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Audiovisual Speech Enhancement: Effects of Development and Hearing Loss

Kaylah Lalonde, Ph.D.

Kaylah Lalonde, PhD

Kaylah Lalonde, Ph.D., is a research scientist and Director of the Audiovisual Speech Processing Lab in the Center for Hearing Research and the Center for Perception and Communication in Children at Boys Town National Research Hospital. She completed a Ph.D. in Speech and Hearing Sciences from Indiana University in 2014. Her research, funded by the National Institutes of Health, focuses on the ability to use visual cues on a talker's face to help perceive speech in noisy environments, the development of this ability from infancy to adulthood, and the effects of pediatric hearing loss on said development.

Disclosures

- **Presenter Disclosure:** Financial: Dr. Lalonde is employed by Boys Town National Research Hospital. Dr. Lalonde's research has been funded by the National Institutes of Health. She received an honorarium for this course. Non-financial: Dr. Lalonde has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
- **Sponsor Disclosure:** This course is presented by the American Auditory Society in partnership with AudiologyOnline.

Learning Outcomes

After this course, participants will be able to:

- list and describe four ways that visual speech cues aid in perception of degraded acoustic speech.
- describe how audiovisual speech enhancement changes with age and differs between children with typical hearing and children who have mild to severe sensorineural hearing loss.
- explain how configuration of hearing loss may impact the degree to which children who are hard of hearing benefit from visual speech cues.

Acknowledgements

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  - R21 DC020544, P20 GM109023
- The content is solely the responsibility of the presenter and does not necessarily represent the official views of the National Institutes of Health.

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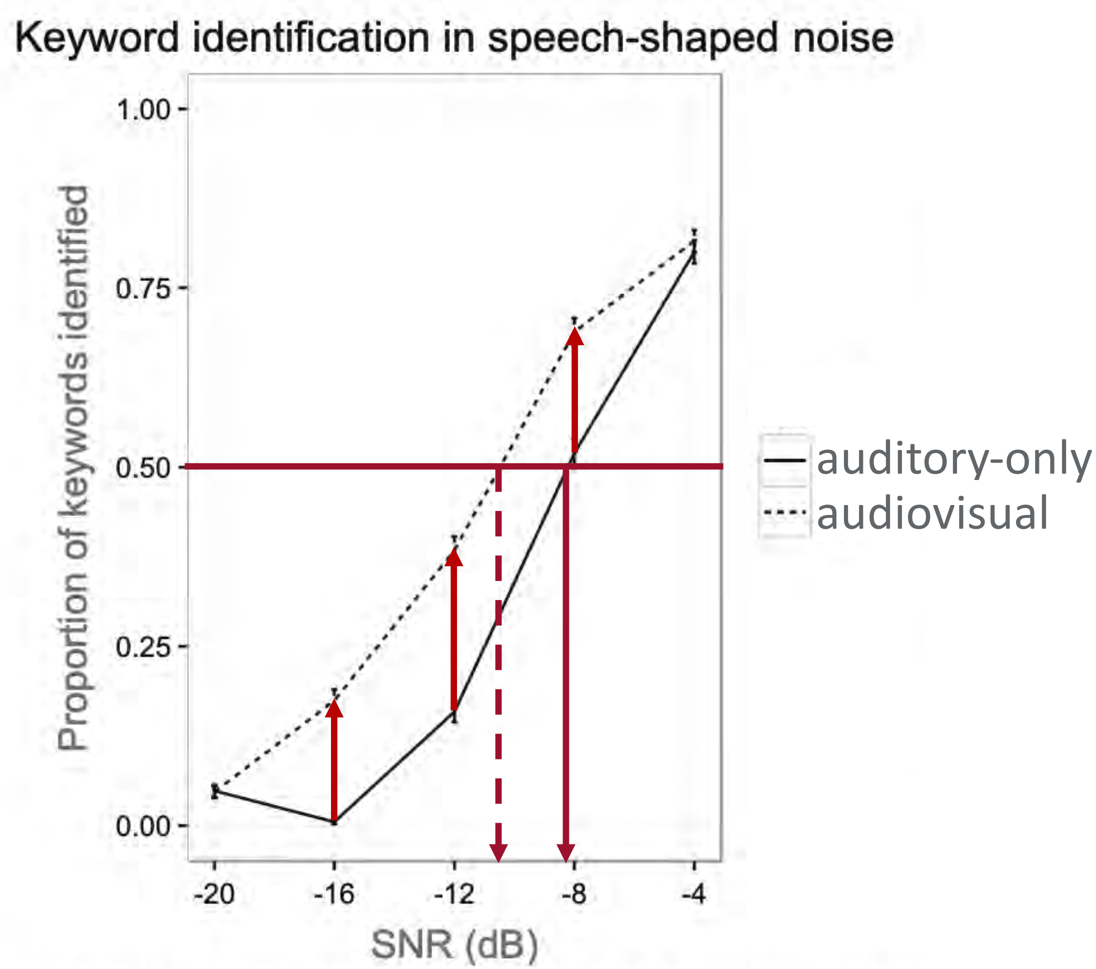
- Participant and Technology Core Members
  - Sarah Al-Salim, Seth Bashford, Kayla Skaggs, Barbara Peterson, Meredith Spratford

Audiovisual Speech Enhancement

- In quiet, too.

  Davis & Kim 2004

  Reisberg et al.1987



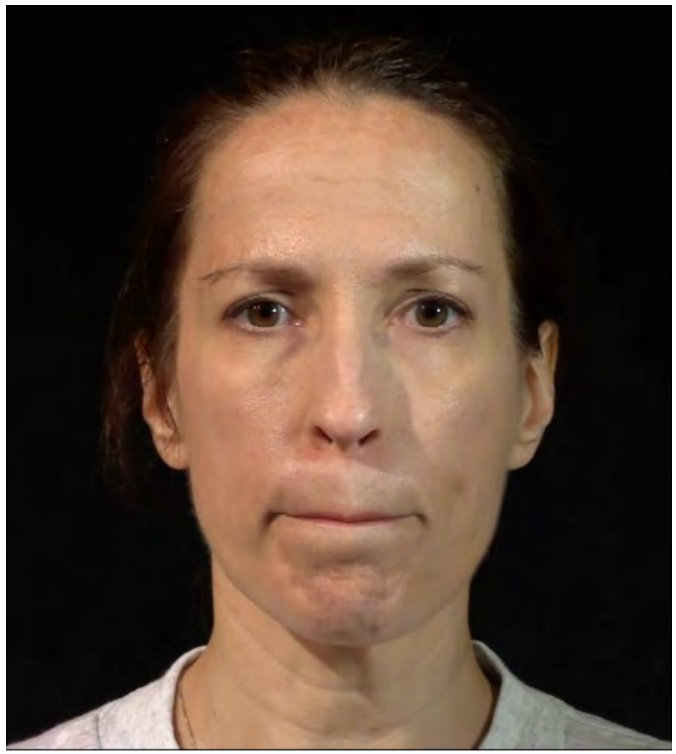
Van Engen, Xie, & Chandrasekaran (2017), *Atten. Percept. Psychophys., 79,* 396-403.

Multiple mechanisms underlie audiovisual speech enhancement

Visual speech:

1. tells you when to listen.
2. provides cues to the auditory amplitude envelope of speech.
3. helps you to access audiovisual speech representations
4. helps you to segregate & attend to a talker.

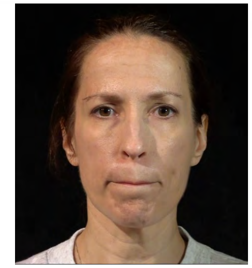
Visual speech tells you when to listen



Bernstein, 2004; Tye-Murray et al., 2011

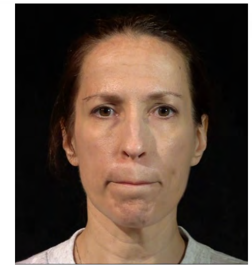
Q1

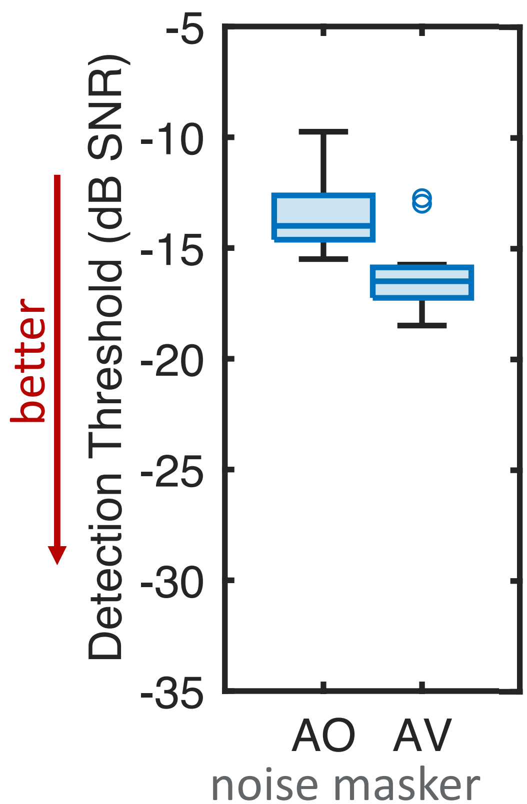
Visual speech tells you when to listen



Lalonde & McCreery (2020). *Ear Hear. 41,* 705-719
see also: Bernstein, 2004; Tye-Murray et al., 2011

Visual speech tells you when to listen

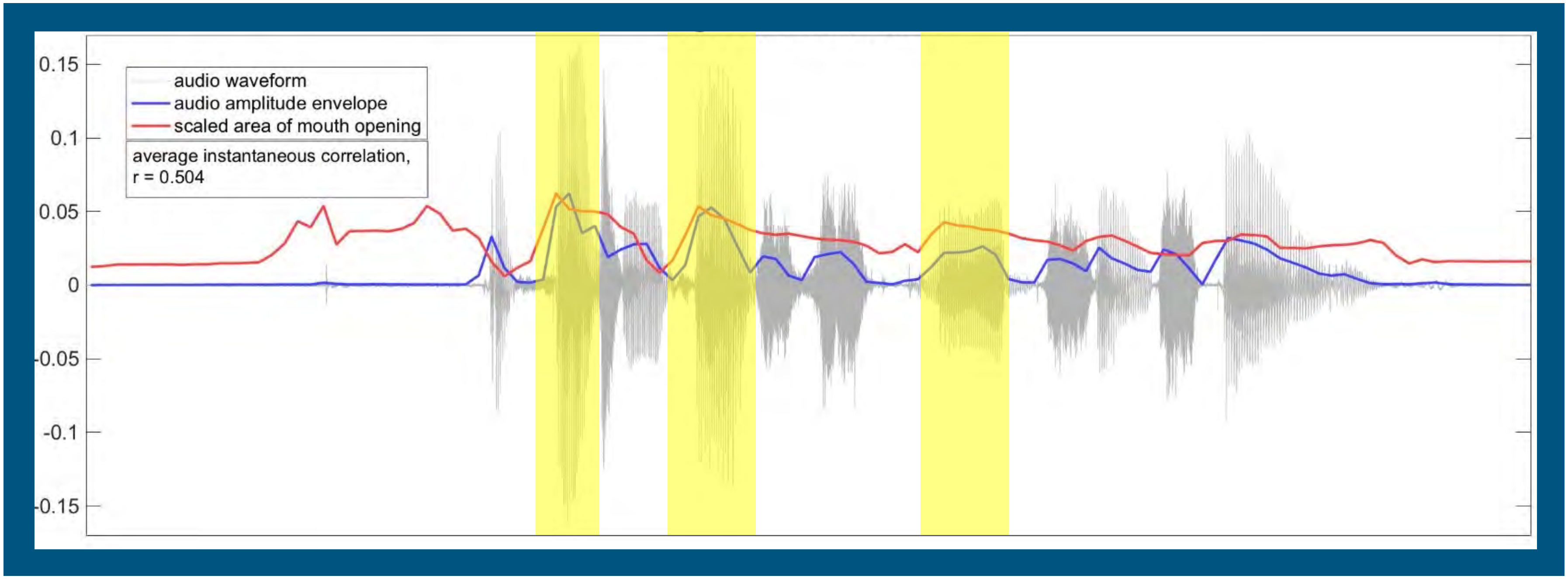




Lalonde & McCreery (2020). *Ear Hear. 41,* 705-719.
see also: Bernstein, 2004; Tye-Murray et al., 2011

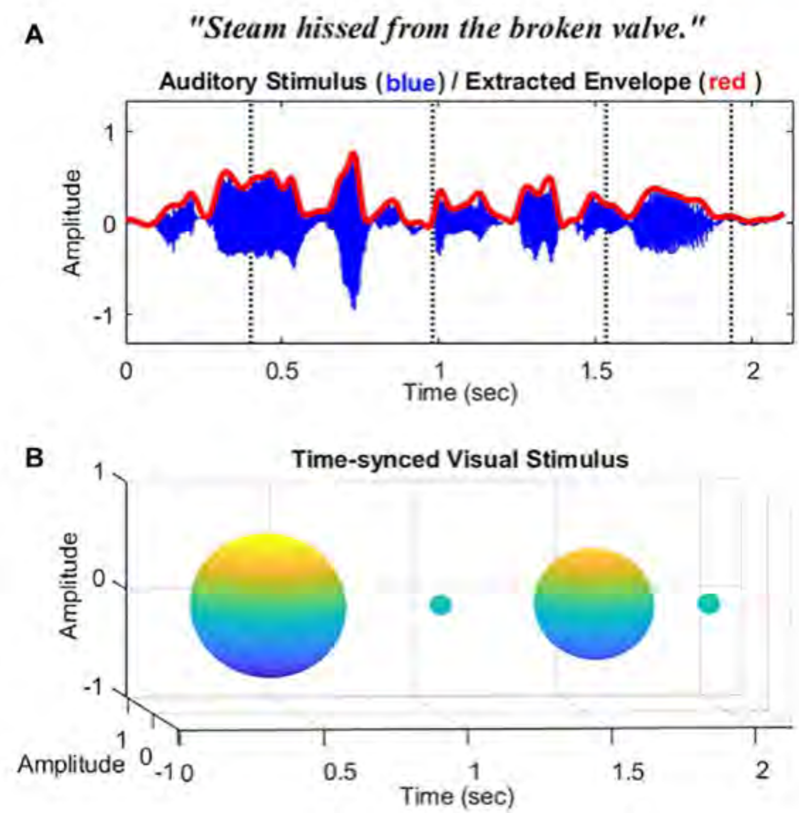
Q1

Visual speech provides cues to the amplitude envelope of speech



Grant & Seitz, 2000; Grant 2001; Kim & Davis 2004;

Visual speech provides cues to the amplitude envelope of speech



Yuan, Lleo, Daniel, White & Oh (2021). *Front. Neurosci., 15,* 678029.
see also: Yuan, et al. (2021). J. Speech Lang. Hear. Res., 64, 2845-2853.

