What Can Brain Imaging Tell Us about Cognitive and Language Development in Children who are Hard of Hearing?

Elizabeth Heinrichs-Graham, Ph.D.
Director, Cognitive and Sensory Imaging Laboratory (CASI Lab)
Institute for Human Neuroscience
Boys Town National Research Hospital

CASI LAB
Boys Town National Research Hospital

INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Outline

- Background
- Why the brain?
- Introduction to magnetoencephalography and oscillations
- Current work: Neural dynamics serving cognitive and language processing in children who are hard-of-hearing

Background

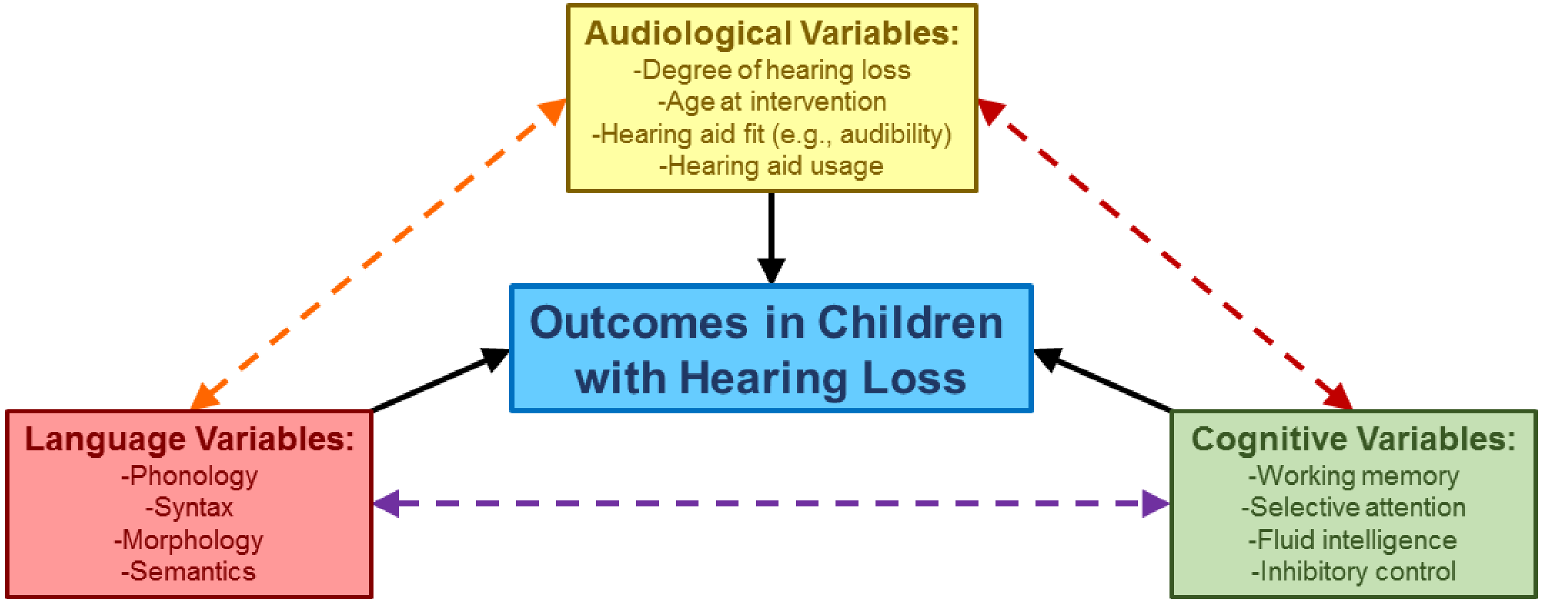
- Children who are hard-of-hearing who wear hearing aids experience significantly higher prevalence of difficulties in language and cognitive function relative to children with normal hearing
  - However, these difficulties are not universal
- Decrements persist despite early detection and intervention
  - Variability in auditory and language experience
  - Cognitive and sensory factors

Why the brain?

- Differences in brain function may inform the underpinnings of individual differences in behavior
    - Often at a thresholds below that of behavioral differences themselves
- Can determine interactions between in specific subprocesses of cognition simultaneously
- Can look at brain differences in *real-time* during behavior

Why the brain?

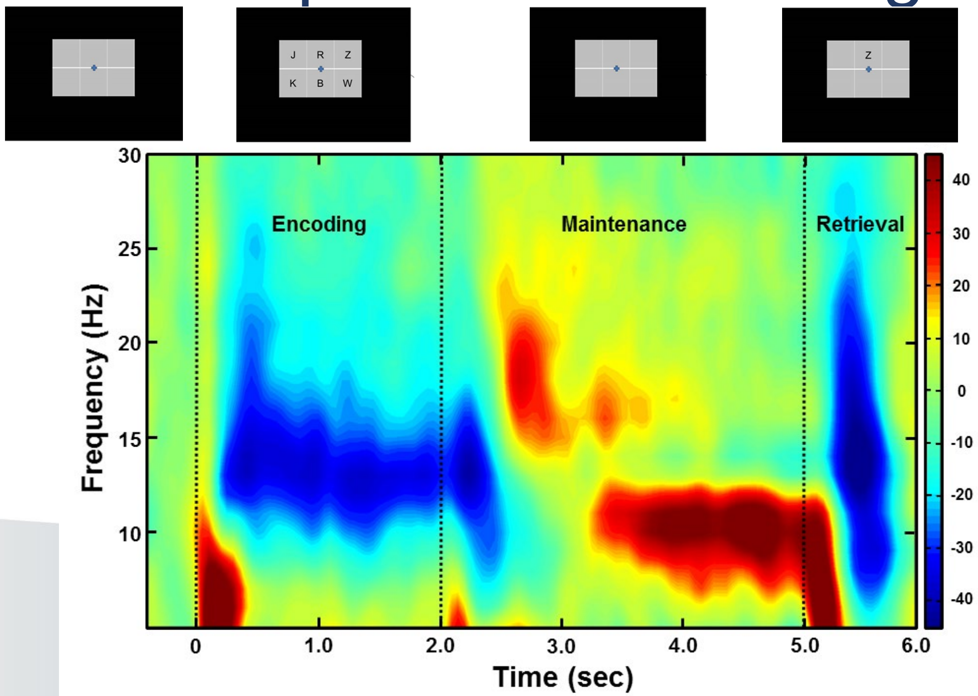
- In the context of children with hearing loss, investigating the brain changes that come with different auditory experiences may help us predict the cause of downstream behavioral differences



INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Oscillatory brain activity

- Brain rhythms are synchronous and frequency-specific
- Can look at how these brain rhythms change throughout the performance of a given task



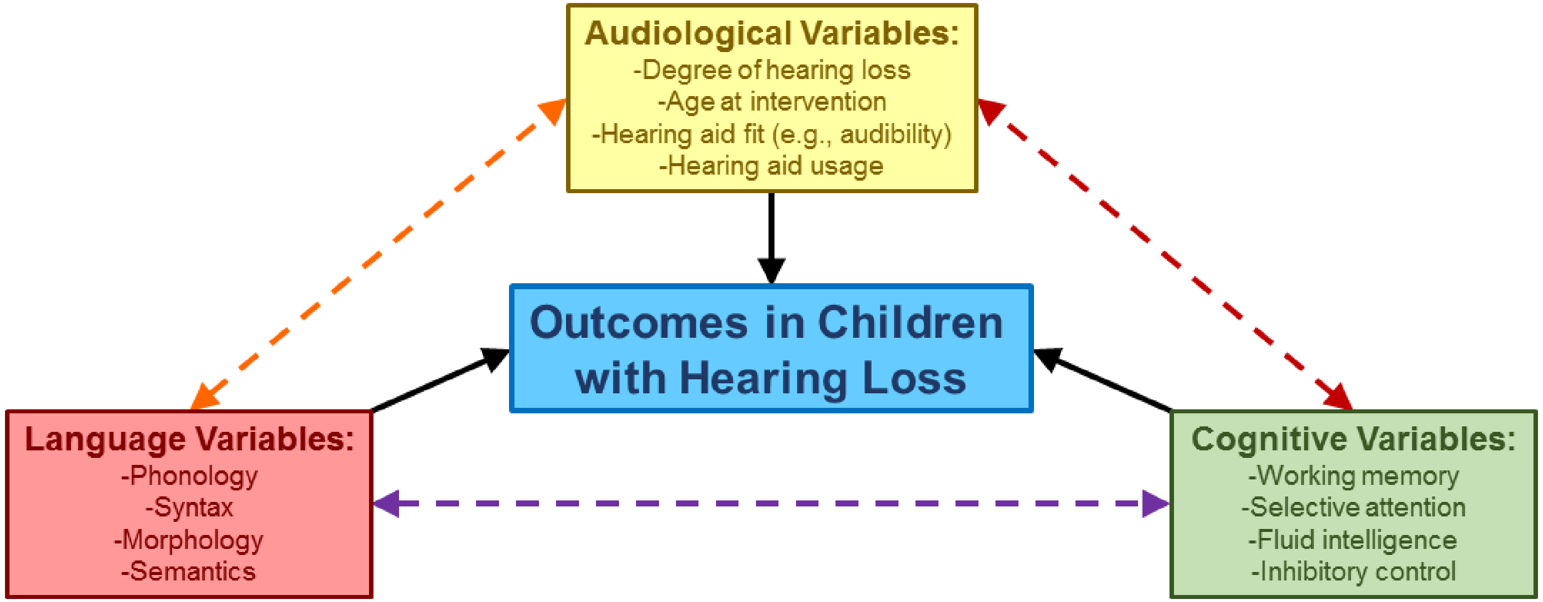
INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

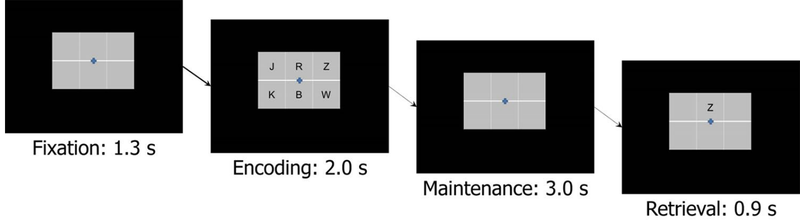
What is magnetoencephalography (MEG)?

