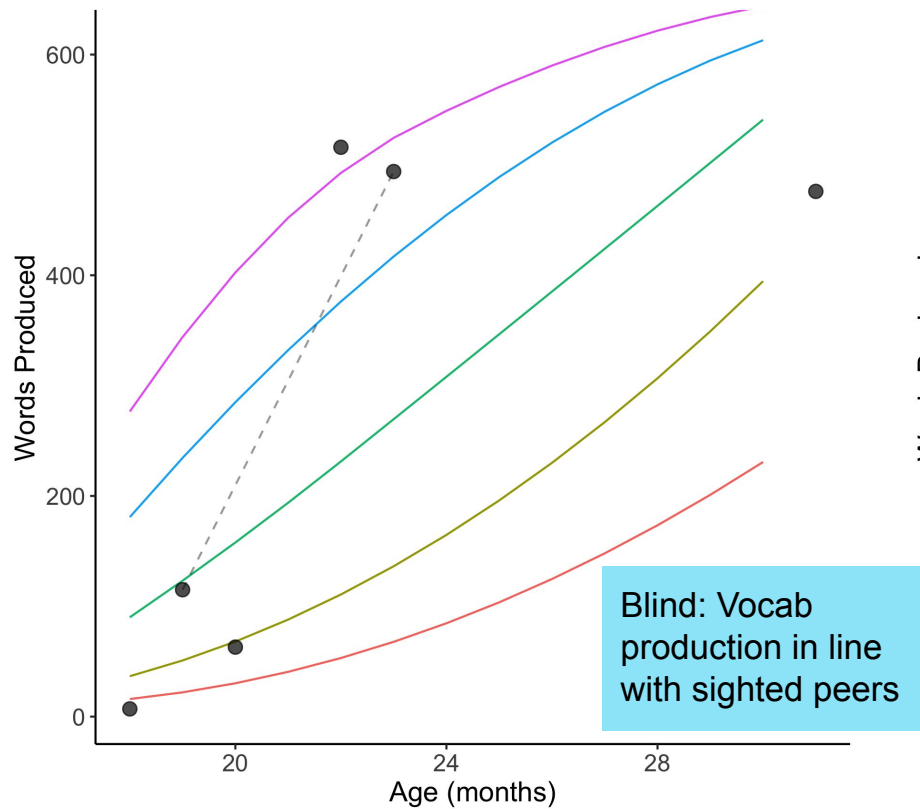
Yes. Child vocalization counts look similar *across* groups; wide variability *within* groups



# Vocabulary (Words Produced)



# Vocabulary (Words Produced)

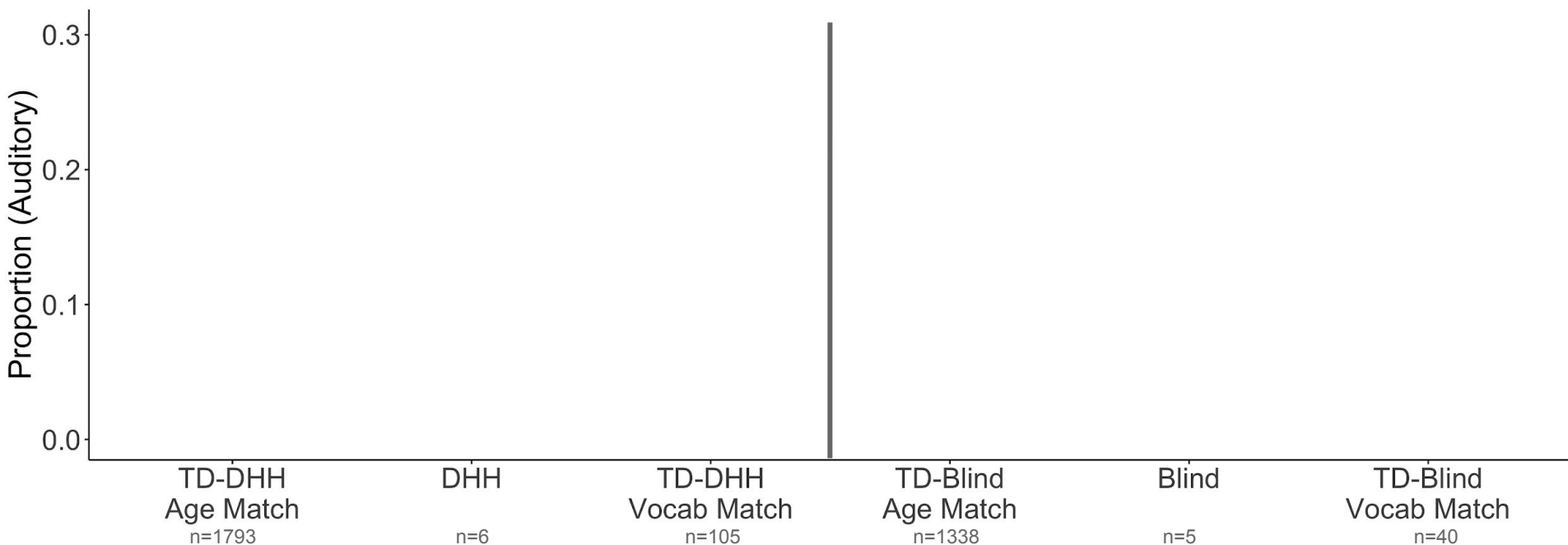


# Sensory Norms in CDI Words

- Is there a relationship between children's sensory experiences and the words they produce?
  - Do DHH children say fewer auditory-dominant words than TD?
  - Do blind children say fewer visual-dominant words than TD?
- Given the vocabulary disparities across DHH and TD kids, we include both TD-age matches, and TD-vocabulary matched infants
  - TD controls from WordBank

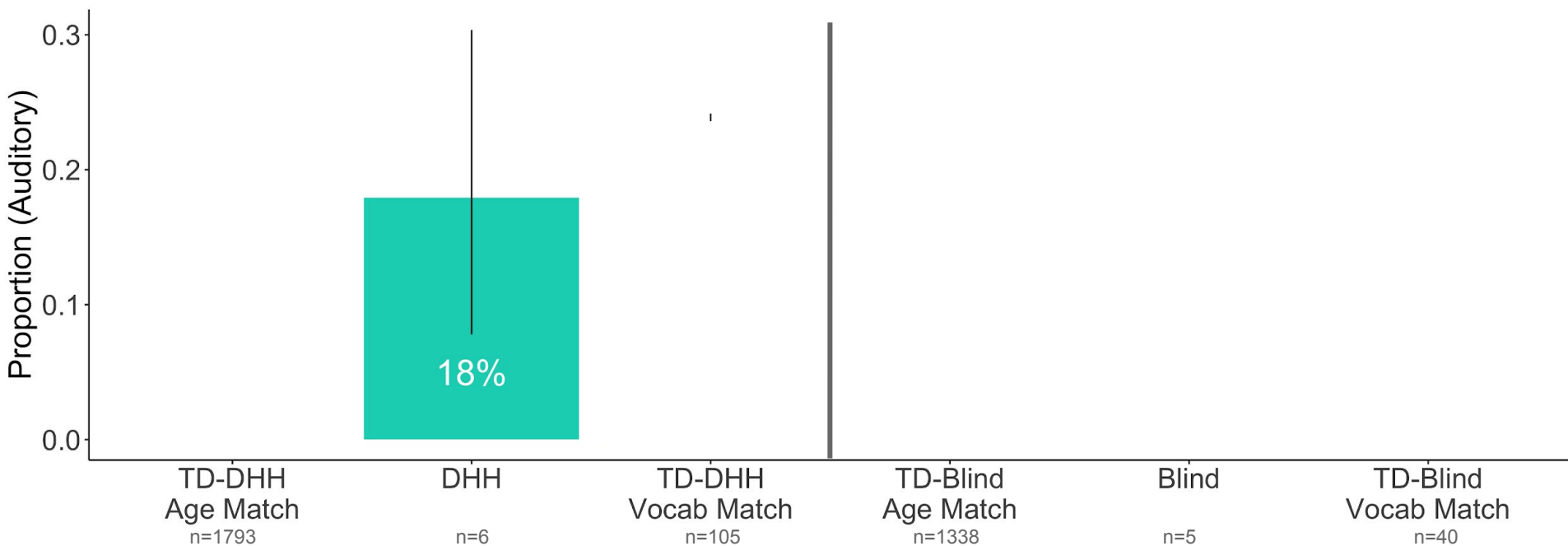


# Does auditory language production differ?



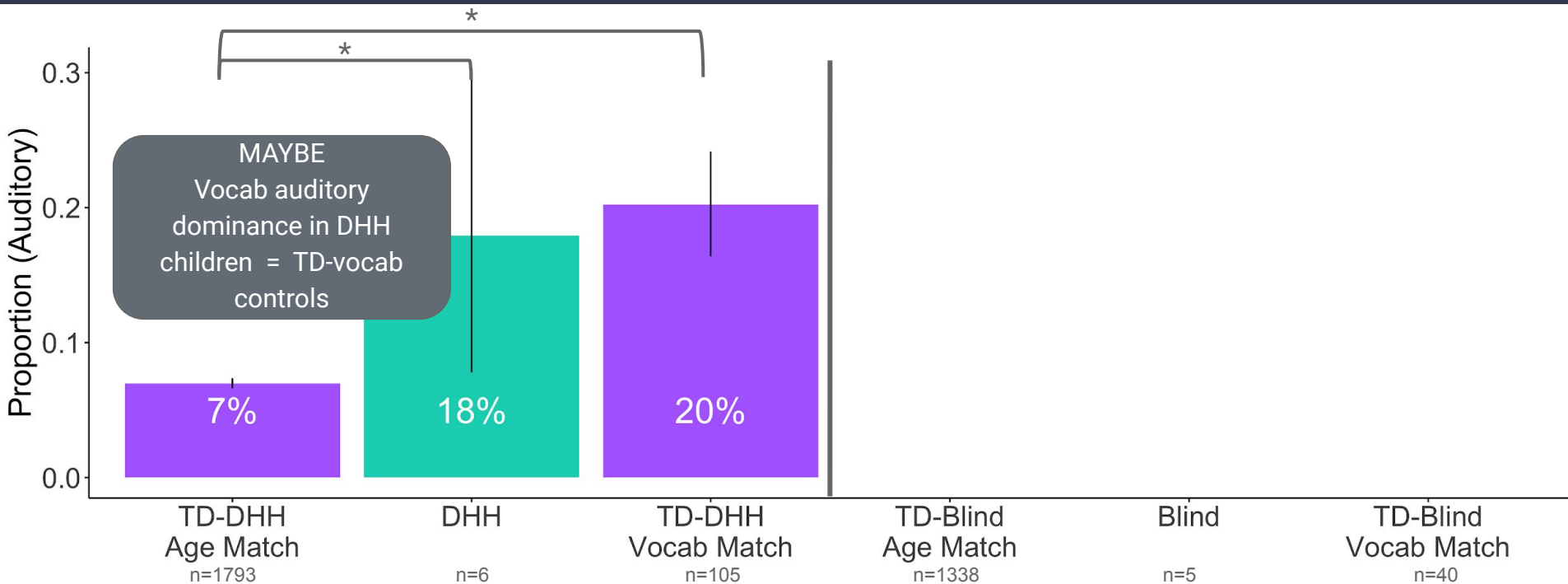
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# Does auditory language production differ?



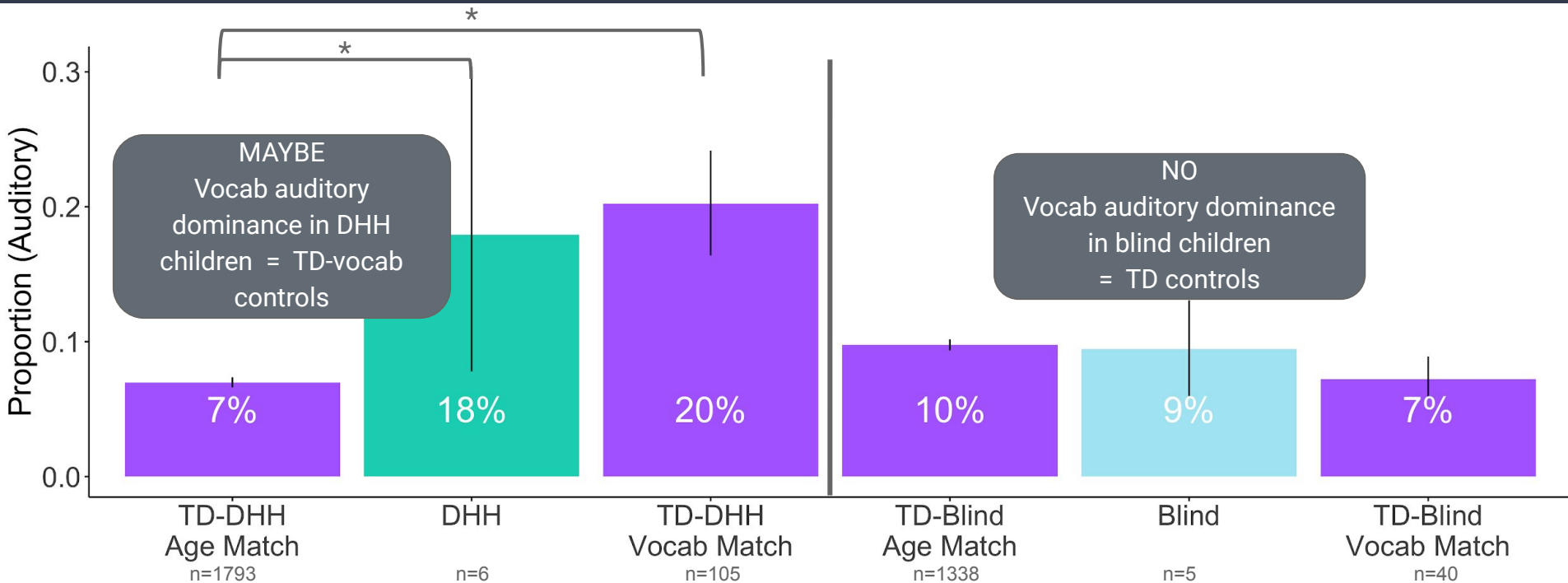
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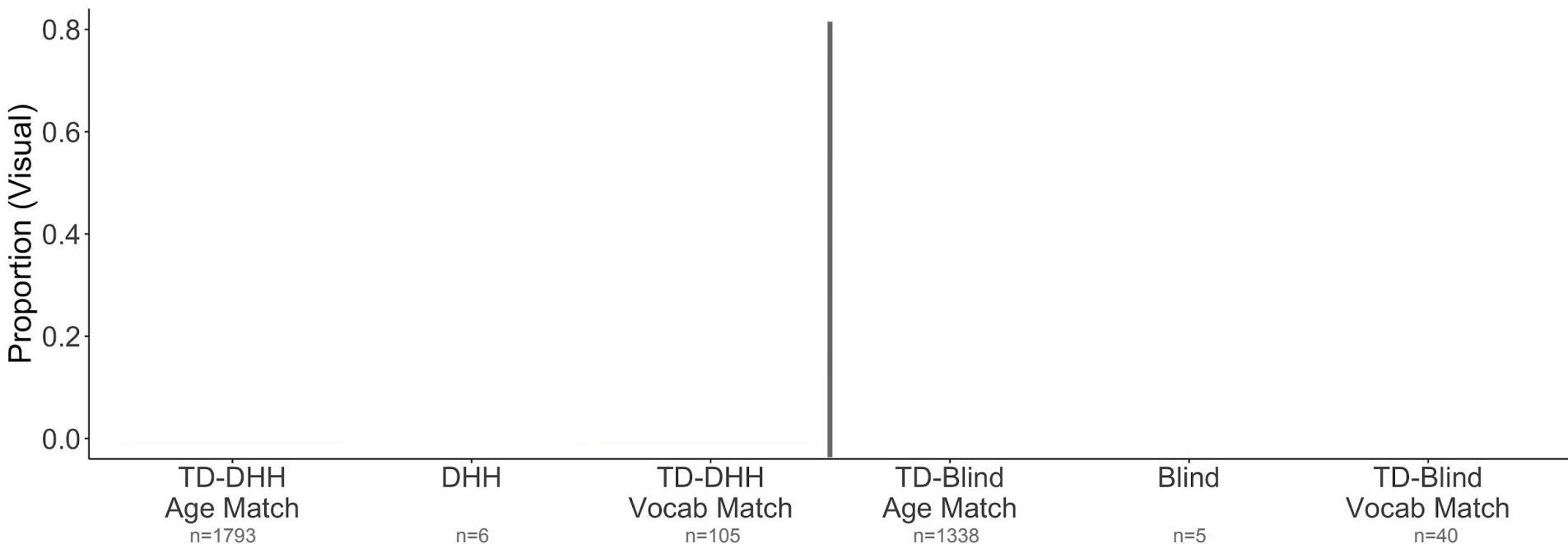
# Sensory Norms in CDI Words

- Is there a relationship between children's sensory experiences and the words they produce?
  - Do **DHH** children say fewer auditory-dominant words than **TD**?
  - Do **blind** children say fewer visual-dominant words than **TD**?

# Sensory Norms in CDI Words

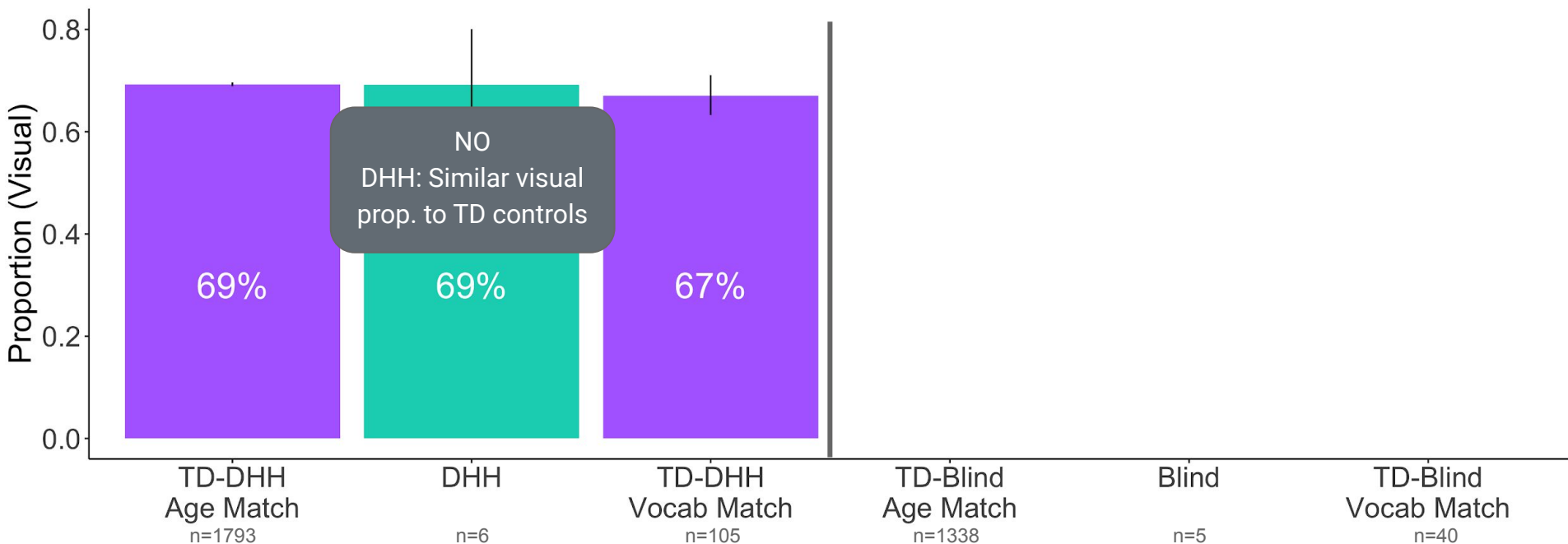
- Is there a relationship between children's sensory experiences and the words they produce?
  - Do **DHH** children say fewer auditory-dominant words than **TD**? → **NO**
  - Do **blind** children say fewer visual-dominant words than **TD**?

# Does visual language production differ?



\*  $p < .05$  on Kruskal- Wallis & follow-up Dunn test

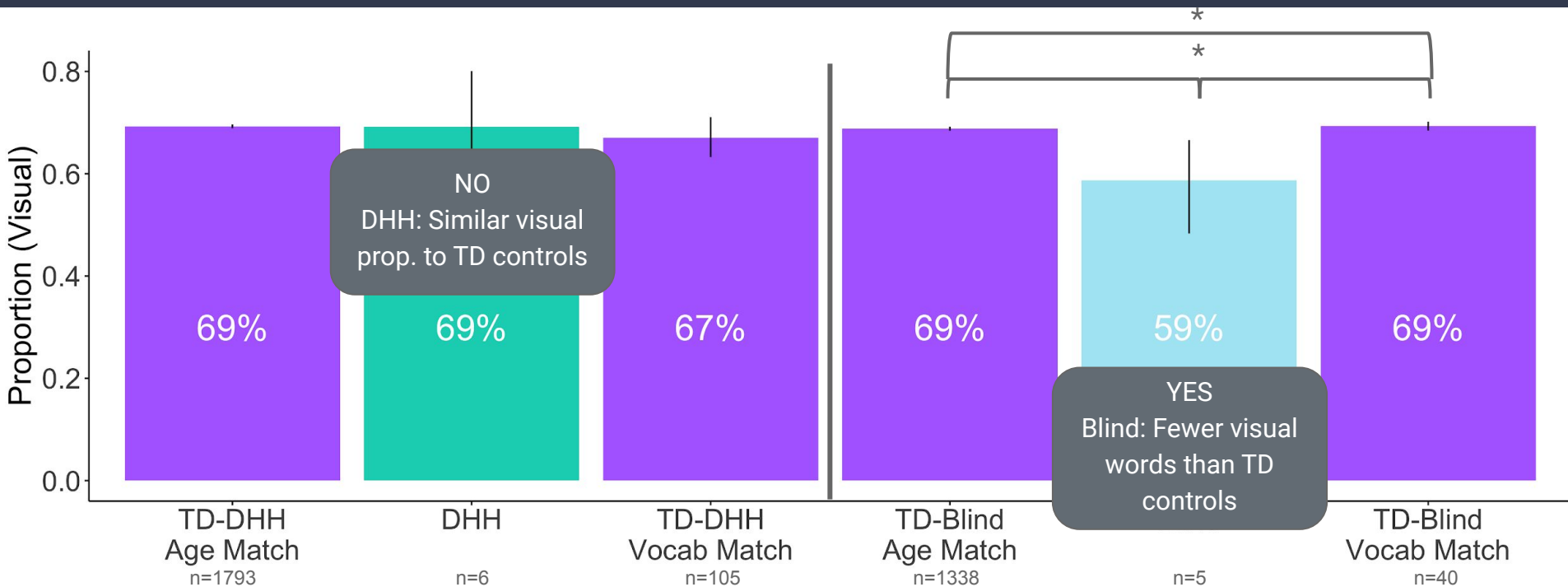
# Does visual language production differ?



\*  $p < .05$  on Kruskal- Wallis & follow-up Dunn test



# Does visual language production differ?



\*  $p < .05$  on Kruskal- Wallis & follow-up Dunn test

# Sensory Norms in CDI Words

- Is there a trade-off between children's sensory experiences and the words they produce?
  - Do **DHH** children say fewer auditory-dominant words than **TD**? → **NO**
  - Do **blind** children say fewer visual-dominant words than **TD**?

# Sensory Norms in CDI Words

- Is there a trade-off between children's sensory experiences and the words they produce?
  - Do **DHH** children say fewer auditory-dominant words than **TD**? → **NO**
  - Do **blind** children say fewer visual-dominant words than **TD**? → **YES**

# Production Results Summary

- Overall:
  - Child Vocalization Counts: similar across Blind, DHH, and TD groups
    - High variability *within* each group (just like for input!)
  - Vocabulary development
    - DHH children delayed relative to hearing peers
    - Blind children within vocab range of sighted peers
- Sensory language in children's early productions:
  - Blind children produce 10% fewer visually-dominant words vs. TD/DHH
  - DHH children produce the same amount of auditory-dominant words as TD vocab-matched peers (but not age-matched peers, who have bigger vocab)

# Open Questions

- What can we learn from sensory norms?
  - Not all semantic information stored at word-level
  - Prior work shows that sensory associations may differ by group
- Why less visual for blind but not less auditory for DHH?
  - Differences in severity and access to input
  - Different goals for DHH children → clinician guidance during aural rehab
- Still unknown: learning process

# What did we learn?

- Overall:
  - Similar # adult words and child vocalizations across groups
  - Vocabulary development
    - DHH children delayed relative to peers, while blind children within vocab range of sighted peers
- Sensory language:
  - DHH vs. TD : largely similar
    - Some differences in production based on vocab size
  - Blind vs. TD: less visual in input and early vocab
    - Parents may tailor input
- Lots of variability, but many similarities across groups
  - Resilience!!

# Thank You!



Bergelson Lab



GRFP to EC  
CAREER to EB  
(BCS-1844710)

## Data Donors

Play session videos from  
DHH / TD children:  
**Ambrose-Moeller corpus**

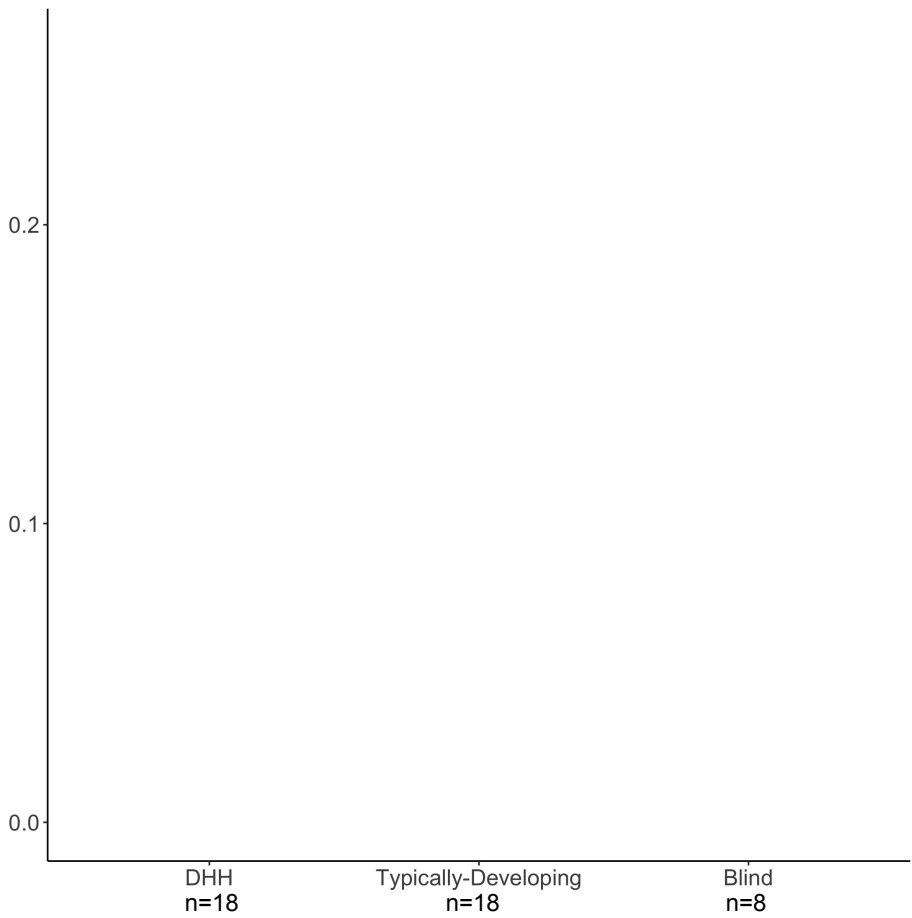
LENA recordings from  
DHH / TD children: **Derek  
Houston (& OSU  
BabyTalkLab)**