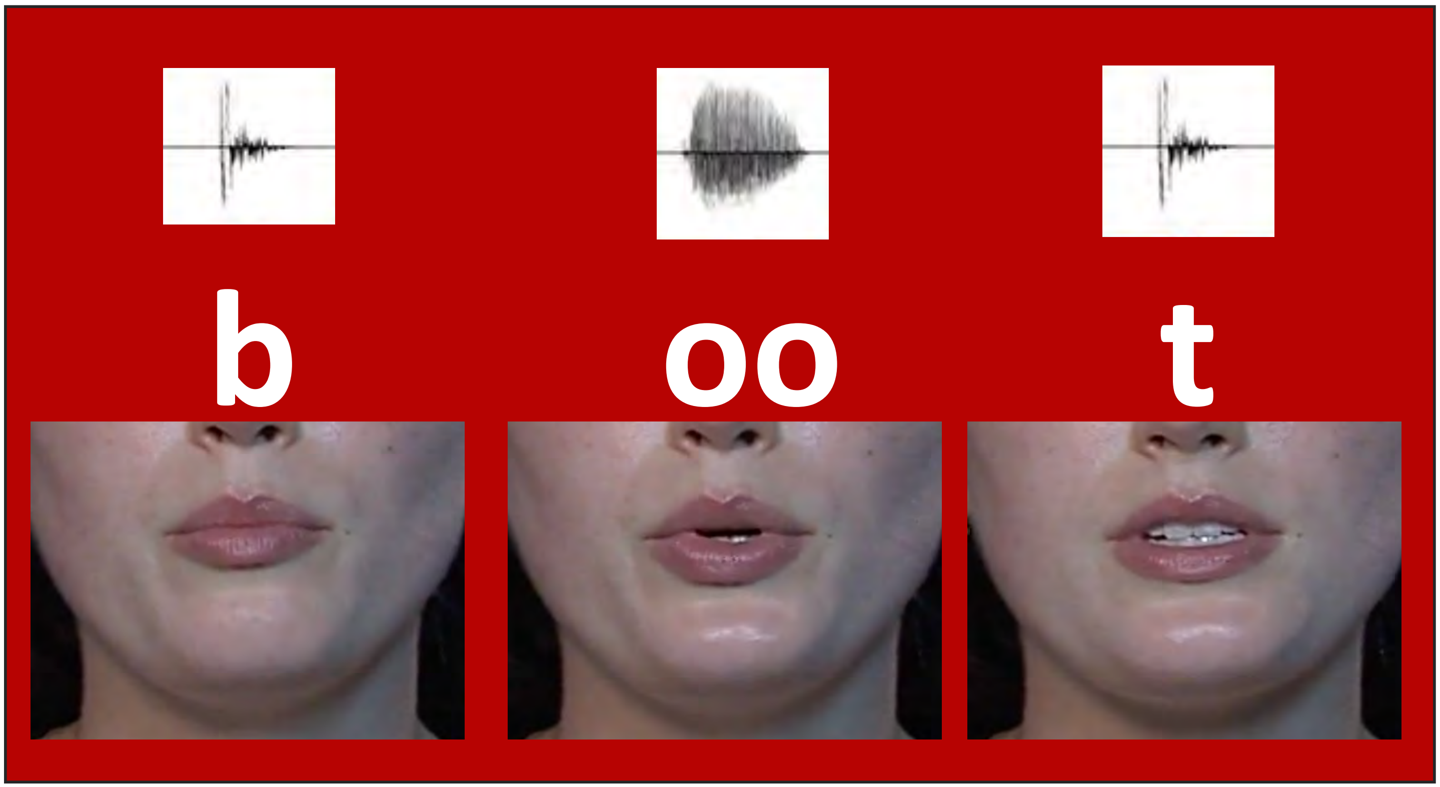
Visual speech provides cues to the amplitude envelope of speech

7% AV benefit.

Yuan, Lleo, Daniel, White & Oh (2021). *Front. Neurosci., 15,* 678029.
see also: Yuan, et al. (2021). J. Speech Lang. Hear. Res., 64, 2845-2853.

Visual speech helps you to access audiovisual speech representations

visual phonetic knowledge: knowledge of what mouth gestures correspond to particular speech sounds



Massaro 2004; Owenz & Blazek 2005; Tye-Murray et al. 2007

Visual speech helps you to access audiovisual speech representations

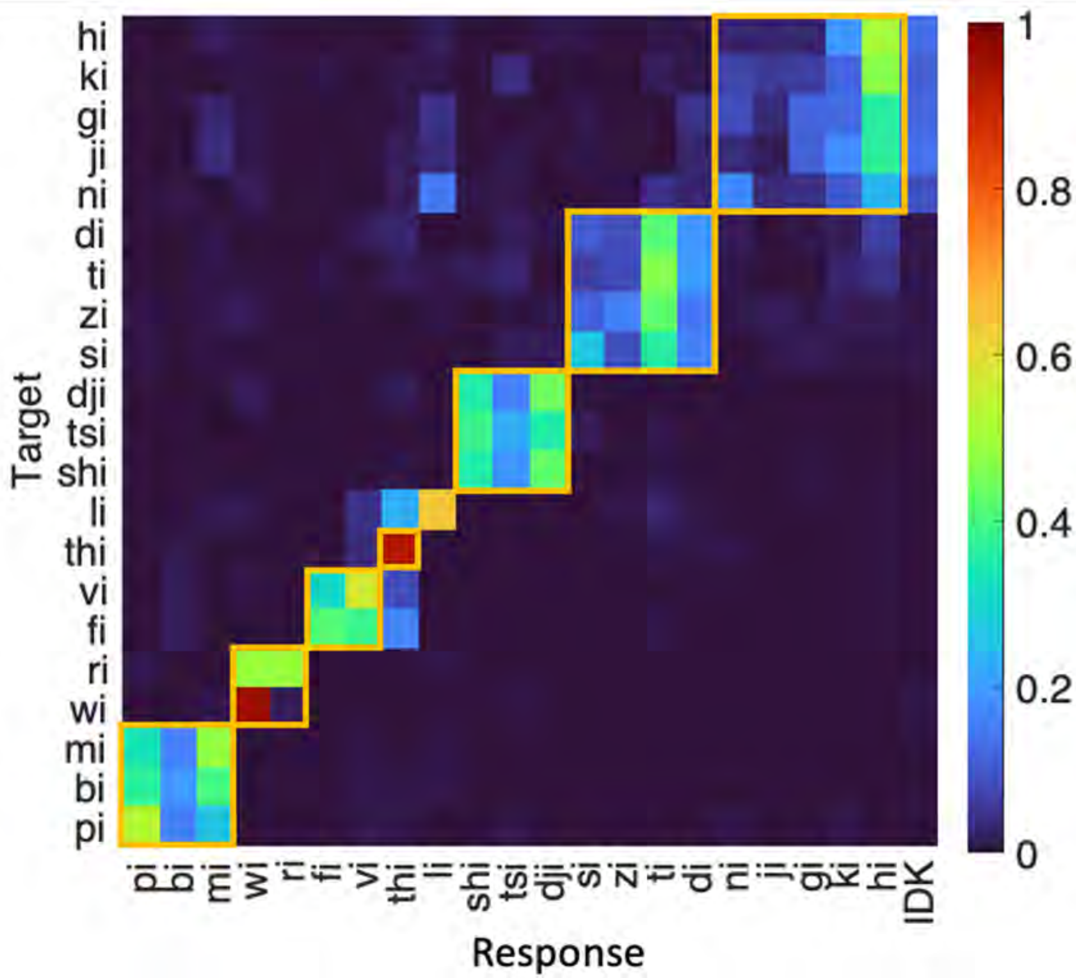
Which does she say?

- good
- mash
- need
- foam

bash, batch, patch

Massaro 2004; Owenz & Blazek 1985; Tye-Murray et al. 2007

Visual speech helps you to access audiovisual speech representations



Visual speech helps you to access audiovisual speech representations

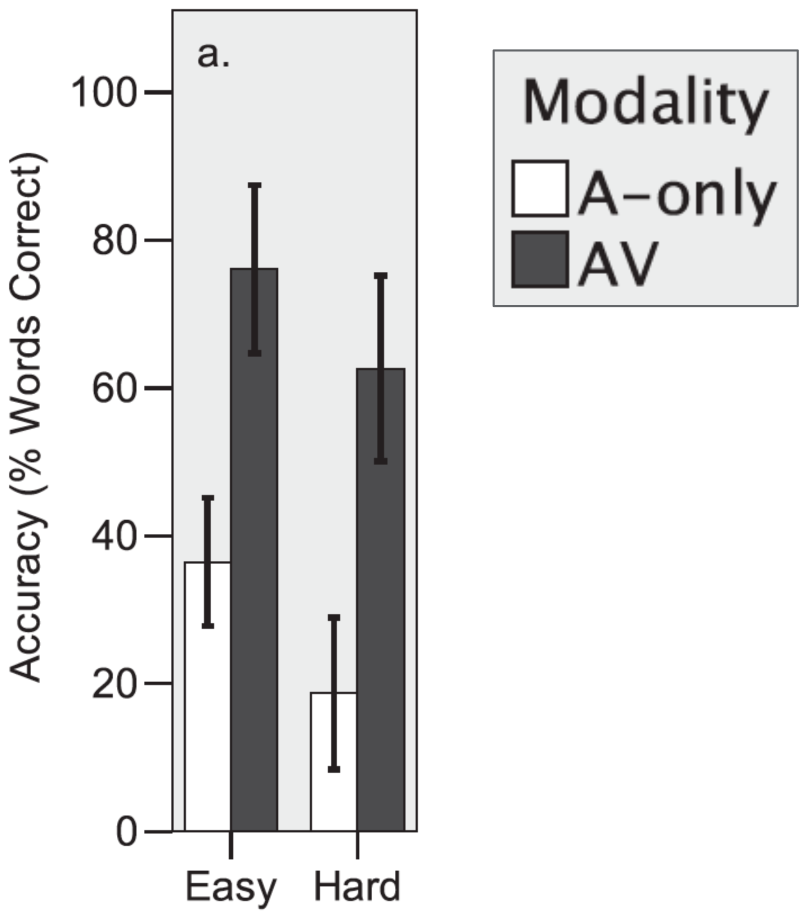
Presented	p	b	m	d	k	g	n	l	w	r
	Response									
p	2		1							
b		5	1			1				
m			7		2					
d				7						
k	1				7	1				
g						5				
n							6			
l					3			3		
w					1				2	
r	1	2							1	1

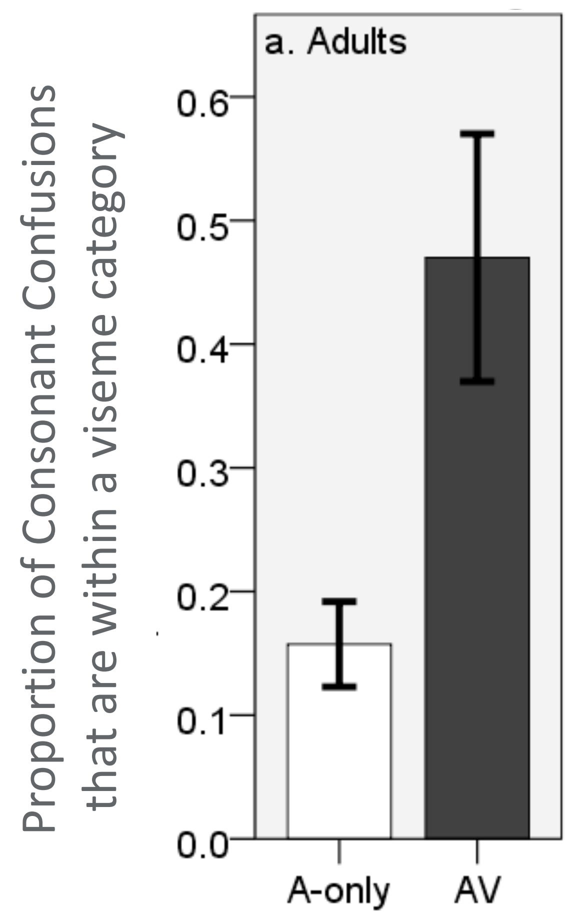
between viseme category substitution

Viseme Category	#
pbm	2
fv	0
θð	0
wr	1
ʧʤʒʃ	2
tdsz	26
kgnl	4

Q1

Visual speech helps you to access audiovisual speech representations



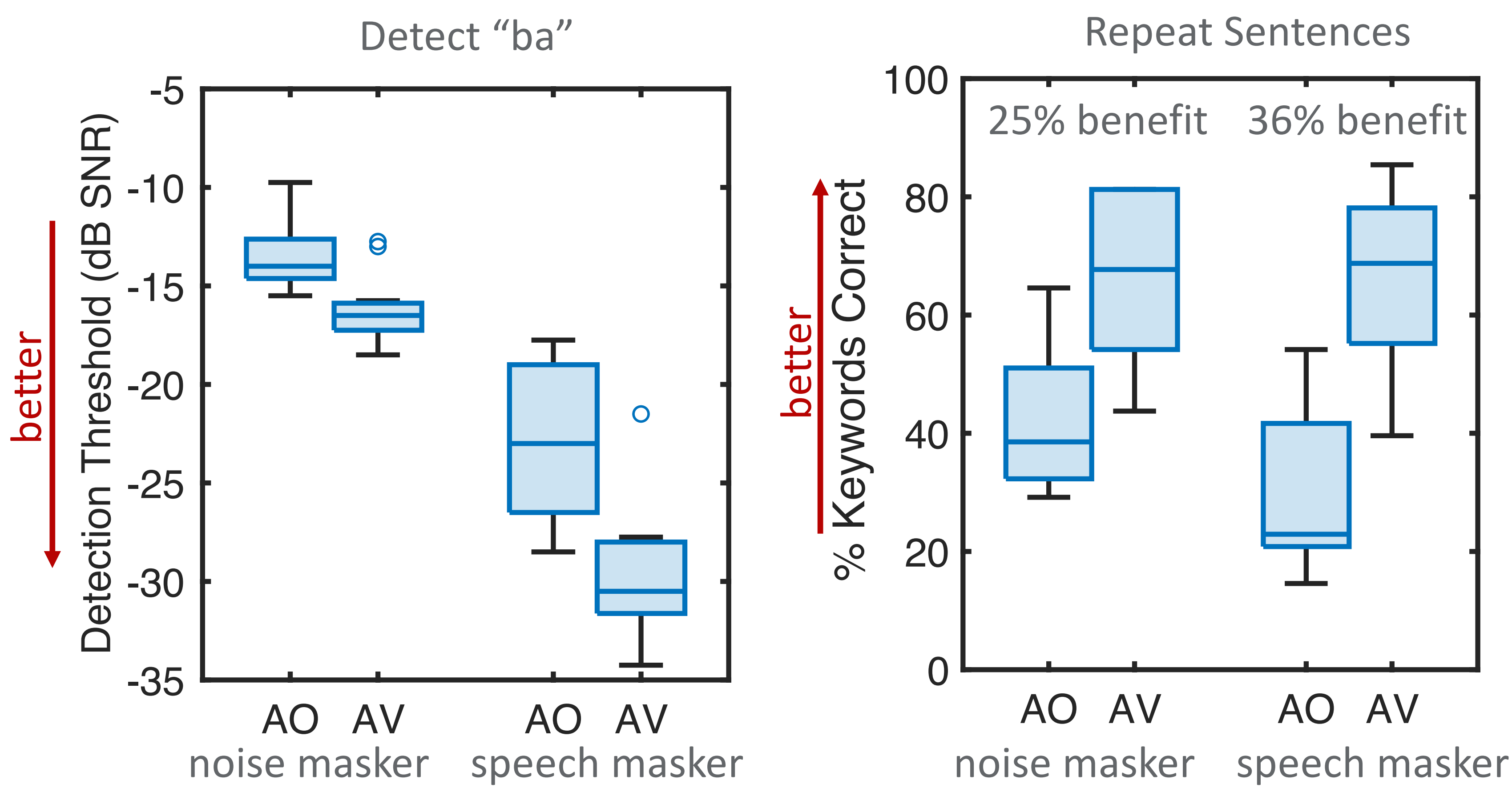


Lalonde & Holt (2015). *J. Speech Lang. Hear. Res. 58,* 151-162.

Visual speech helps you to segregate & attend to a talker

Helfer & Freyman, 2005

Visual speech helps you to segregate & attend to a talker



Lalonde & McCreery (2020). *Ear Hear., 41,* 705-719.
Helfer & Freyman 2005; Van Engen et al. 2017

Multiple Mechanisms underlie audiovisual speech enhancement

Visual speech:

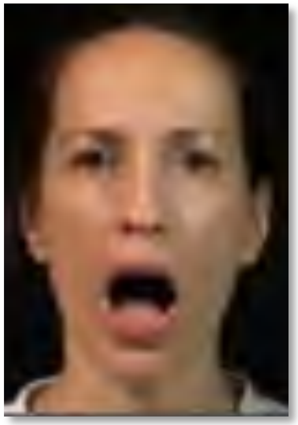
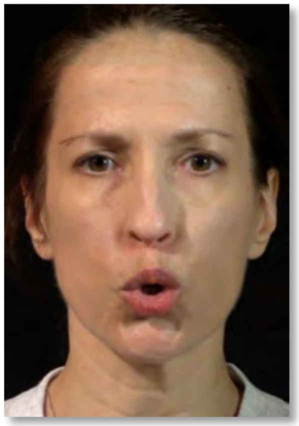
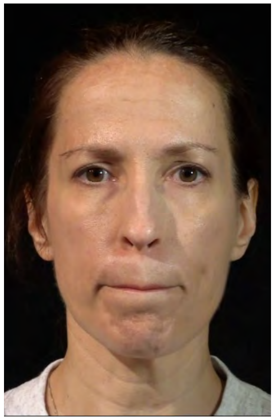
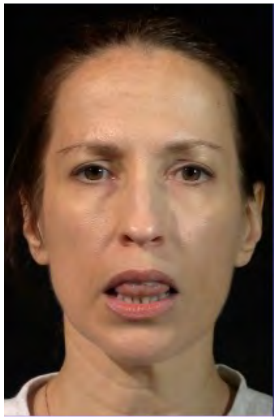
1. tells you when to listen.
2. provides cues to the auditory amplitude envelope of speech.
3. helps you to access audiovisual speech representations
4. helps you to segregate & attend to a talker.