- Noninvasive physiological recording device that measures the minute magnetic fields that emanate from the brain (10-15 T fields)
  - Spatial precision of 3-5 mm
  - Temporal accuracy of 1 ms
- Spatial and temporal resolution of MEG makes it an ideal instrument to study brain dynamics in the context of cognitive neuroscience

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

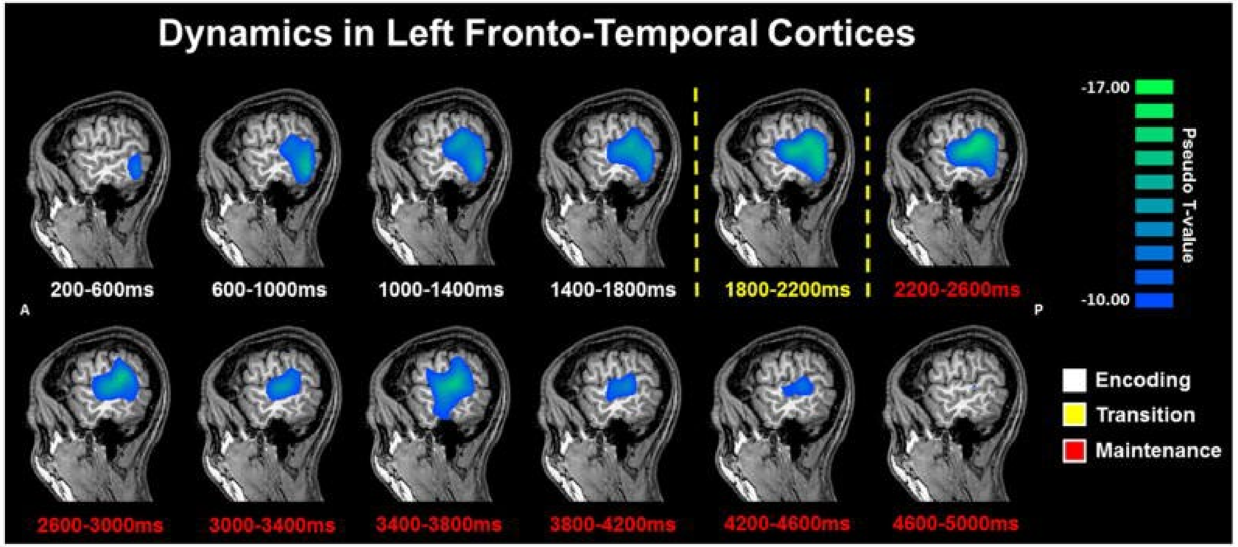
Current work:
The impact of mild-to-severe hearing loss on brain dynamics

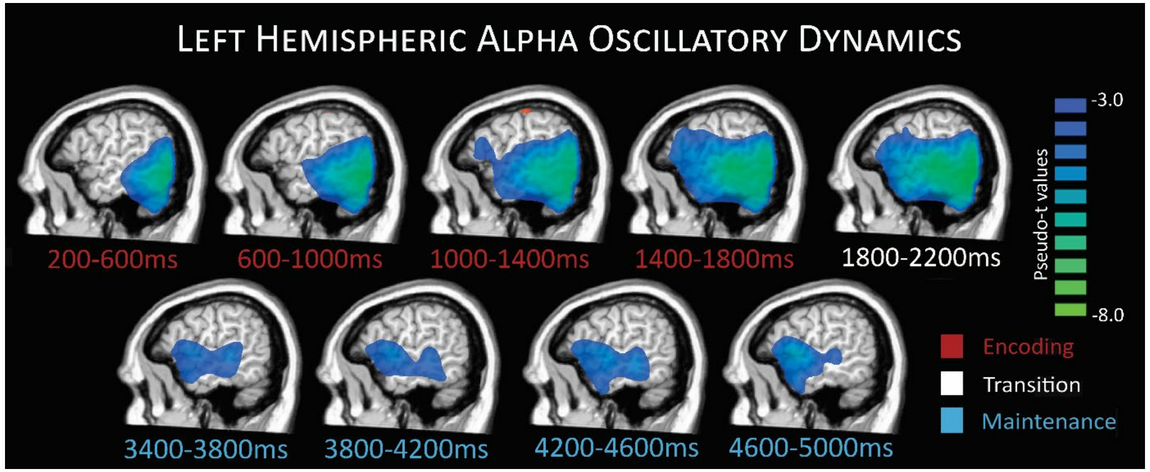




Verbal working memory function

- Background: typical oscillatory patterns

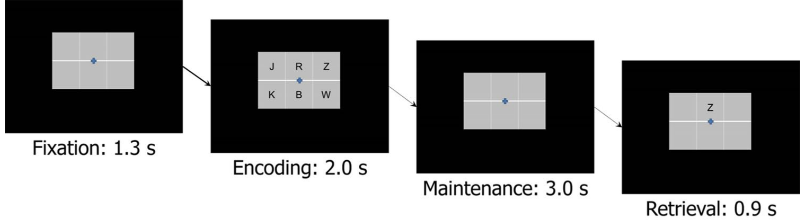




Healthy Adolescents
Embury et al. (2019) *NeuroImage*

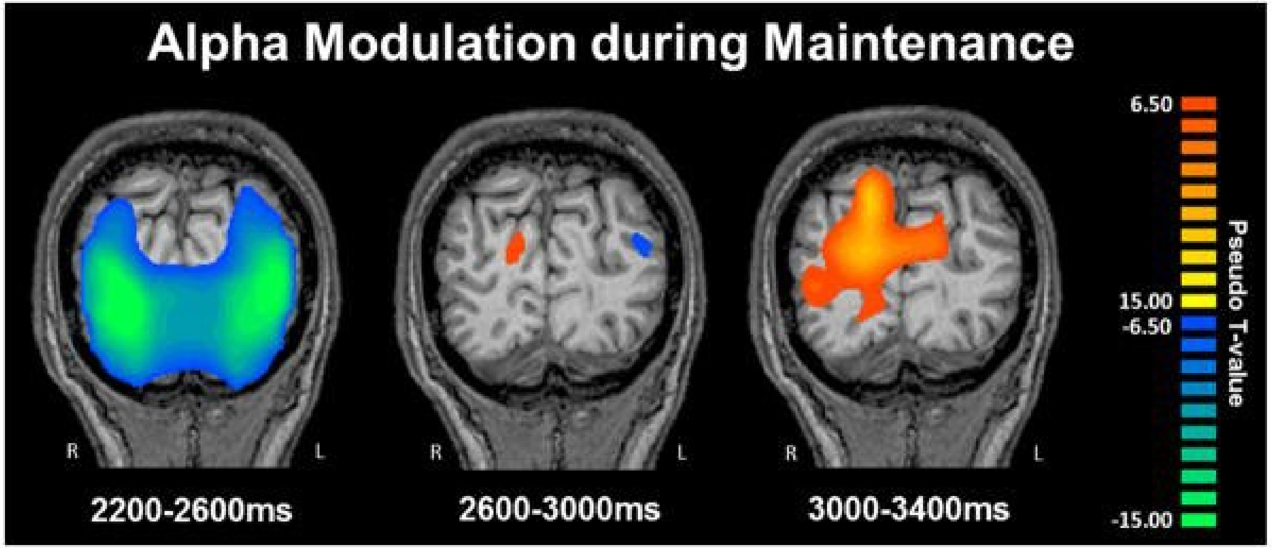
Healthy adults
Heinrichs-Graham & Wilson (2015) *Cortex*