CDI data from TD children:  
**Wordbank**

# Backup Slides

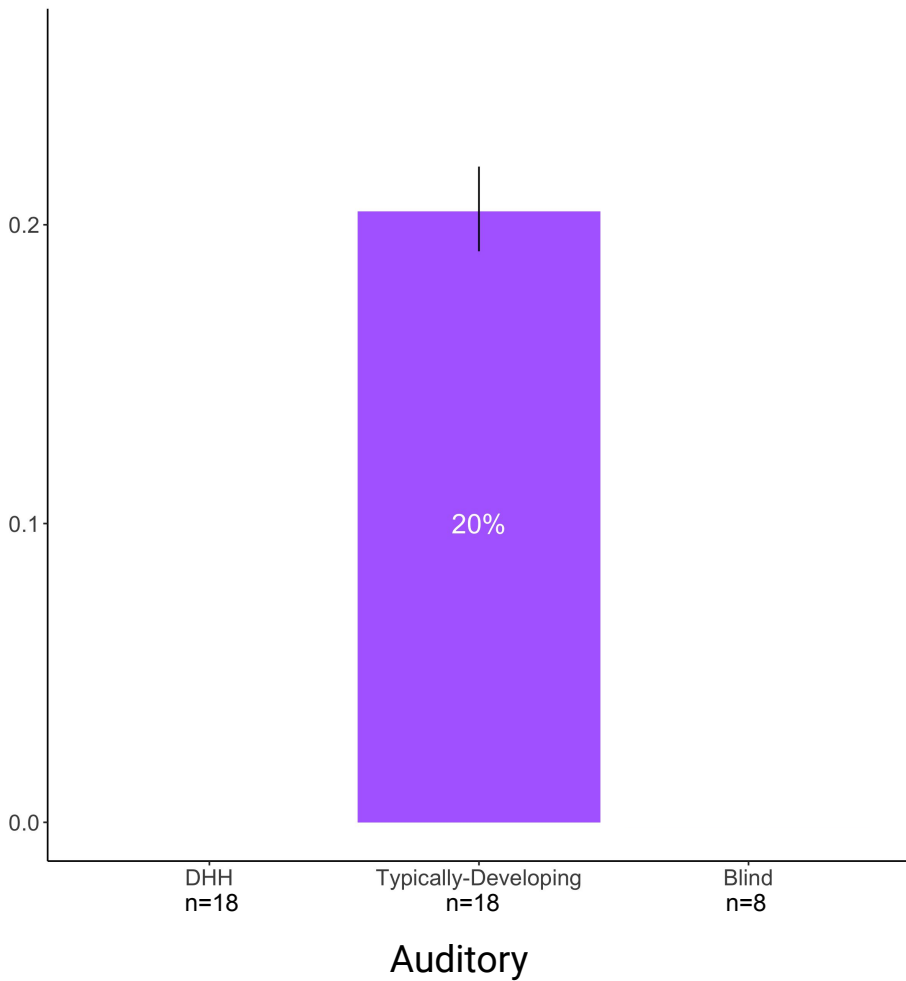




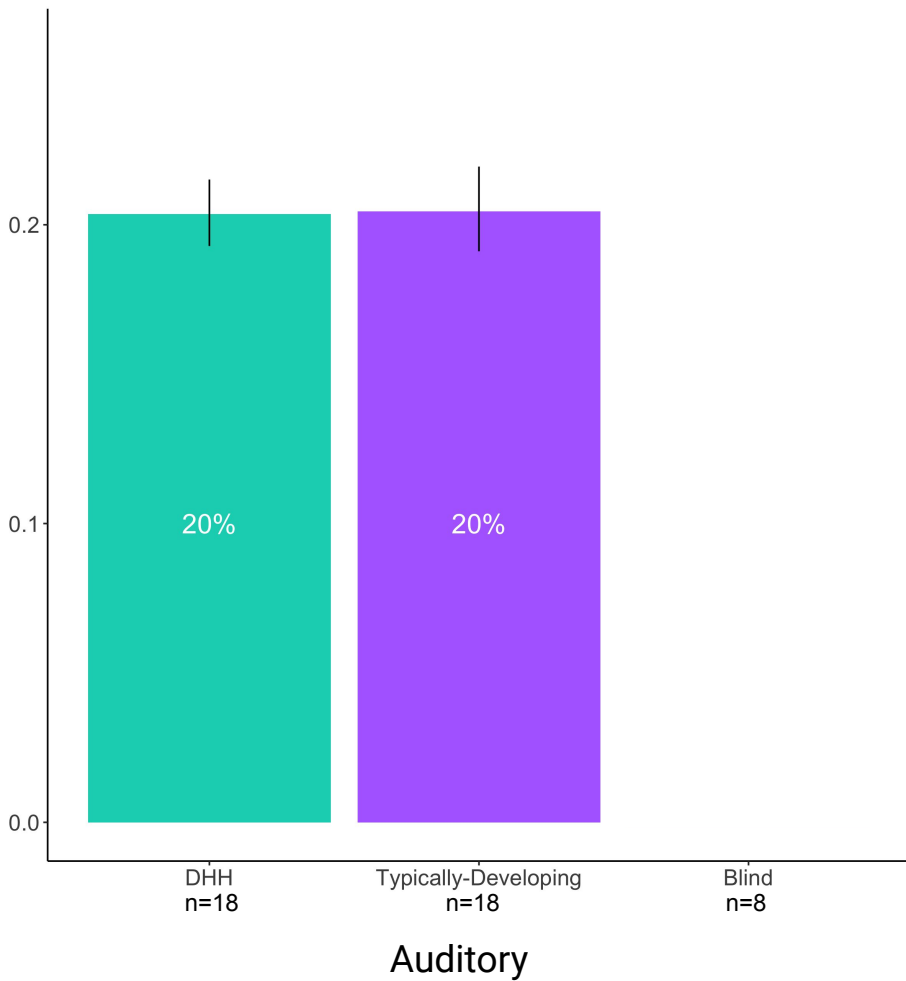


Auditory

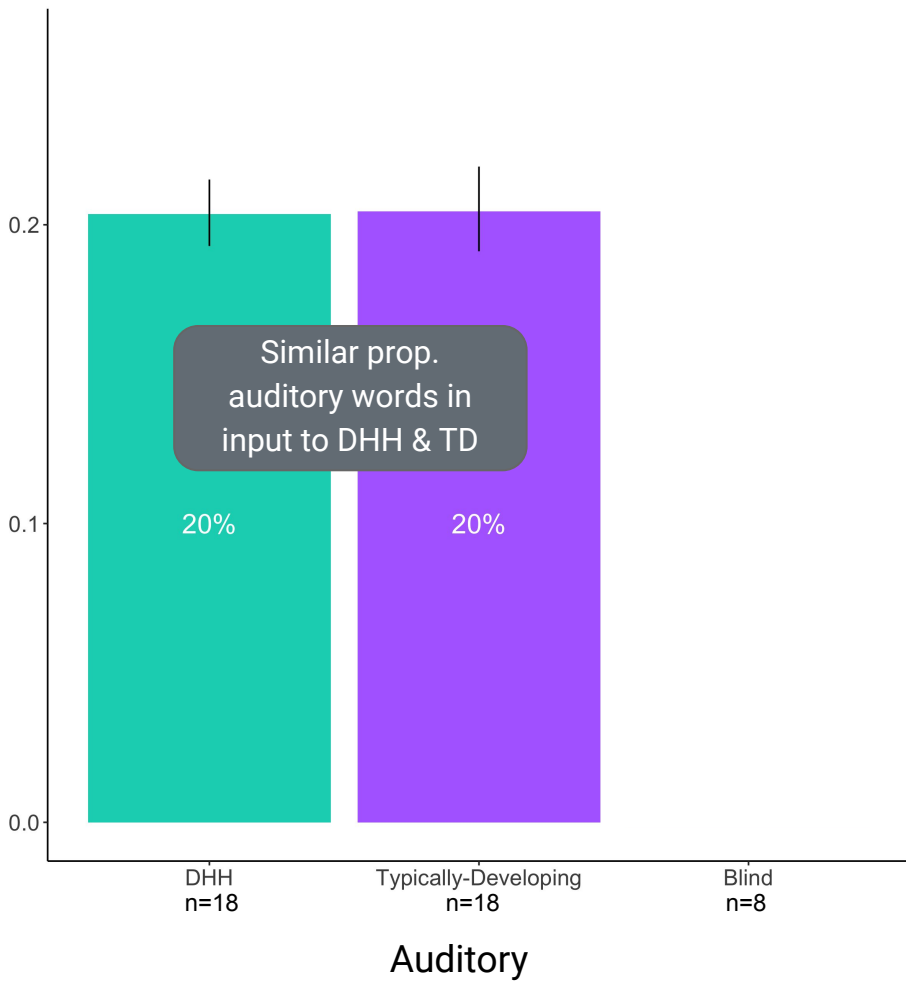
Proportion of Words by Sensory Domain



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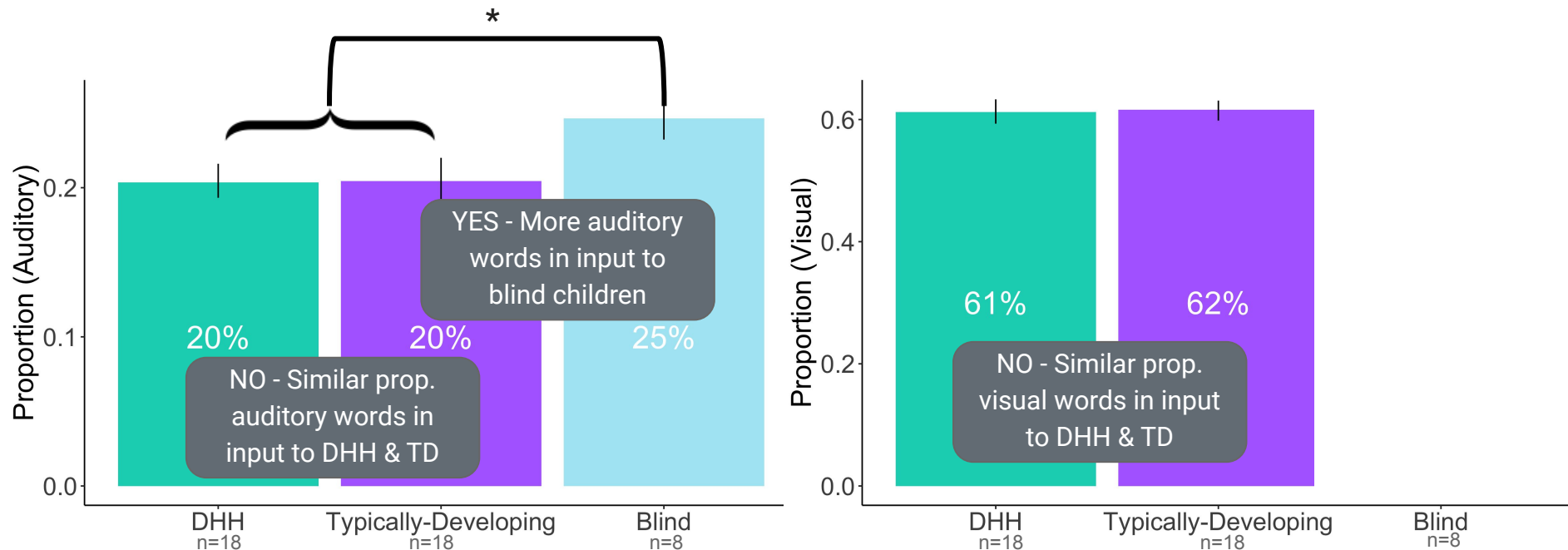


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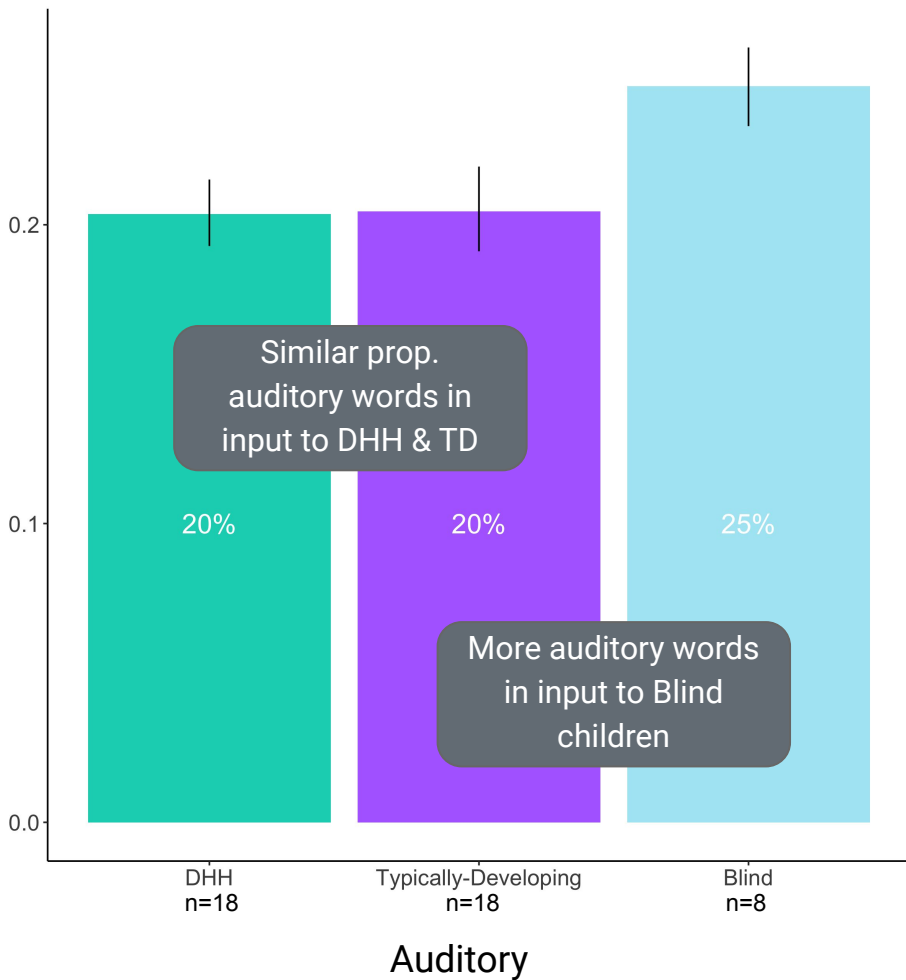


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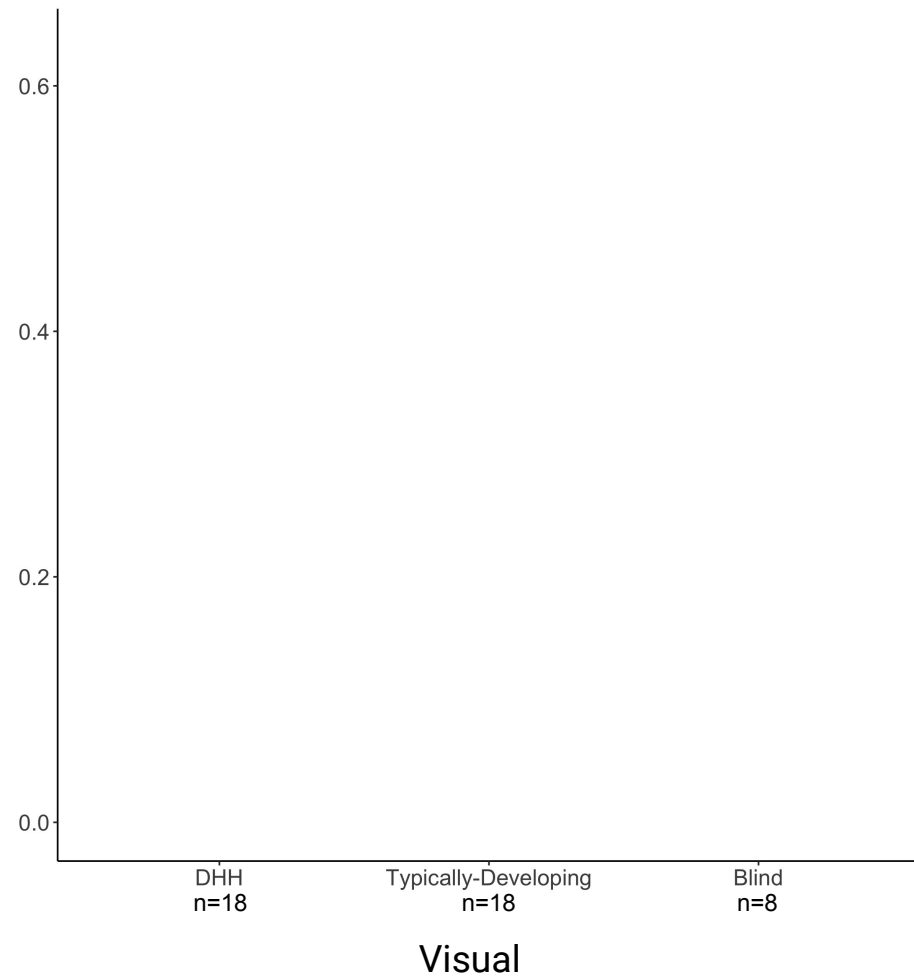
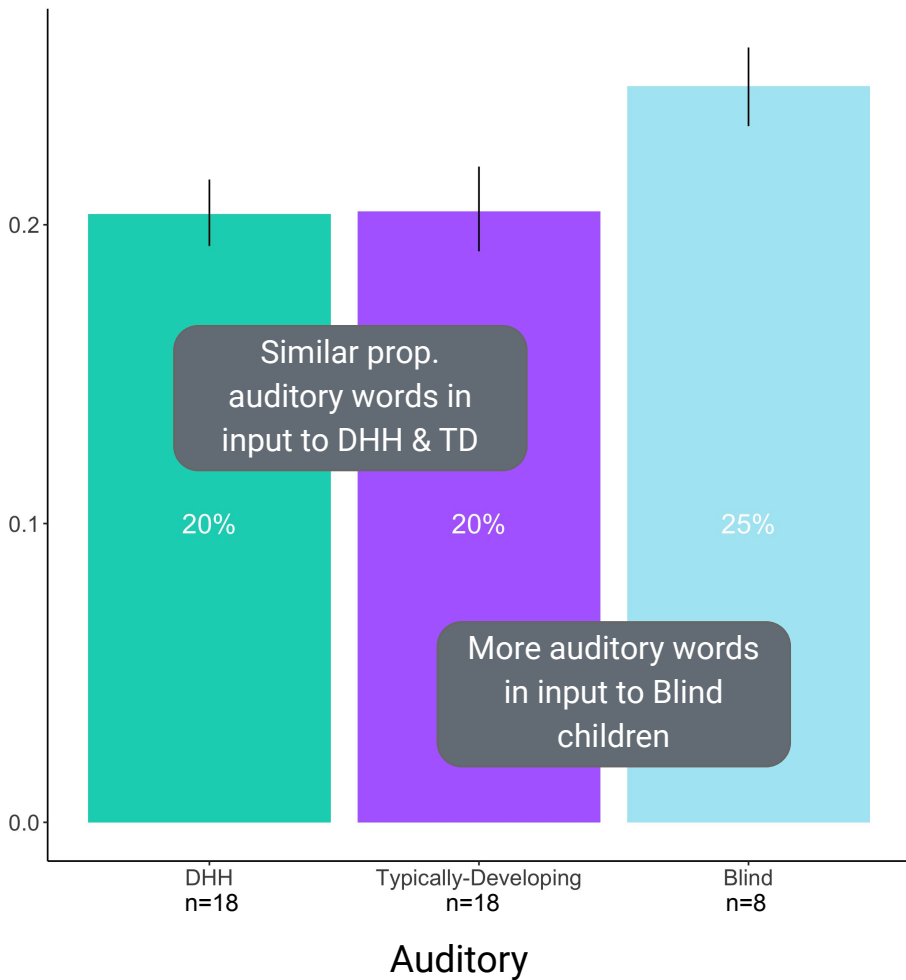
# Does sensory language input differ across groups?



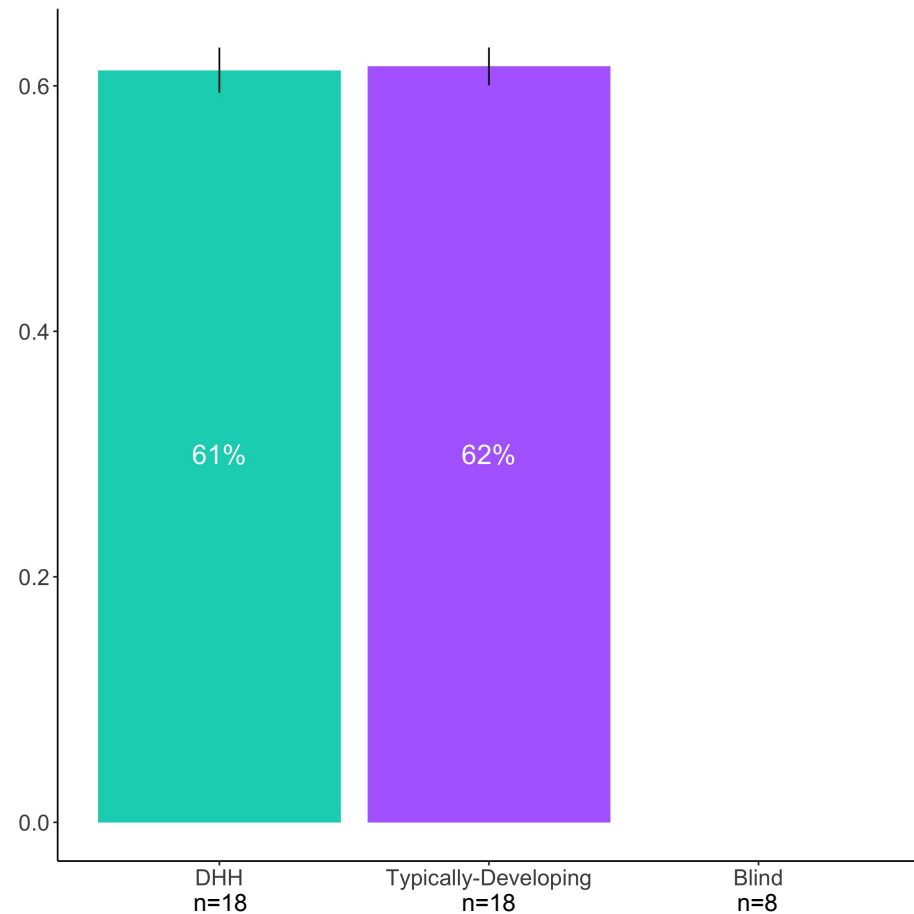
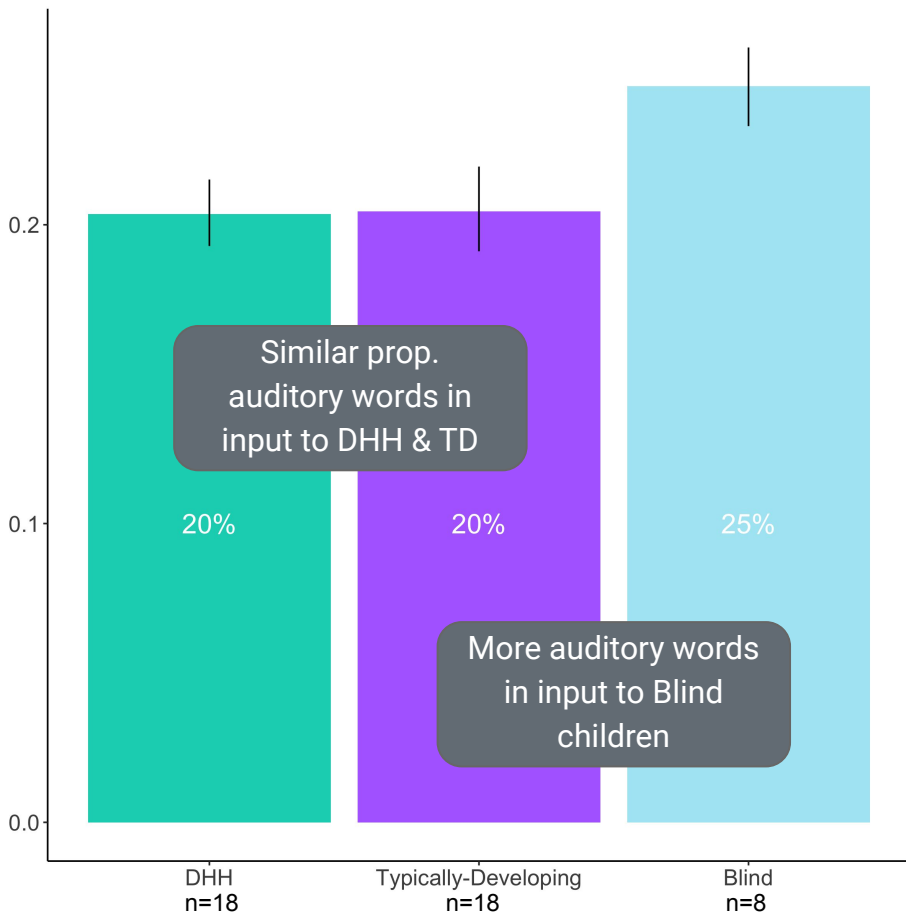
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Proportion of Words by Sensory Domain

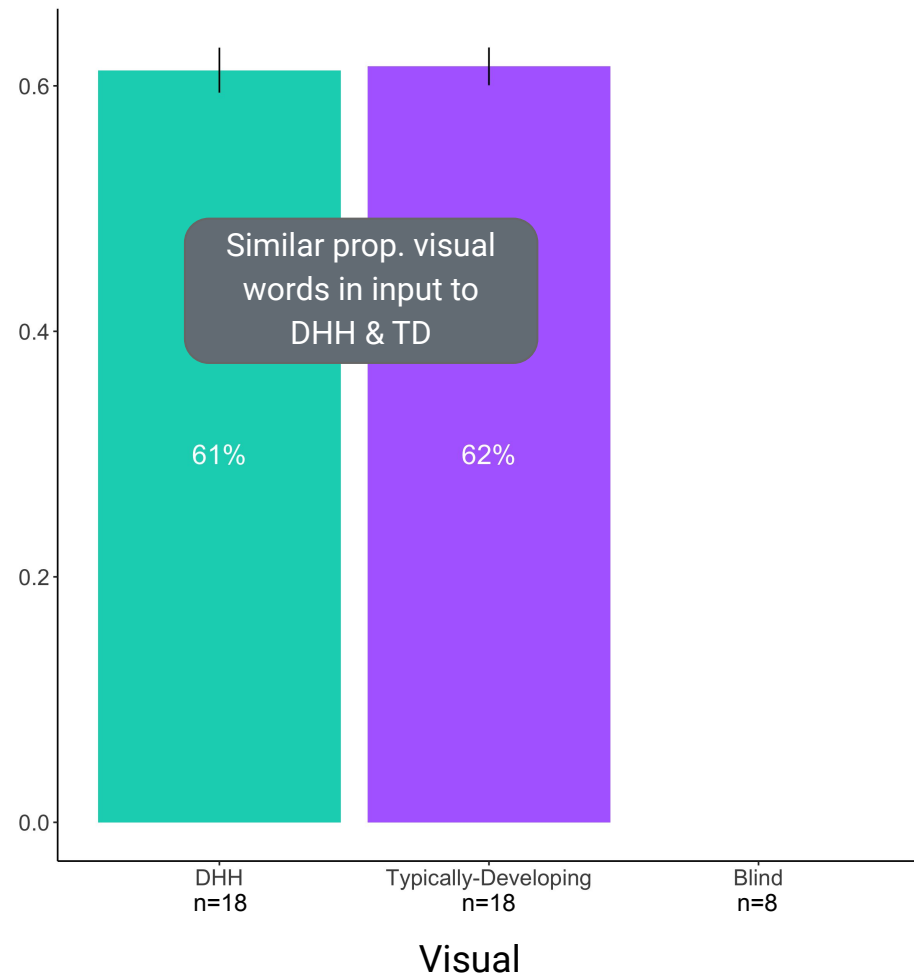
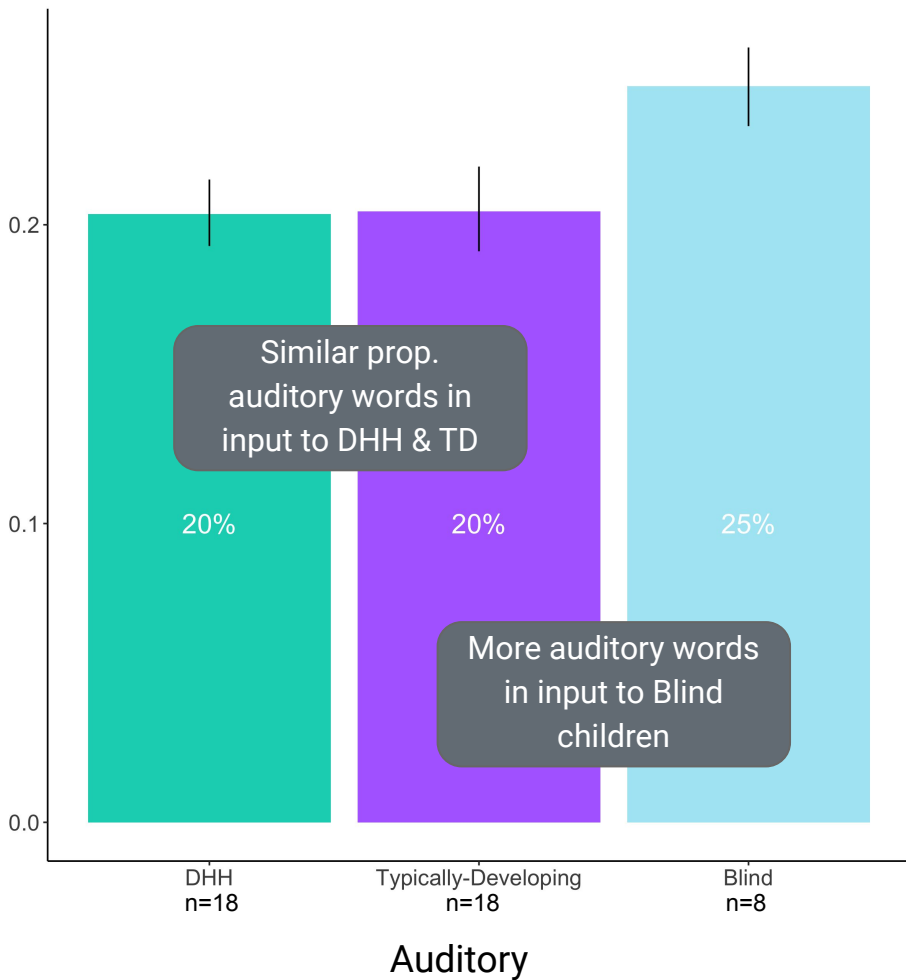