Development of audiovisual speech enhancement in children with typical hearing

Development of Audiovisual Speech Enhancement

INFANTS

- Infants are sensitive to the correspondence between audiovisual speech cues
  - e.g., Kuhl & Meltzoff 1982
- Infants use temporal cues in visual speech to improve detection and discrimination of speech in noise.
  - Lalonde & Werner 2019; 2021 for review

Development of Audiovisual Speech Enhancement

CHILDREN

- Preschool- and school-age children benefit from visual speech
  - Holt et al. 2020; Knowland et al. 2016; Lalonde & Holt, 2015, 2016; Ross et al. 2011
- Studies typically show in increase in audiovisual enhancement with age.
  - Wightman et al. 2006; Ross et al. 2011
- However, some studies suggest no change in benefit over age or a decrease in benefit in the early school years.
  - Jerger et al. 2009; Knowland et al. 2016

Development of Audiovisual Speech Enhancement

Participants

- 63 children (33 male) and 18 adults (8 male) with normal hearing and vision
- between 5 to 16 years of age

Auditory-only (AO) and AV measures of:

1. sentence recognition in noise thresholds (adaptive)
2. sentence recognition in noise accuracy (Fixed-SNR)
3. syllable recognition in noise accuracy (Fixed-SNR)

AO and AV sentence recognition in noise thresholds

High-Probability SPIN sentences (Bilger et al. 1984)

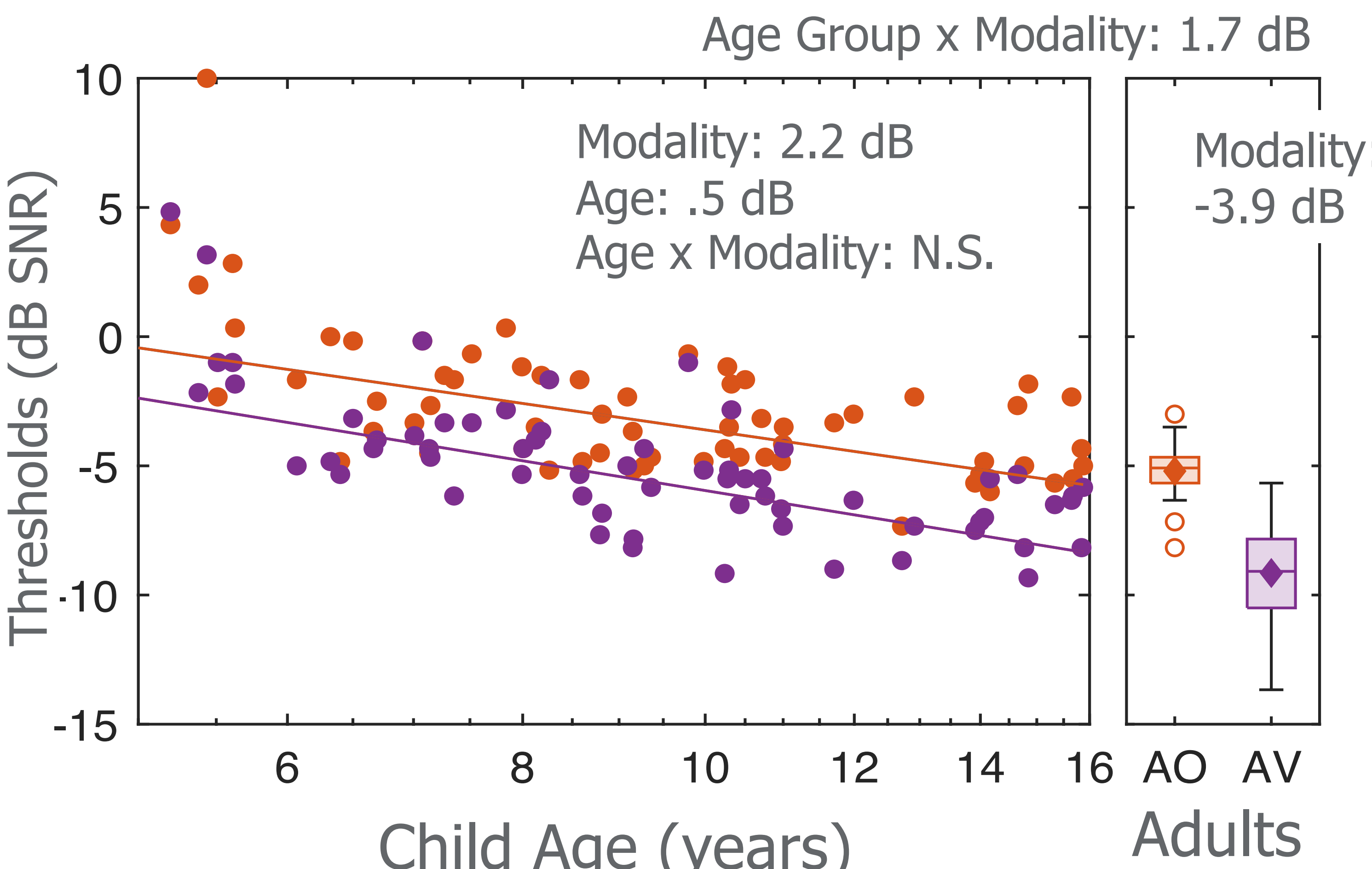
auditory-only
audiovisual

Increase in benefit across school-age

NO

Greater benefit in adults than children

YES



AO and AV word-in-sentence recognition in noise accuracy

Multisyllabic Lexical Neighborhood Sentence Test for Children
(Kirk et al. 2012)

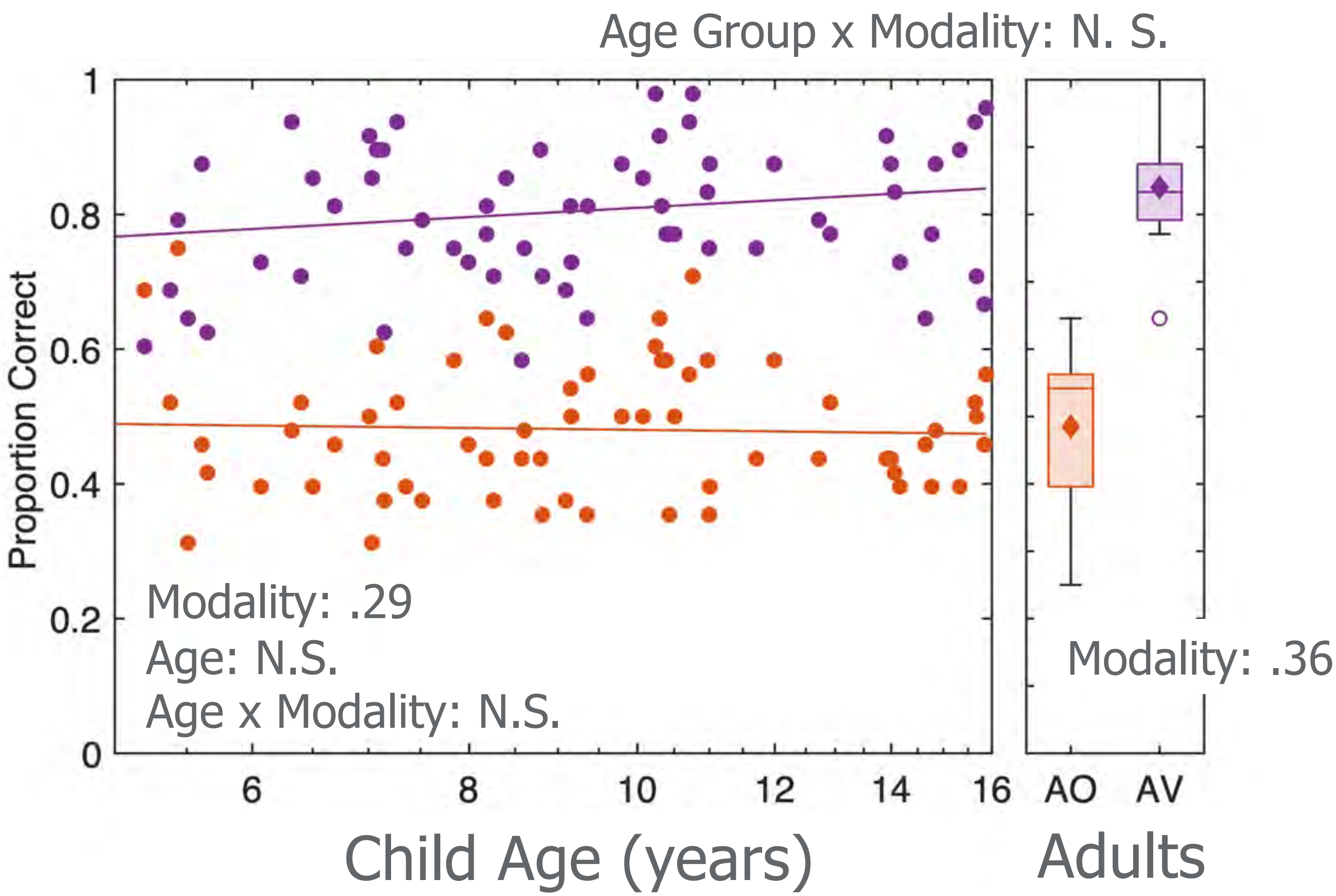
auditory-only
audiovisual

Increase in benefit across school-age

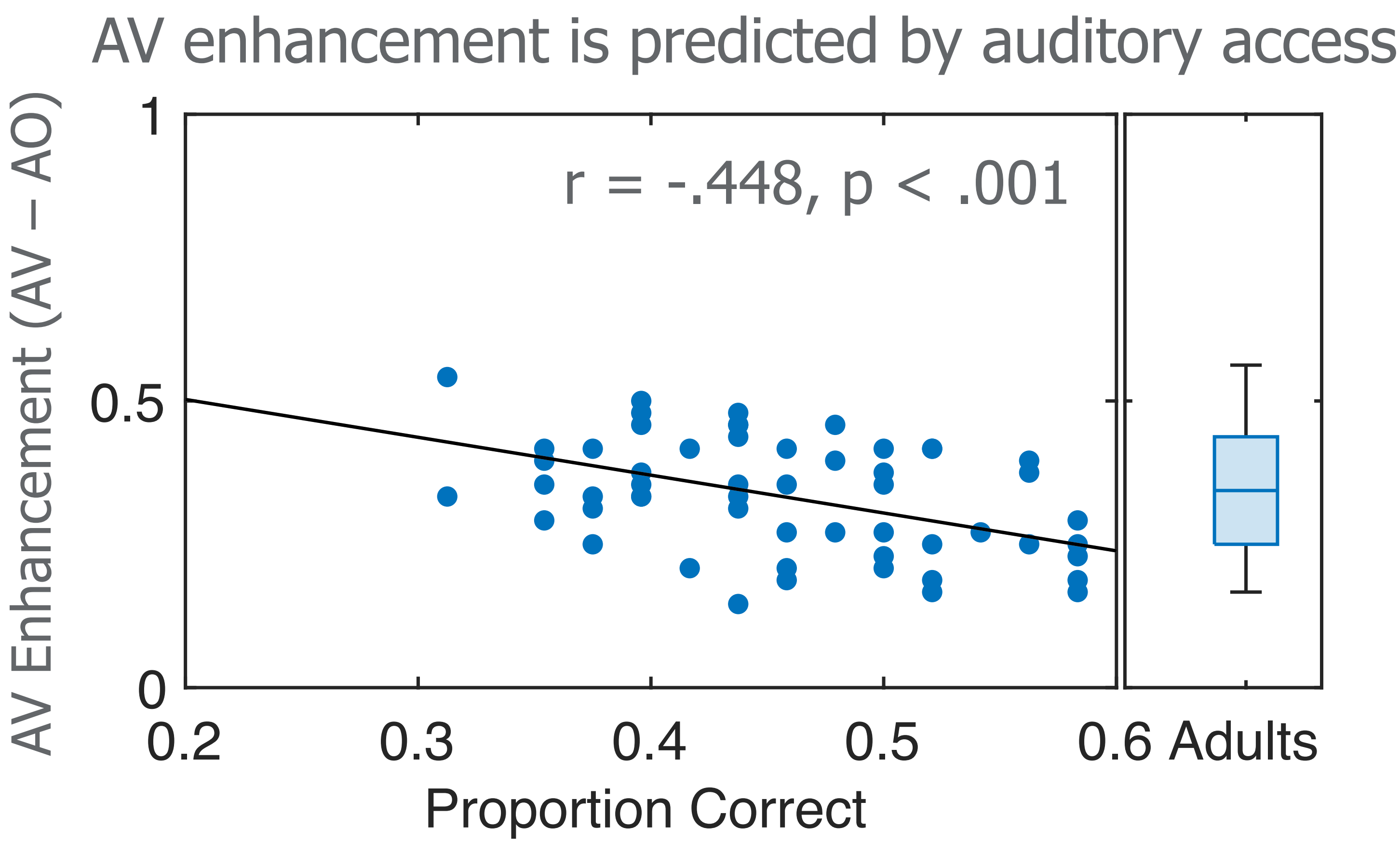
NO

Greater benefit in adults than children

NO



AO and AV word-in-sentence recognition in noise accuracy



VO, AO and AV syllable recognition in noise thresholds

Consonant vowel syllables with vowel /i/

"Say me." "Say key."