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital



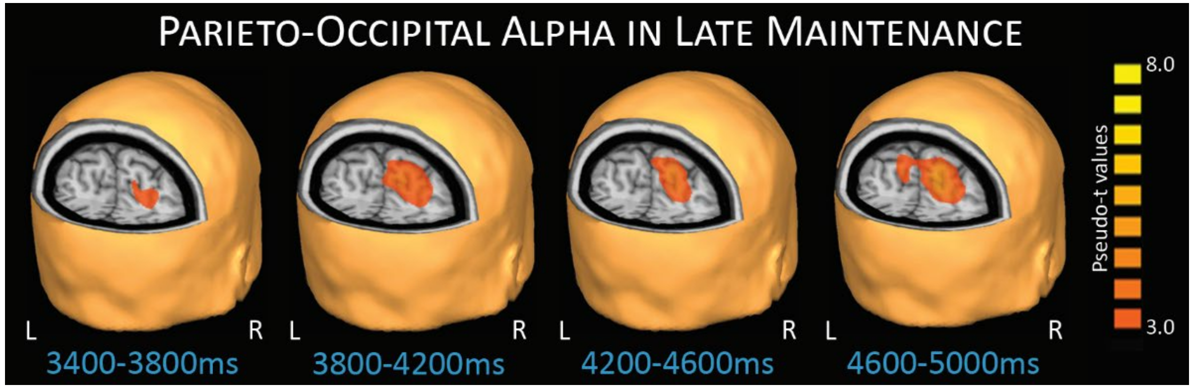
Verbal working memory function

- Background: typical oscillatory patterns



Healthy adults

Heinrichs-Graham & Wilson (2015) *Cortex*

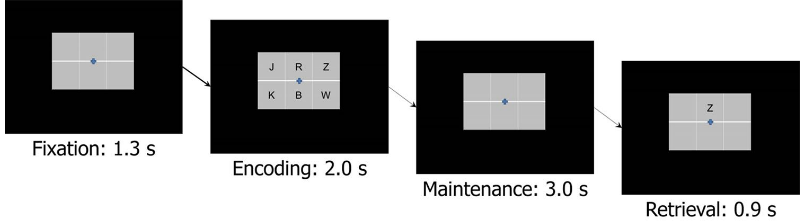


Healthy Adolescents

Embury et al. (2019) *NeuroImage*

INSTITUTE FOR HUMAN NEUROSCIENCE

Boys Town National Research Hospital

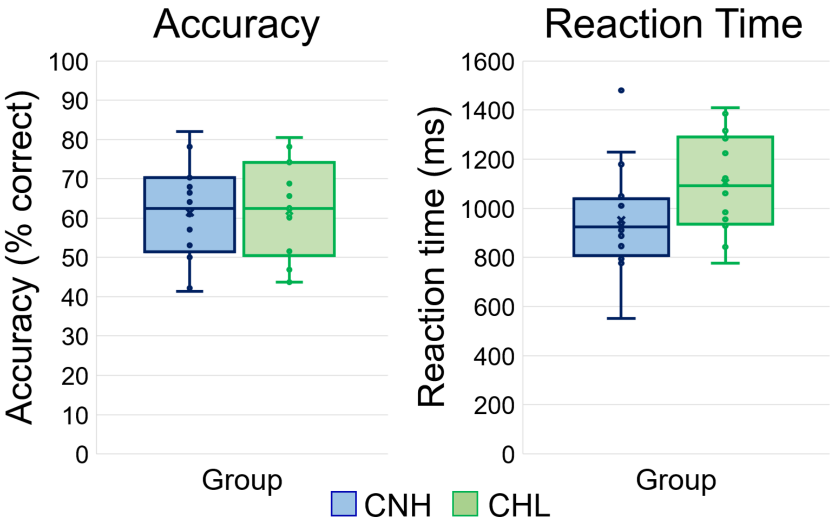


Verbal working memory function

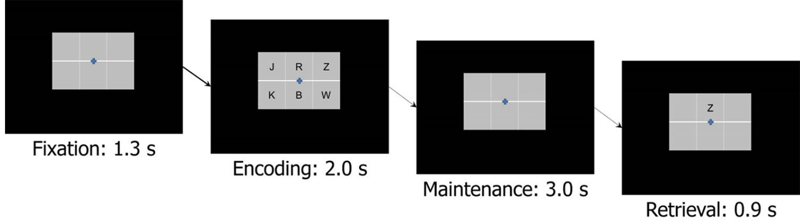
- Current study: 16 CNH and 14 CHH
  - 7-15 years old, half female

	CNH		CHH			
Metric	**Mean**	**SD**	**Mean**	**SD**	***t***	***p***
Age (months)	141.31	23.04	143.50	23.07	-.259	.797
Accuracy (% correct)	61.43	11.92	61.77	12.58	-.078	.938
Reaction time (ms)	980.58	223.62	1118.78	191.63	-1.804	.082
WASI-II Verbal Comprehension Index (VCI)	98.38	15.95	102.00	11.70	-.701	.489
WASI-II Perceptual Reasoning Index (PRI)*	105.56	18.00	108.36	10.37	-.529	.602

Notes: CNH = children with normal hearing; CHL = children with hearing loss;
*WASI-II PRI: Levene's Test for Equality of Variances was significant; *t* and *p* values are corrected accordin