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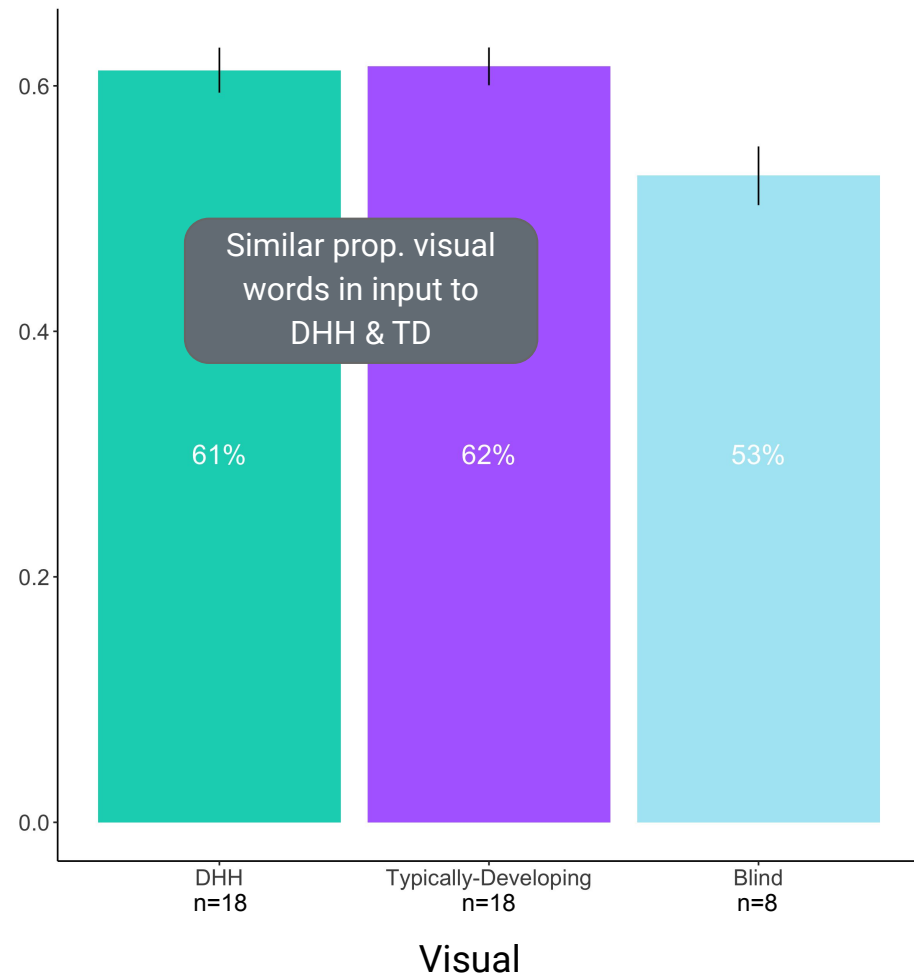
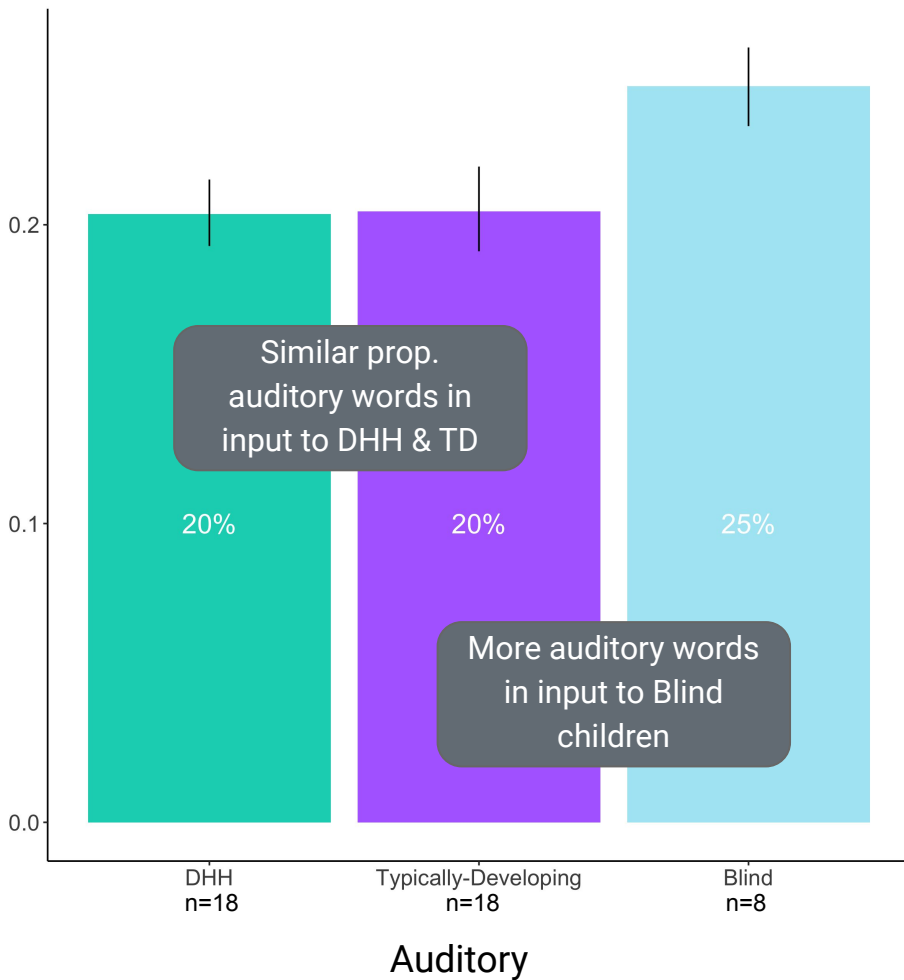


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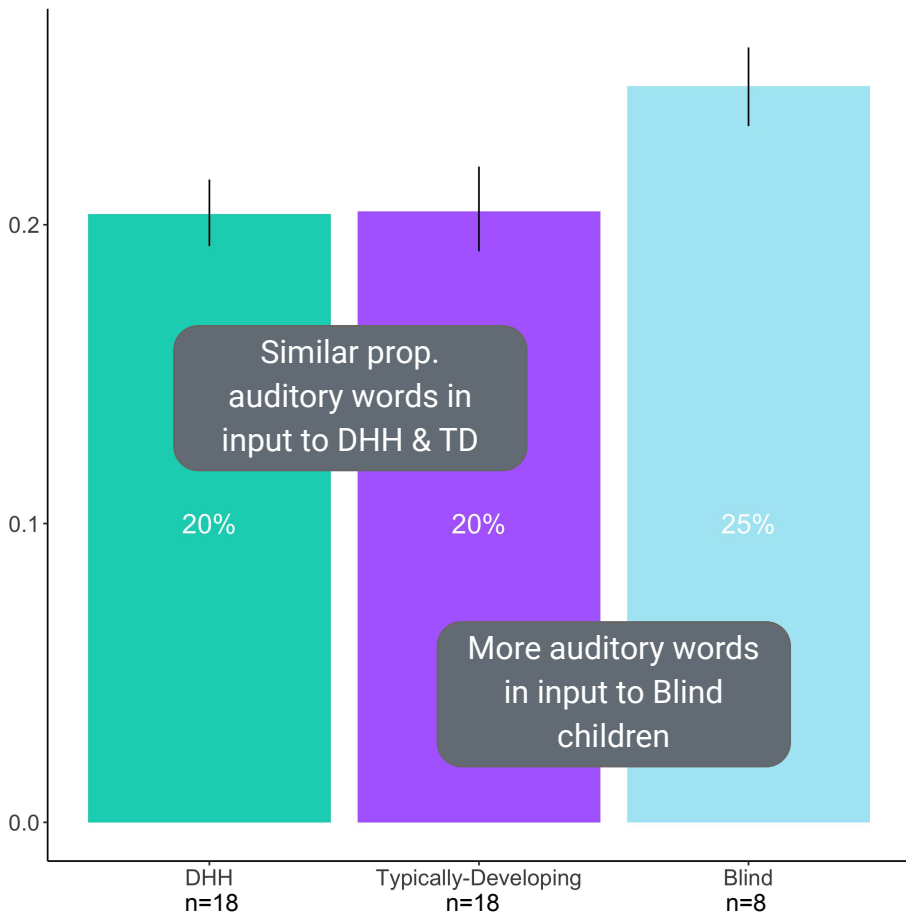




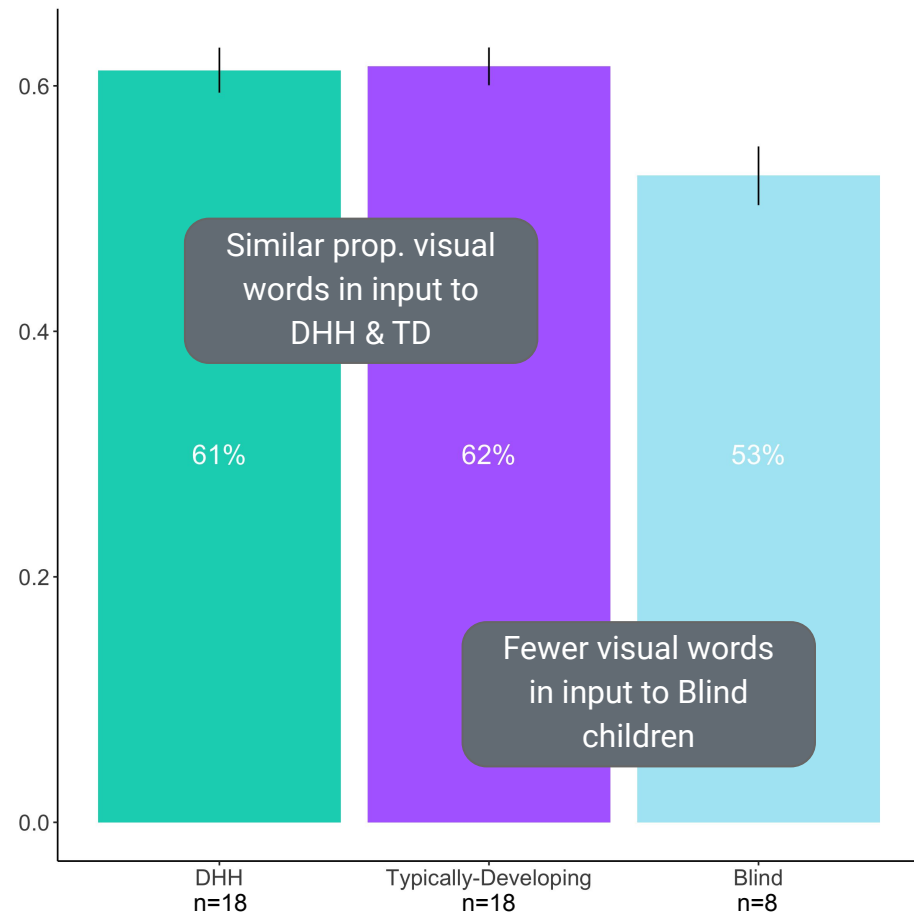
Proportion of Words by Sensory Domain



Proportion of Words by Sensory Domain



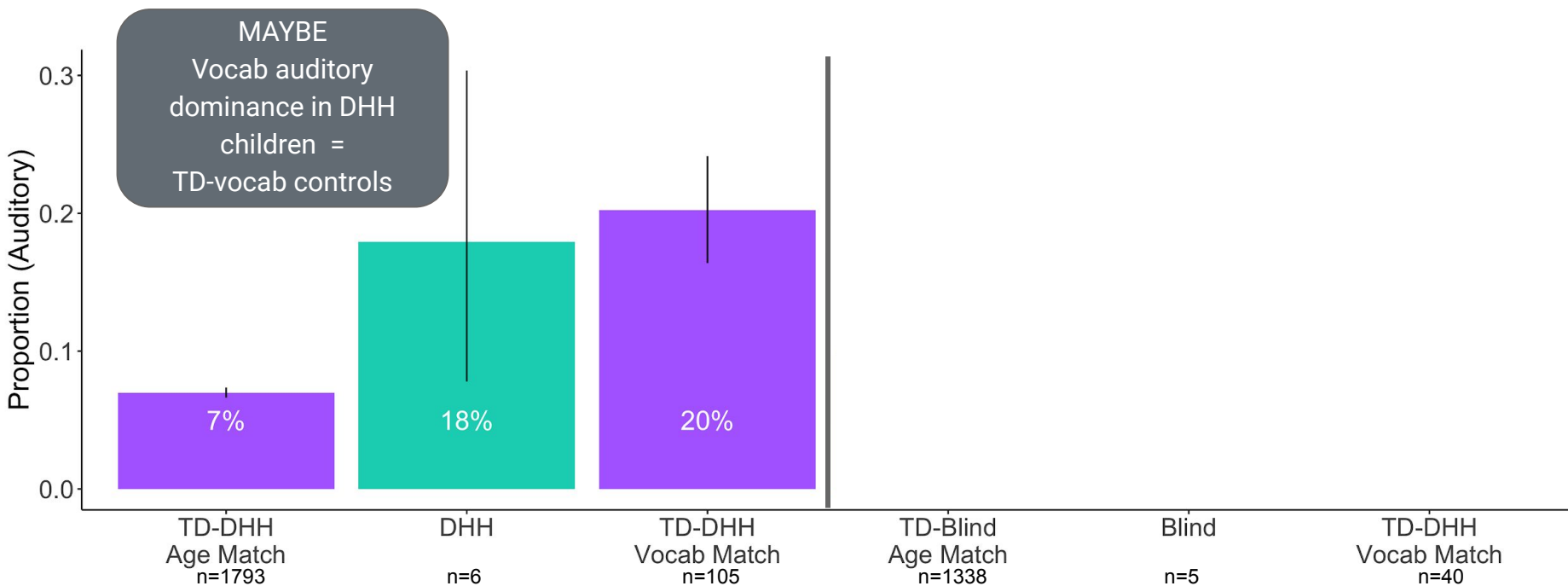
Auditory



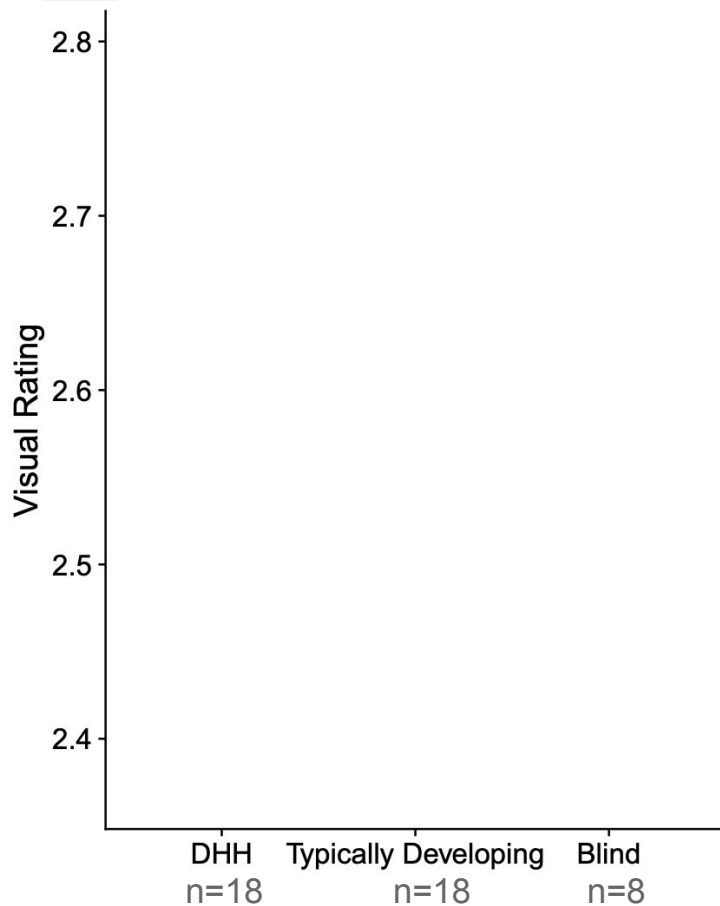
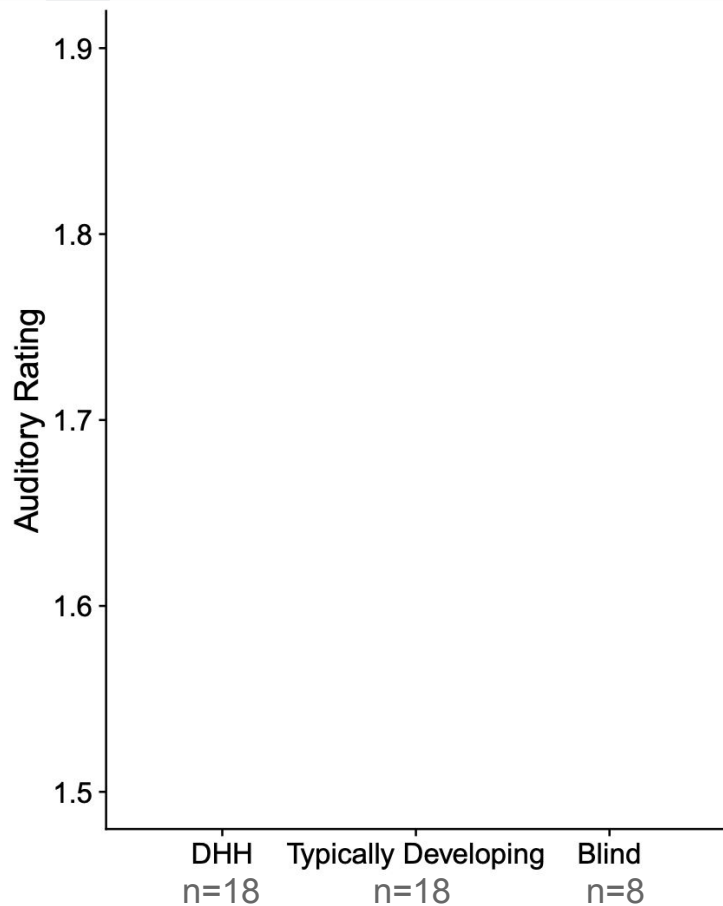
Visual

Proportion of Words by Sensory Domain

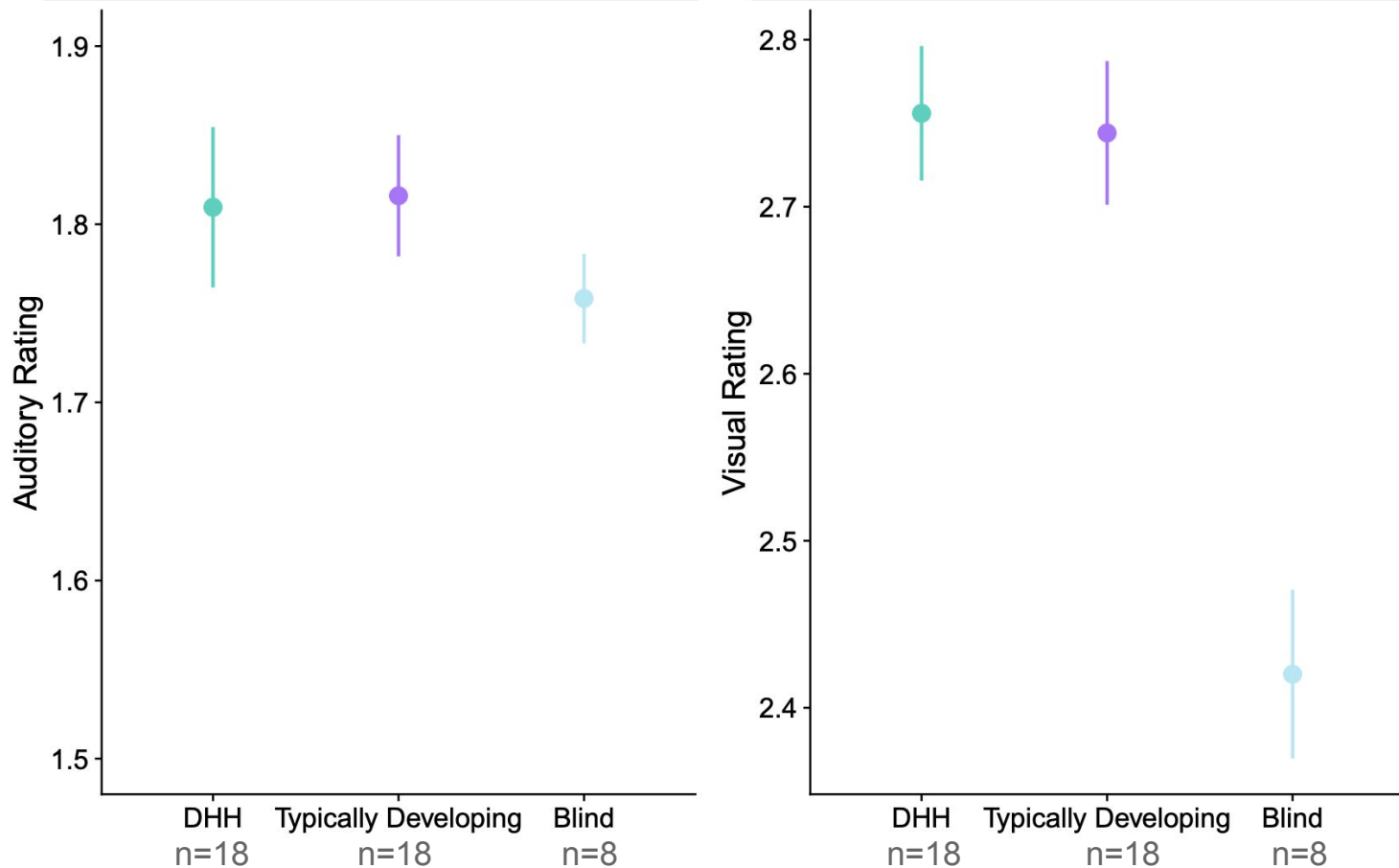
# Does auditory language production differ across groups?



# Perceptual Strength of Input

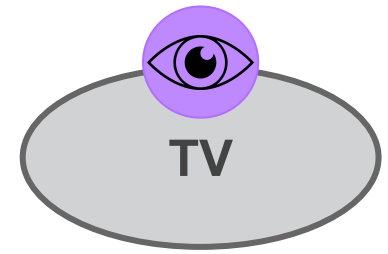
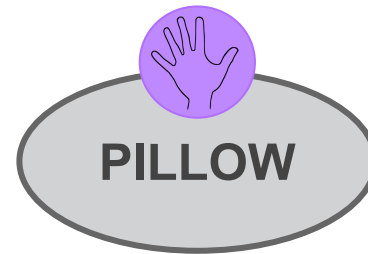
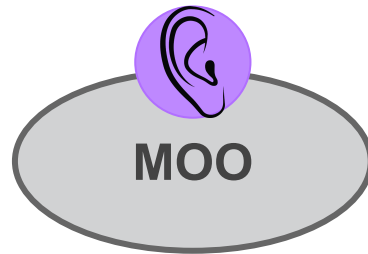
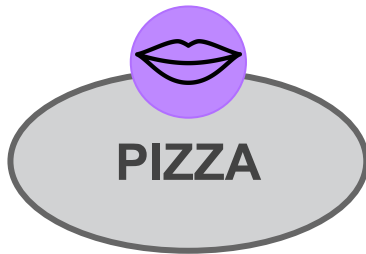


# Perceptual Strength of Input



# Lancaster Sensorimotor Norms

- Ratings of **sensory associations** of words from typically-developing adults; each word rated 1-5 on each sense
  - **Which sensory domain the word taps into**
  - How *strongly* associated with each sensory domain



# Lancaster Sensorimotor Norms

- Ratings of **sensory associations** of words from typically-developing adults; each word rated 1-5 on each sense
  - Which *sensory domain* the word taps into
  - How **strongly** associated with each sensory domain

PRETTY



ZEBRA



SPLASH



THIS



TOMORROW

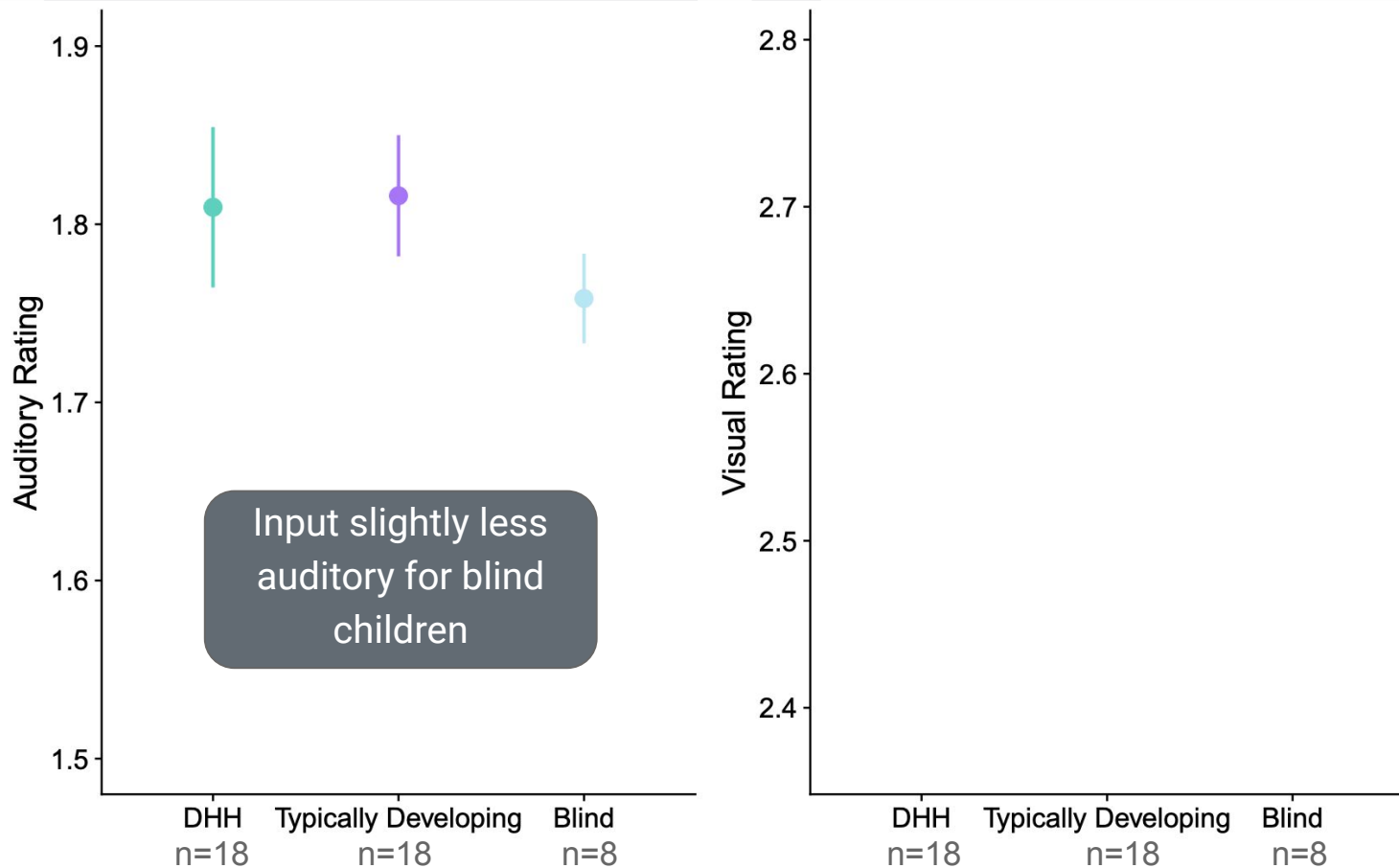




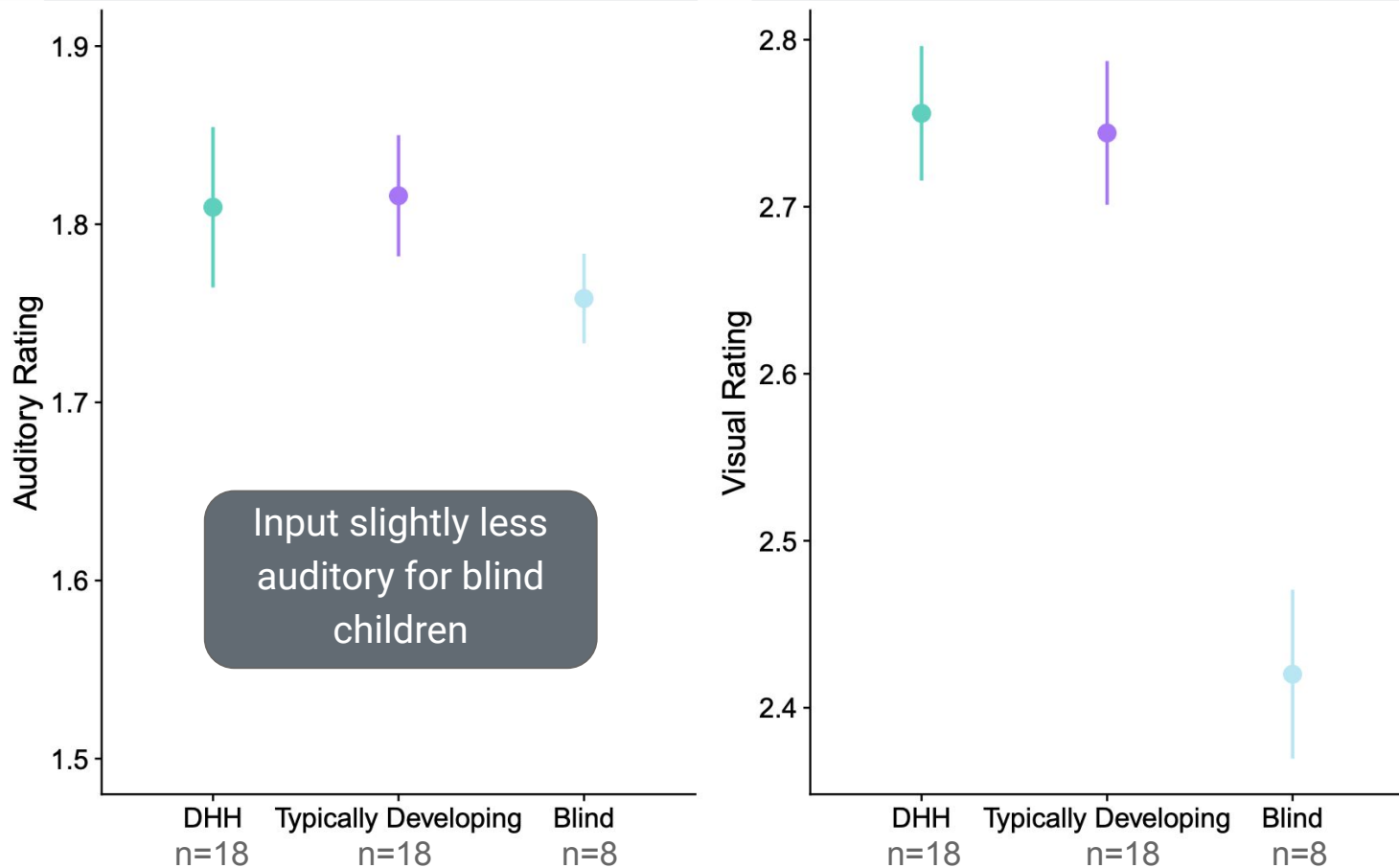
# Lancaster Sensorimotor Norms

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  - Which *sensory domain* the word taps into
  - How *strongly* associated with each sensory domain
- Norms in use:
  - Sensory domain predicts adult word recognition, lexical decision performance
  - Sensory strength predicts words' age of acquisition
  - Used to describe sensory characteristics of English