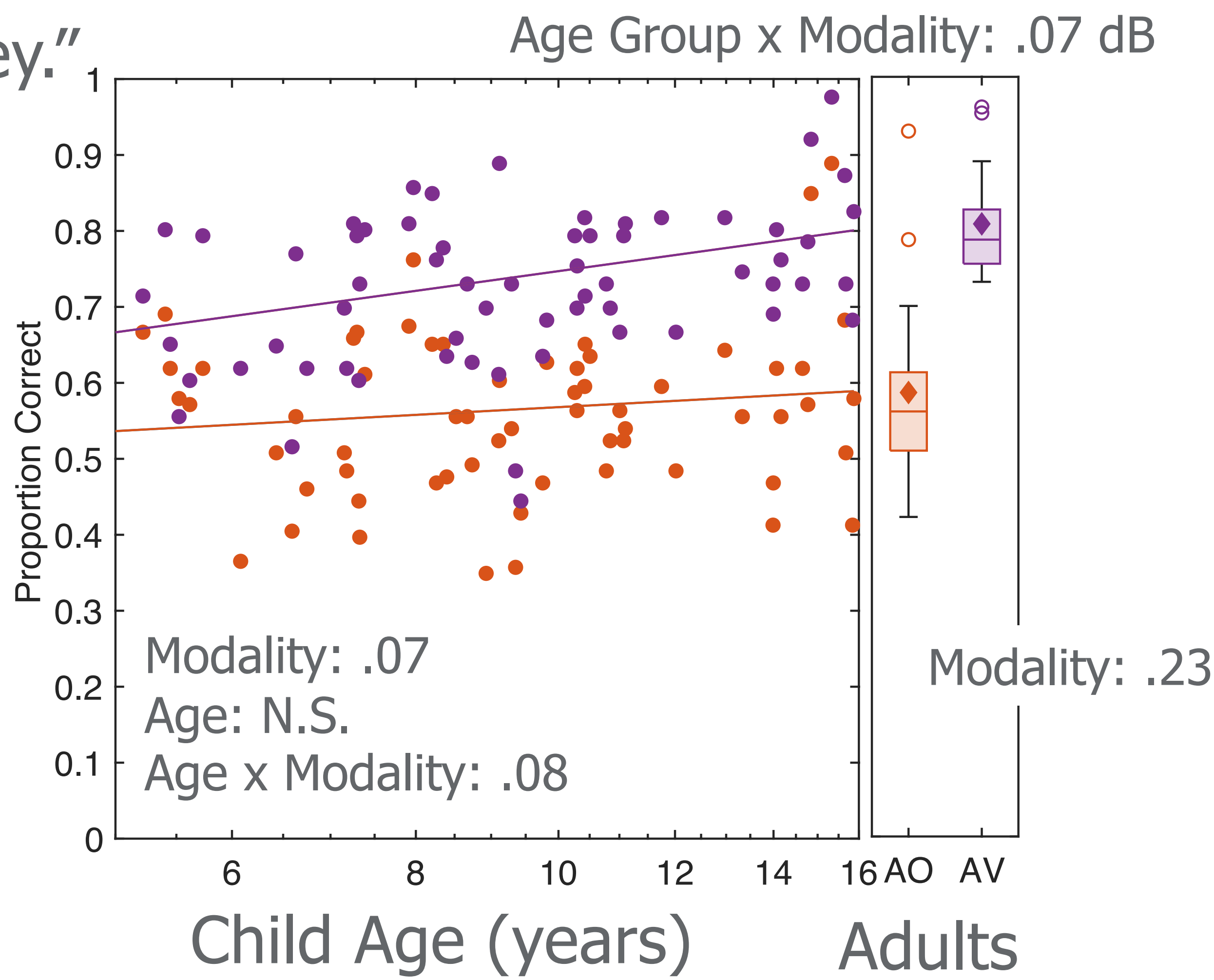
auditory-only
audiovisual

Increase in benefit across school-age

YES

Greater benefit in adults than children

YES



VO, AO and AV syllable recognition in noise thresholds

Consonant vowel syllables with vowel /i/

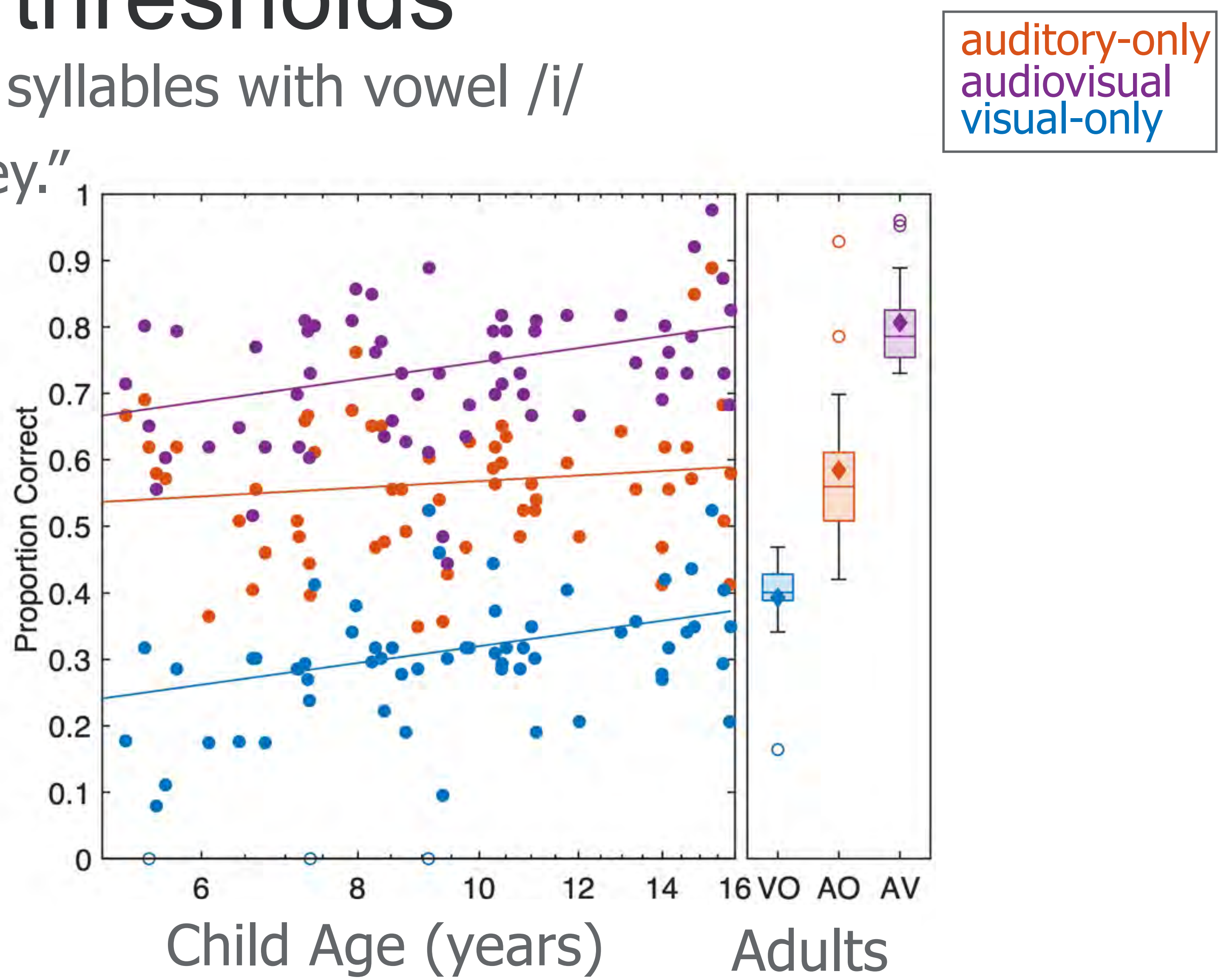
"Say me." "Say key."

Increase in benefit across school-age

YES

Greater benefit in adults than children

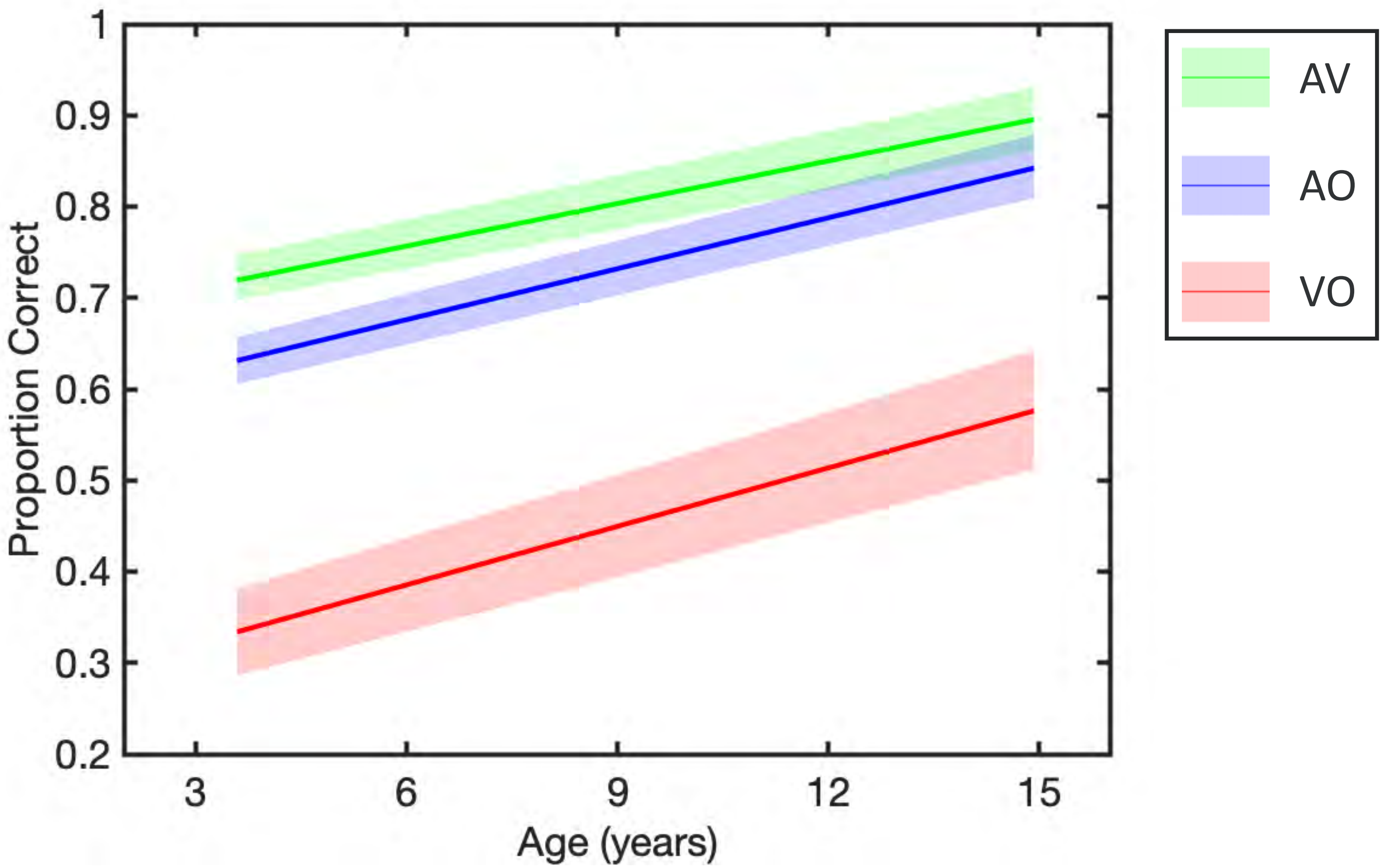
YES



word recognition in noise, 4-AFC

Increase in benefit across school-age

NO



Gijbels, Yeatman, Lalonde, Doering & Lee, submitted

Development of Audiovisual Speech Enhancement

- What is the developmental trajectory?
  - between 5 and 16 years of age

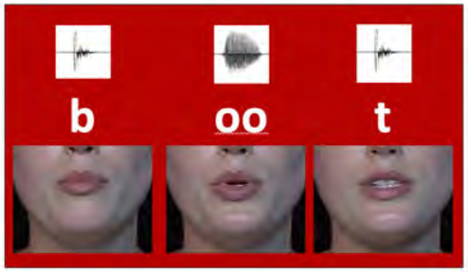
	Increase in benefit across school-age	Greater benefit in adults than children
Sentence Thresholds	NO	YES
Sentence Accuracy	NO	NO
Syllable Accuracy	YES	YES
4AFC Word Accuracy	NO	--

Age-related changes in AV enhancement across school age (5-16 years) are <u>inconsistent</u> across measures.

Development of Audiovisual Speech Enhancement

- What is the developmental trajectory?
  - between 5 and 16 years of age

	Increase in benefit across school-age	Greater benefit in adults than children
Sentence Thresholds	NO	YES
Sentence Accuracy	NO	NO
Syllable Accuracy	YES	YES
4AFC Word Accuracy	NO	--



Access to AV speech representations: using visual phonetic knowledge

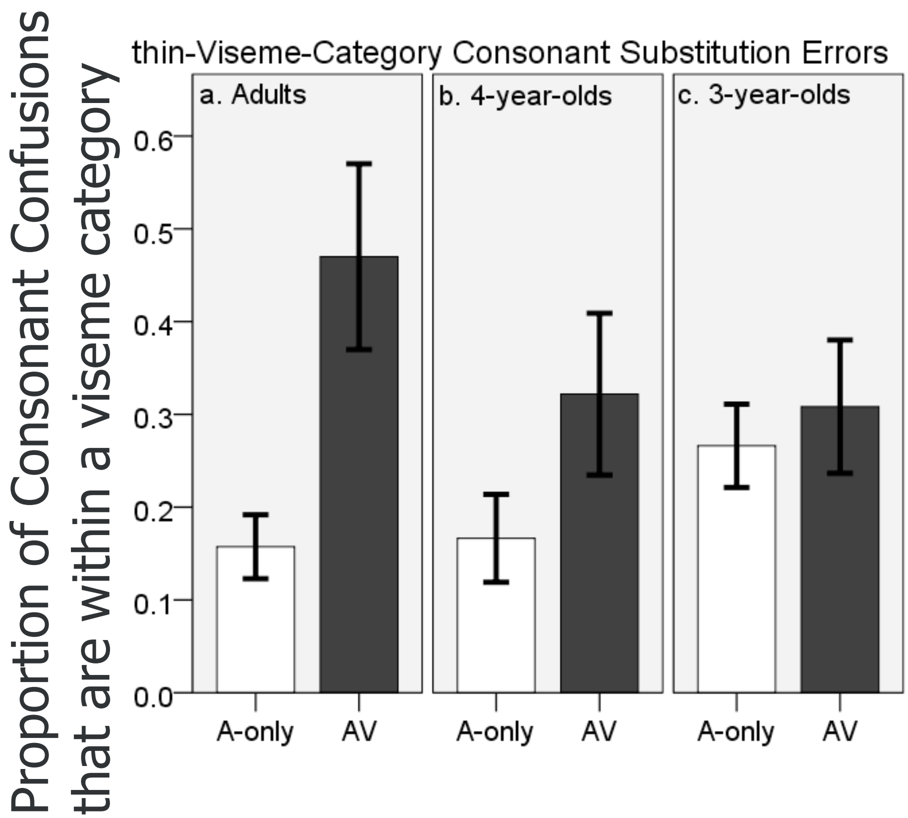
- analysis of consonant confusion errors to quantify children's visual phonetic knowledge

Presented	p	b	m	d	k	g	n	l	w	r	Response
p	2		1								
b		5	1			1					
m			7		2						
d				7							
k	1				7	1					
g						5					
n							6				
l					3			3			
w					1				2		
r	1	2							1	1	

between viseme category substitution

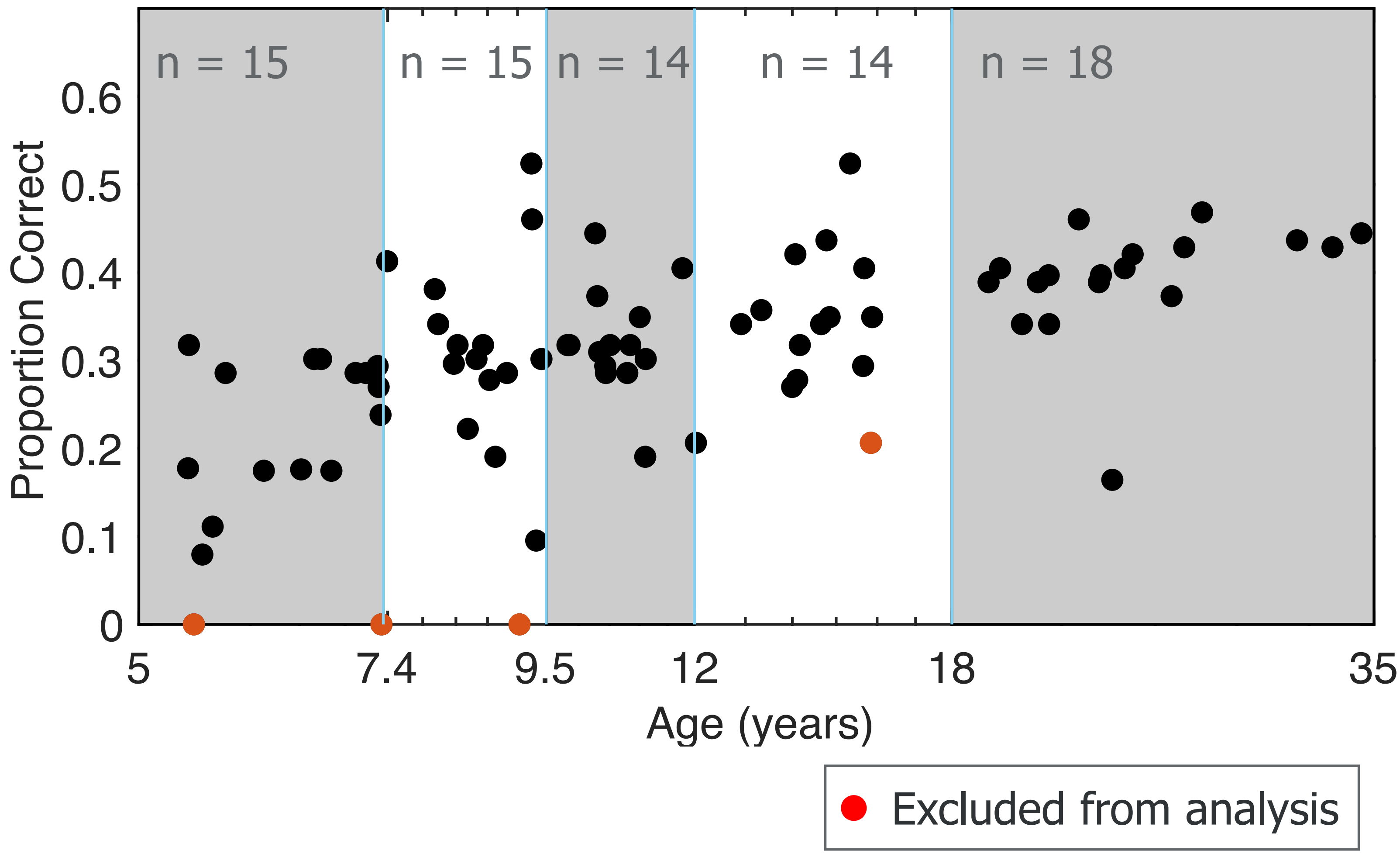
Viseme Category	#
pbm	2
fv	0
θð	0
wr	1
ʧʤʃʒ	2
tdsz	26
kgnl	4

Access to AV speech representations: using visual phonetic knowledge



Lalonde & Holt (2015). *J. Speech Lang. Hear. Res. 58,* 151-162.