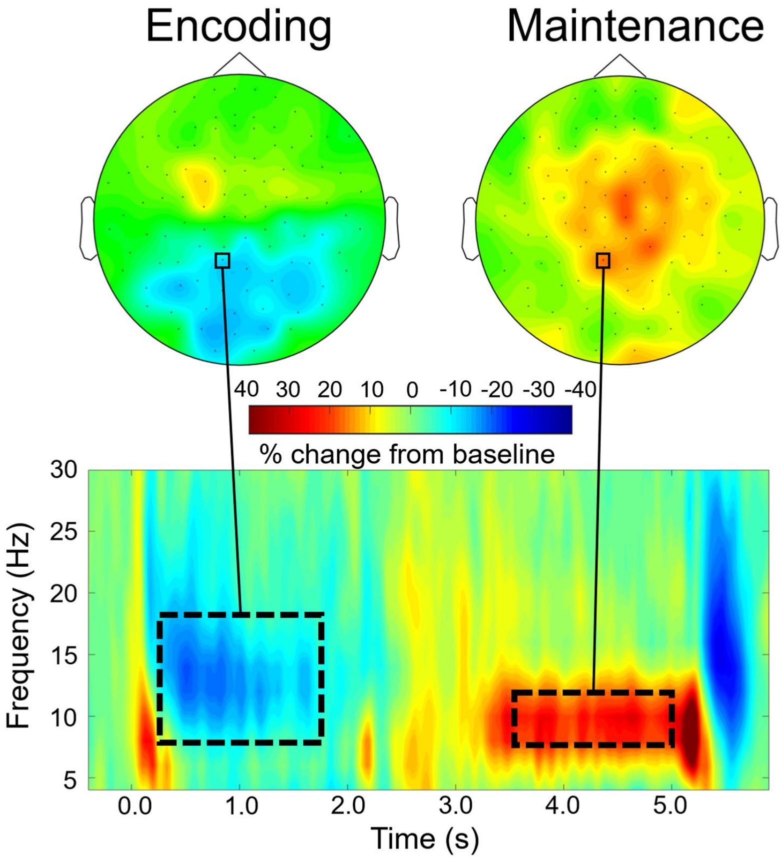


INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

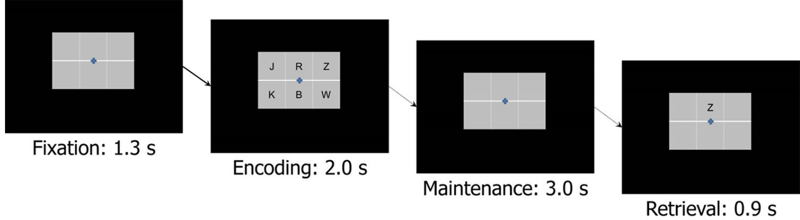


Verbal working memory function

- Time-frequency responses: encoding and maintenance

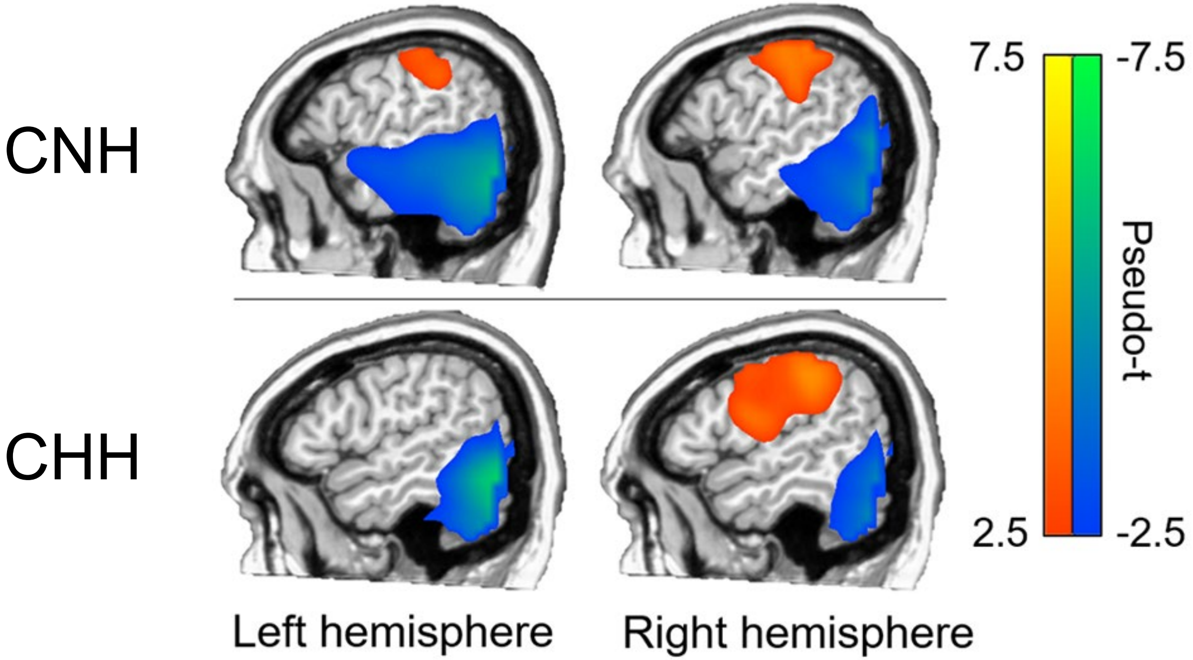


INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

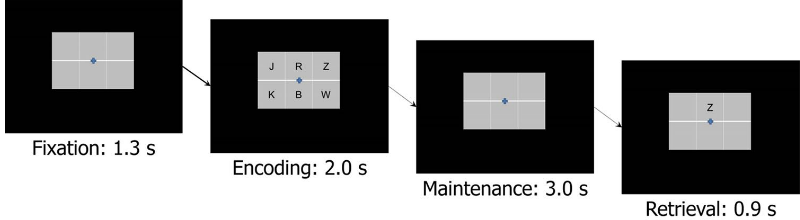


Verbal working memory function

- Neural oscillatory responses: Encoding

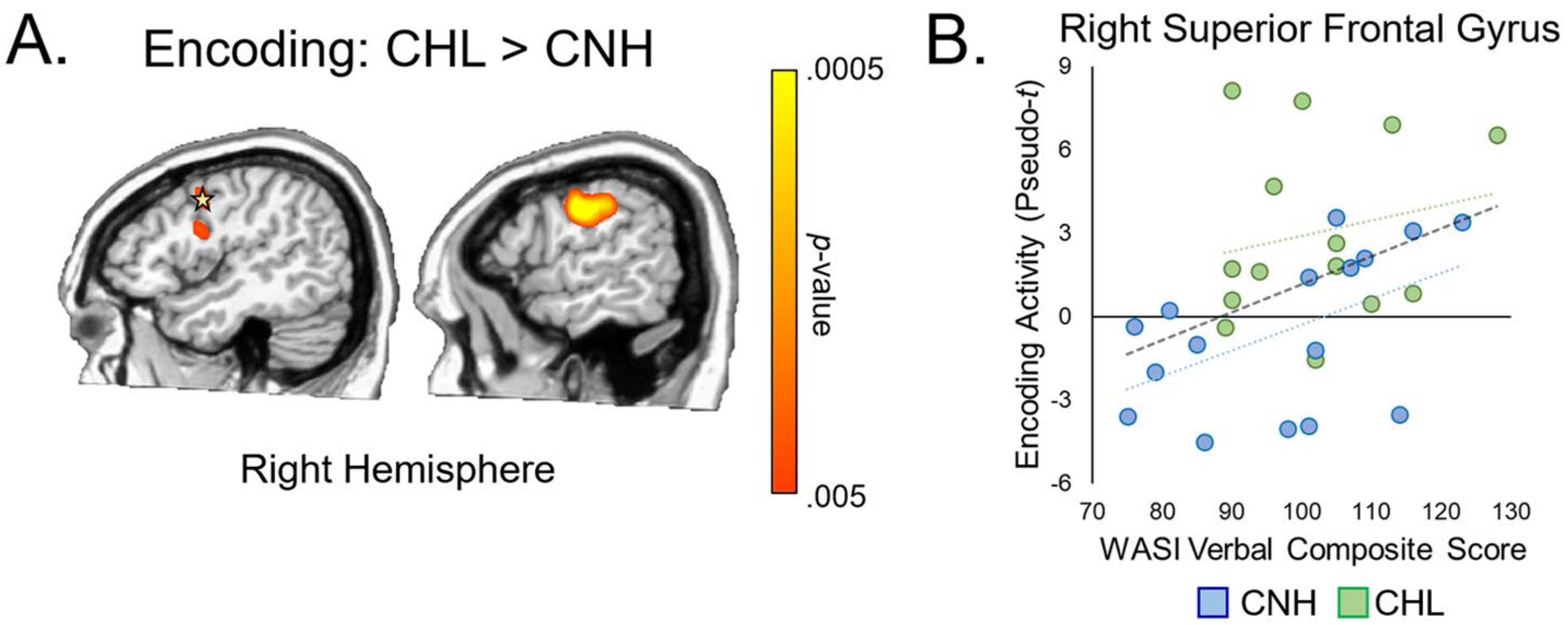


INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

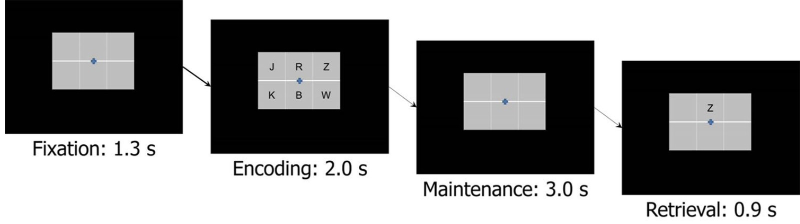


Verbal working memory function

- Neural oscillatory responses: Encoding

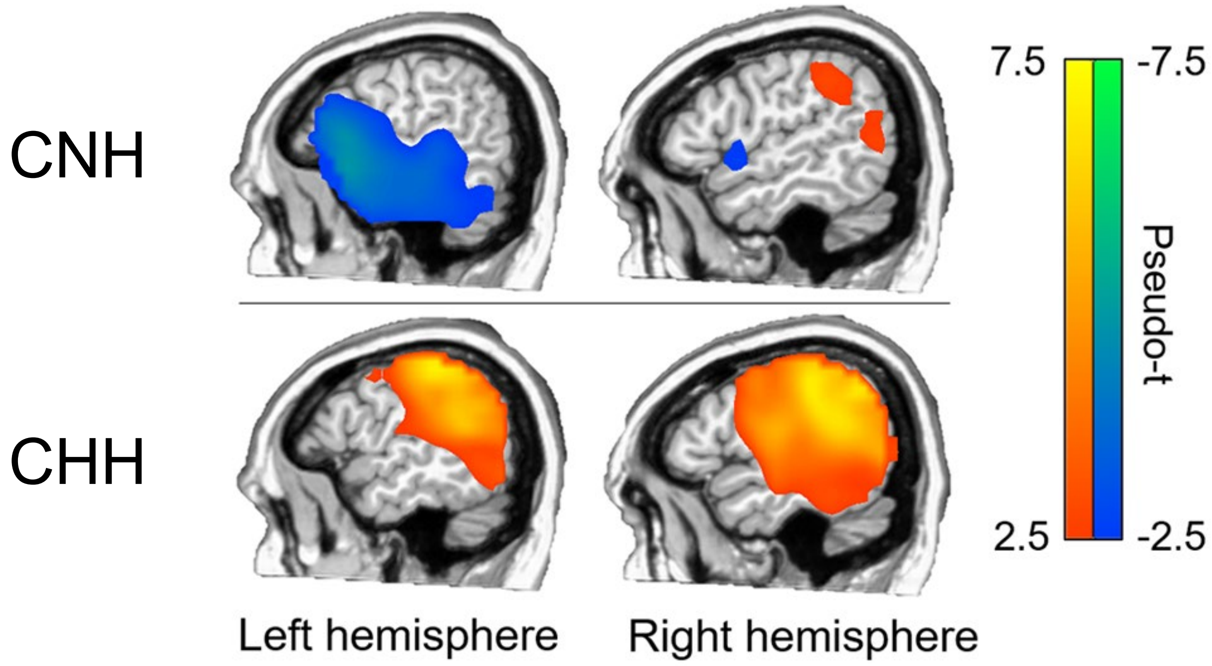


INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

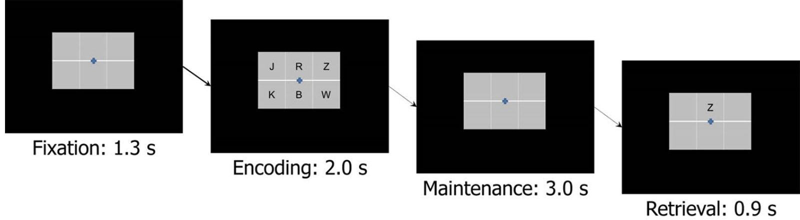


Verbal working memory function

- Neural oscillatory responses: Maintenance

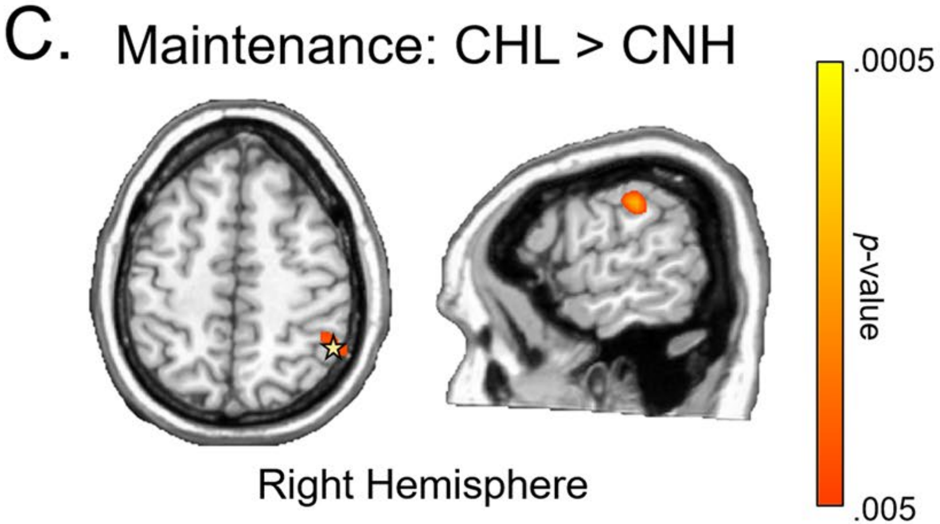


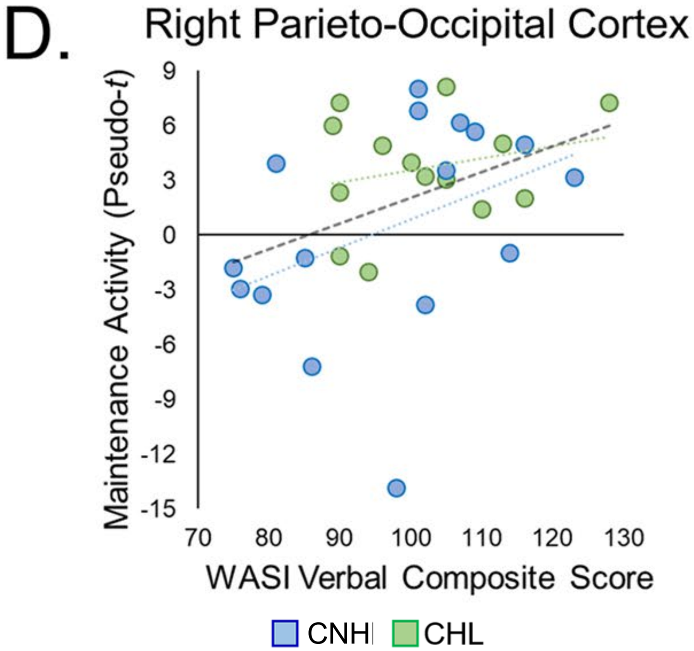
INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital



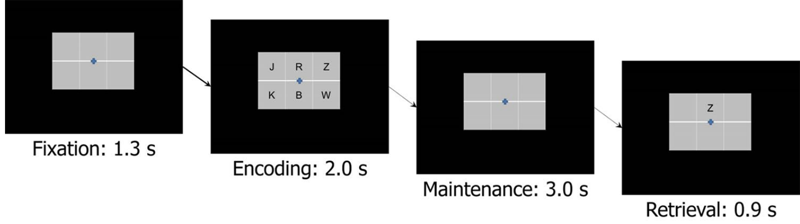
Verbal working memory function

- Neural oscillatory responses: Maintenance



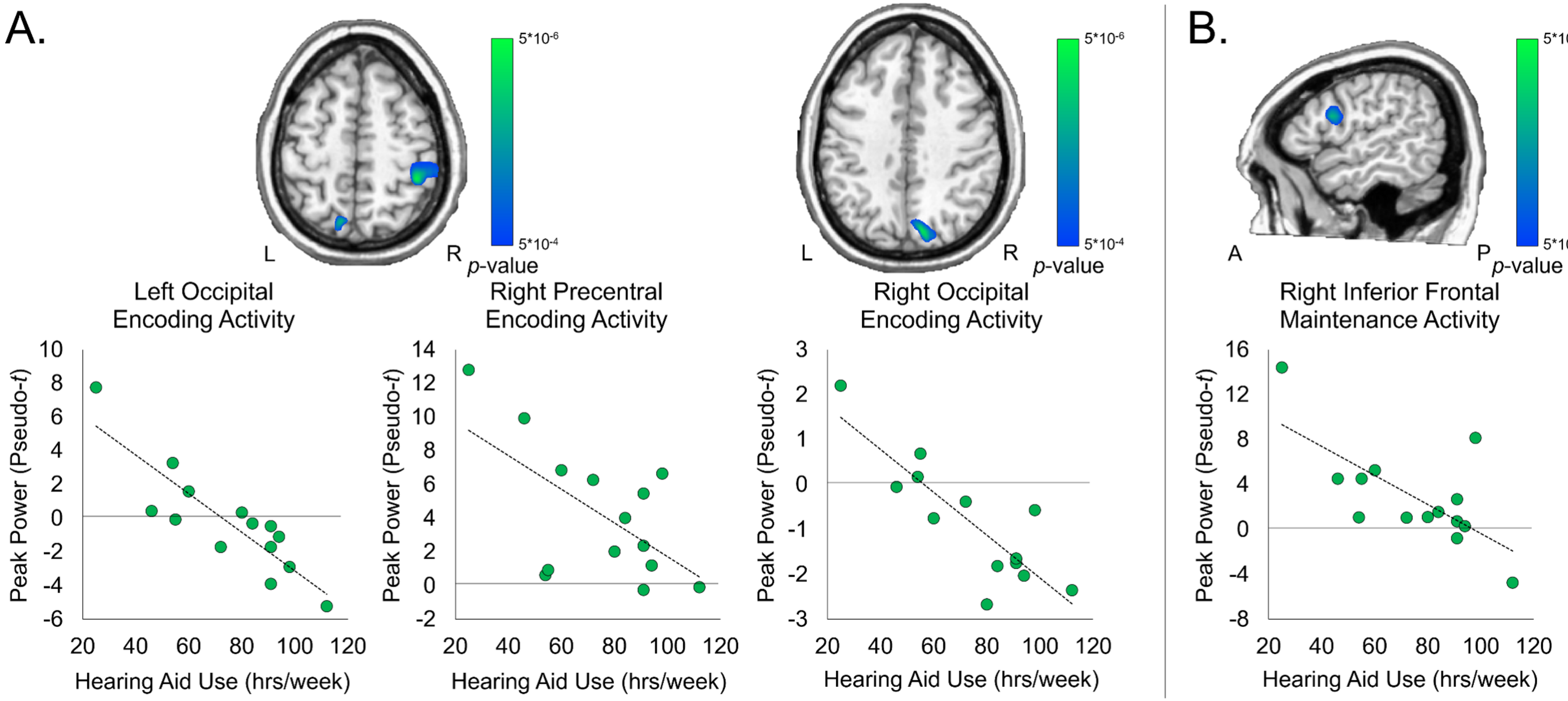


INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

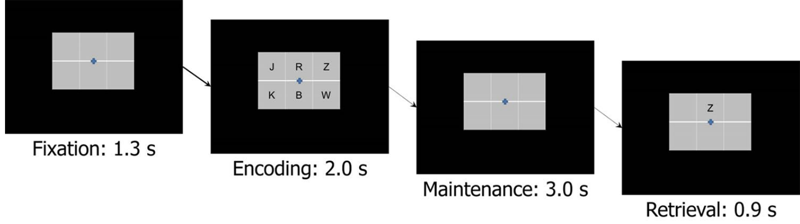


Verbal working memory function

- Effects of hearing aid use



INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

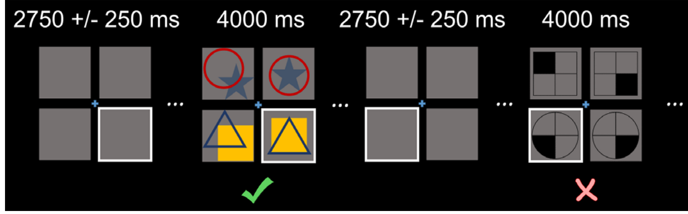


Verbal working memory function

- Interim conclusions
  - Group effects vs. individual differences
  - Relationship between brain responses and behavior
  - “Normalization” of activity with greater hearing aid use

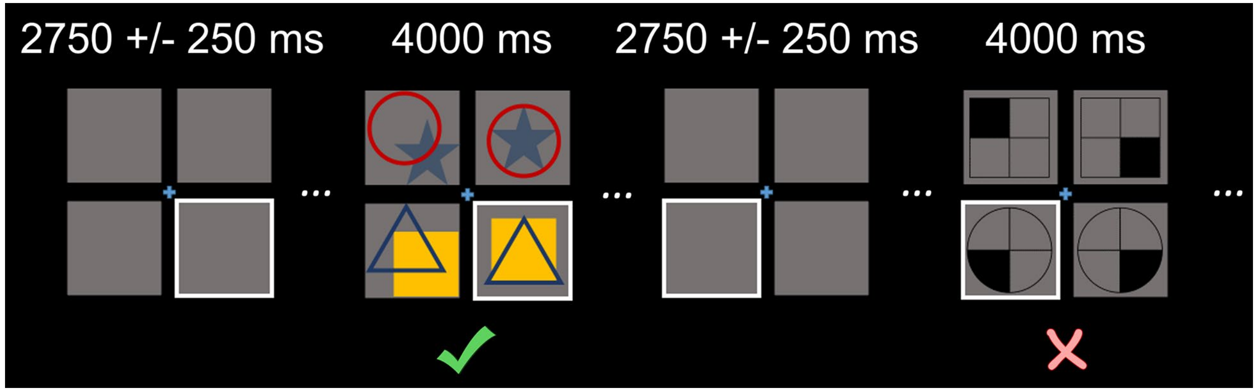
- Clinical applications
  - Relationship between working memory and language function
  - Differences between encoding and maintenance
  - Importance of consistent auditory experience