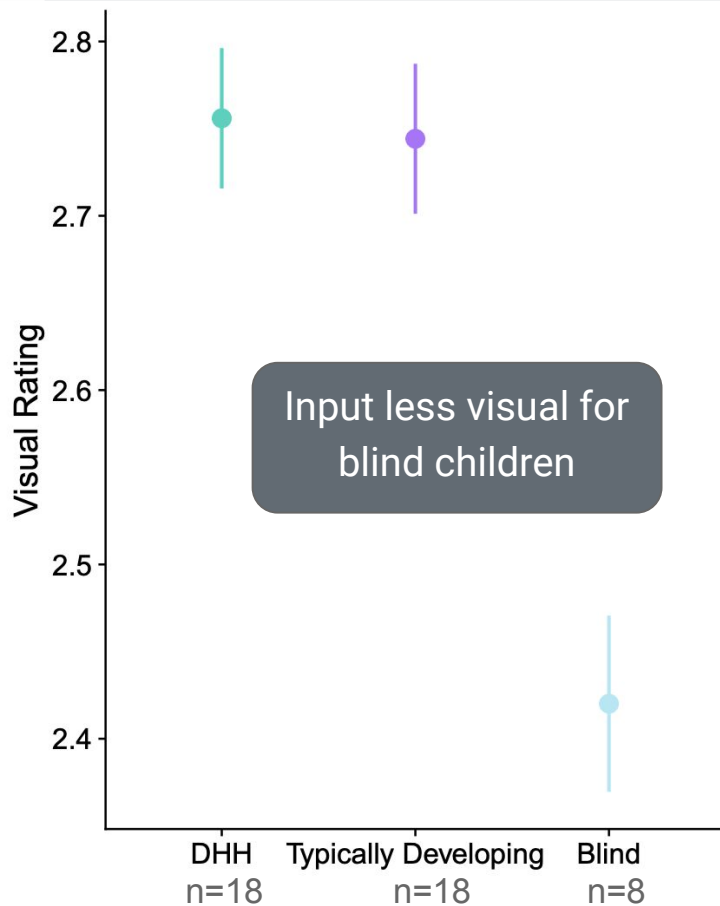
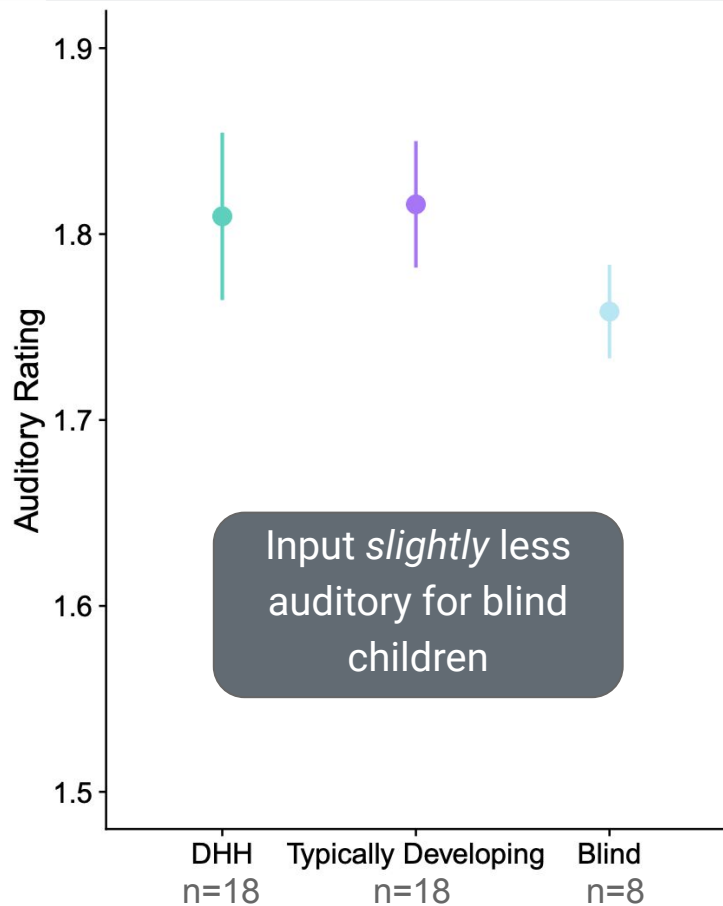
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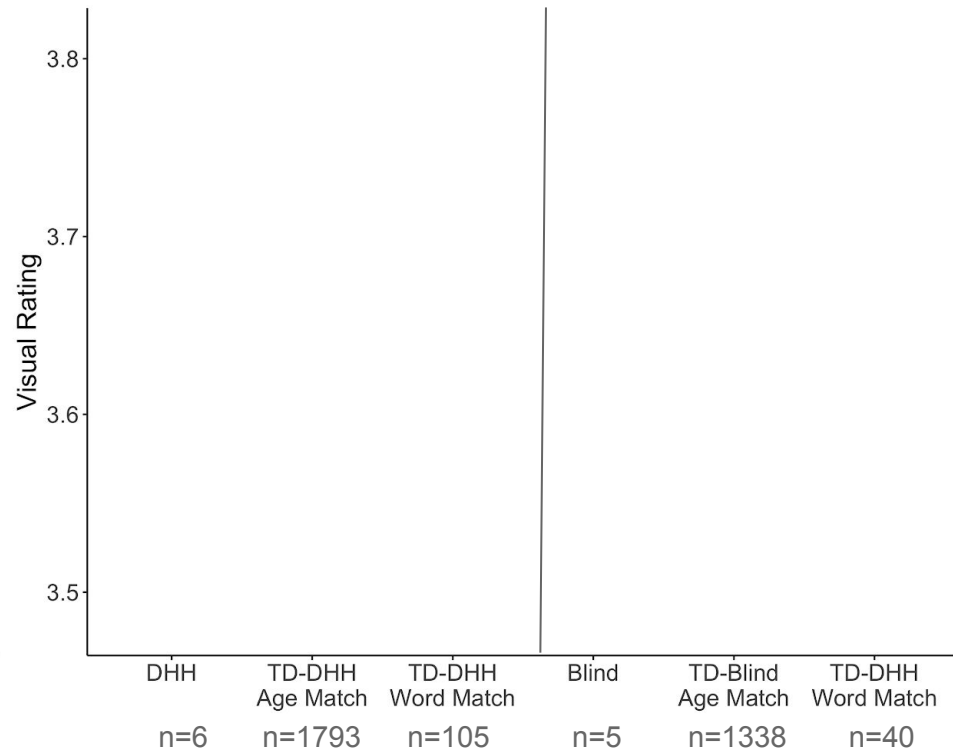
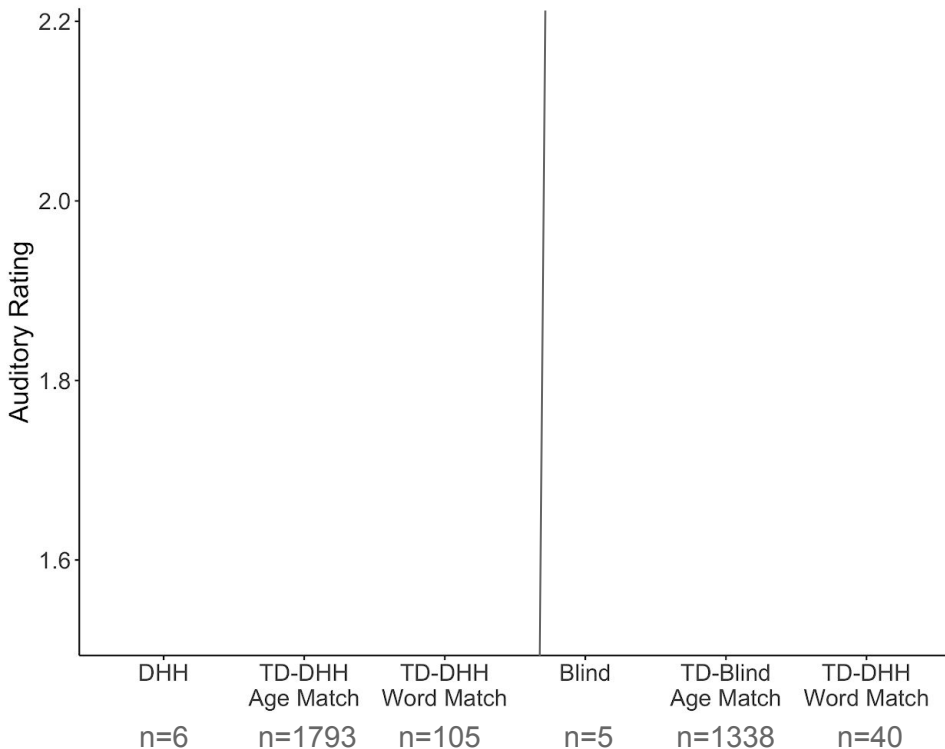
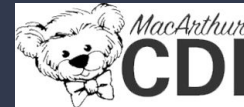
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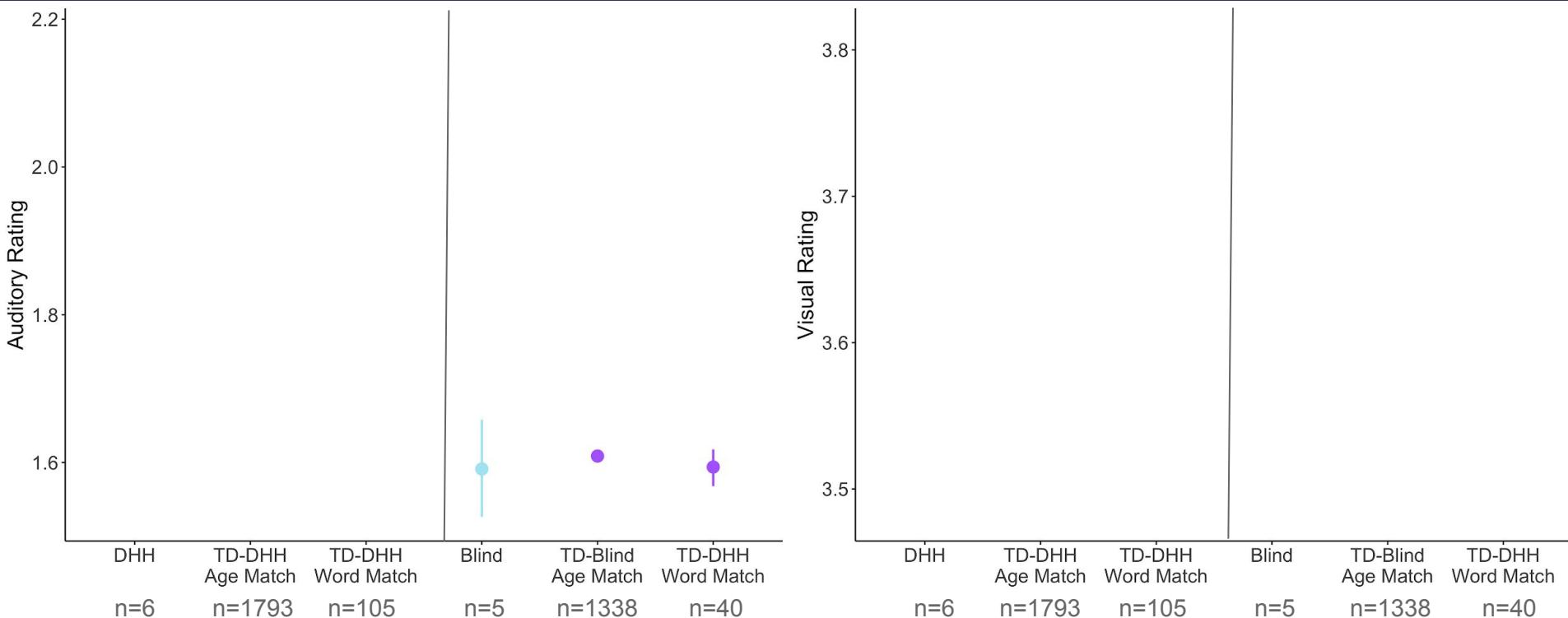
# Perceptual Strength of Input



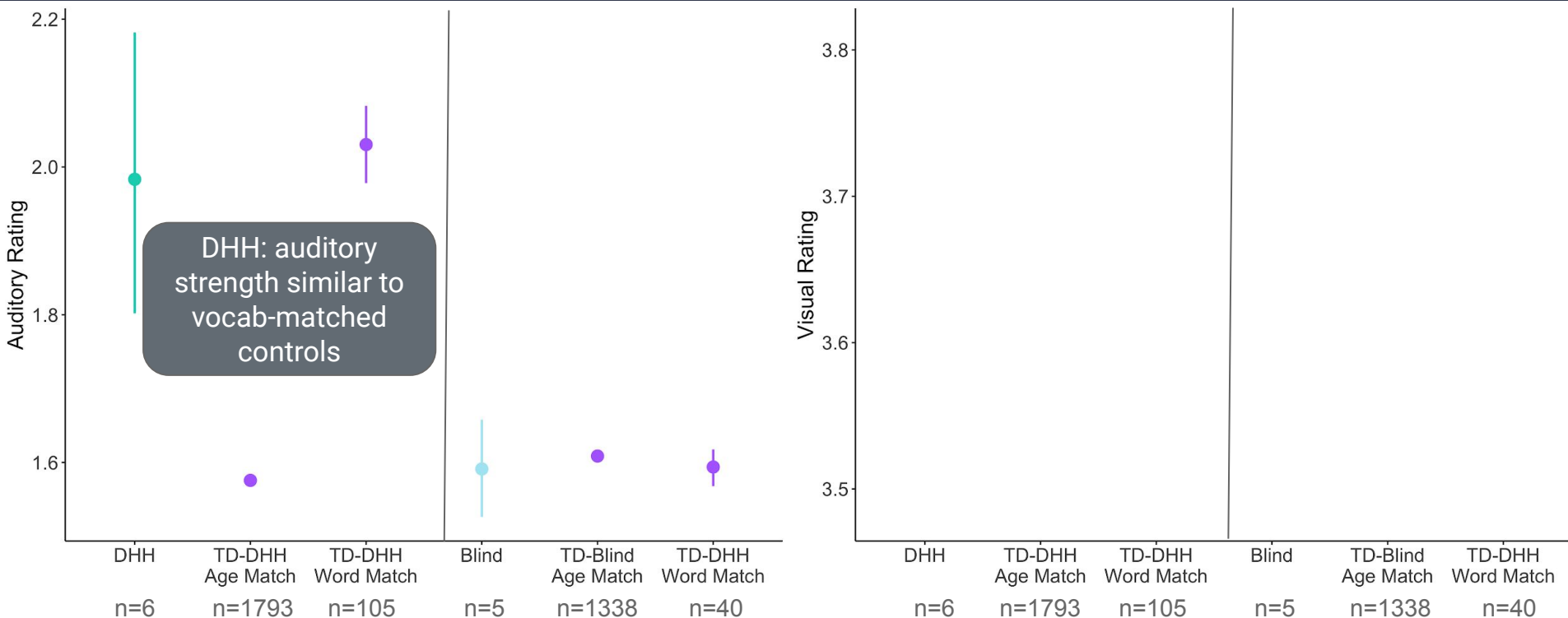
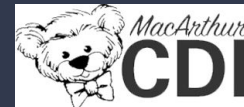
# Perceptual Strength of Vocabulary



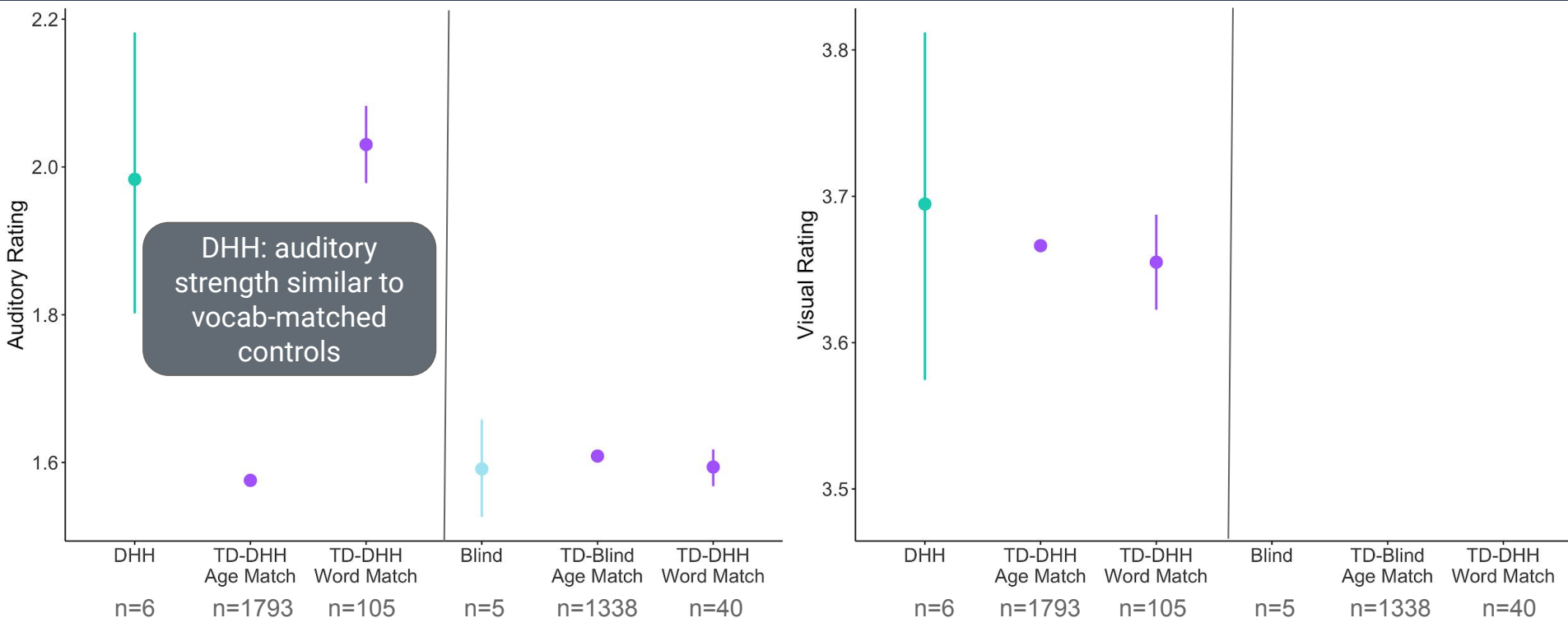
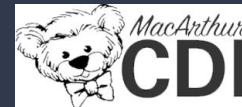
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# Perceptual Strength of Vocabulary

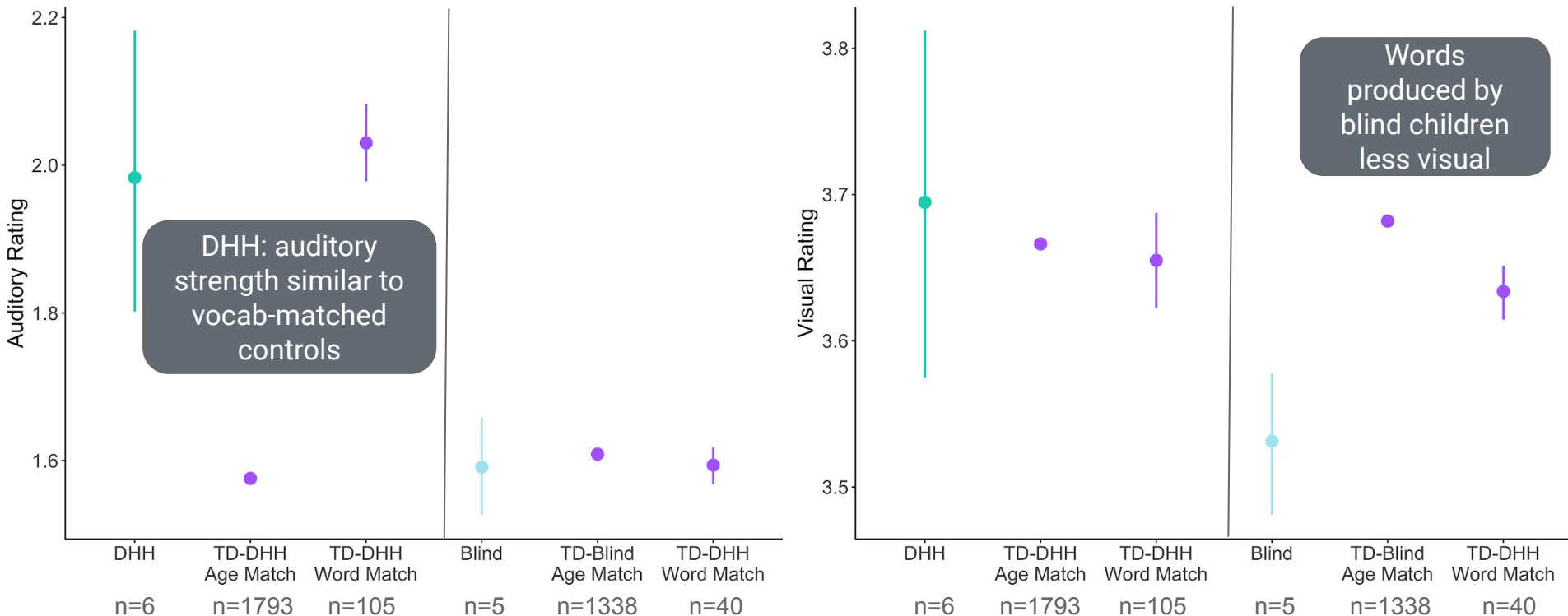
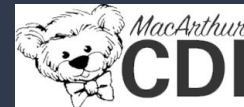