Visual-only syllable recognition accuracy



Consonant confusion matrices

Adults:

~ velar/glottal:
/ni, ji, gi, ki, hi/   72.5-82.3%

alveolar: /si, zi, ti, di/
83.8-84.6%

Post-alveolar: /ʃi, tʃi, dʒi/   96.9%

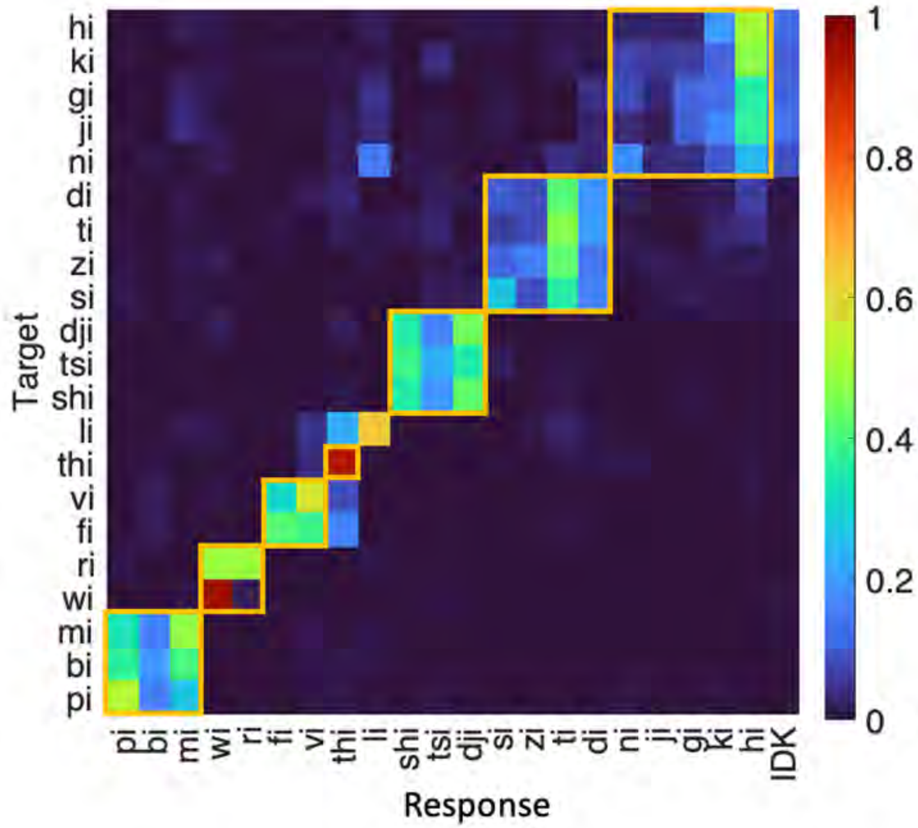
/li/   63.9%

interdental: /ði/   92.6%

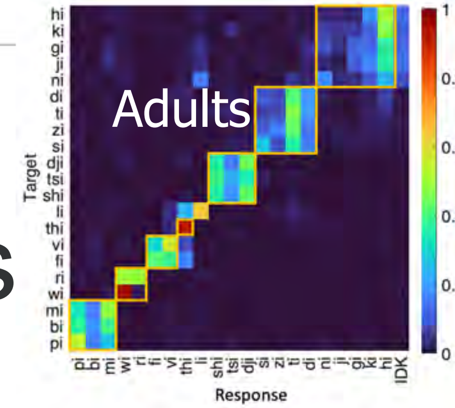
labiodentals: /fi, vi/   84.3%

/wi, ri/   98.1%

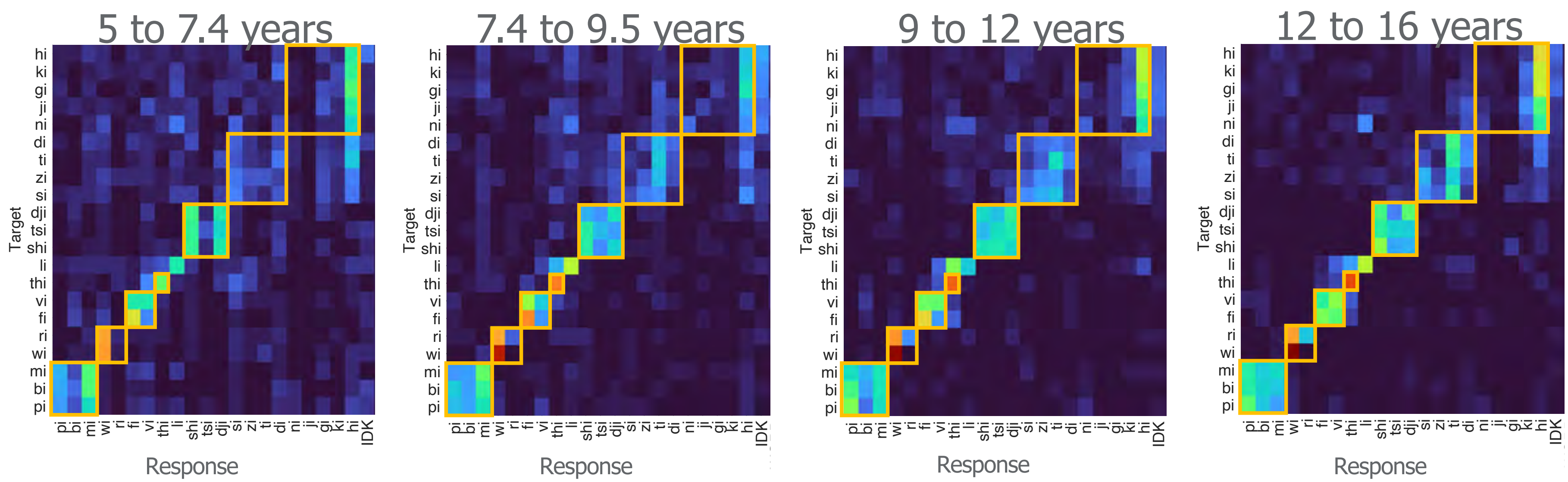
bilabials: /pi, bi, mi/   96.9%



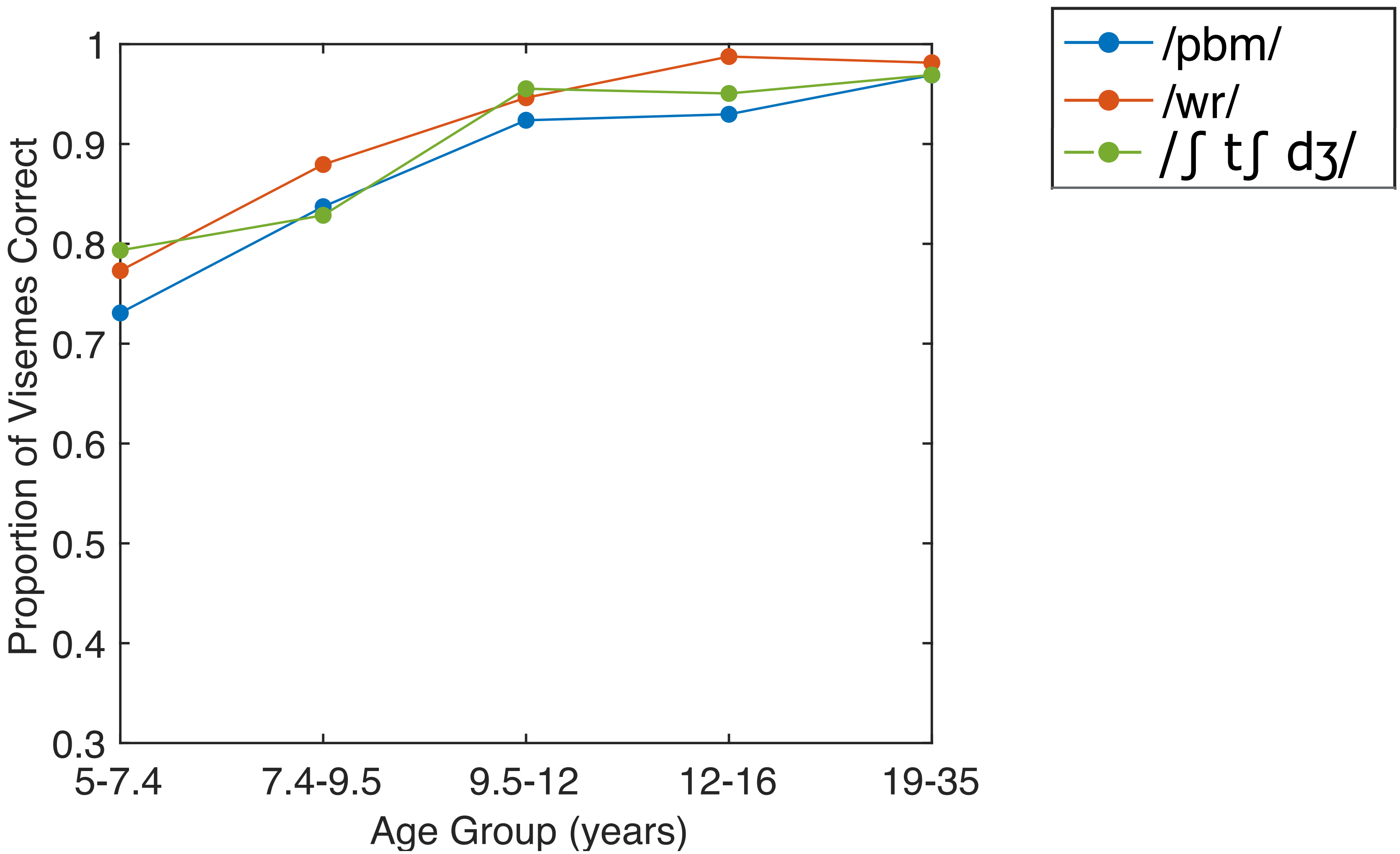
Consonant confusion matrices



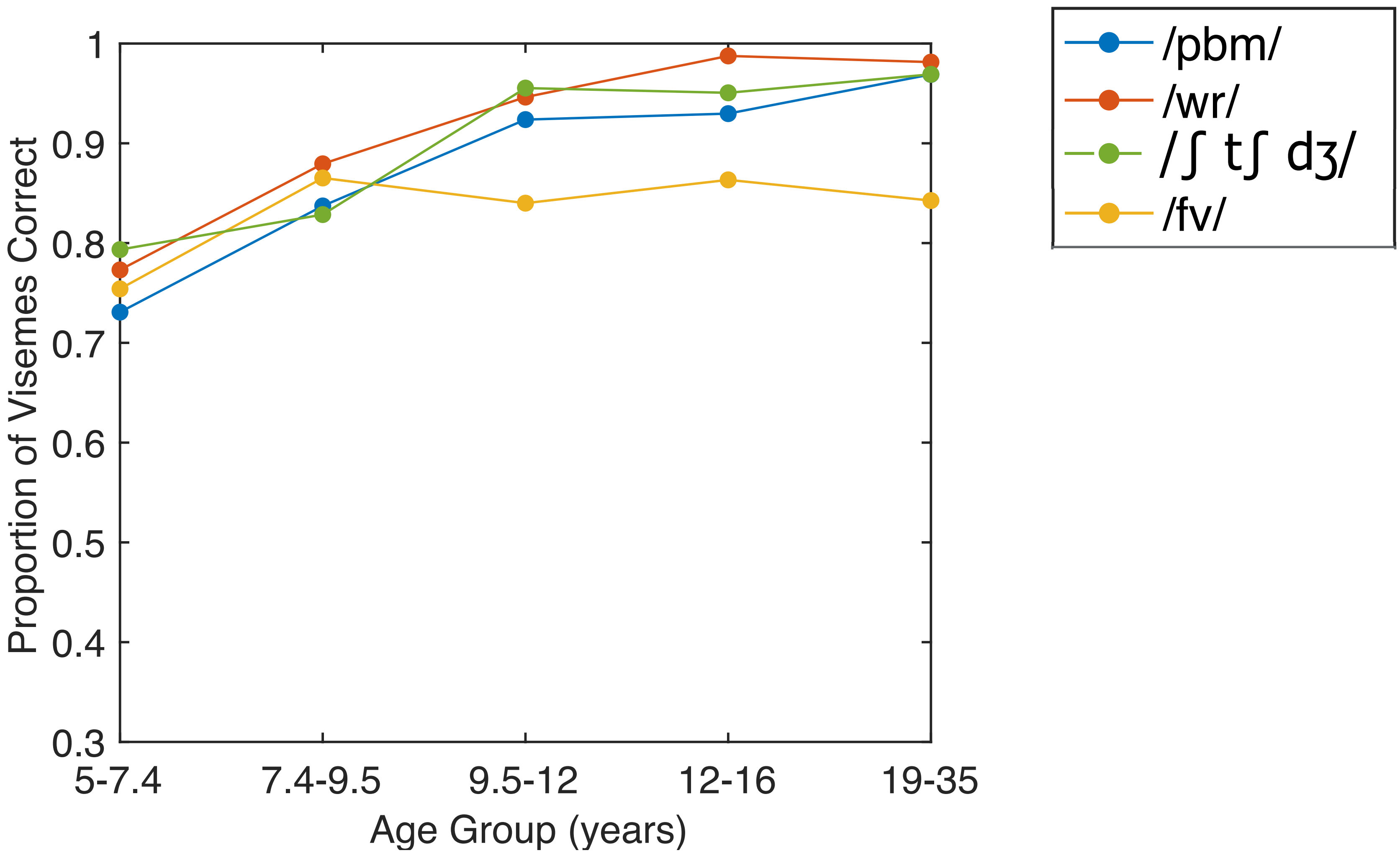
Adults:



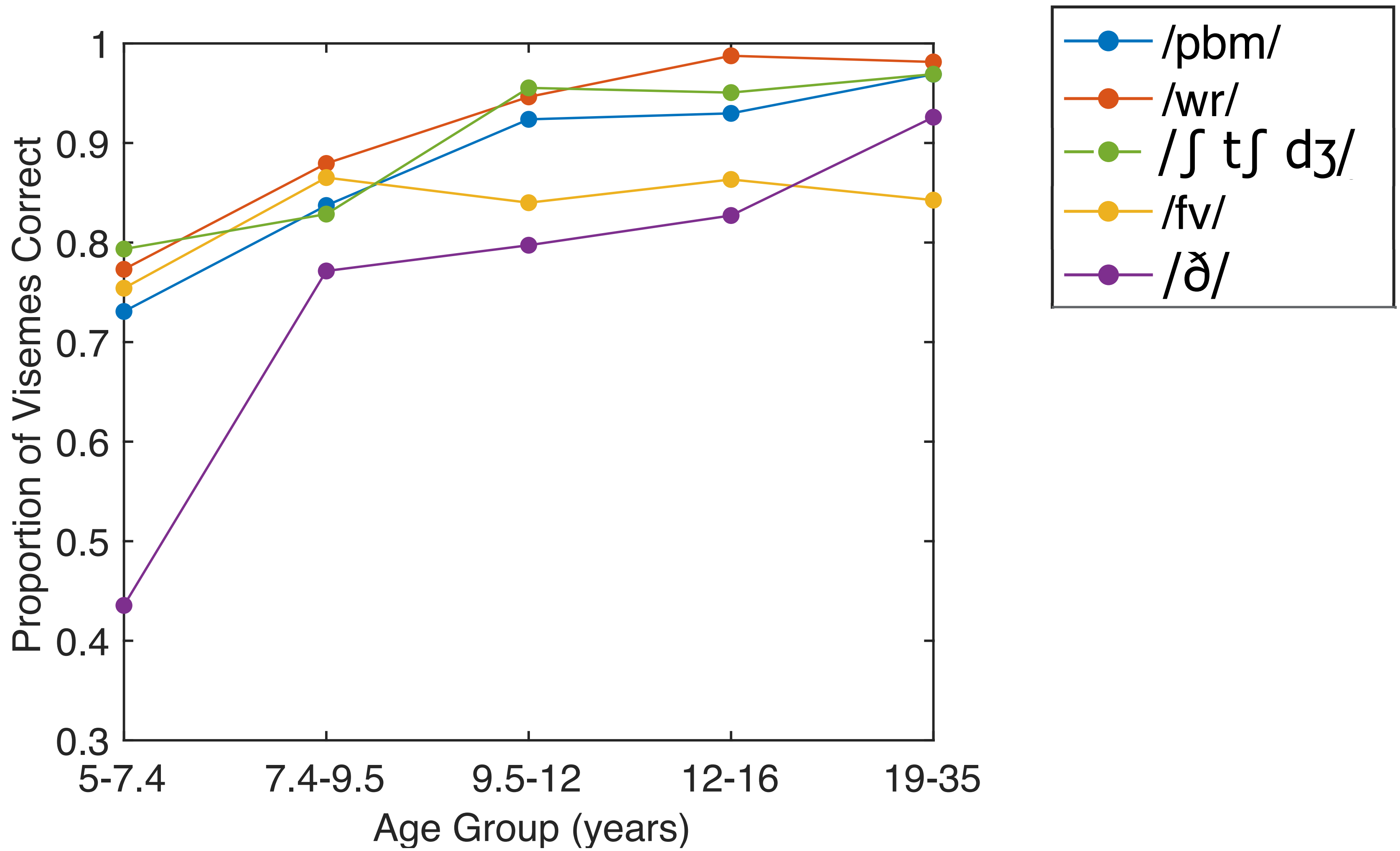
Age-related change in visual-phonetic knowledge