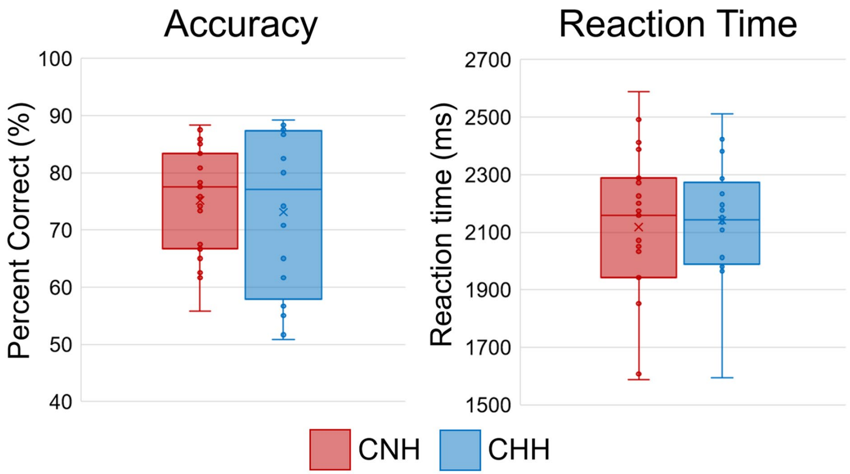
INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital



Fluid Intelligence

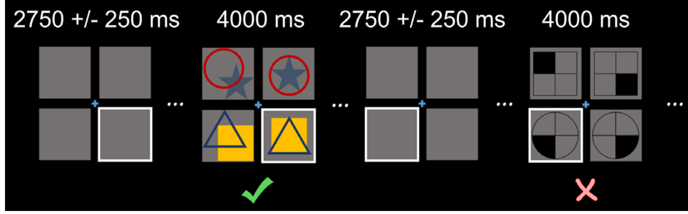
- 19 CNH and 16 CHH
  - 7-15 years old, half female





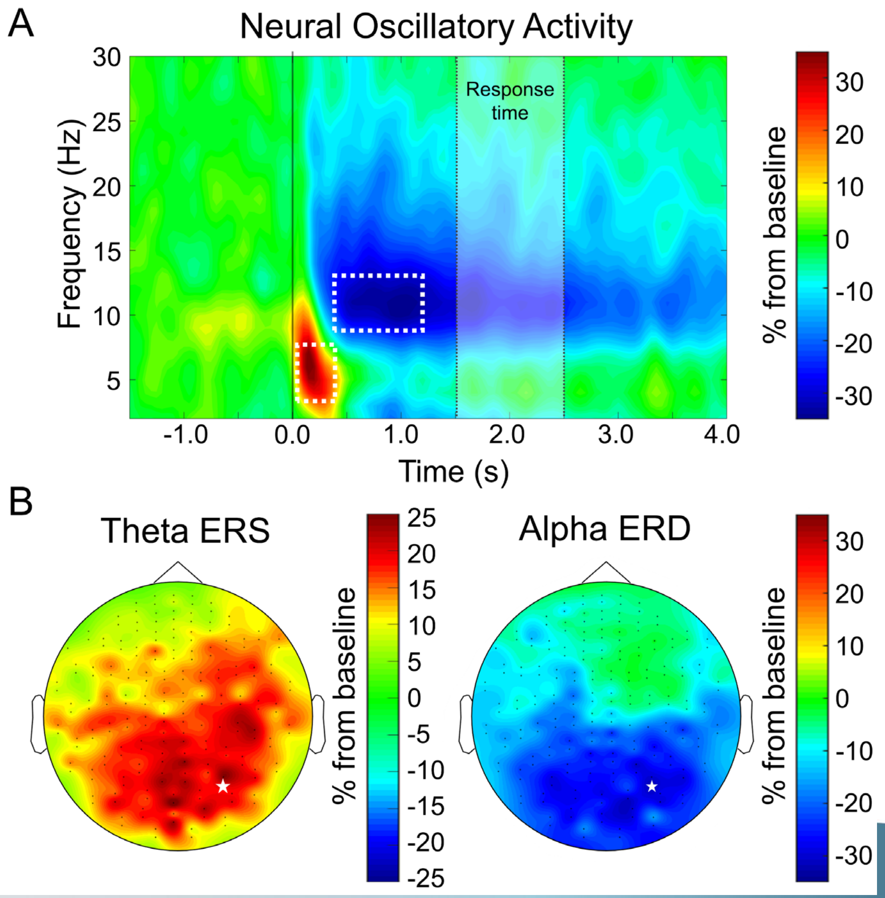
*$t(25.4) = 0.478, p = .636$ $t(33) = -0.276, p = .785$

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital



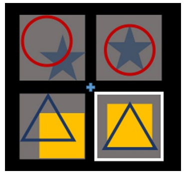
Fluid Intelligence

- Time-frequency responses

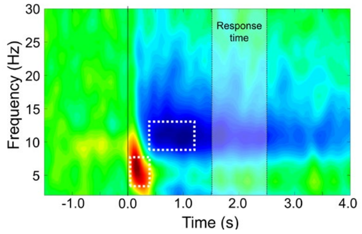


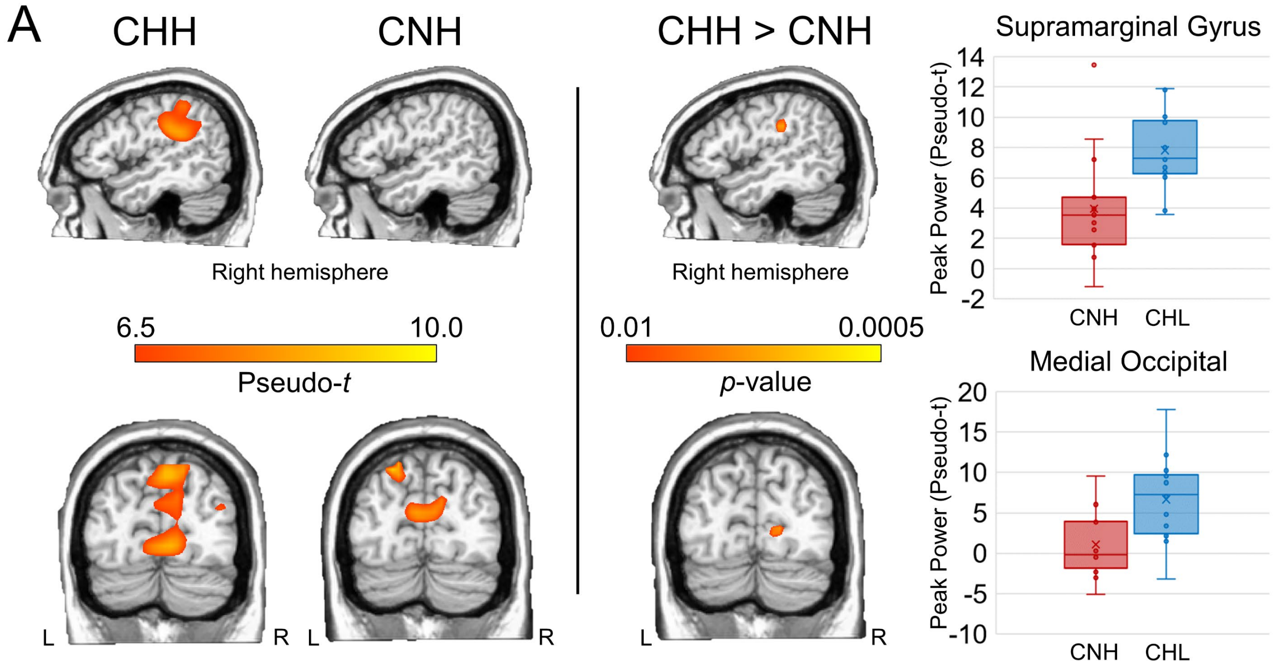
INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

Impact of auditory experience on fluid intelligence dynamics



- Neural oscillatory responses: Early theta

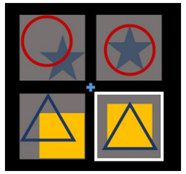


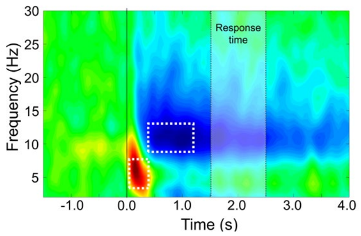


INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

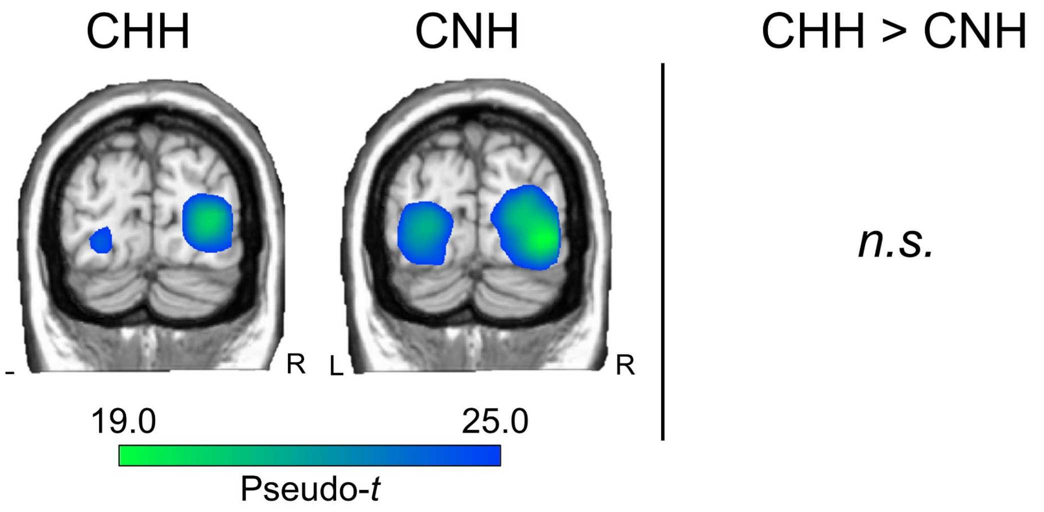
Heinrichs-Graham et al. (2022) *Brain Communications*