# Perceptual Strength of Vocabulary

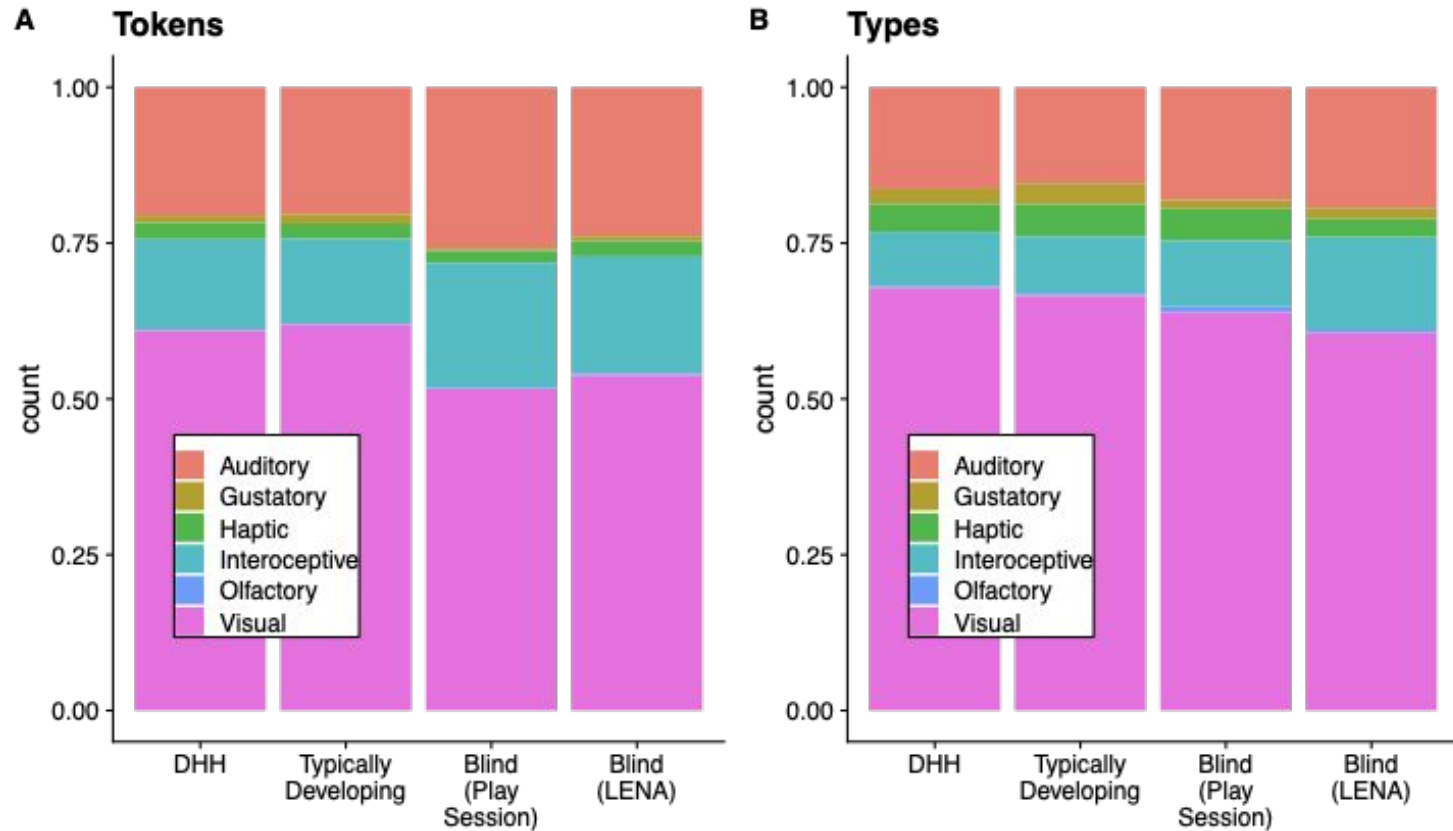




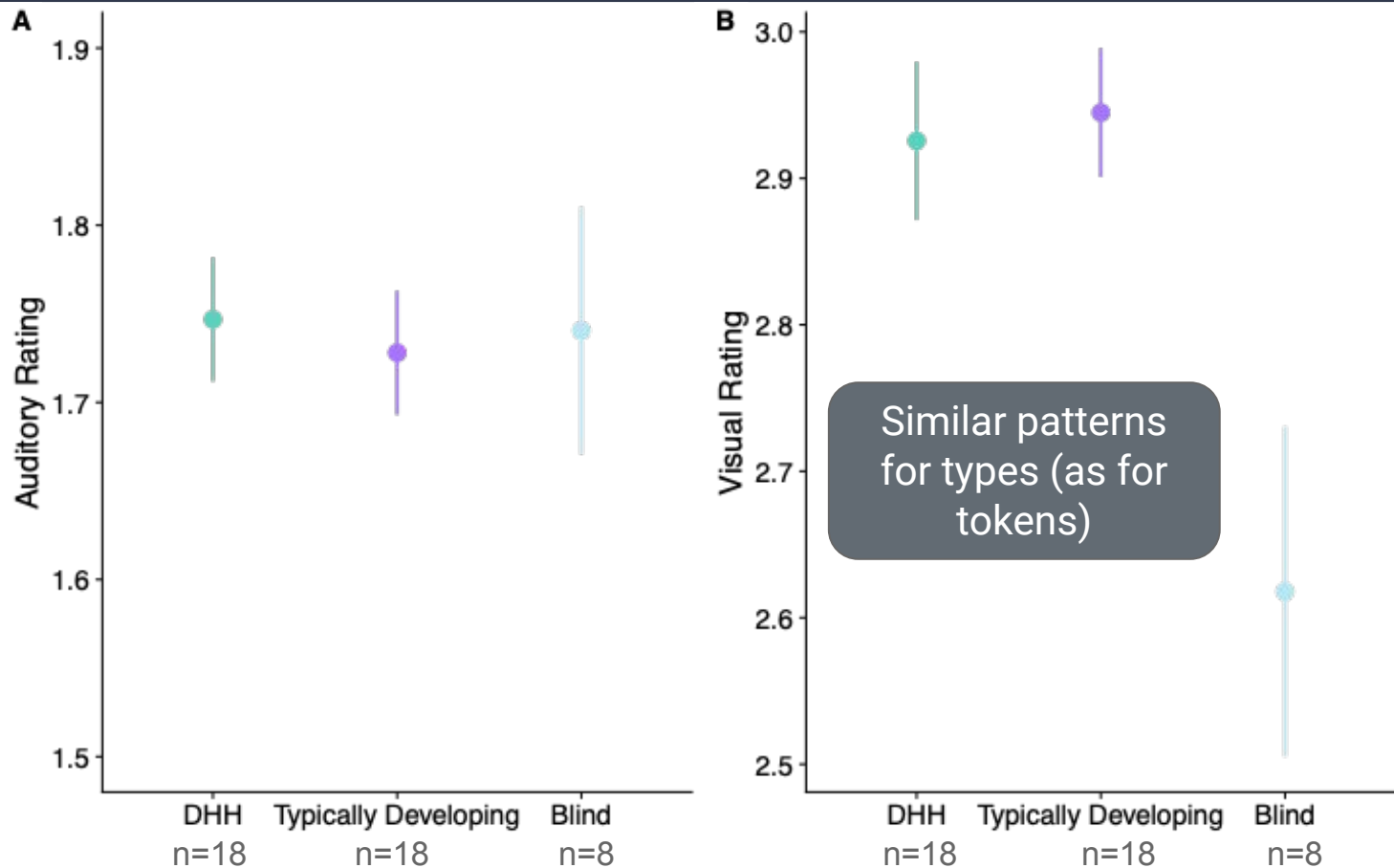
# Perceptual Strength of Vocabulary



# Does the degree of sensory associations in input vary by group?



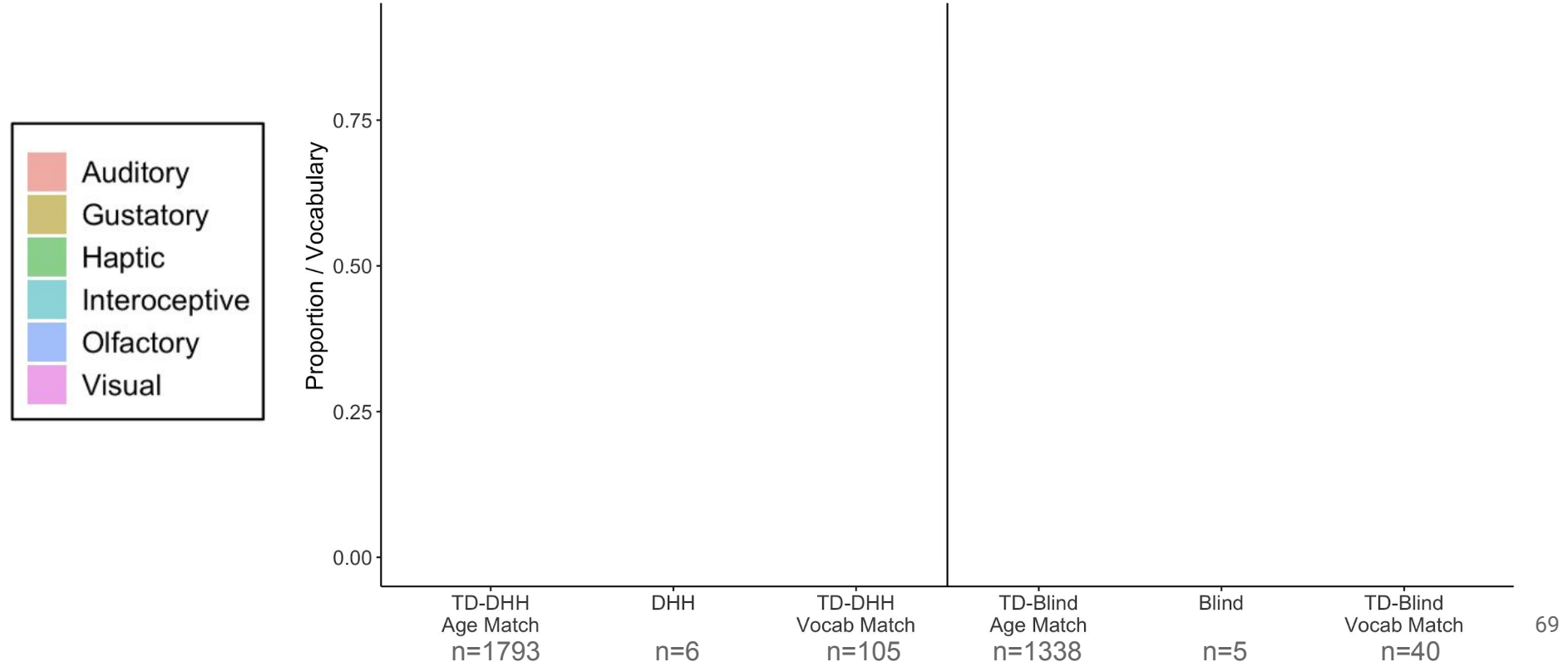
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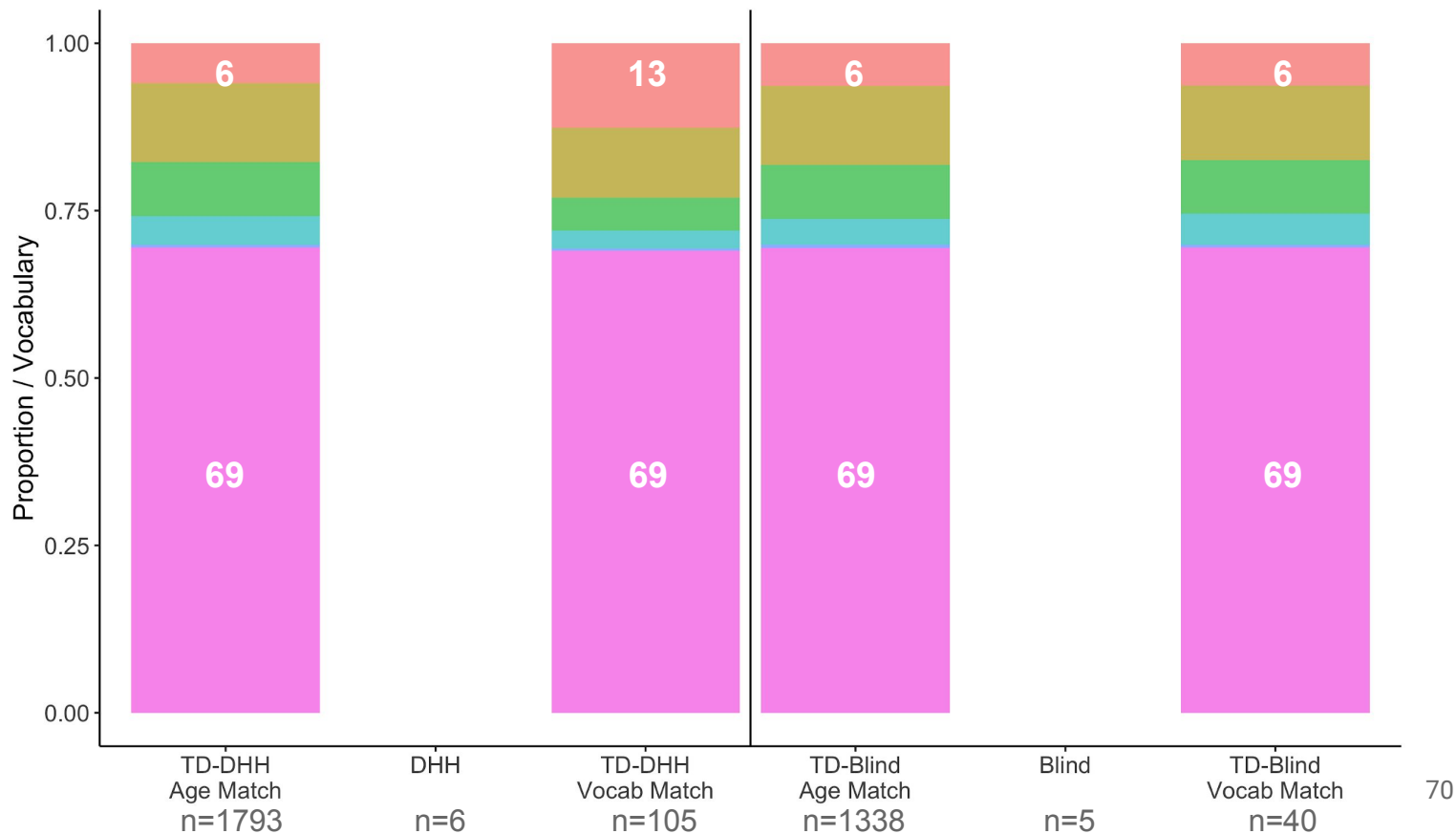
# Why sensory norms?

- For typically-developing children, perceptual features seem to play a role in early vocab development
  - Sensory association norms predict words' age of acquisition
- Ability to link concept to referent facilitates word learning
  - Visual referents not accessible for blind children; auditory referents less accessible for DHH children
  - Perhaps differences in word learning too

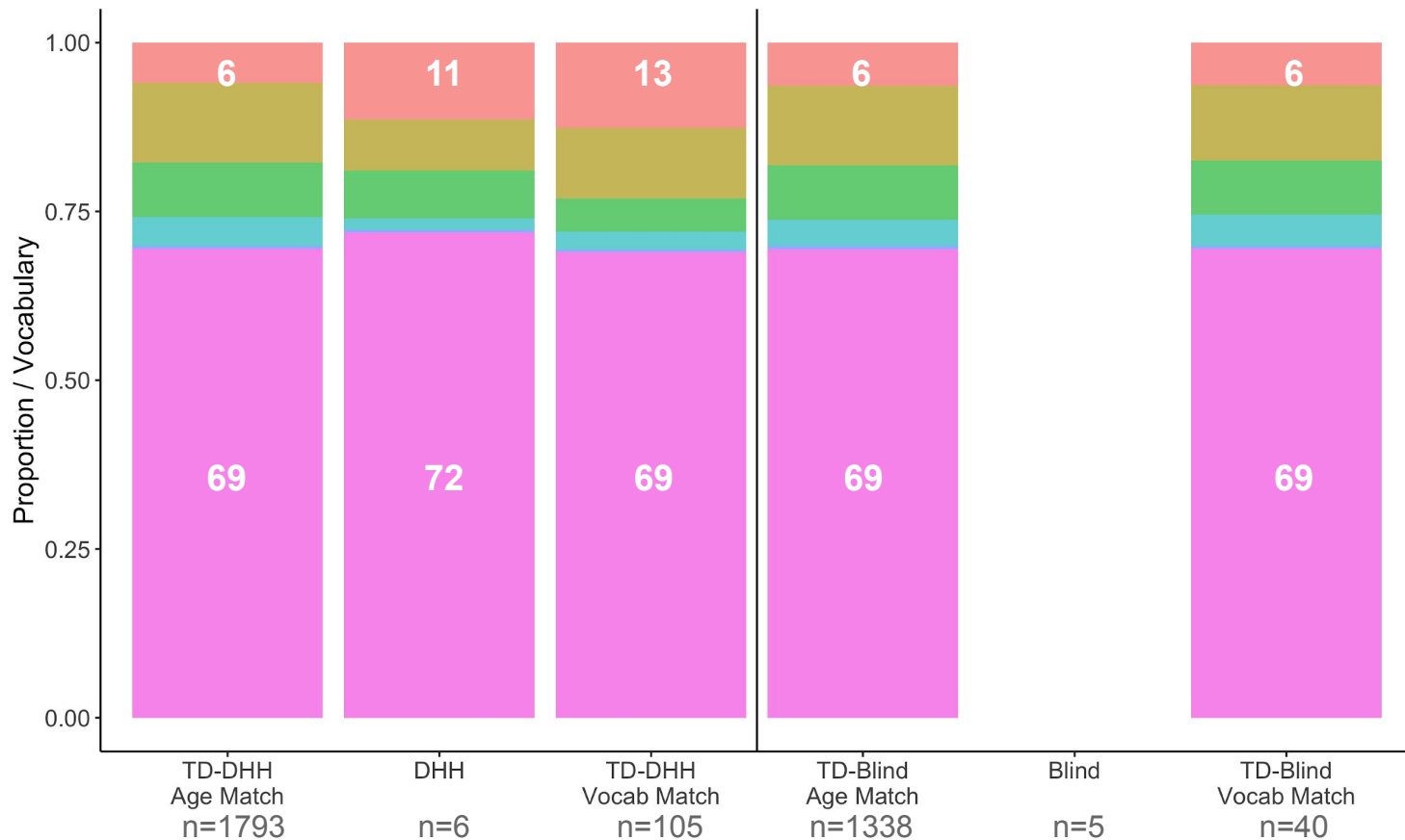
# Is the sensory content of early vocabulary similar across groups?



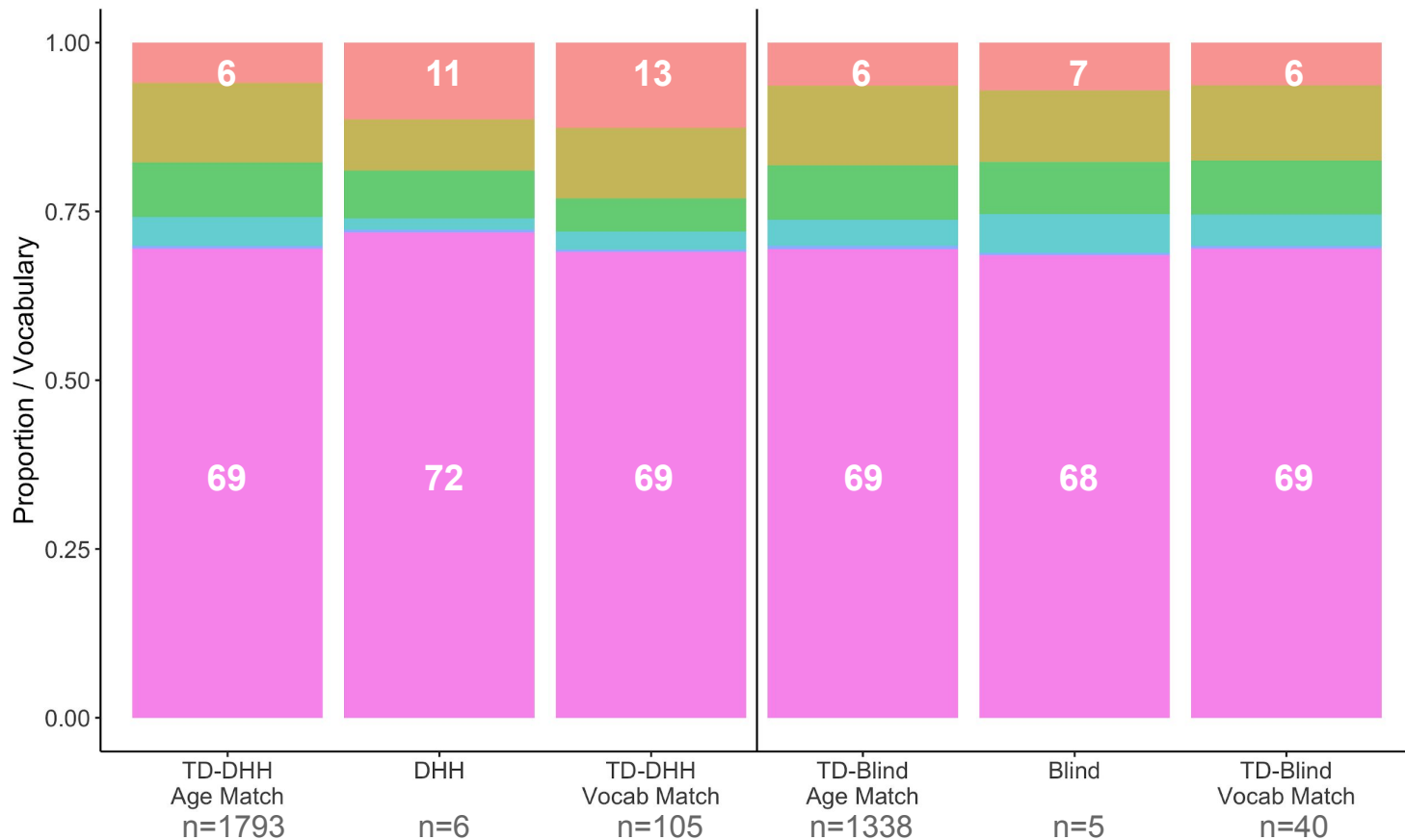
# Do the sensory associations in early vocabulary vary across groups?



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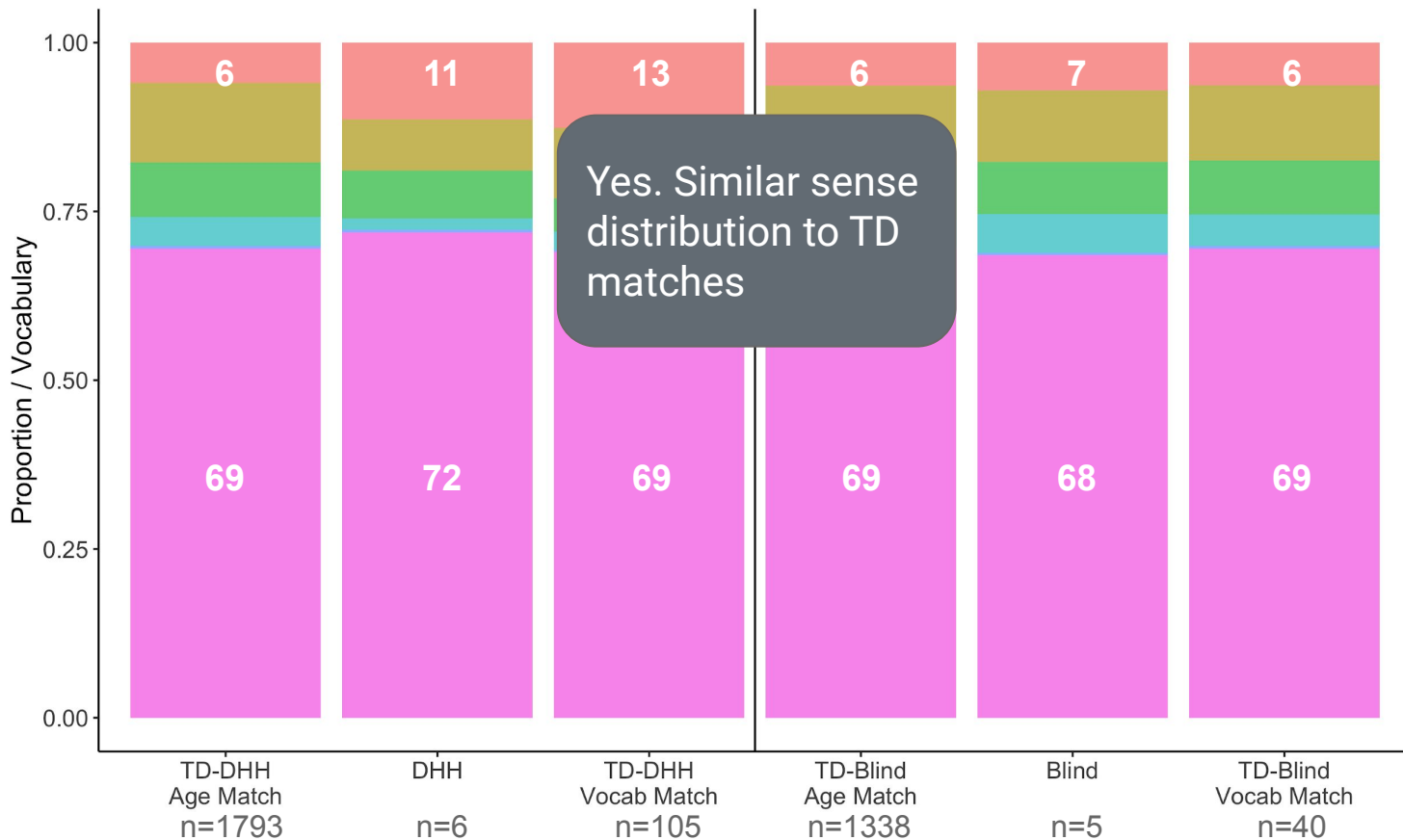
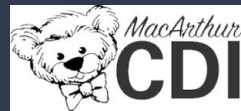


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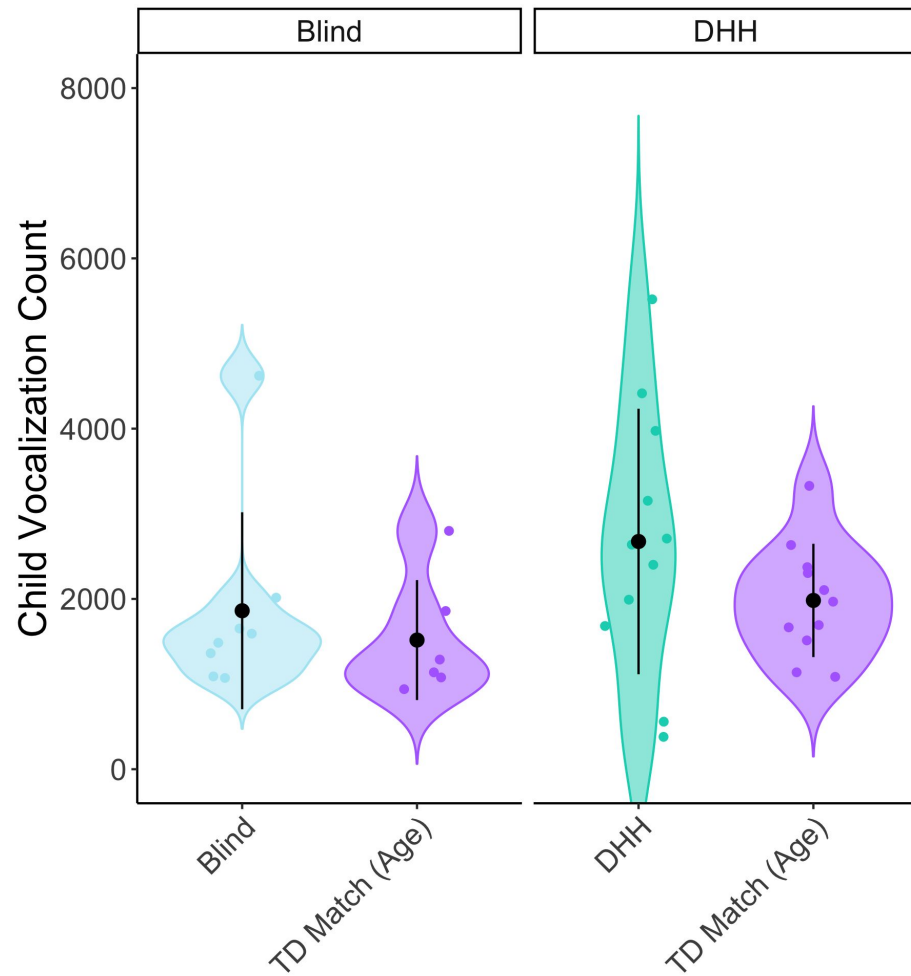




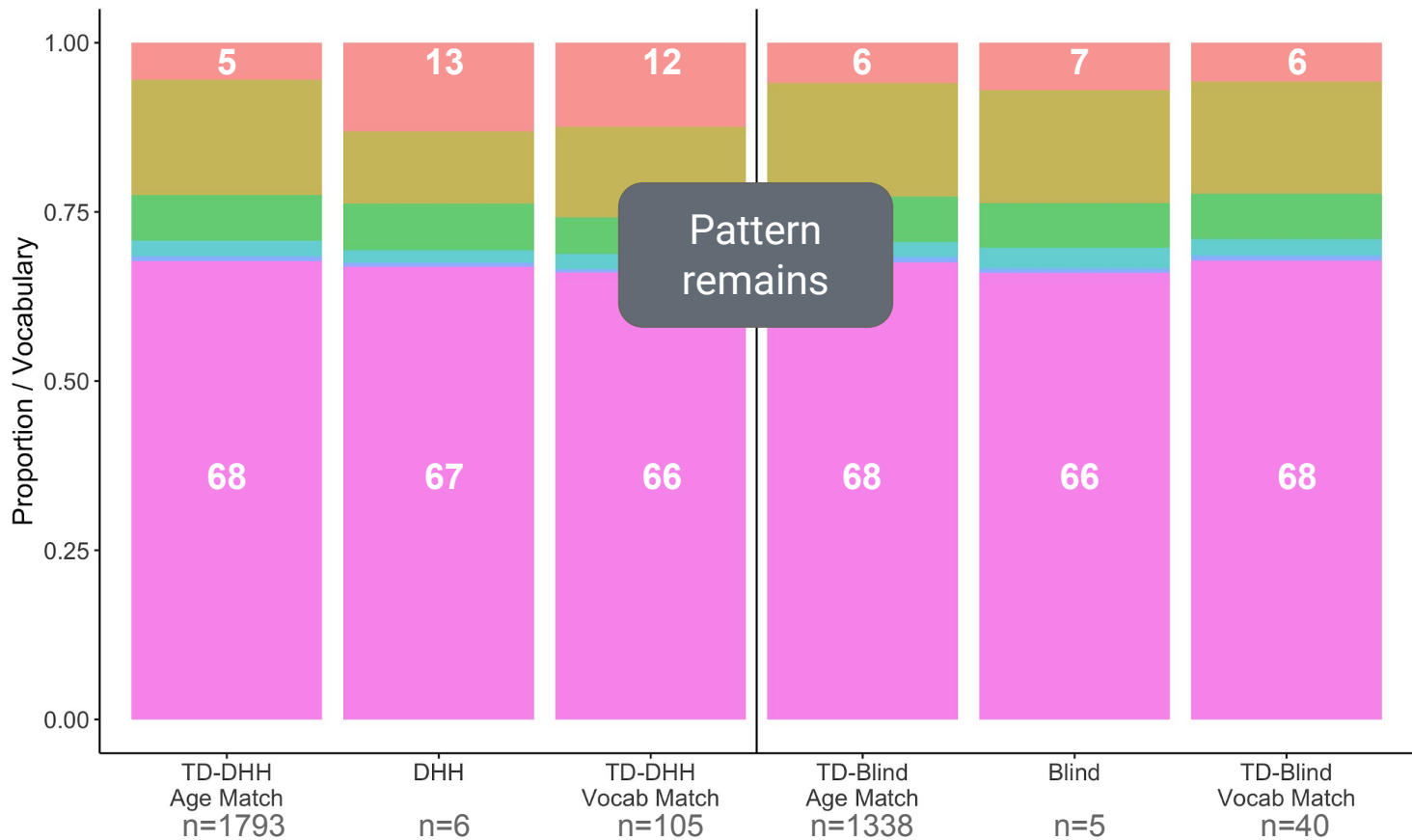
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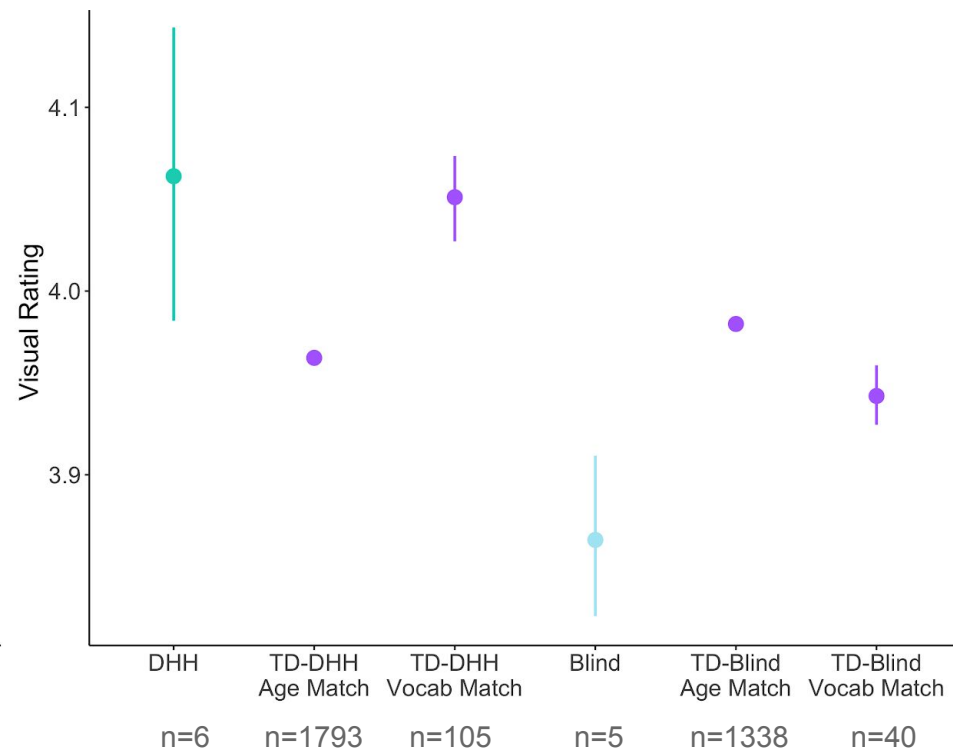
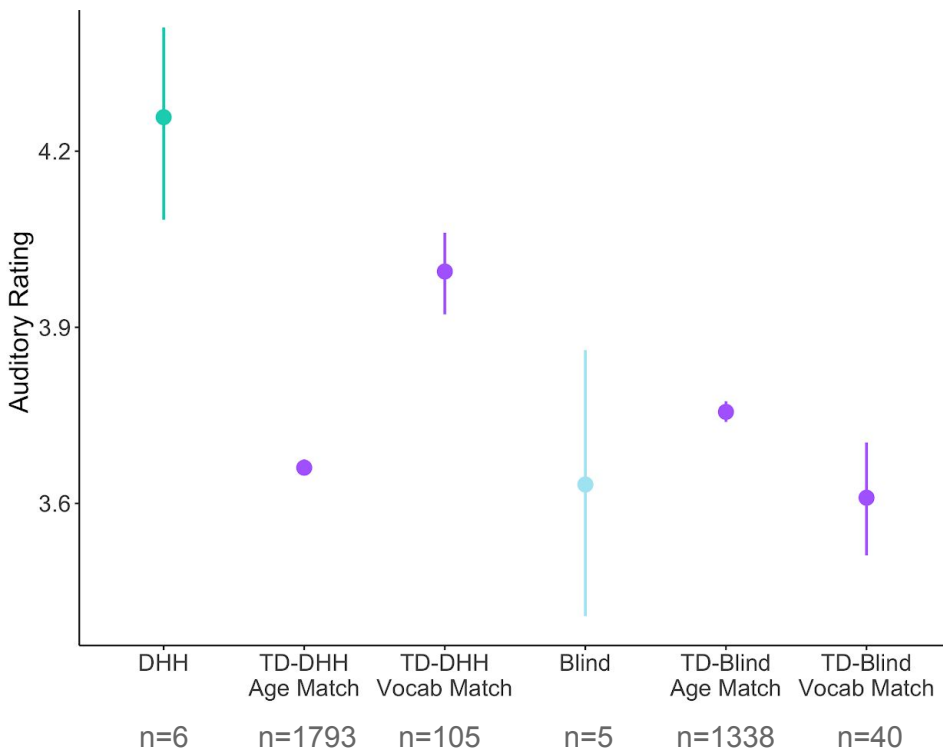
# Split by TD group (CVC)