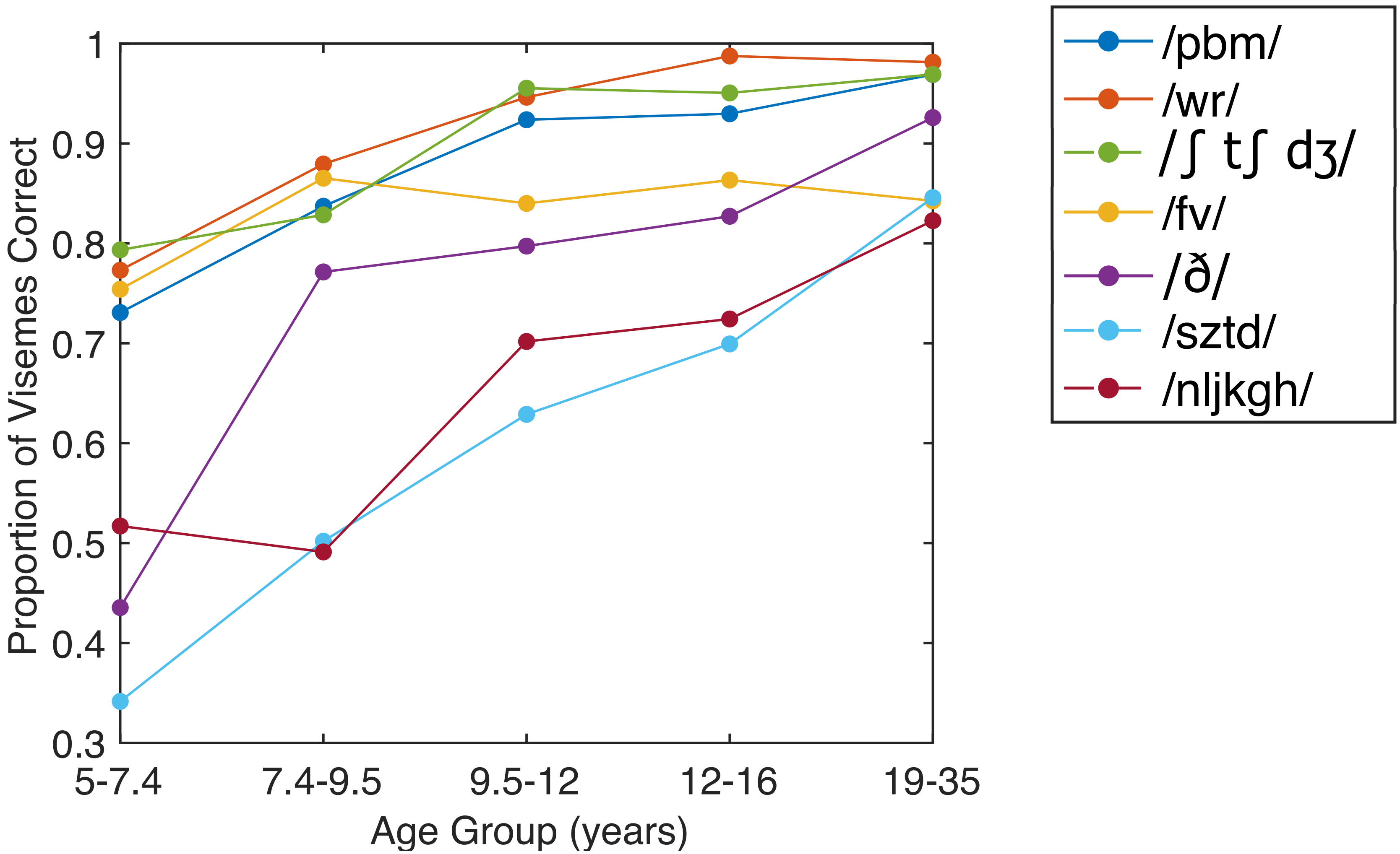
Age-related change in visual-phonetic knowledge



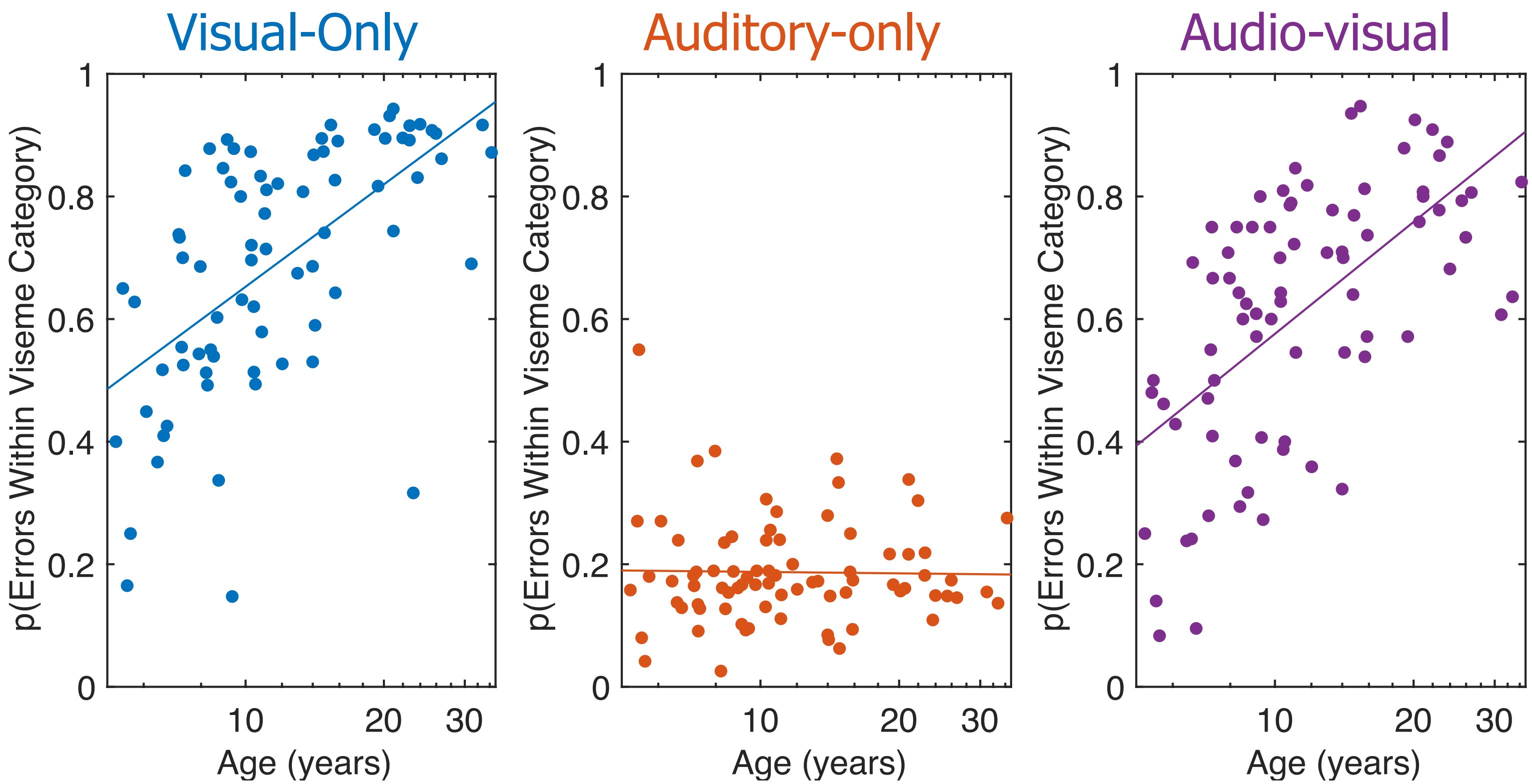
Age-related change in visual-phonetic knowledge



Age-related change in visual-phonetic knowledge



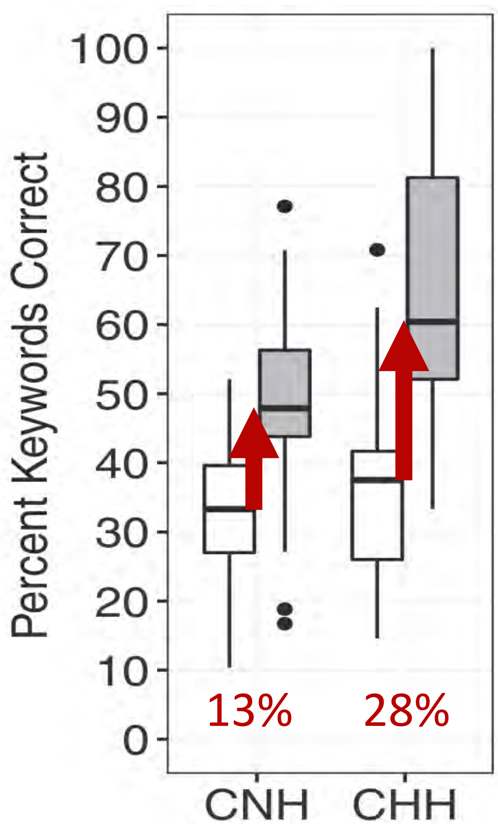
Age-related change in visual-phonetic knowledge



- There is some early developed visual phonetic knowledge.
- There is also age-related change in (use of) visual phonetic knowledge across the school years.

Effects of pediatric hearing loss on audiovisual speech enhancement

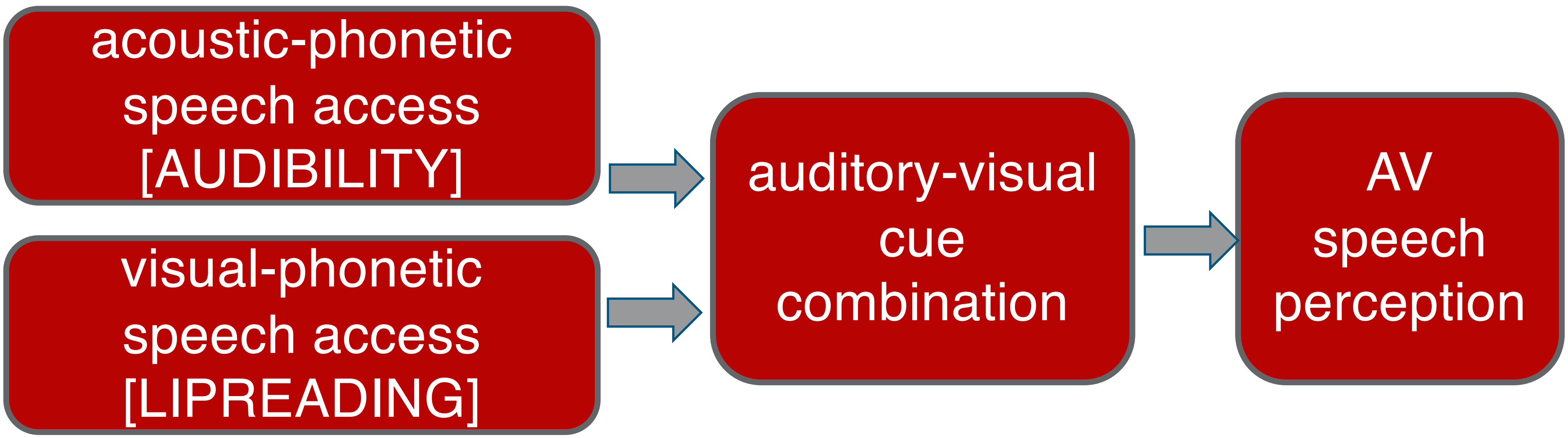
Effect of pediatric hearing loss on AV speech enhancement



- AV speech enhancement is greater in 6- to 12-year-old children who are hard of hearing than 6- to 12-year-old children with normal hearing

Lalonde & McCreery (2020). *Ear Hear., 41,* 705-719.

Effects of pediatric hearing loss on AV speech enhancement



Model of AV speech enhancement

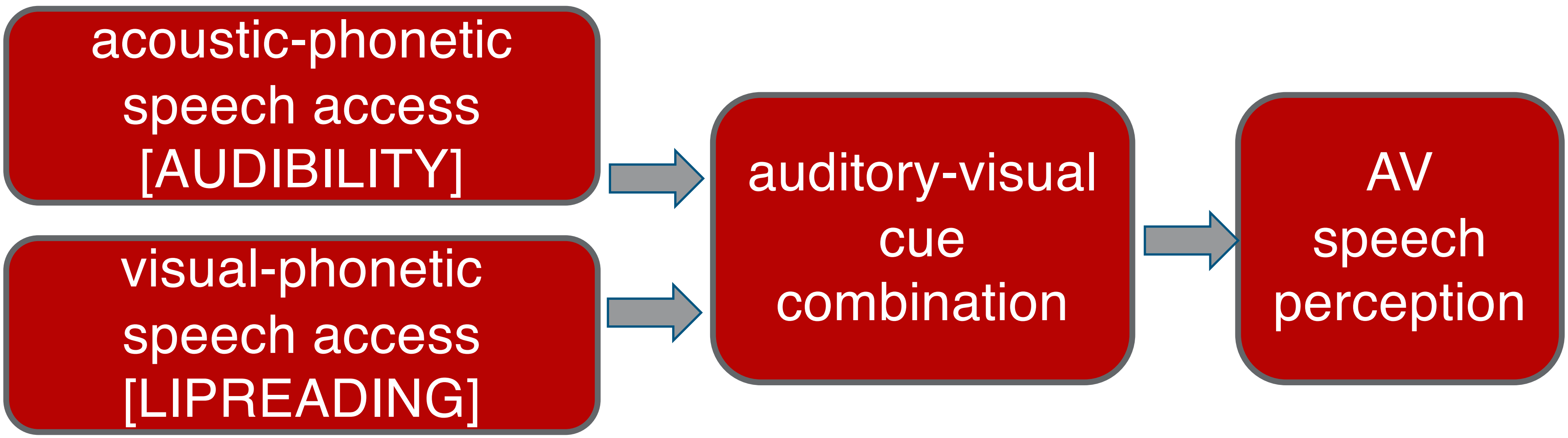
Effects of pediatric hearing loss on AV speech enhancement

visual-phonetic speech access [LIPREADING]

- Enhanced lipreading in children with hearing loss?
  - **Yes:** Jerger et al. 2009; Tye-Murray et al. 2014; Beattie & Markides 1992; Lyxell & Holmberg 2000; Tye-Murray et al. 2014 ; Chen Lei Gong 2018
  - **No:** Arnold & Köpsel 1996; Conrad 1977; Kyle et al. 2013; Lalonde Buss Miller & Leibold 2022

- Group differences may be caused by some extremely skilled lipreaders in the HL group.
  - Lyxell & Holmberg 2000