Impact of auditory experience on fluid intelligence dynamics





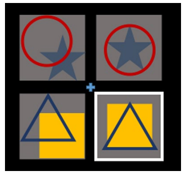
- Neural oscillatory responses: Later alpha



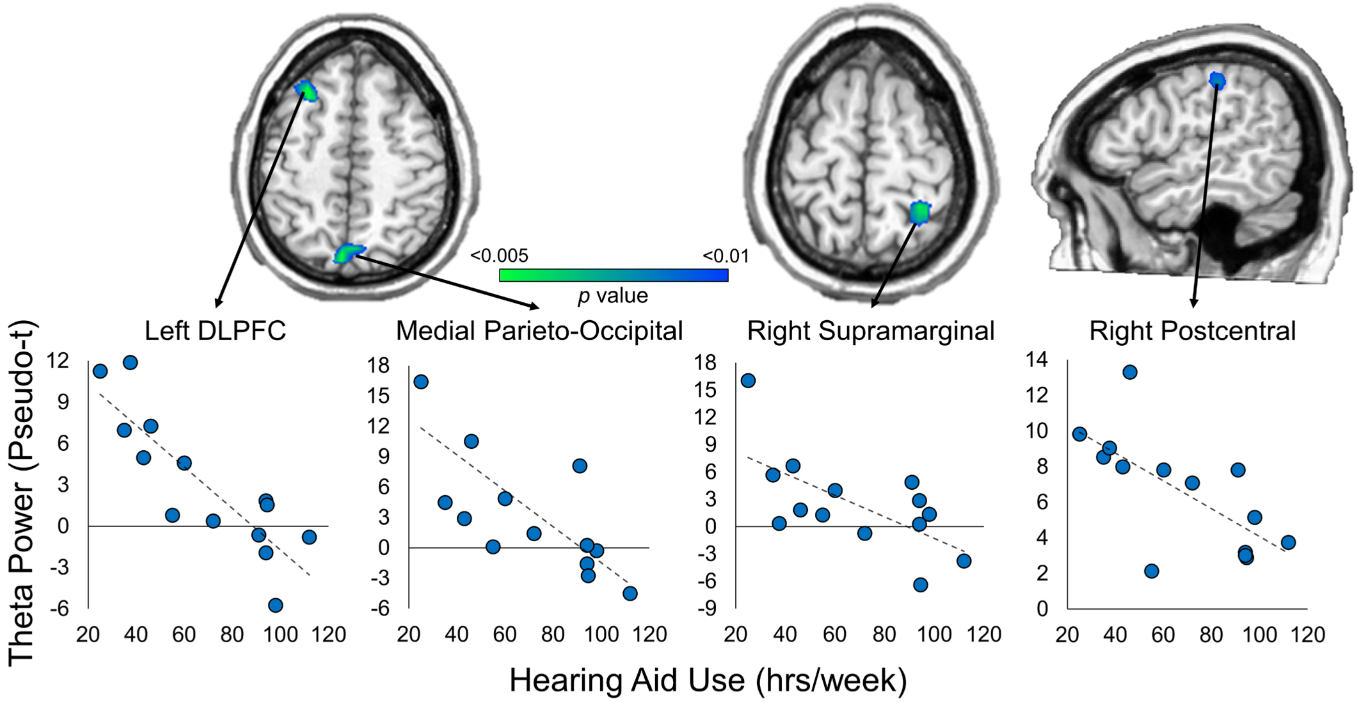
INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

Heinrichs-Graham et al. (2022) *Brain Communications*

Impact of auditory experience on fluid intelligence dynamics



- Theta oscillatory responses: Hearing aid use
  - No significant correlations with alpha activity



Heinrichs-Graham et al. (2022) *Brain Communications*

Interim Conclusions

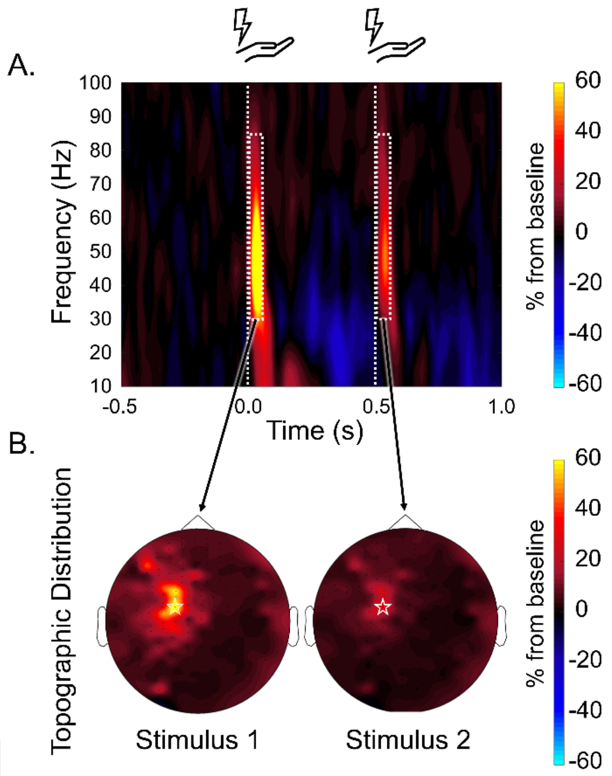
- Children who are hard of hearing show phase-specific elevations in activity in order to perform cognitive tasks, *despite comparable performance*

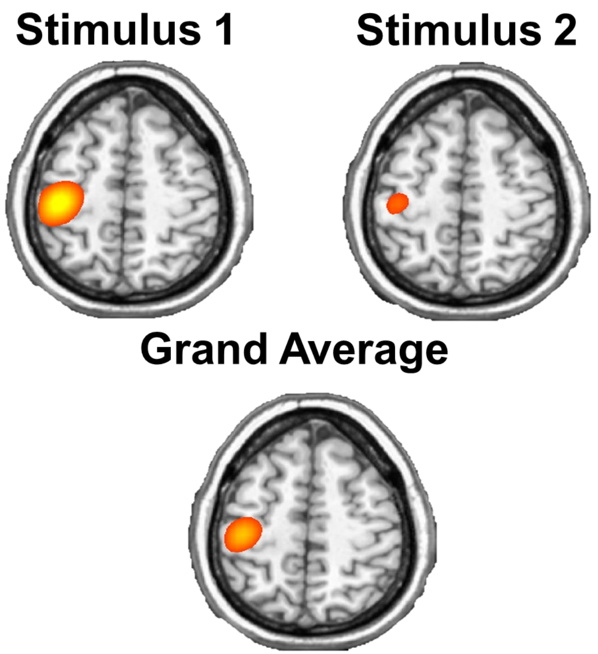
- Consistent hearing aid use serves to normalize activity throughout regions that have been implicated in cognitive processing

- Importance of groupwise comparisons and individual differences

Current work: Impact of hearing loss on neural markers of sensory processing

- Somatosensory Gating



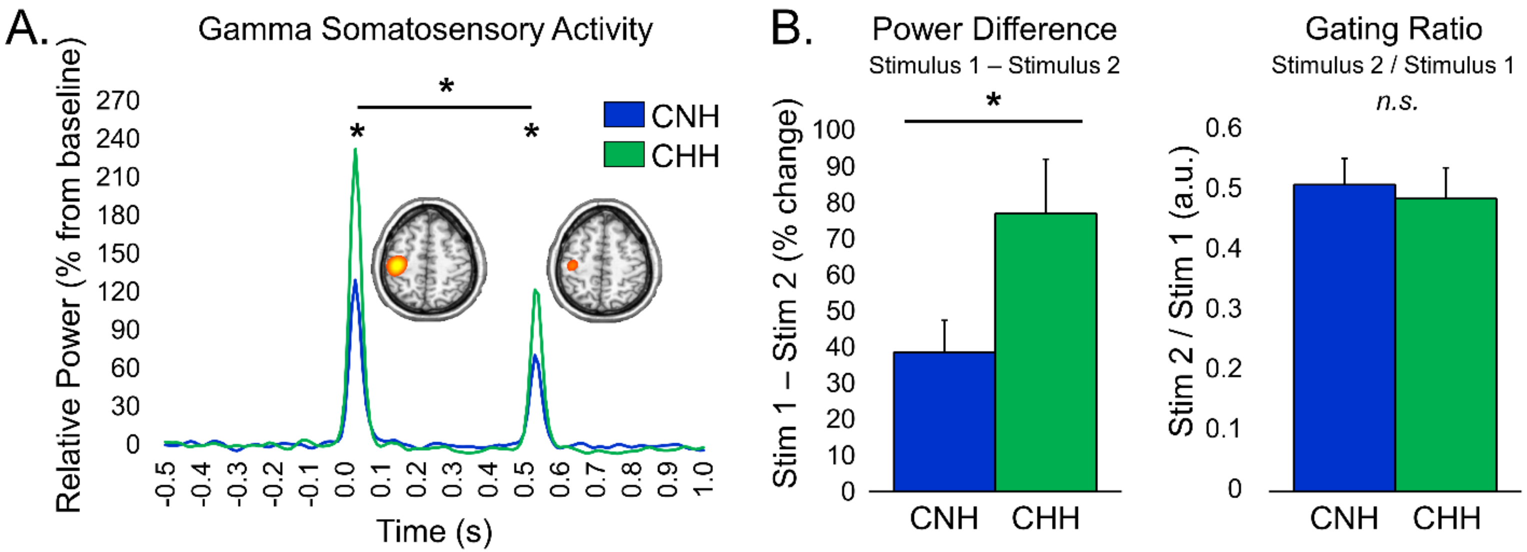


INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Heinrichs-Graham et al. (in press) *Cerebral Cortex*