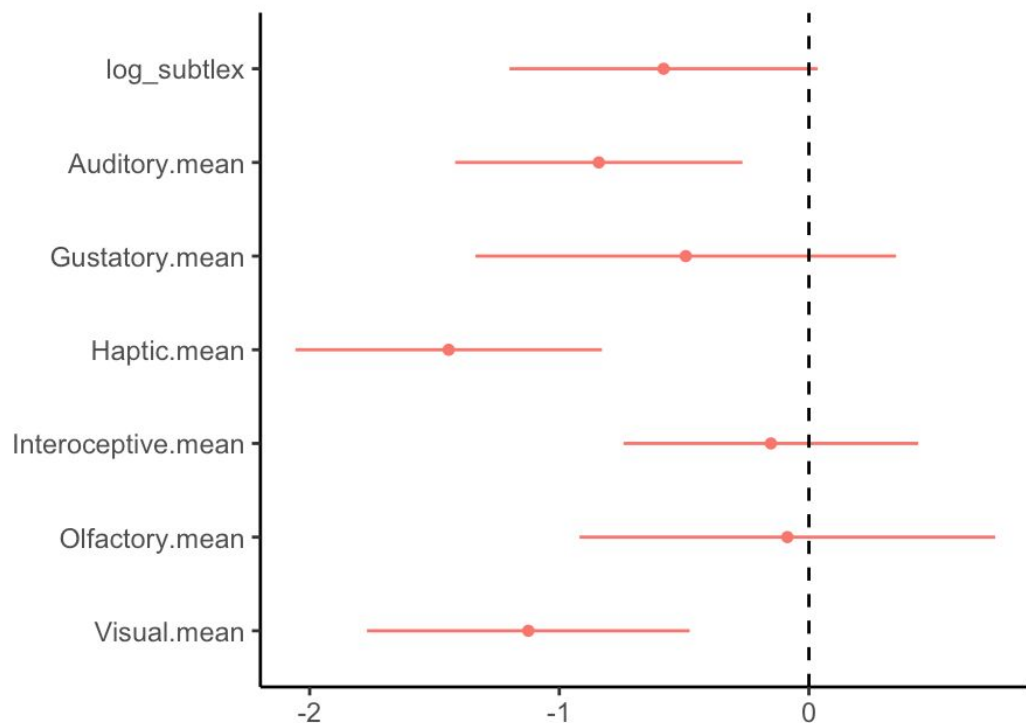
# Perceptual Strength $\geq 4$



# Within category ratings only



# Predicting CDI AoA with sensory norms



Call:

```
lm(formula = cdi_aoa ~ log_subtlex + Auditory.mean + Gustatory.mean +  
    Haptic.mean + Interoceptive.mean + Olfactory.mean + Visual.mean,  
    data = cdi_with_SN)
```

Residuals:

Min	1Q	Median	3Q	Max
-11.0686	-1.6441	0.3929	2.0544	6.4994

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	29.90775	0.98974	30.218	< 2e-16 ***
log_subtlex	-0.26989	0.14578	-1.851	0.064661 .
Auditory.mean	-0.36124	0.12578	-2.872	0.004240 **
Gustatory.mean	-0.18070	0.15718	-1.150	0.250826
Haptic.mean	-0.60509	0.13112	-4.615	4.92e-06 ***
Interoceptive.mean	-0.08105	0.15992	-0.507	0.612512
Olfactory.mean	-0.04156	0.20450	-0.203	0.839019
Visual.mean	-0.59473	0.17411	-3.416	0.000684 ***

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Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

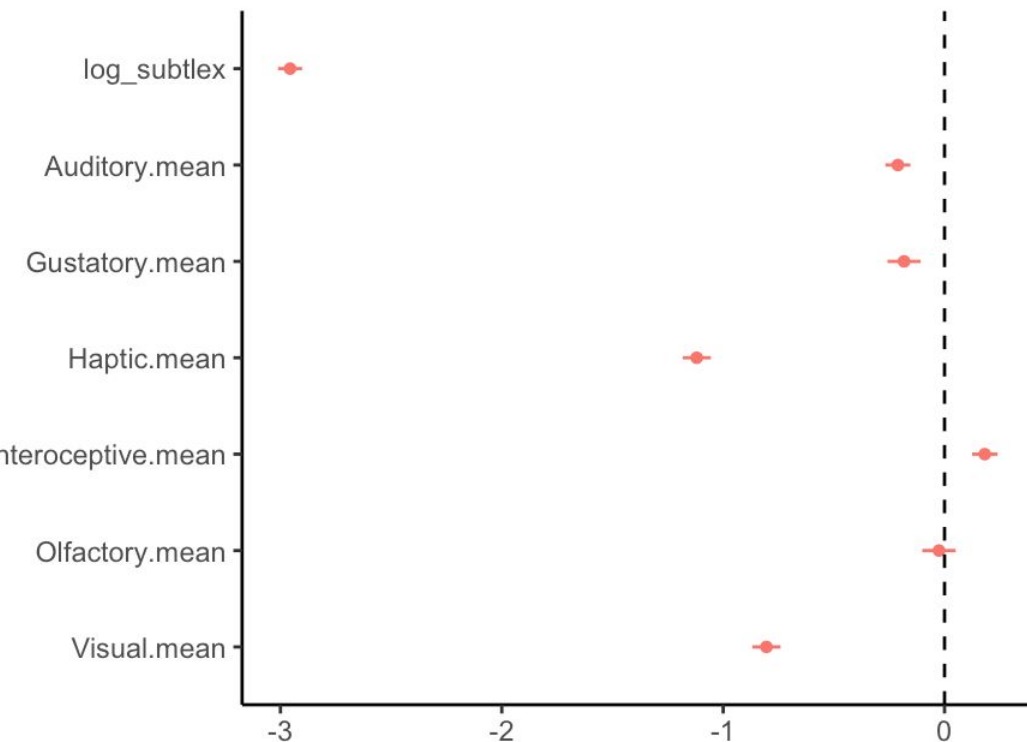
Residual standard error: 3.171 on 539 degrees of freedom

(93 observations deleted due to missingness)

Multiple R-squared: 0.09027, Adjusted R-squared: 0.07846

F-statistic: 7.641 on 7 and 539 DF, p-value: 8.282e-09

# Predicting Kuperman AoA with sensory norms



Call:

```
lm(formula = spoken_aoa ~ log_subtlex + Auditory.mean + Gustatory.mean +  
    Haptic.mean + Interoceptive.mean + Olfactory.mean + Visual.mean,  
    data = norming_data)
```

Residuals:

Min	1Q	Median	3Q	Max
-8.4030	-1.3940	0.0112	1.4104	8.4766

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	14.79447	0.06248	236.806	< 2e-16 ***
log_subtlex	-1.60484	0.01504	-106.694	< 2e-16 ***
Auditory.mean	-0.10424	0.01428	-7.299	2.99e-13 ***
Gustatory.mean	-0.12301	0.02565	-4.796	1.63e-06 ***
Haptic.mean	-0.59200	0.01717	-34.487	< 2e-16 ***
Interoceptive.mean	0.10066	0.01626	6.192	6.05e-10 ***
Olfactory.mean	-0.01896	0.02897	-0.654	0.513
Visual.mean	-0.44749	0.01813	-24.684	< 2e-16 ***

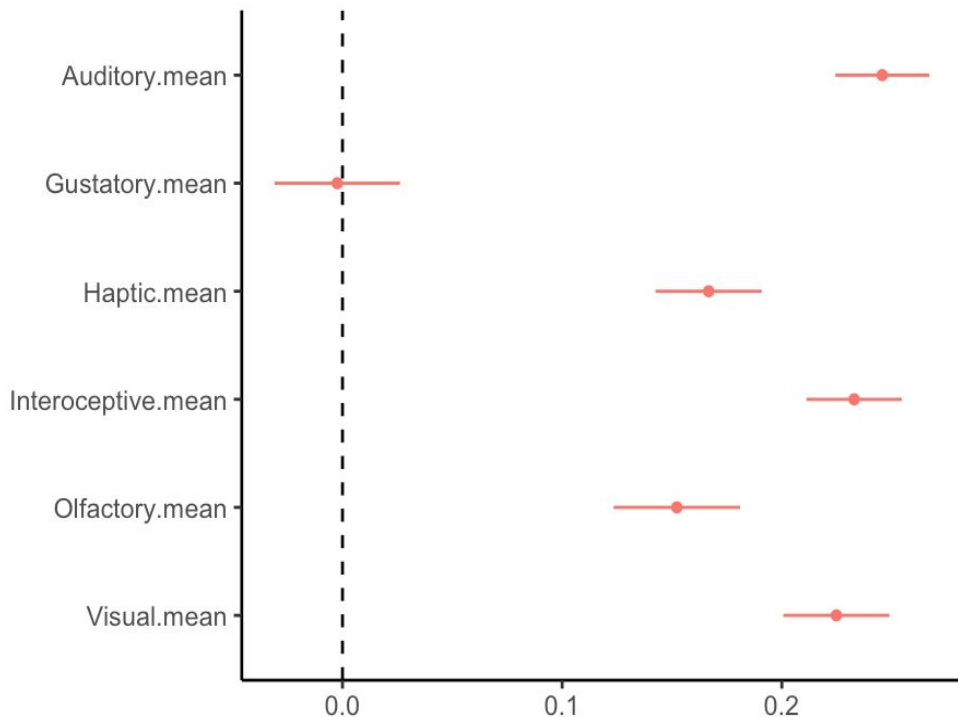
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.072 on 23741 degrees of freedom  
(15958 observations deleted due to missingness)

Multiple R-squared: 0.4308, Adjusted R-squared: 0.4306

F-statistic: 2567 on 7 and 23741 DF, p-value: < 2.2e-16

# Predicting word frequency (subtlex) with sensory norms



Call:

```
lm(formula = log_subtlex ~ Auditory.mean + Gustatory.mean + Haptic.mean +  
  Interoceptive.mean + Olfactory.mean + Visual.mean, data = norming_data)
```

Residuals:

Min	1Q	Median	3Q	Max
-2.5340	-0.9012	-0.0913	0.6745	5.5655

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	0.320291	0.022963	13.948	<2e-16 ***
Auditory.mean	0.123991	0.005506	22.520	<2e-16 ***
Gustatory.mean	-0.001717	0.010470	-0.164	0.87
Haptic.mean	0.089213	0.006598	13.522	<2e-16 ***
Interoceptive.mean	0.132270	0.006302	20.989	<2e-16 ***
Olfactory.mean	0.122974	0.011870	10.360	<2e-16 ***
Visual.mean	0.124553	0.006831	18.234	<2e-16 ***

---  
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

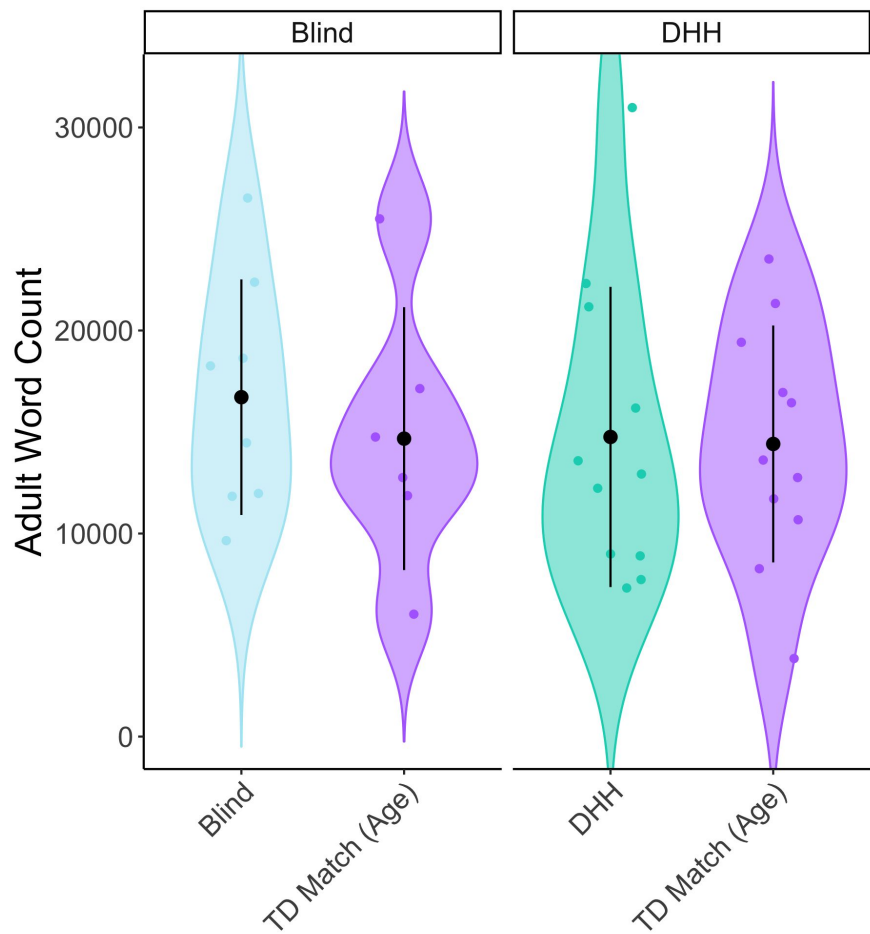
Residual standard error: 1.025 on 39684 degrees of freedom  
(16 observations deleted due to missingness)

Multiple R-squared: 0.04662, Adjusted R-squared: 0.04648

F-statistic: 323.4 on 6 and 39684 DF, p-value: < 2.2e-16

# Do blind and DHH children receive different amounts of language input?

No. Adult word count looks the same across groups.



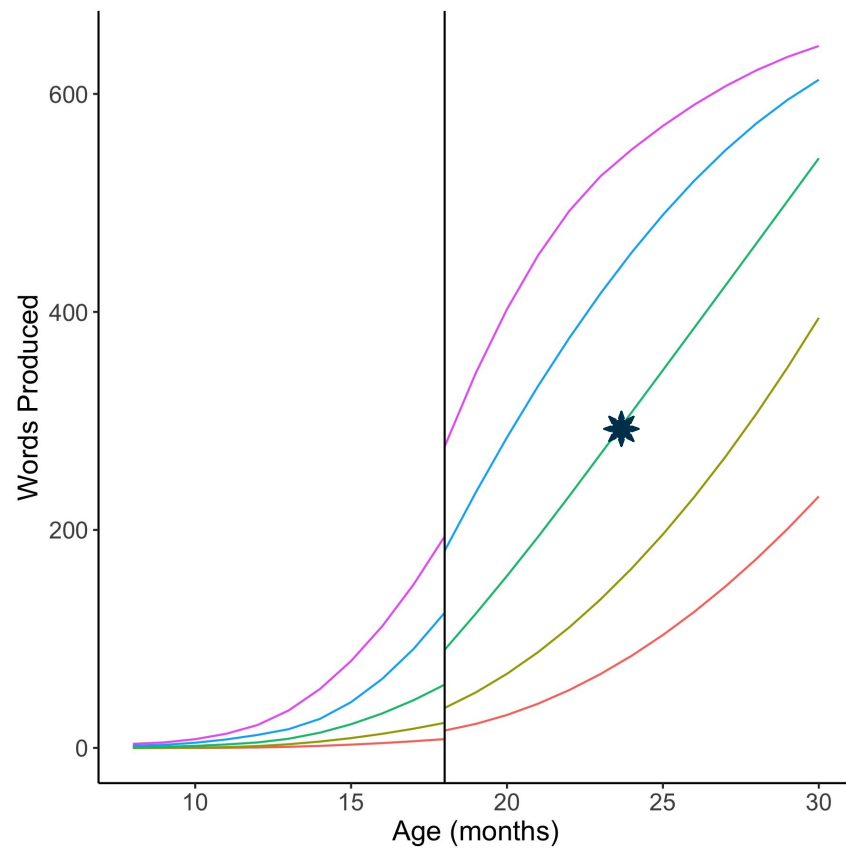
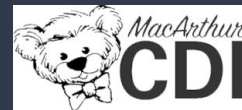


# Why sensory norms?

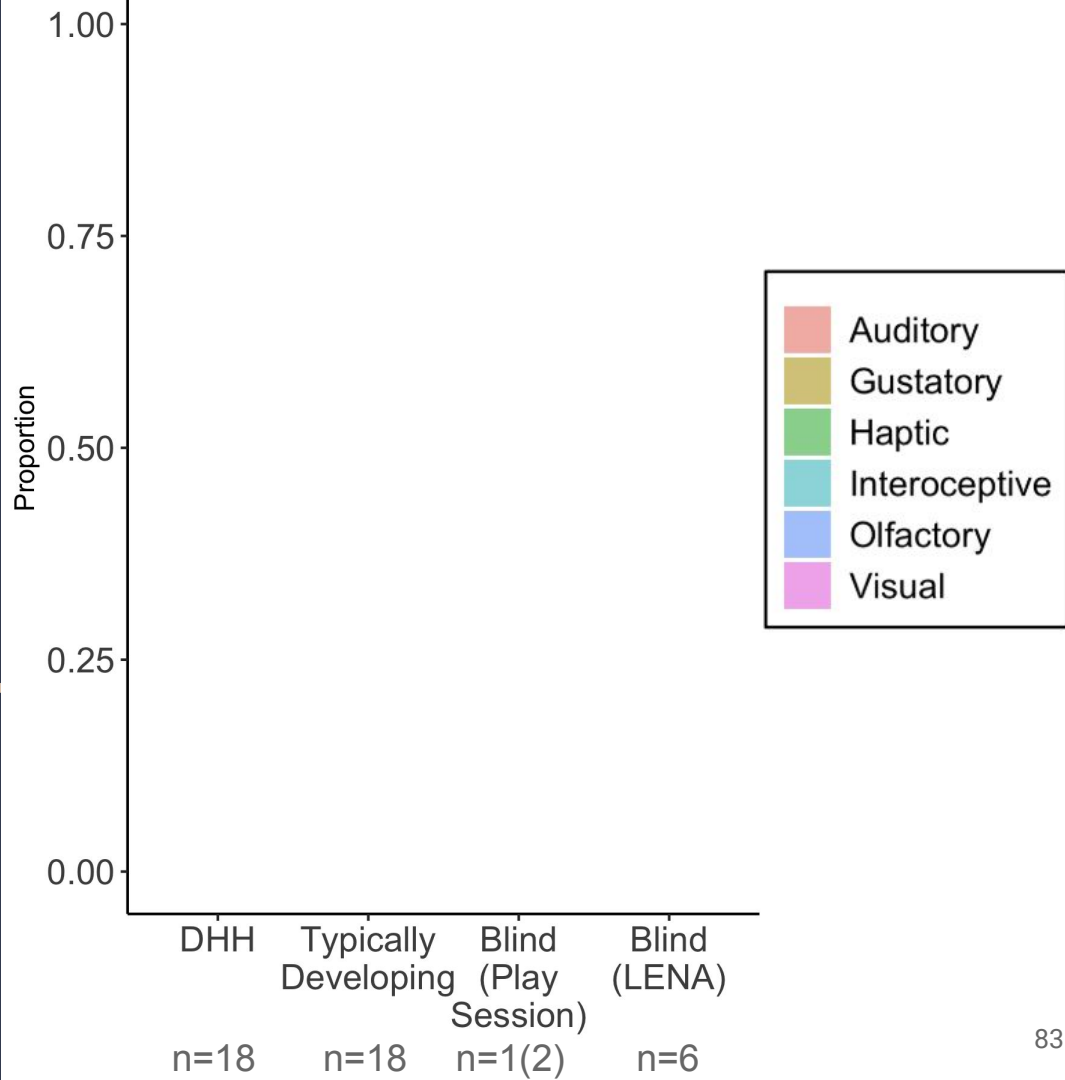
- Direct perceptual access not available → want to quantify perceptual info in language input
- Predict lexical decision and word naming performance over and above concreteness or imageability (Connell & Lycott, 2012)
- Word recognition faster when presented in the sensory domain of the referent (Connell & Lycott, 2014)
- Perceptual modality predicted by word co-occurrence (Louwerse & Connell 2011)
- For typically-developing children, perceptual features seem to play a role in early vocab development
  - Sensory association norms predict words' age of acquisition
- Ability to link concept to referent facilitates word learning
  - Visual referents not accessible for blind children; auditory referents less accessible for DHH children
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## How do we quantify sensory content?

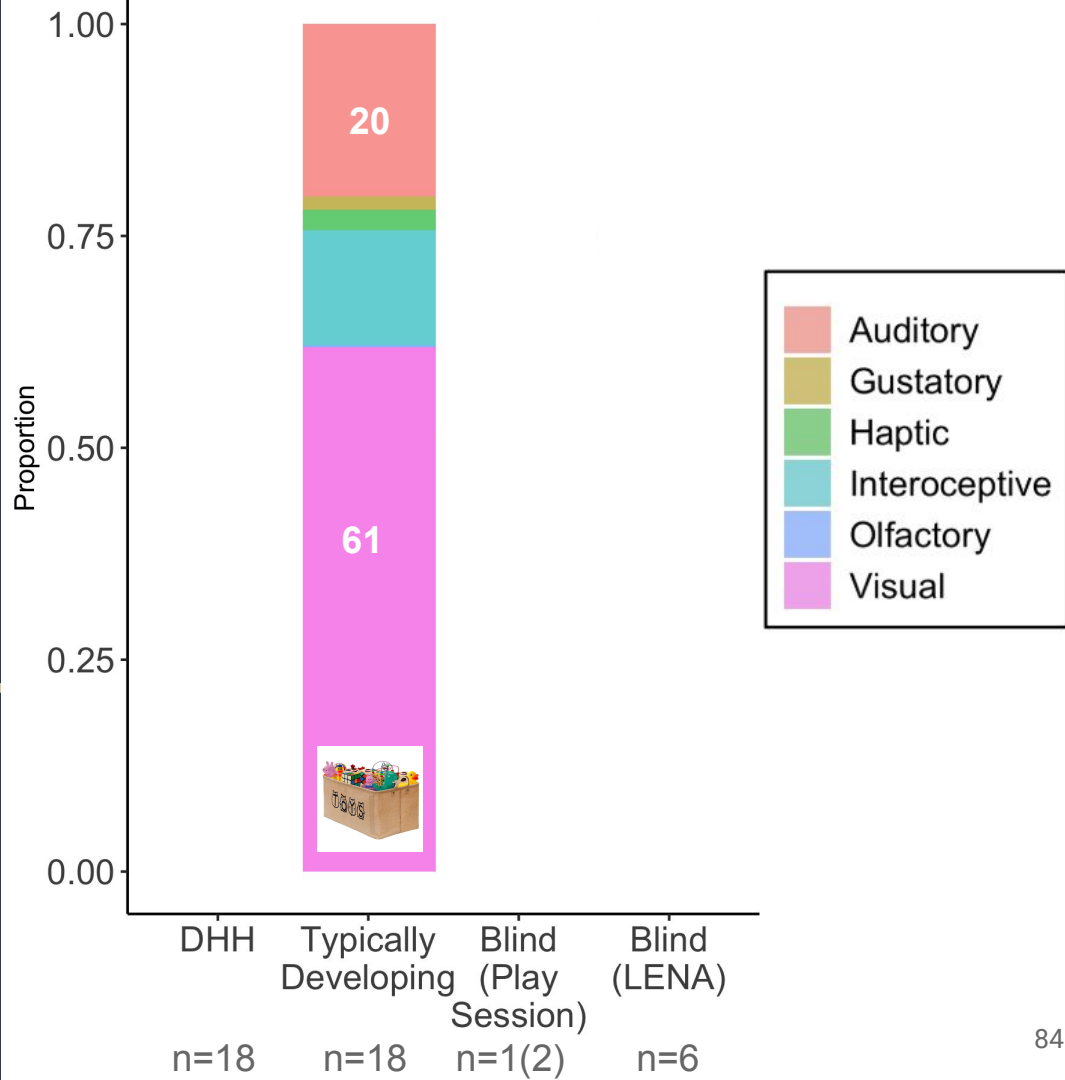
# Vocabulary



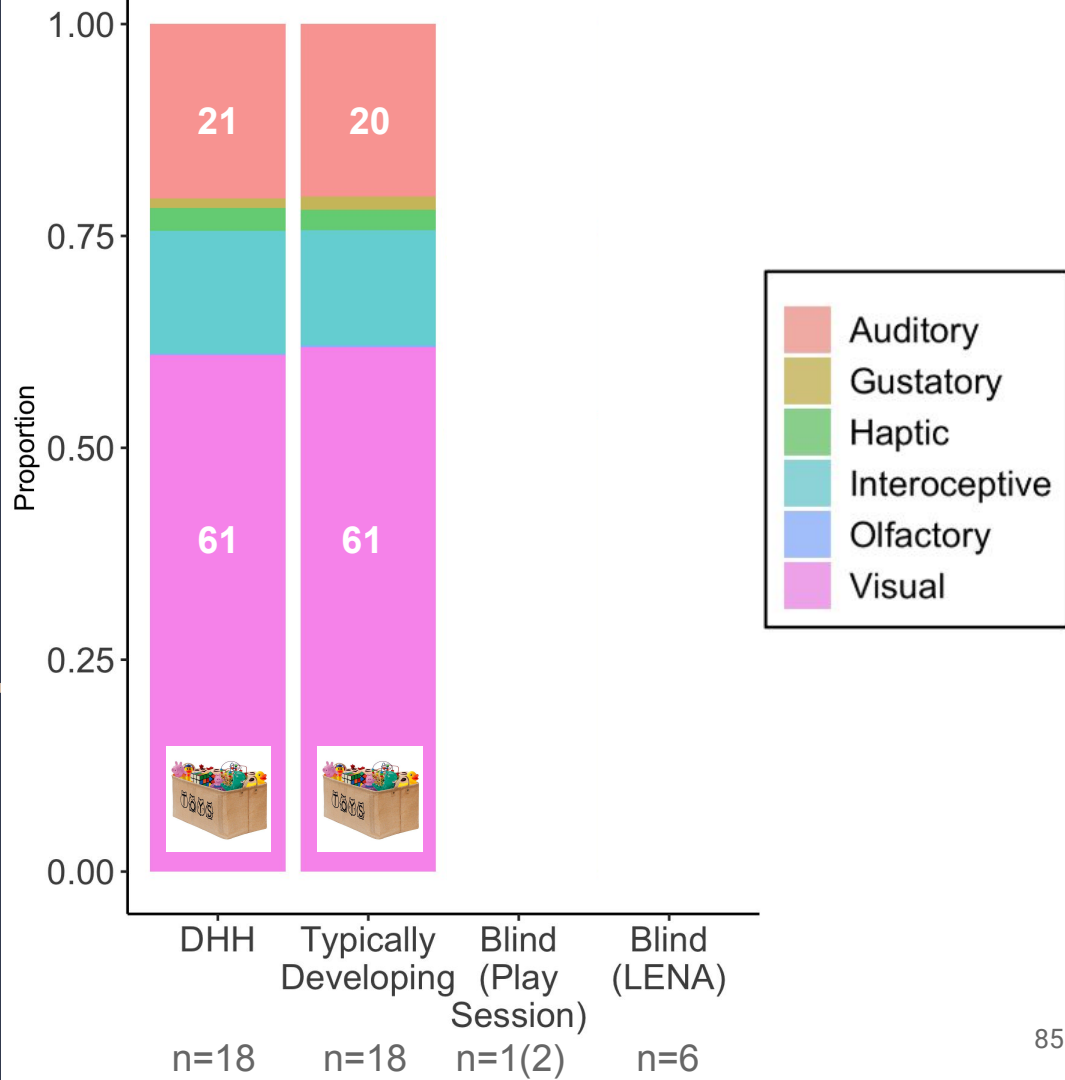
Do the proportions of sensory domains in language input vary by group?