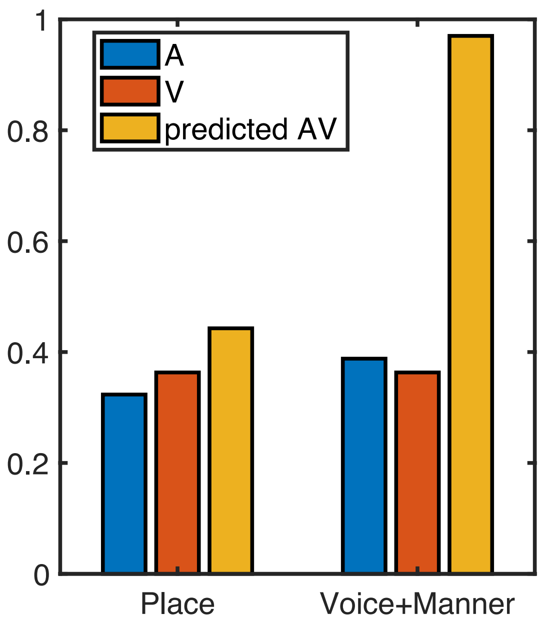
Effects of pediatric hearing loss on AV speech enhancement

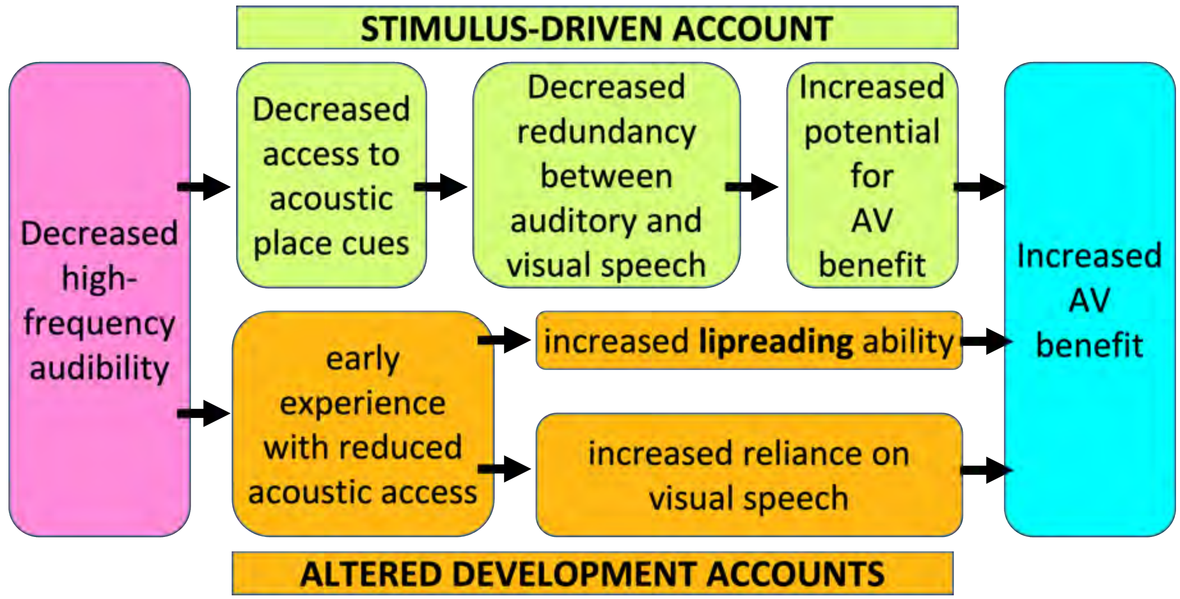


Model of AV speech enhancement

Effects of pediatric hearing loss on AV speech enhancement

acoustic-phonetic speech access (AUDIBILITY)





Does decreasing high-frequency audibility in **children with normal hearing** result in increased AV benefit?

Grant, Walden & Seitz, 1998

Does decreasing high-frequency audibility in **children with normal hearing** result in increased AV benefit?

Method

- Participants: 30 children (14 female, 16 male)
  - 7 to 12.9 years of age
- Hearing, vision, and articulation screenings
- Speech perception testing
  - repeat words and sentences

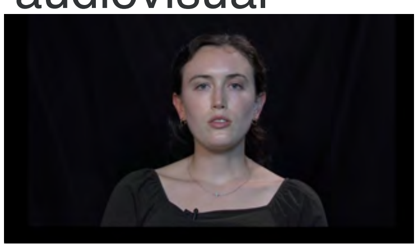
Stimuli: CVC word recognition

- Phonetically-balanced lists of CVC words
  - 50 words per condition

Modality

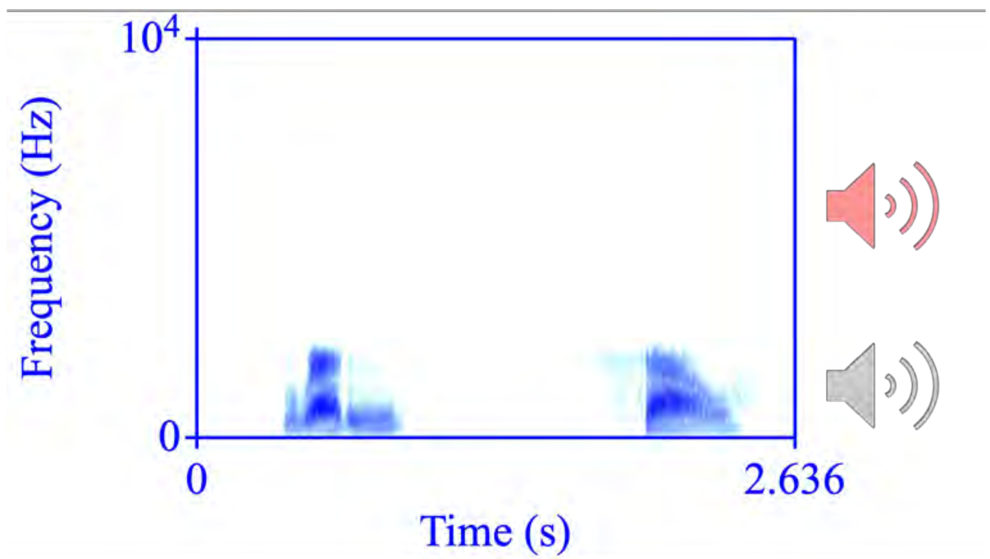
auditory-only

audiovisual



Acoustic filtering condition

FIR filter with 2 kHz cutoff



high-pass filtered

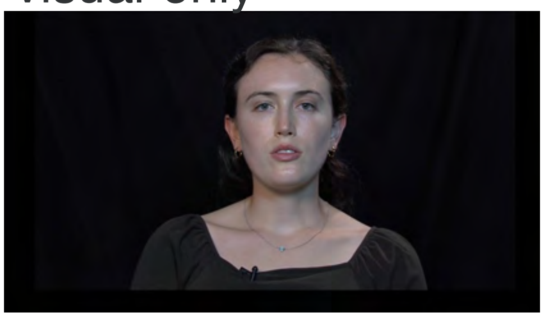
low-pass filtered

Stimuli: CVC word recognition

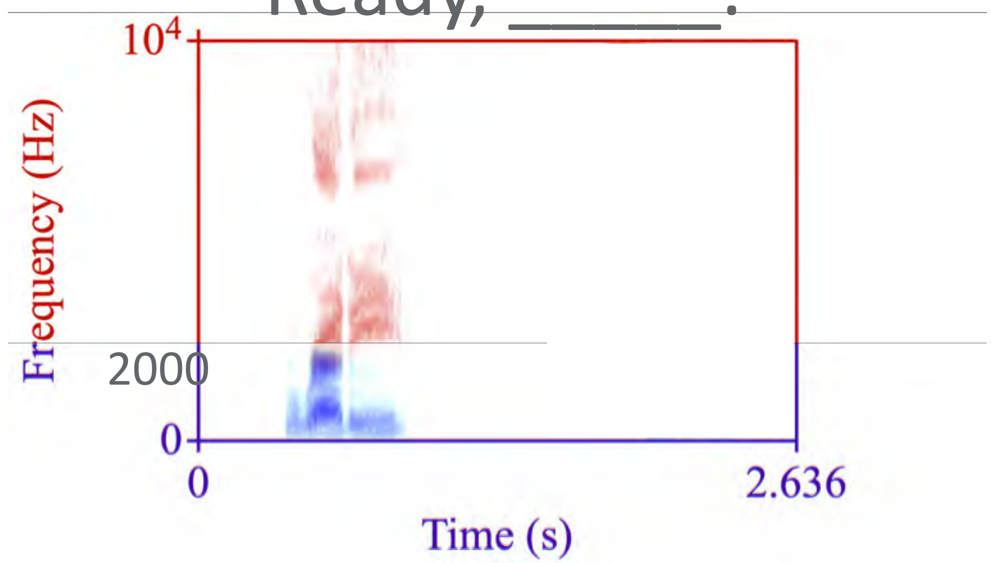
- Phonetically-balanced lists of CVC words
  - 50 words per condition

Modality

visual-only



“Ready, _____.”

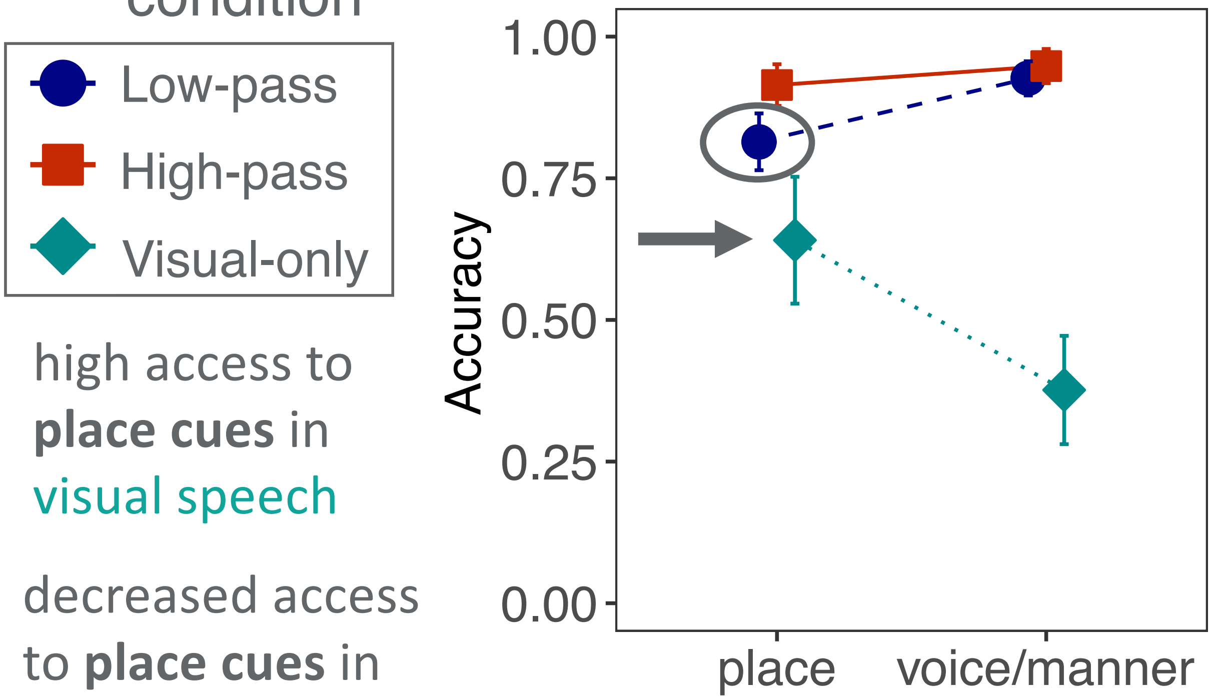


Hypotheses (stimulus-driven)

- H1: Less redundancy between auditory and visual speech cue access in low-pass filtered condition than in high-pass filtered condition
  - due to high access to **place cues** in visual speech and decreased access to **place cues** in low-pass filtered condition
- H2: Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered

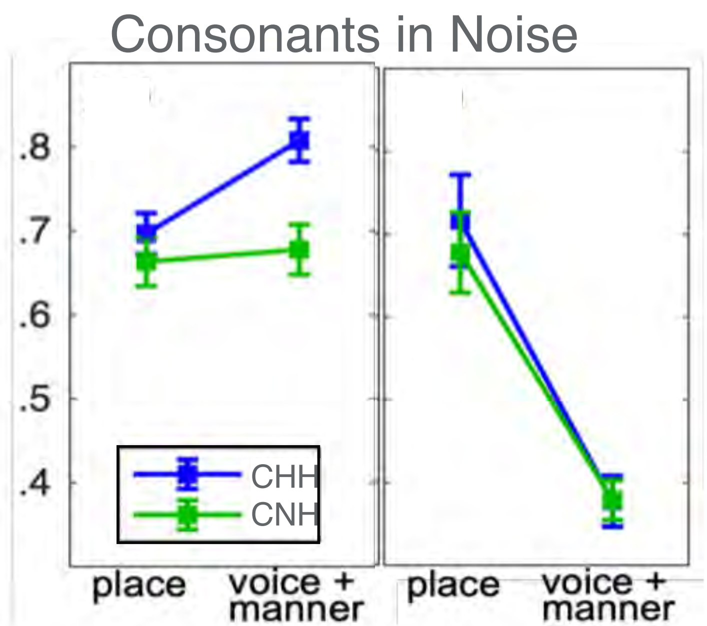
Results

- H1: Less redundancy between auditory and visual speech cue access in low-pass filtered condition than in high-pass filtered condition



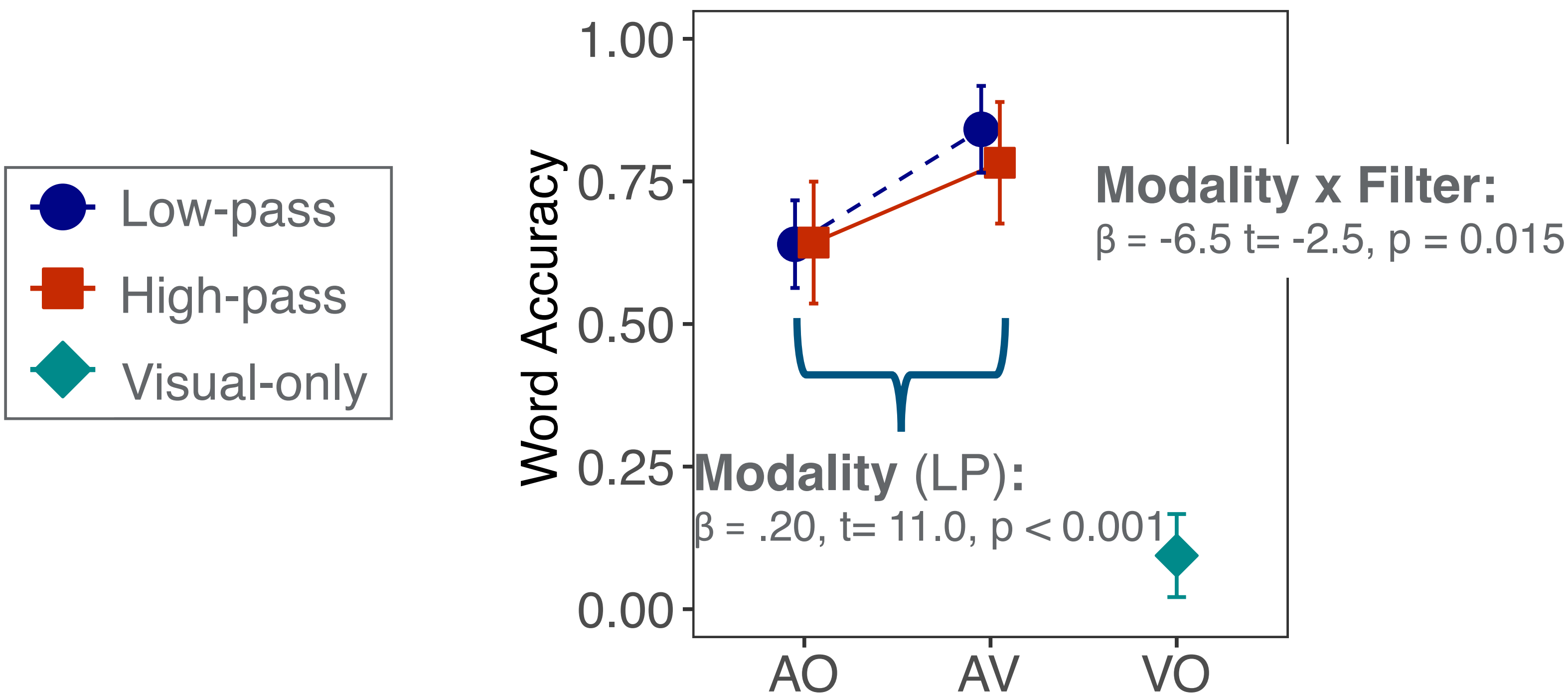
high access to **place cues** in visual speech