Current work: Impact of hearing loss on neural markers of sensory processing

- Somatosensory Gating

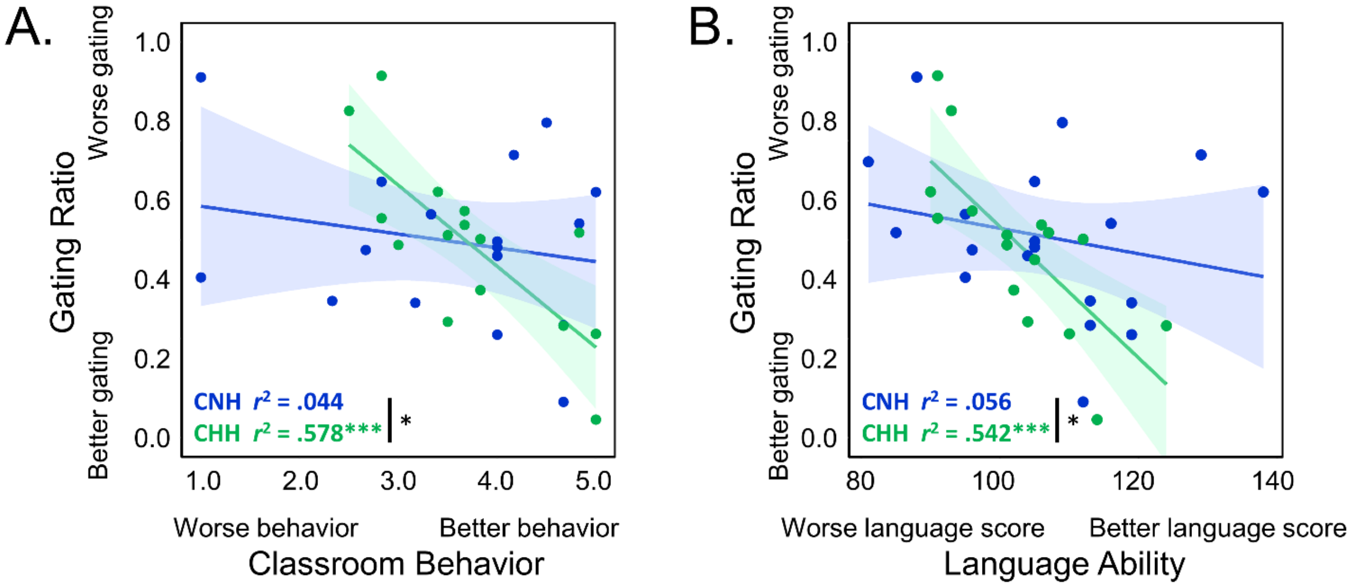


INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Heinrichs-Graham et al. (in press) *Cerebral Cortex*

Current work: Impact of hearing loss on neural markers of sensory processing

- Somatosensory Gating



INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Heinrichs-Graham et al. (in press) *Cerebral Cortex*

Interim Conclusions

- Children who are hard of hearing have hyper-responsivity to somatosensory stimulation, but intact gating relative to children with normal hearing

- Individual variability in gating is related to verbal and academic performance in CHH but not CNH

- Future research should consider how CHH process their multisensory environment

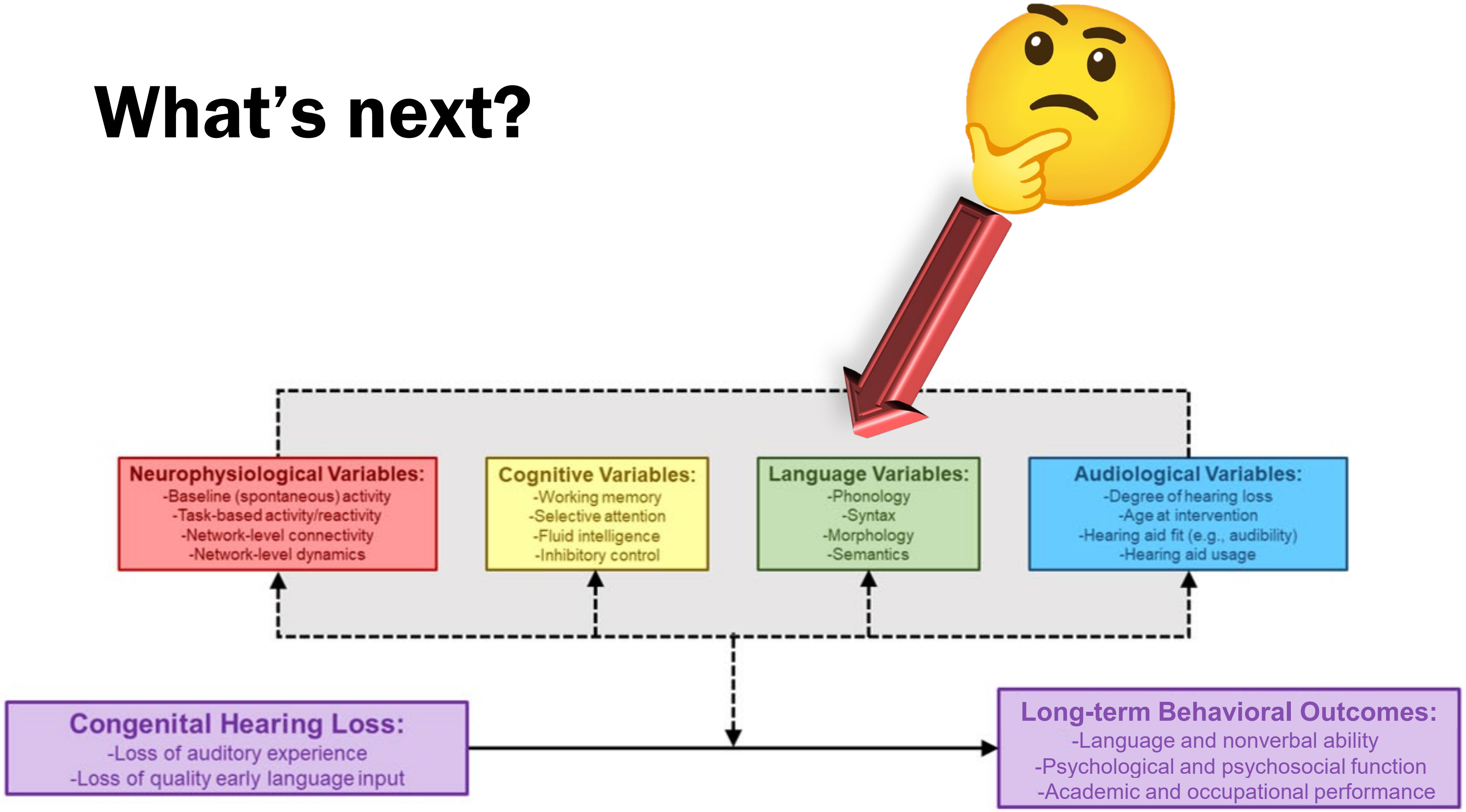
INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

Overall Conclusions

- The brain matters!
- Children who are hard of hearing show differential patterns of brain activity when performing cognitive, sensory, and motor activities, despite behavioral performance
- Variability in these compensatory patterns may relate to variability in real-world behavioral performance
  - Exhaustion of neural resources in our big, loud, distracting, demanding world

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

What's next?



INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Next-generation MEG: Optically-pumped magnetometry (OPM)

- From measuring behavioral ability in late childhood and adolescence to predicting milestones in infancy and early childhood

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

Acknowledgements

Boys Town National Research Hospital

Ryan McCreery, Ph.D.
Lori Leibold, Ph.D.
Merry Spratford, Au.D.
Jake Eastman
Christine Embury
Anson Lee
Amanda Benavente
Mike Shen
Phillip Astorino
Augusto Diedrich
Mary Thomas
Amberlee Haggerty
Maggie Heusinkvelt
All the other HH research groups for their recruitment help!

NIH NIGMS

University of Iowa

Elizabeth Walker, Ph.D.

Jean Hong

INSTITUTE FOR HUMAN NEUROSCIENCE
Boys Town National Research Hospital

Acknowledgements

Research reported in this presentation was supported by the National Institute of General Medical Sciences (P20GM144641, PI: Wilson) and the National Institute of Deafness and Communication Disorders (R21DC020270, PI: Heinrichs-Graham) of the National Institutes of Health. The funders had no role in the study design, analysis, or interpretation of the data.

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital

Acknowledgements

CASI LAB
Boys Town National Research Hospital

INSTITUTE FOR HUMAN
NEUROSCIENCE
Boys Town National Research Hospital