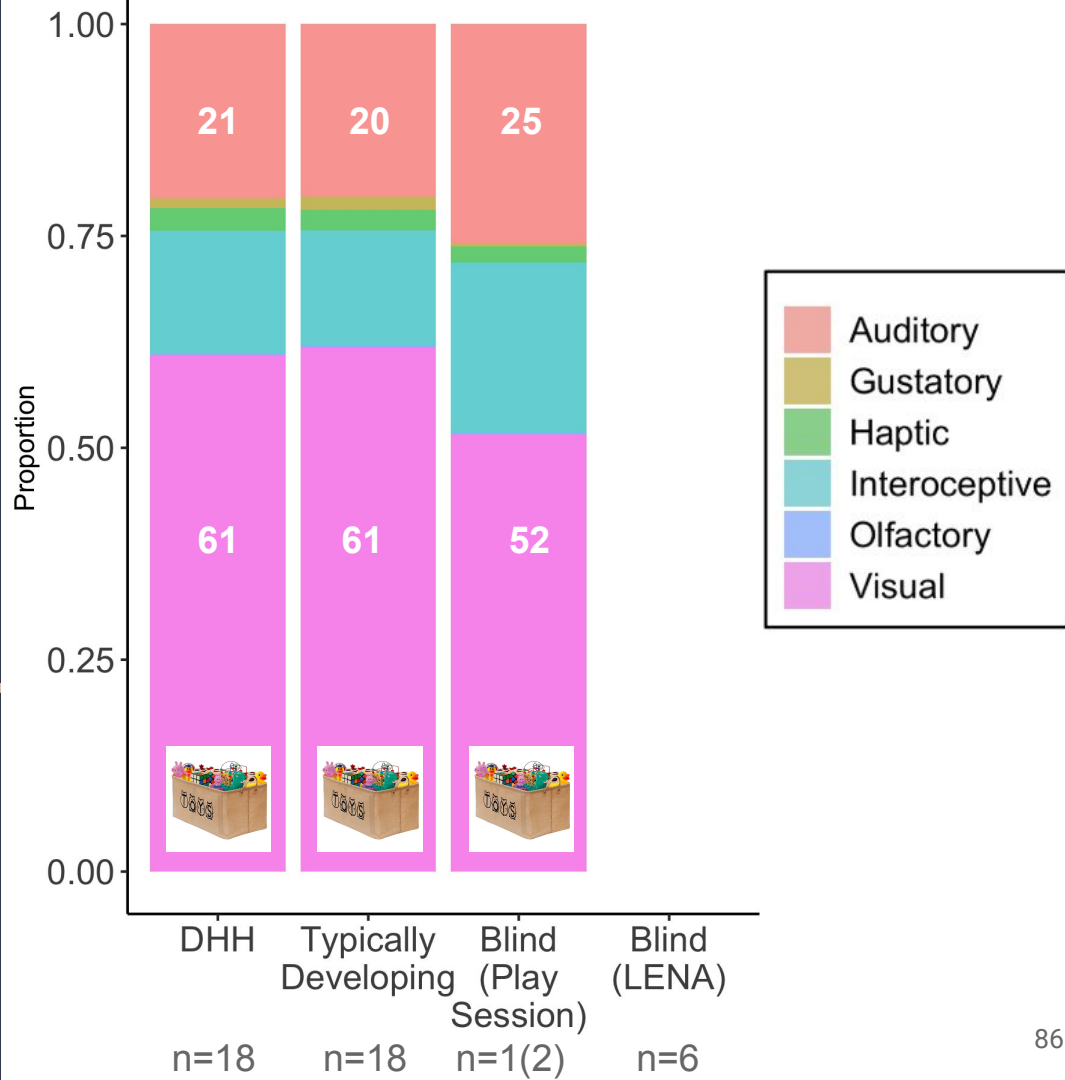
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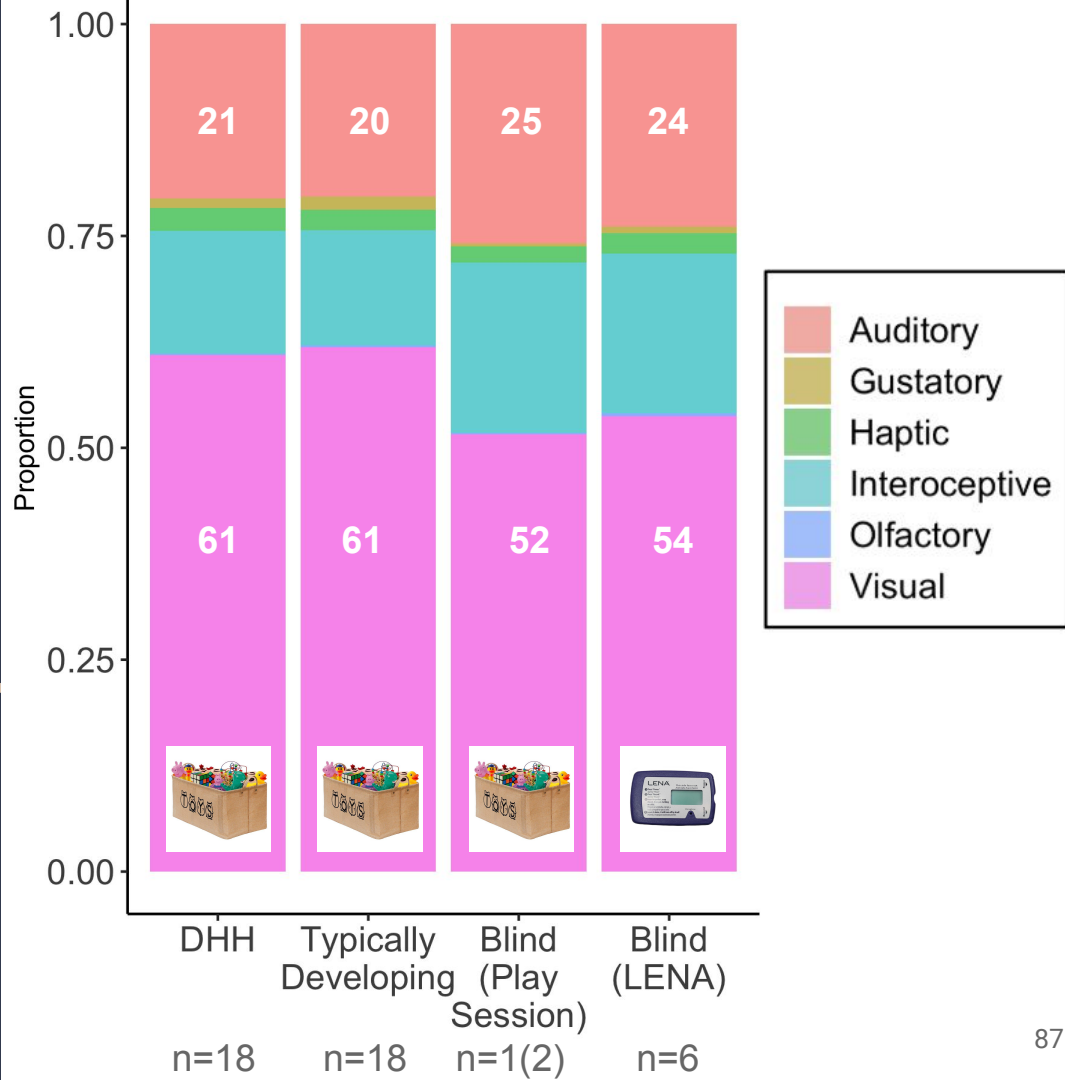
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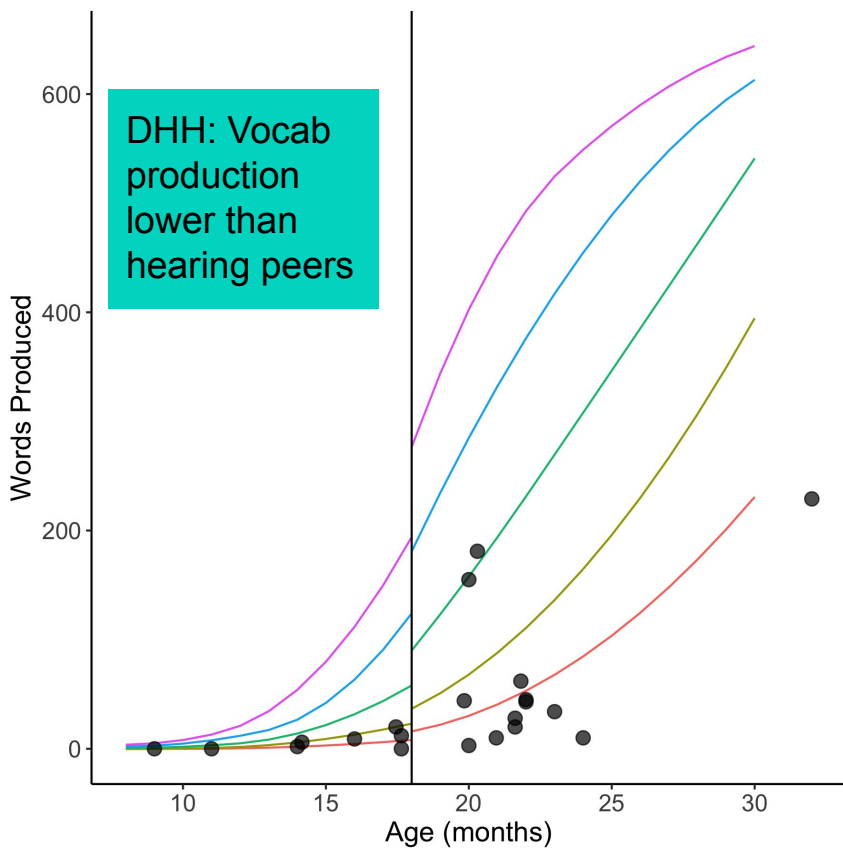
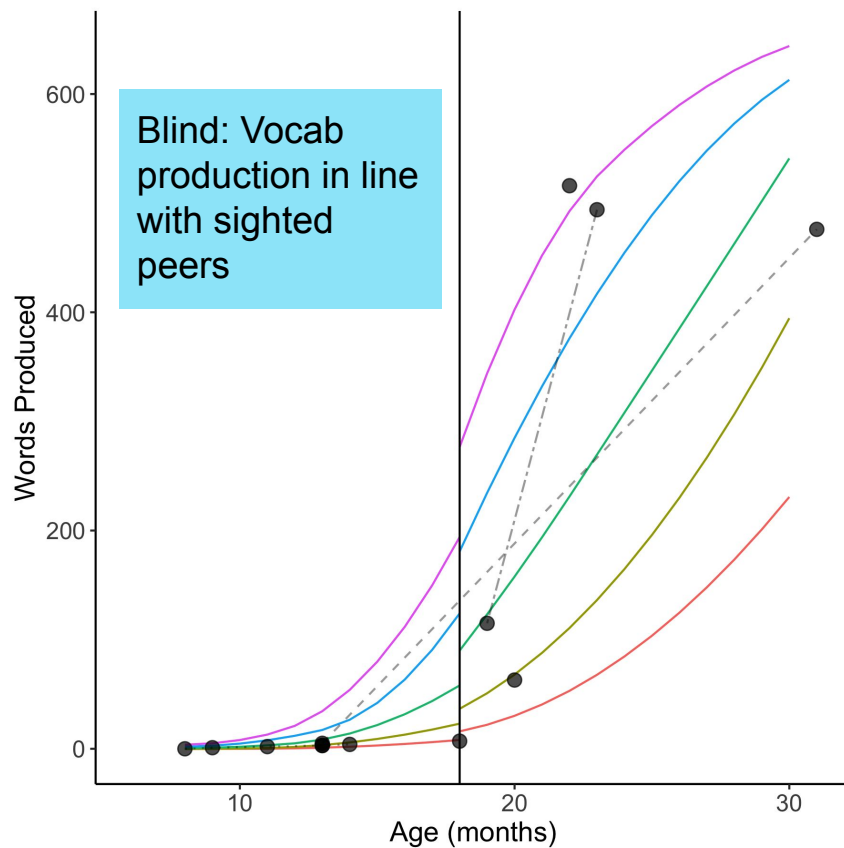
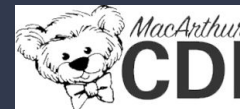
# Do the proportions of sensory domains in language input vary by group?

Distributions of sensory domains look largely the same.

For blind group:  
vision dominates  
input less



# Vocabulary (Words Produced)

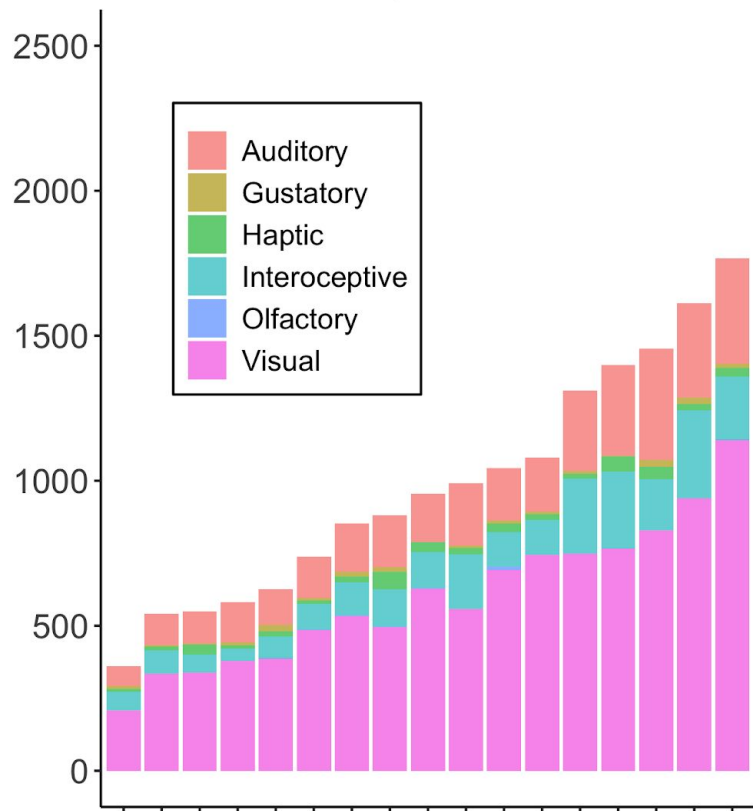




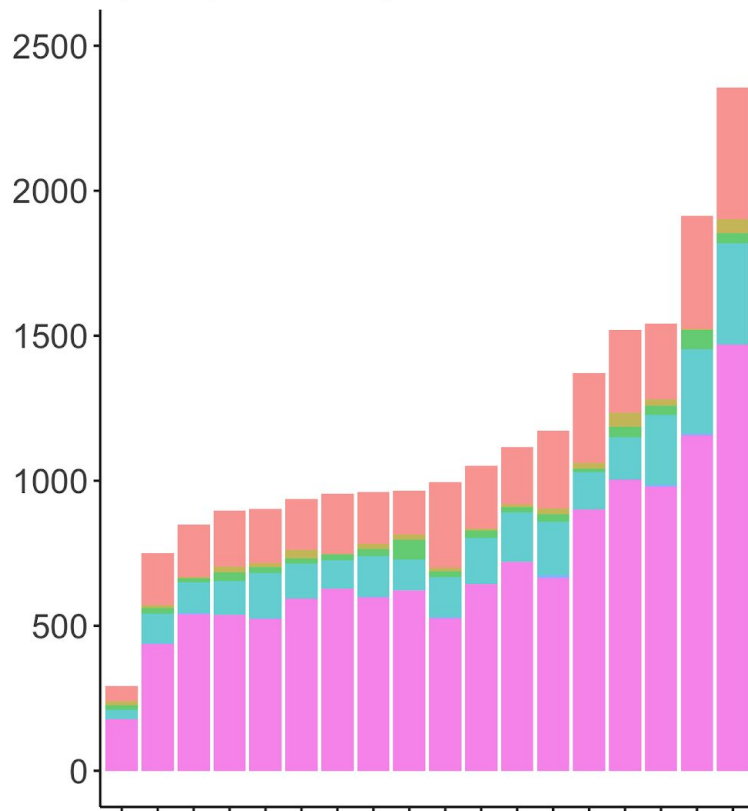
# Does the sensory content of language input vary by group?



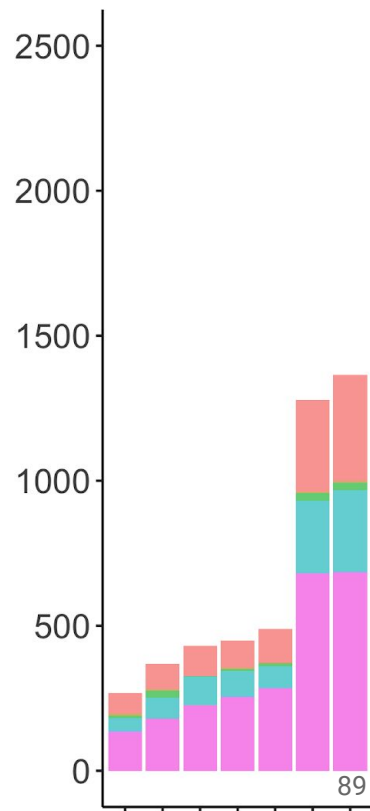
Deaf/Hard-of-Hearing



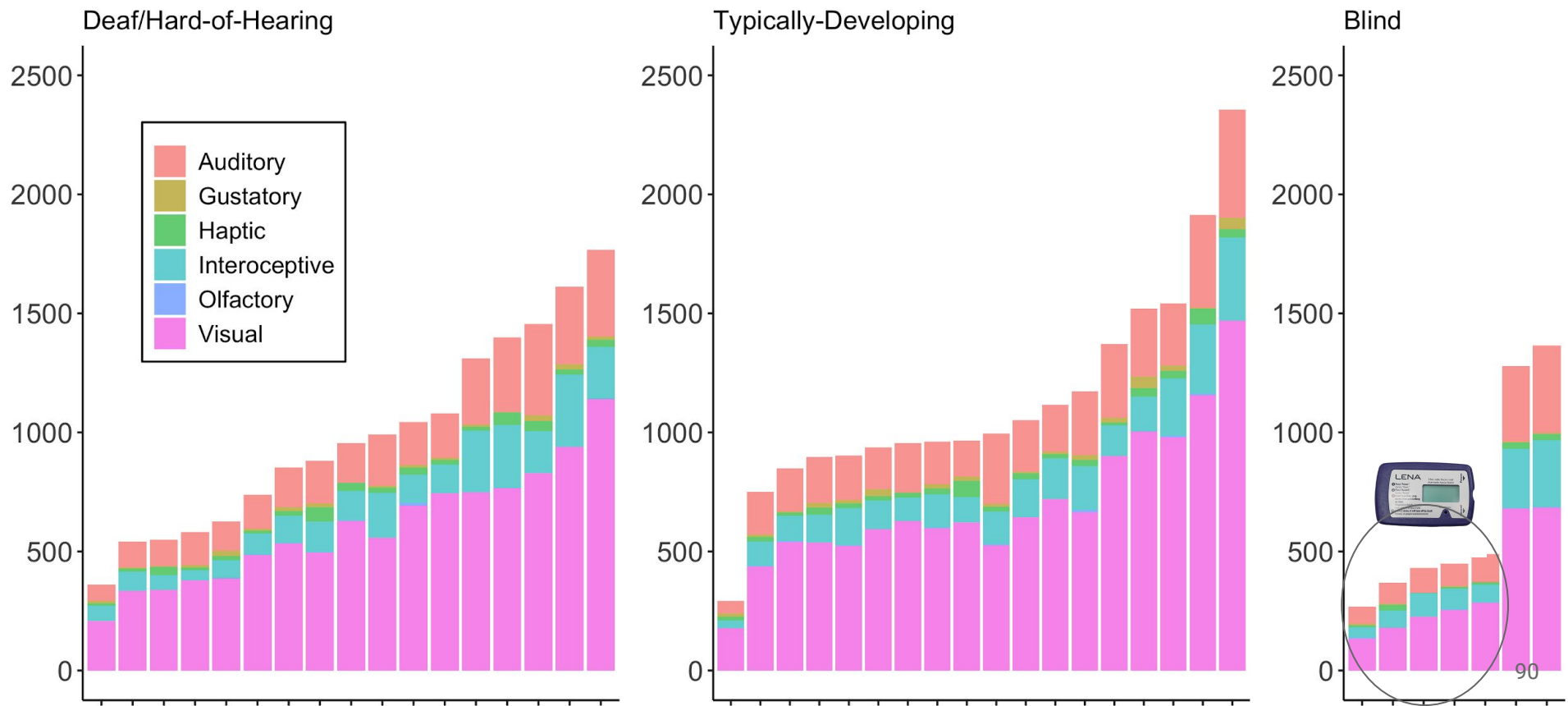
Typically-Developing



Blind



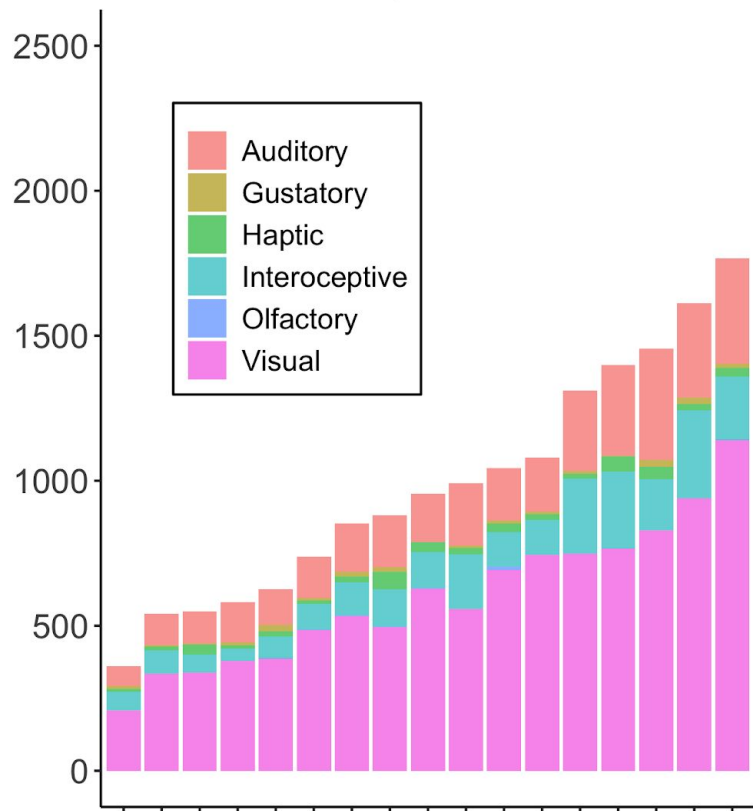
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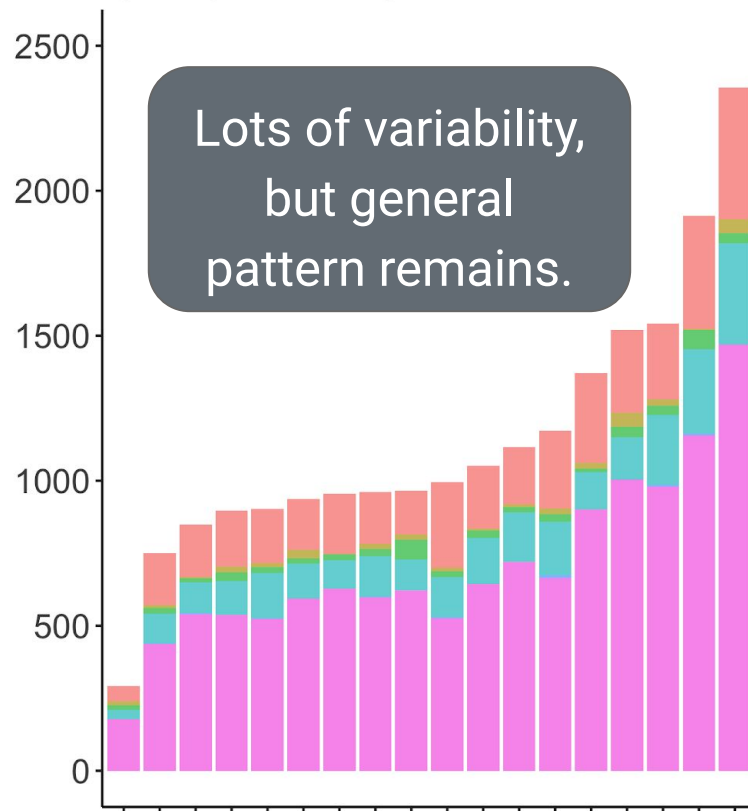
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Deaf/Hard-of-Hearing

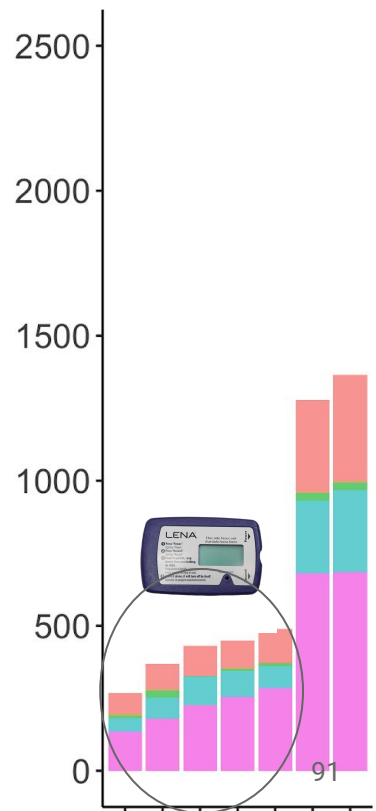


Typically-Developing

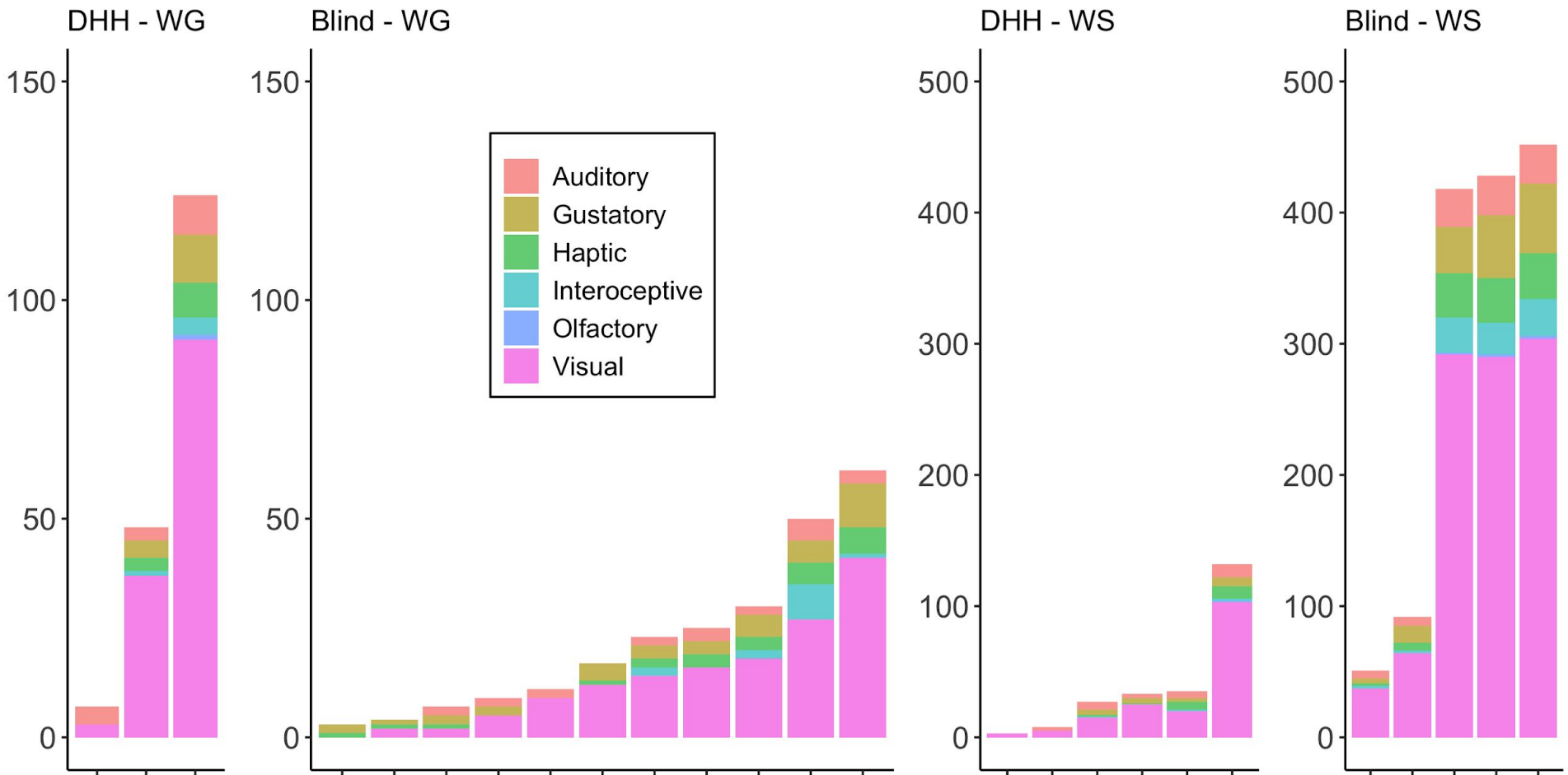


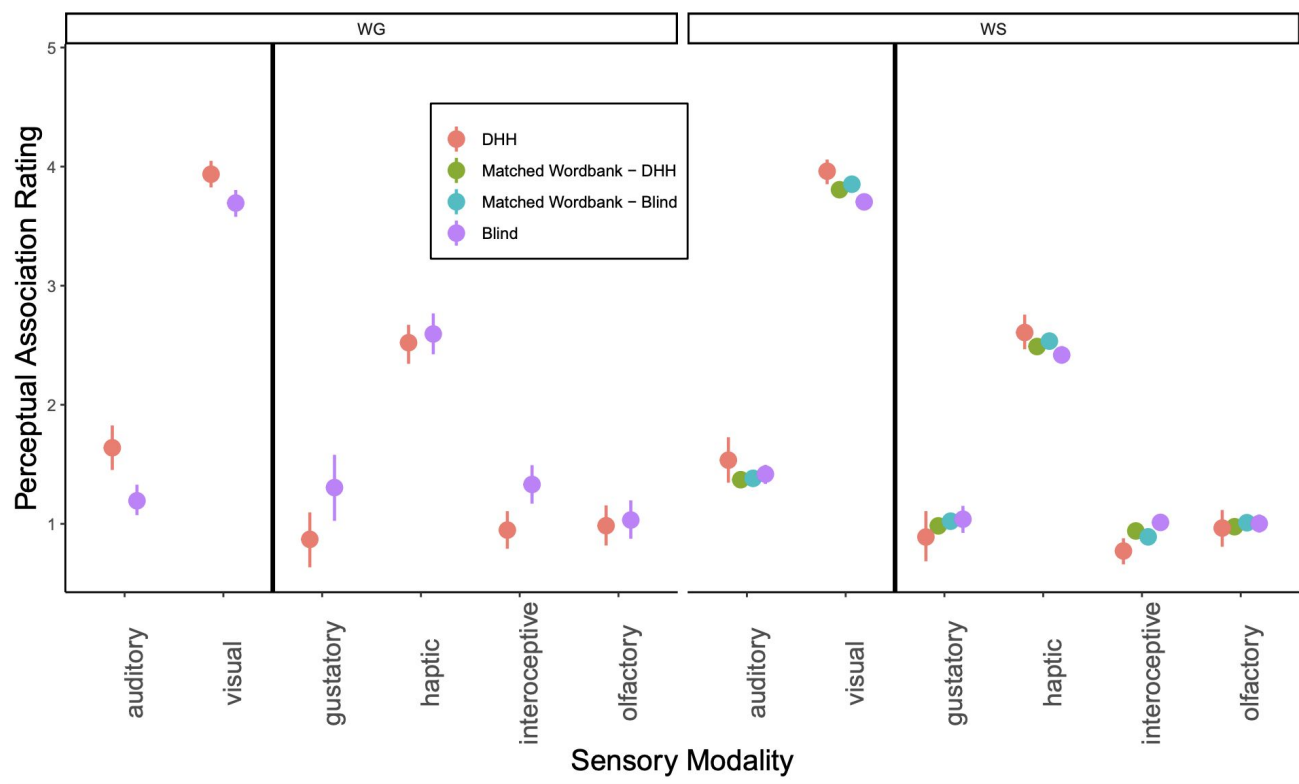
Lots of variability,  
but general  
pattern remains.