decreased access to **place cues** in low-pass filtered condition



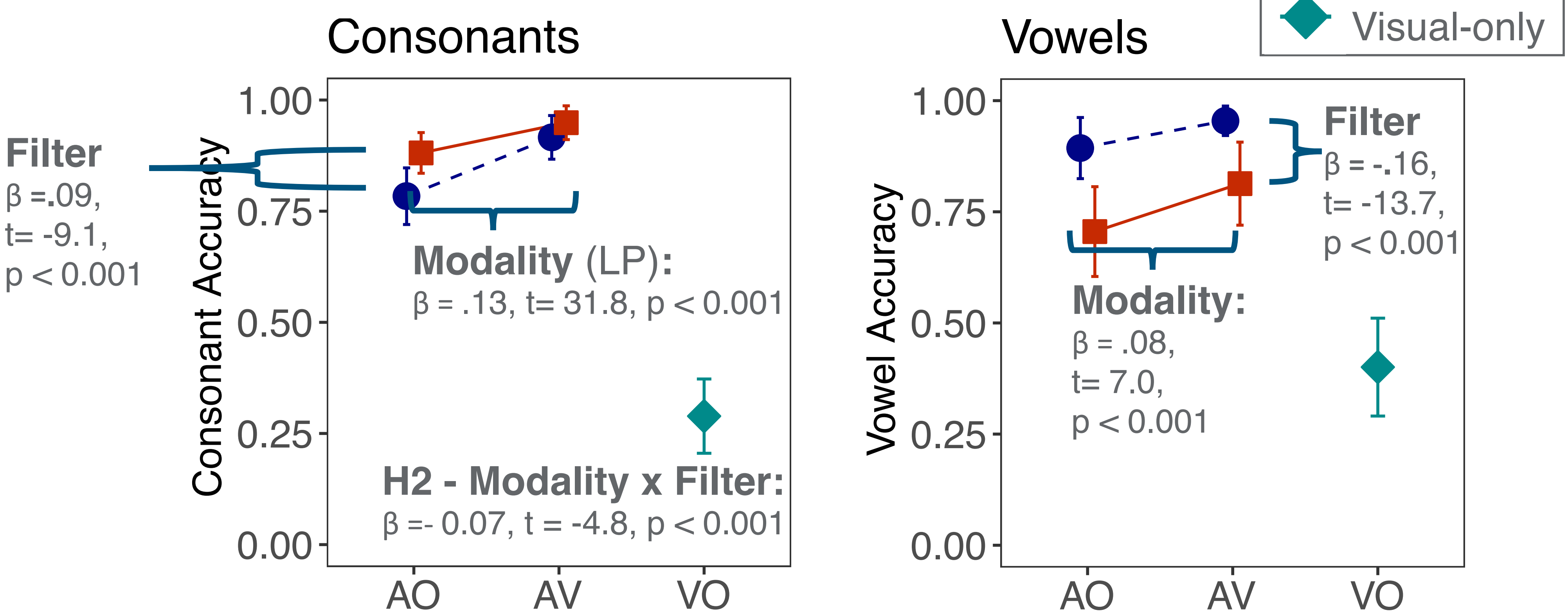
Word Accuracy

- H2: Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered



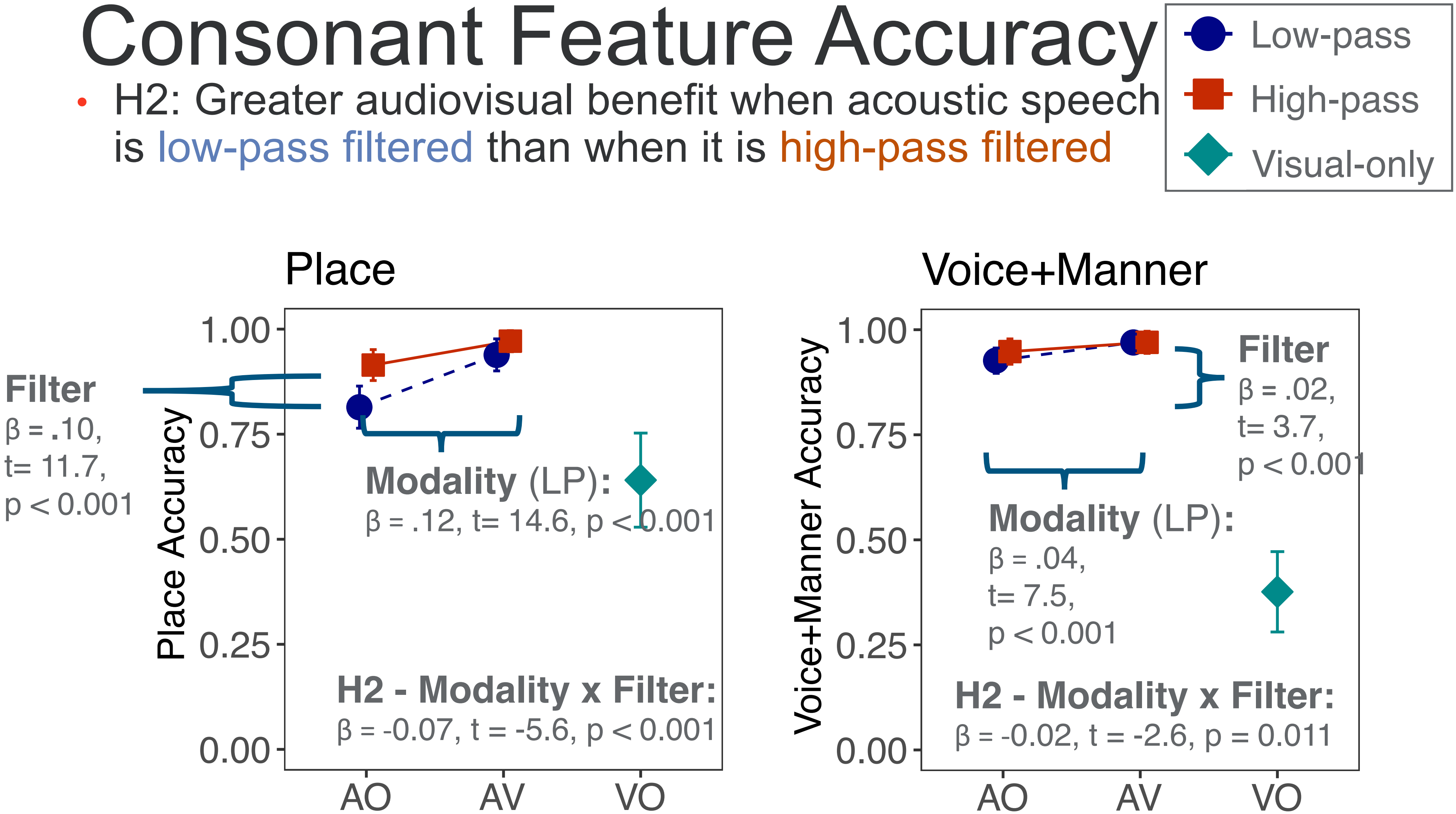
Consonant and Vowel Accuracy

- H2: Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered



Consonant Feature Accuracy

- H2: Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered



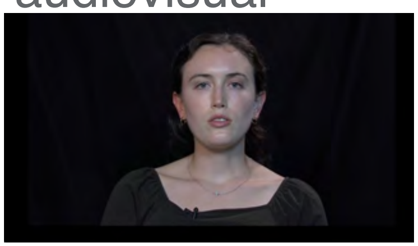
Stimuli: word-in-sentence recognition

- Multisyllabic Lexical Neighborhood Sentence Test for Children (Kirk et al. 2012)
  - 16 sentences/48 keywords per condition

Modality

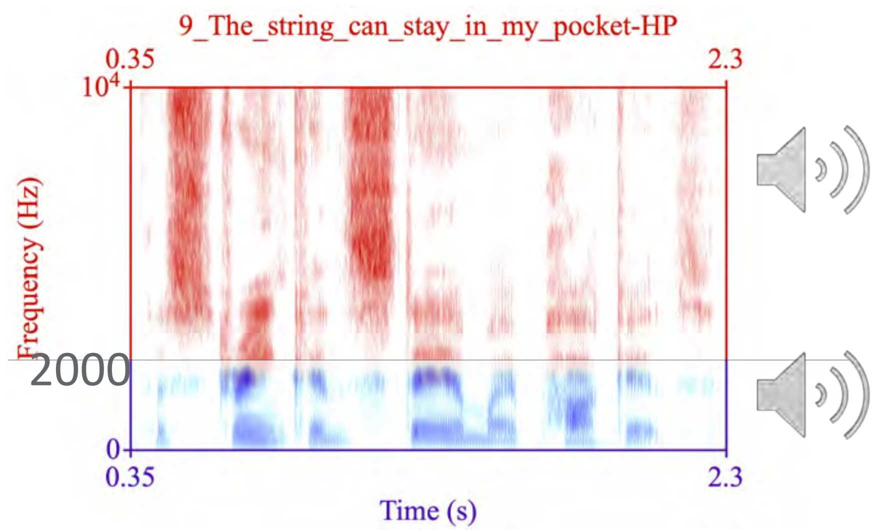
auditory-only

audiovisual



Acoustic Filtering Condition

FIR filter with 2 kHz cutoff

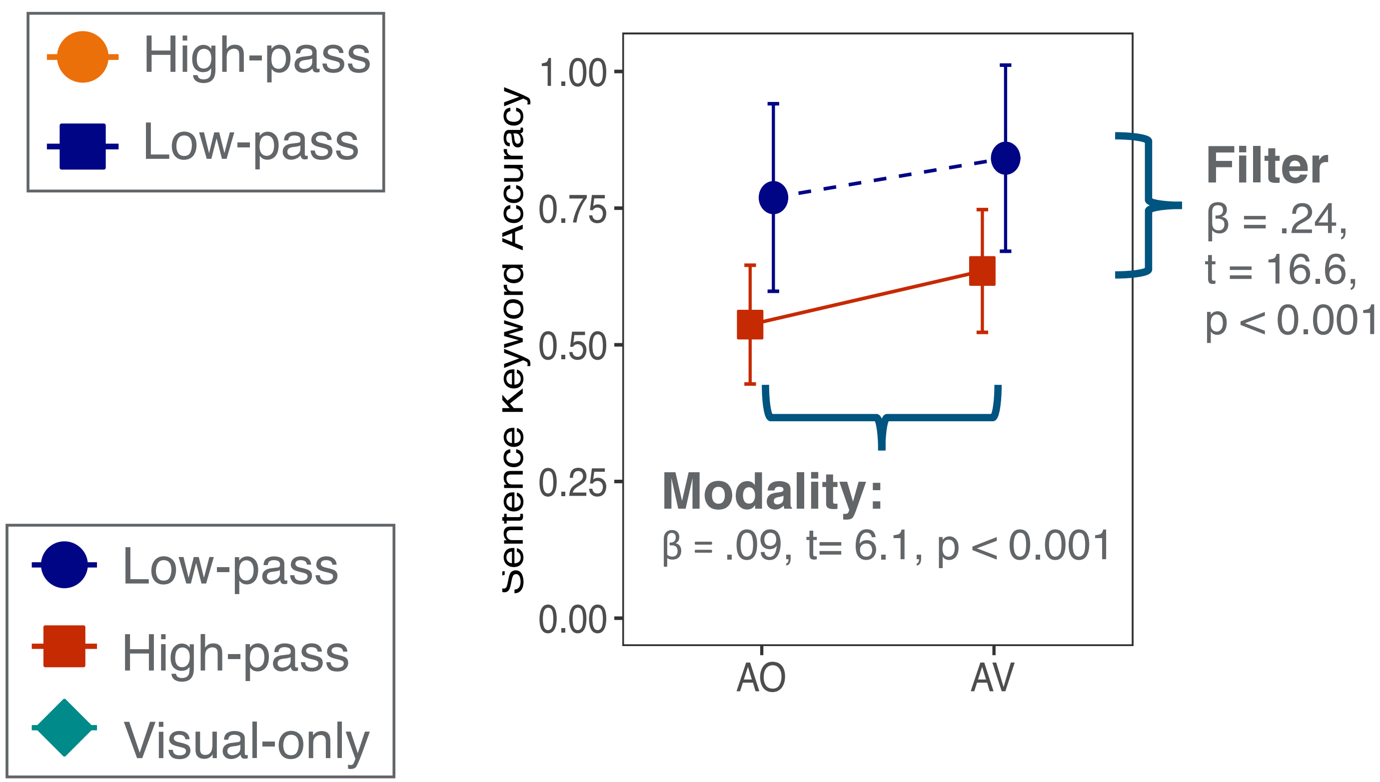


high-pass filtered

low-pass filtered

Sentence Keyword Accuracy

- H2: Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered

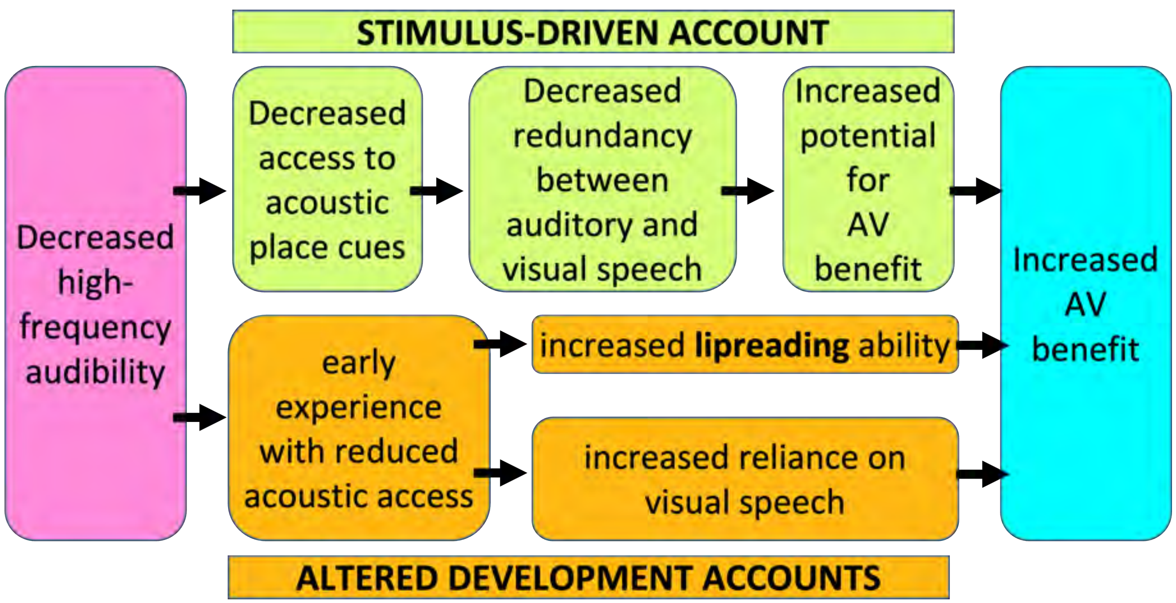


Does decreasing high-frequency audibility in **children with normal hearing** result in increased AV benefit?

- Less redundancy between auditory and visual speech cue access in low-pass filtered condition than in high-pass filtered condition
- Greater audiovisual benefit when acoustic speech is low-pass filtered than when it is high-pass filtered
  - words, phonemes, consonants, consonant place of articulation: yes
    - **Preliminarily suggests that some differences between CNH and CHH are due to differences in redundancy**
    - **However, cannot fully rule out ceiling effects as cause of interaction**
  - vowels, sentences
    - **Preliminarily suggests that some differences between CNH and CHH are not due to differences in redundancy**

Impact of frequency-specific audibility on audiovisual speech enhancement

- These data suggest that visual speech may be particularly helpful for children who have **decreased high-frequency audibility.**



Summary

- Visual speech cues can help to compensate for environmental noise and hearing loss.
- Visual speech cues can help in quiet conditions, when the listening task is difficult or the speech is complex.

Summary

Visual speech helps because it:

1. tells you when to listen.
2. provides cues to the auditory amplitude envelope of speech.
3. helps you to access audiovisual speech representations
4. helps you to segregate & attend to a talker.

Summary

- Infants, children, and adults all benefit from visual speech cues.
- The cues we use from visual speech seems to differ across development.

Summary

- School-age children who are hard of hearing benefit more from visual speech in noisy conditions than children with typical hearing.
- This may be due to enhanced lipreading skills in a subset of children.
- This may occur because decreased high-frequency audibility decreases the redundancy between auditory and visual speech, increasing the potential for AV benefit.
- It is possible that early experience with reduced acoustic access causes children who are hard of hearing to rely more on visual speech.

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