Blind



# Is the sensory content of early vocabulary similar across groups?





# LENA Recordings

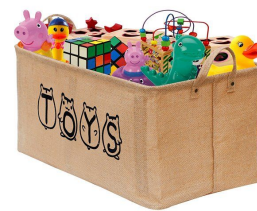


- Daylong audio recording in the home (~25,000 total minutes)

	Blind	Blind Matches	DHH	DHH Matches
n	8	7	11	22
Age Range (mean)	6.7 - 23.2 (14.7)	?	14.1 - 31.5 (20.5)	14 - 31.5 (20.5) 6 - 8.8 (8.9)

- Extracted Adult Word Count and Child Vocalization Count (LENA algorithm) for each recording

# Play Session



- 30-minute video recordings in the lab

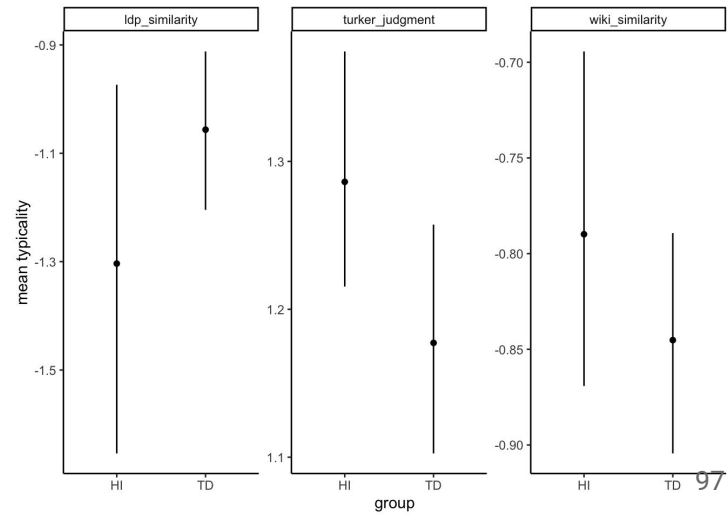
	Blind	DHH	Matches
<b>n</b>	1 (2 recordings)	18	18
<b>Age Range (mean)</b>	10 & 14.4 (12.2)	12.9 - 14.8 (13.7)	13.2 - 13.8 (13.5)

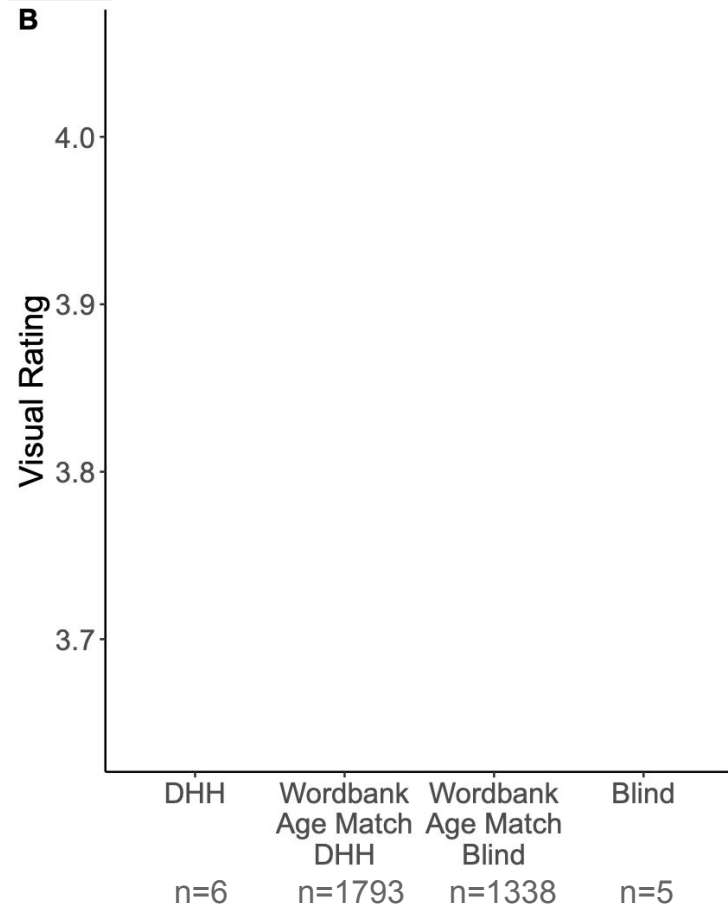
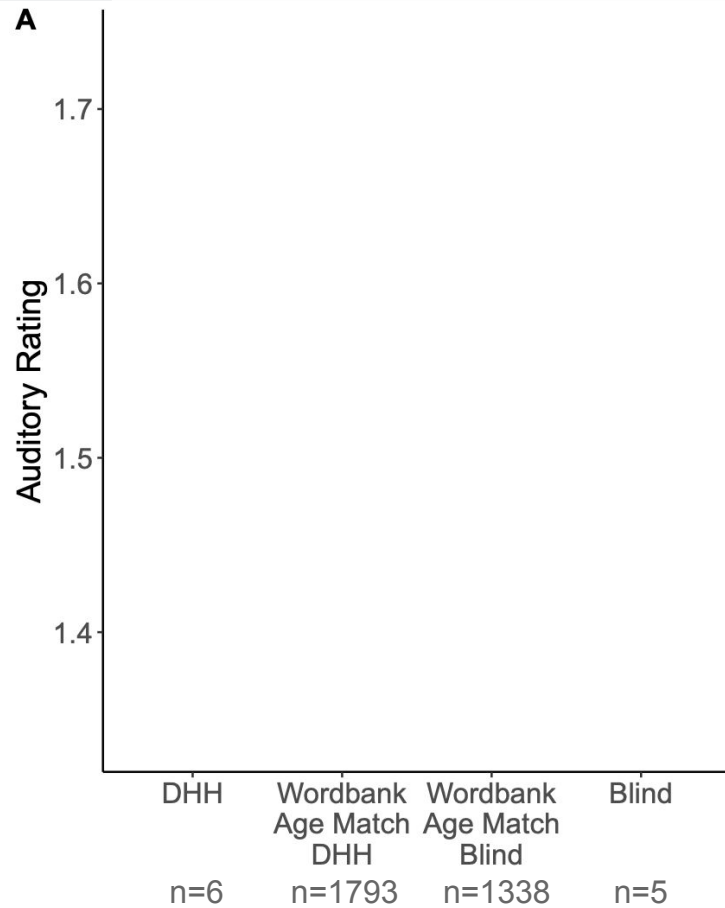
# Communicative Development Inventory (CDI)

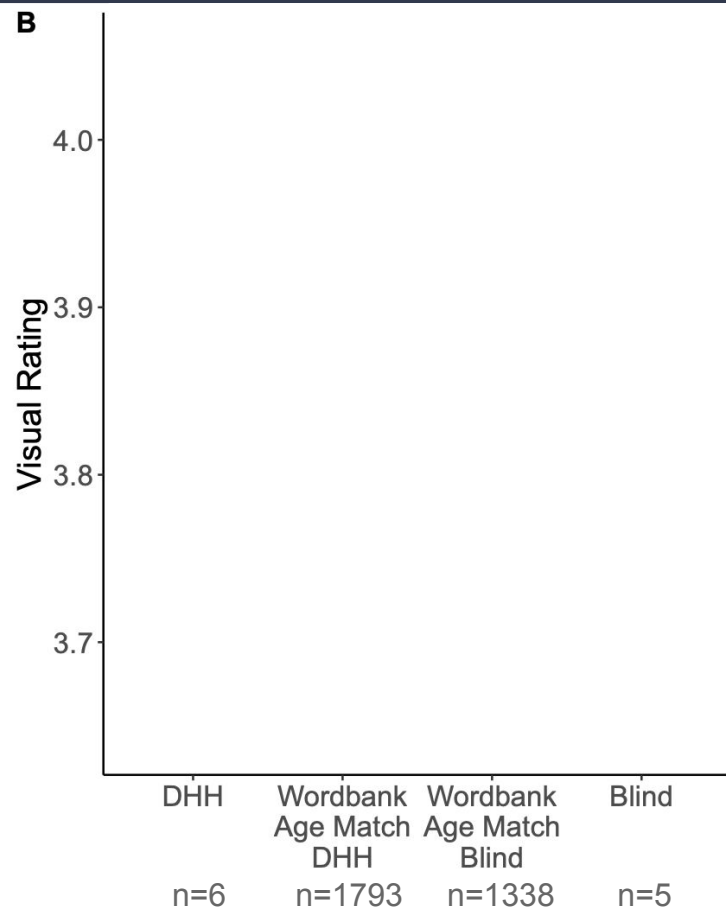
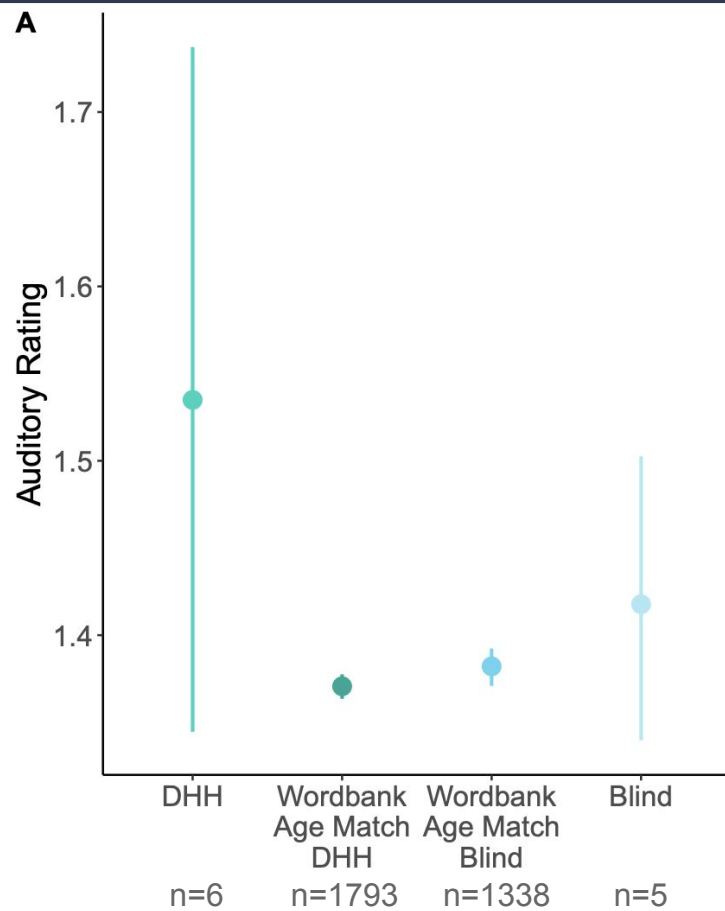
- Parent-report vocabulary checklist

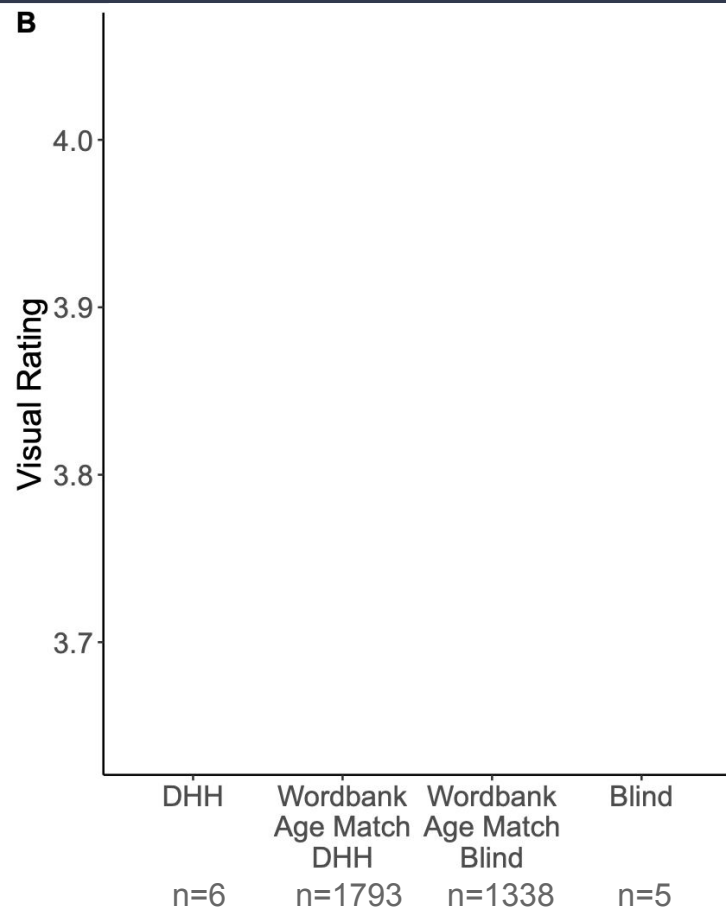
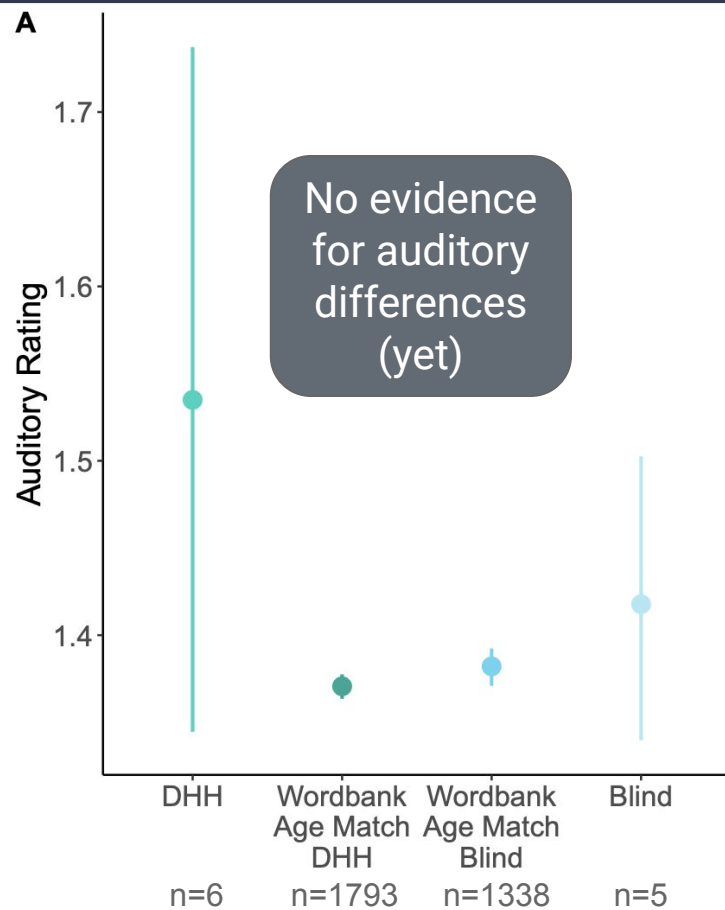
	Blind	DHH	Matches
n	17 (12 unique)	10 (9 unique)	?
Age Range (mean)	6 - 31 (15.6)	9 - 24 (18.1)	?

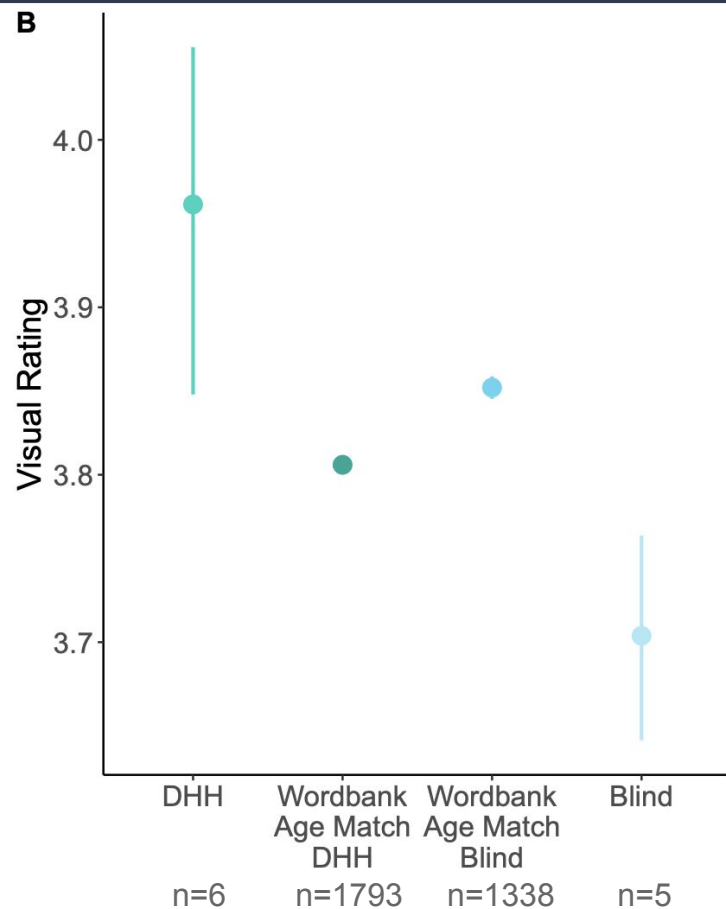
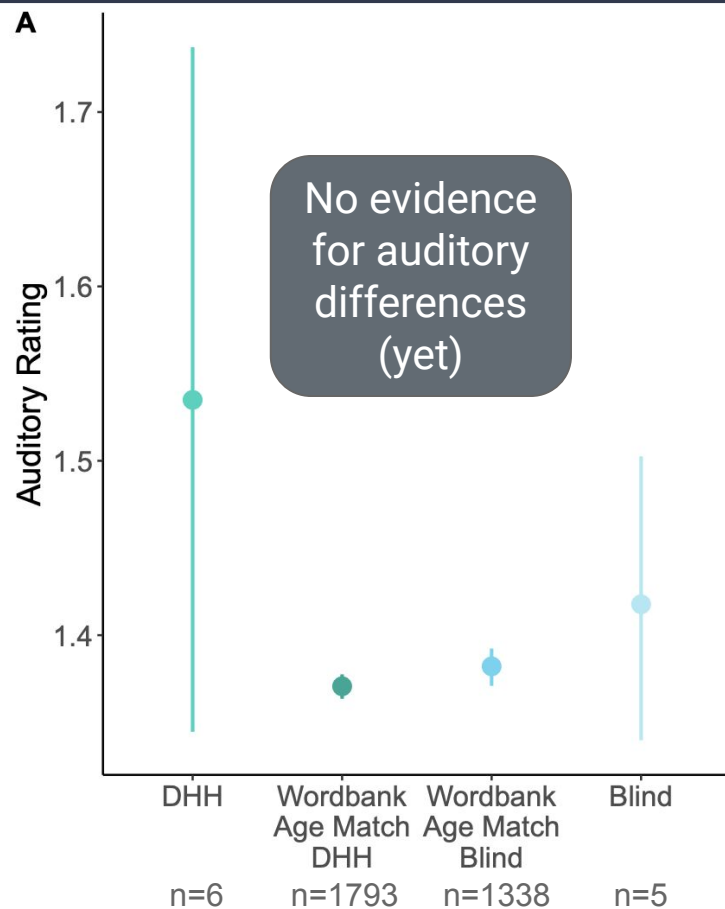


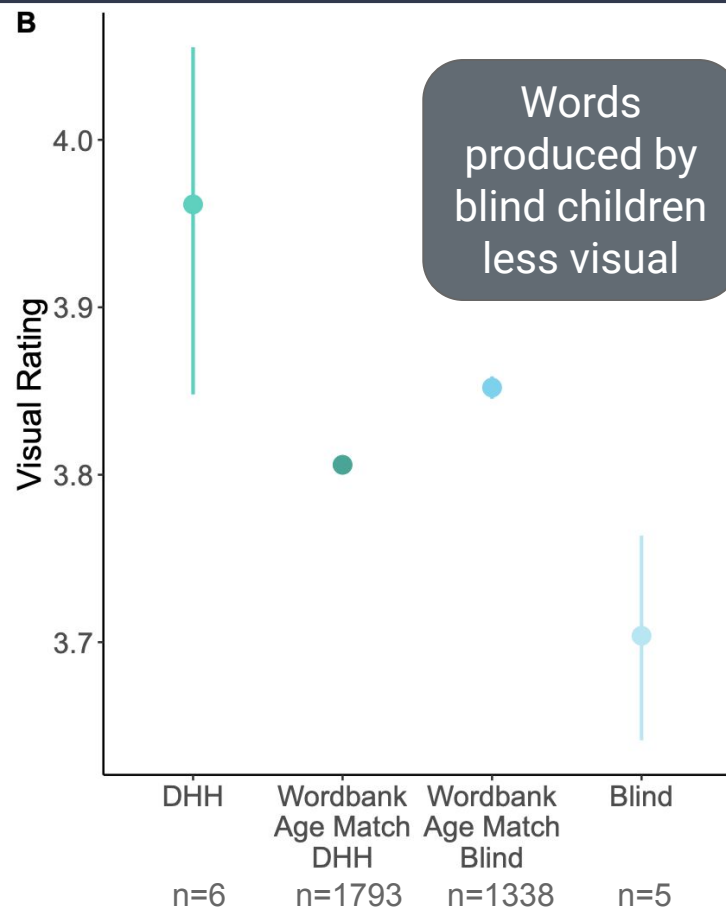
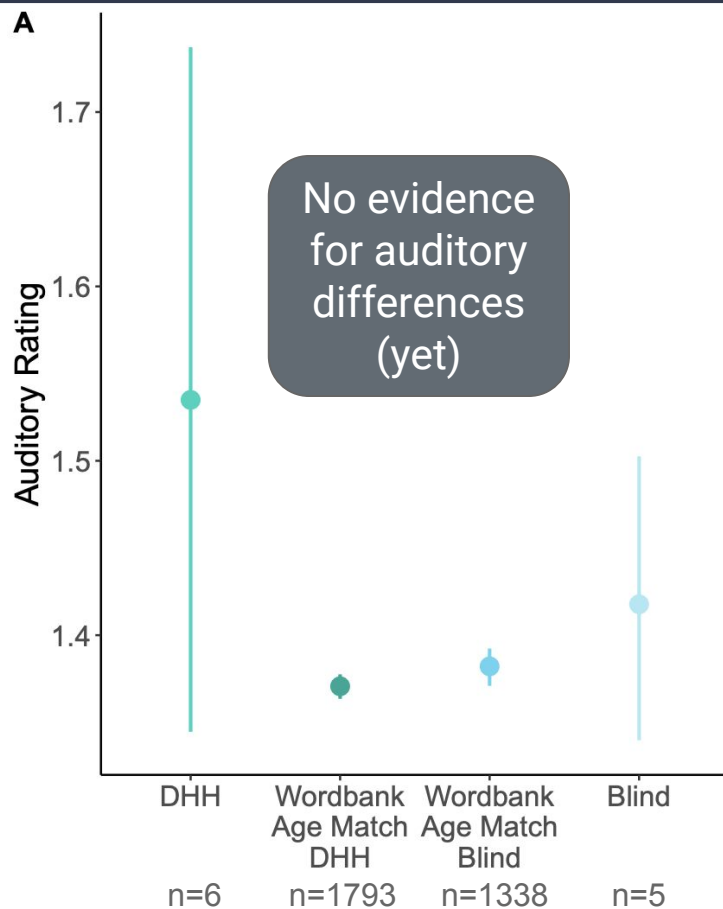






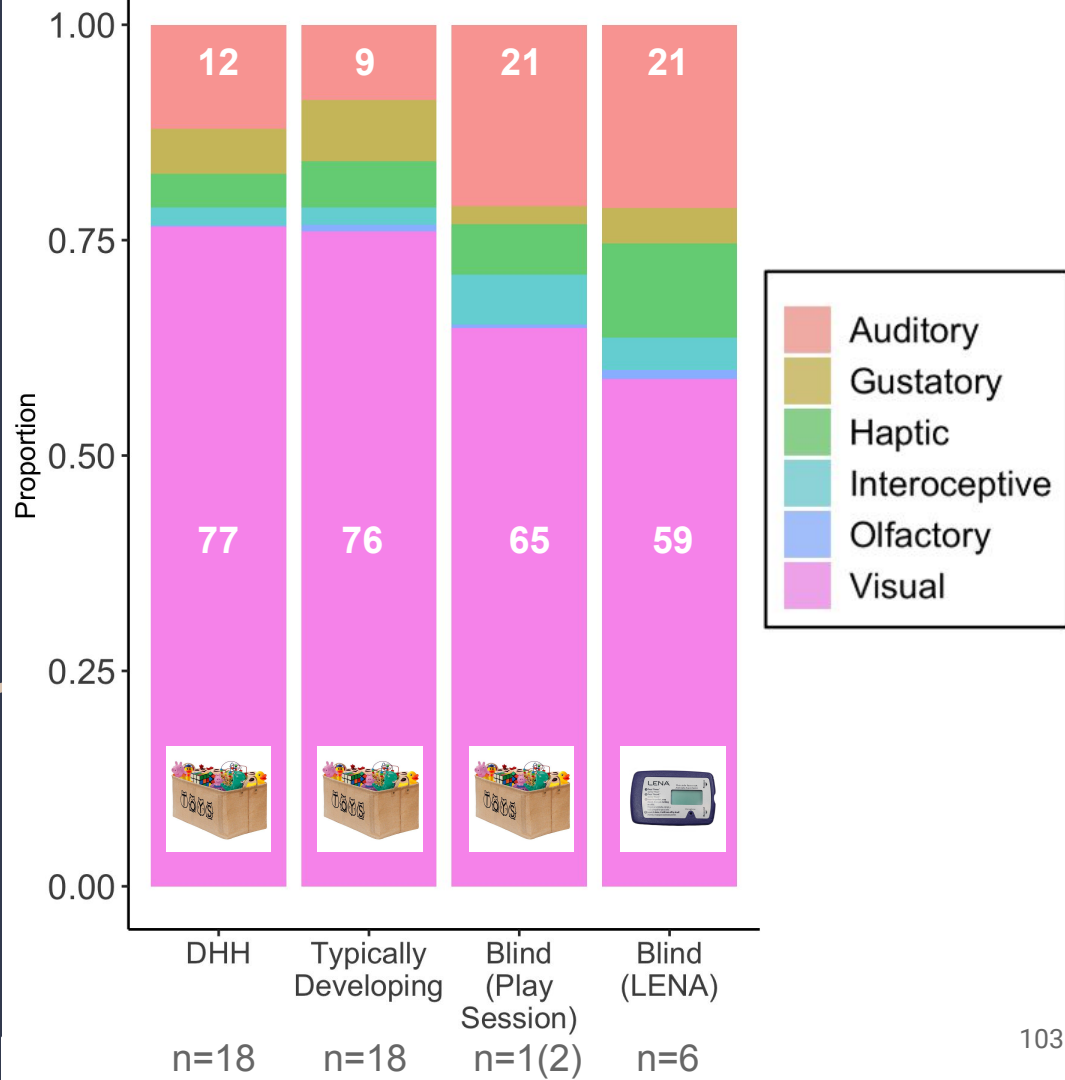


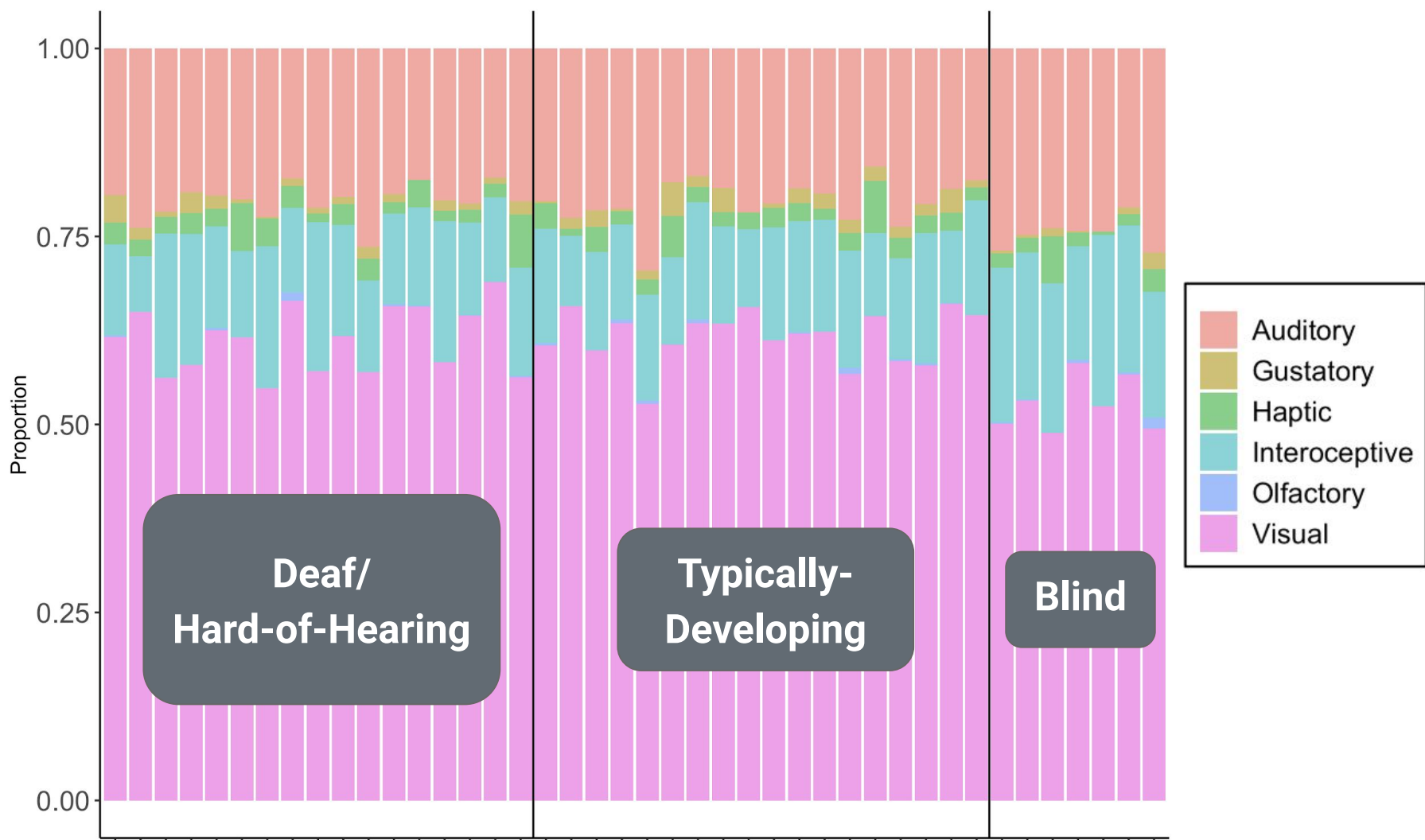




Perceptual Strength  $\geq 4$

Distributions look largely the same.







Is the early input and production of **DHH** and **Blind** children different from typically-developing peers?

**A little!** Many similarities, but some interesting differences....