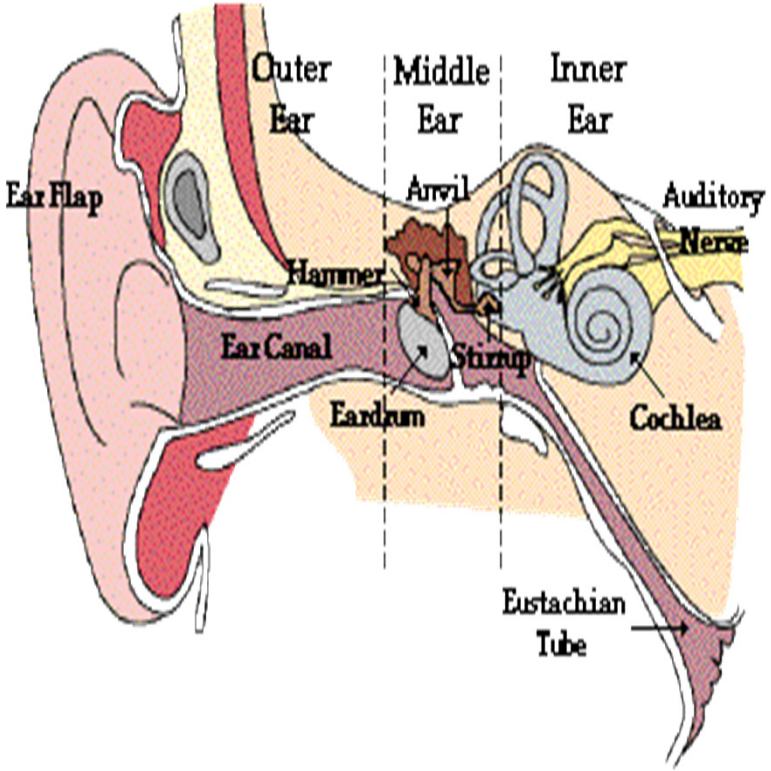
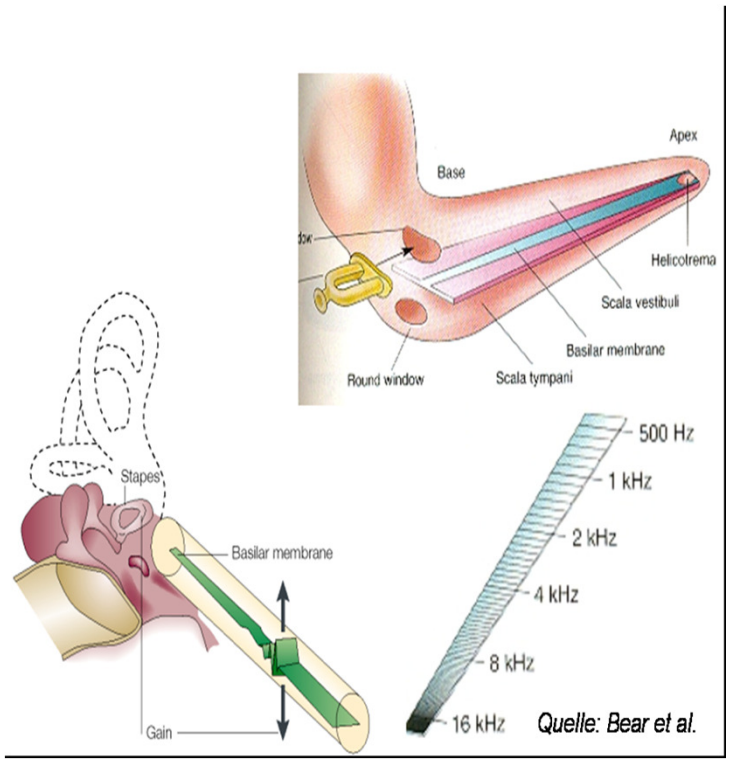
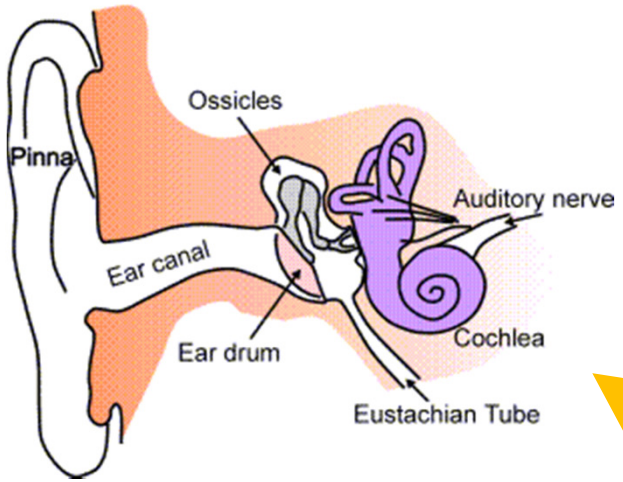
Central Auditory Processing: From Molecule to Behavior

Patrick C. M. Wong
The Chinese University of Hong Kong
Northwestern University
p.wong@cuhk.edu.hk
brain.cuhk.edu.hk

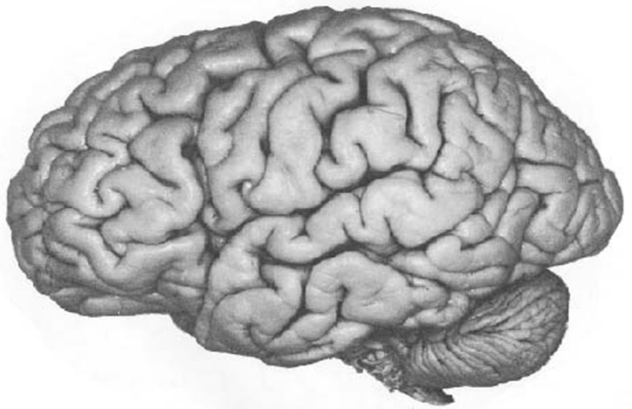
“The Auditory System”

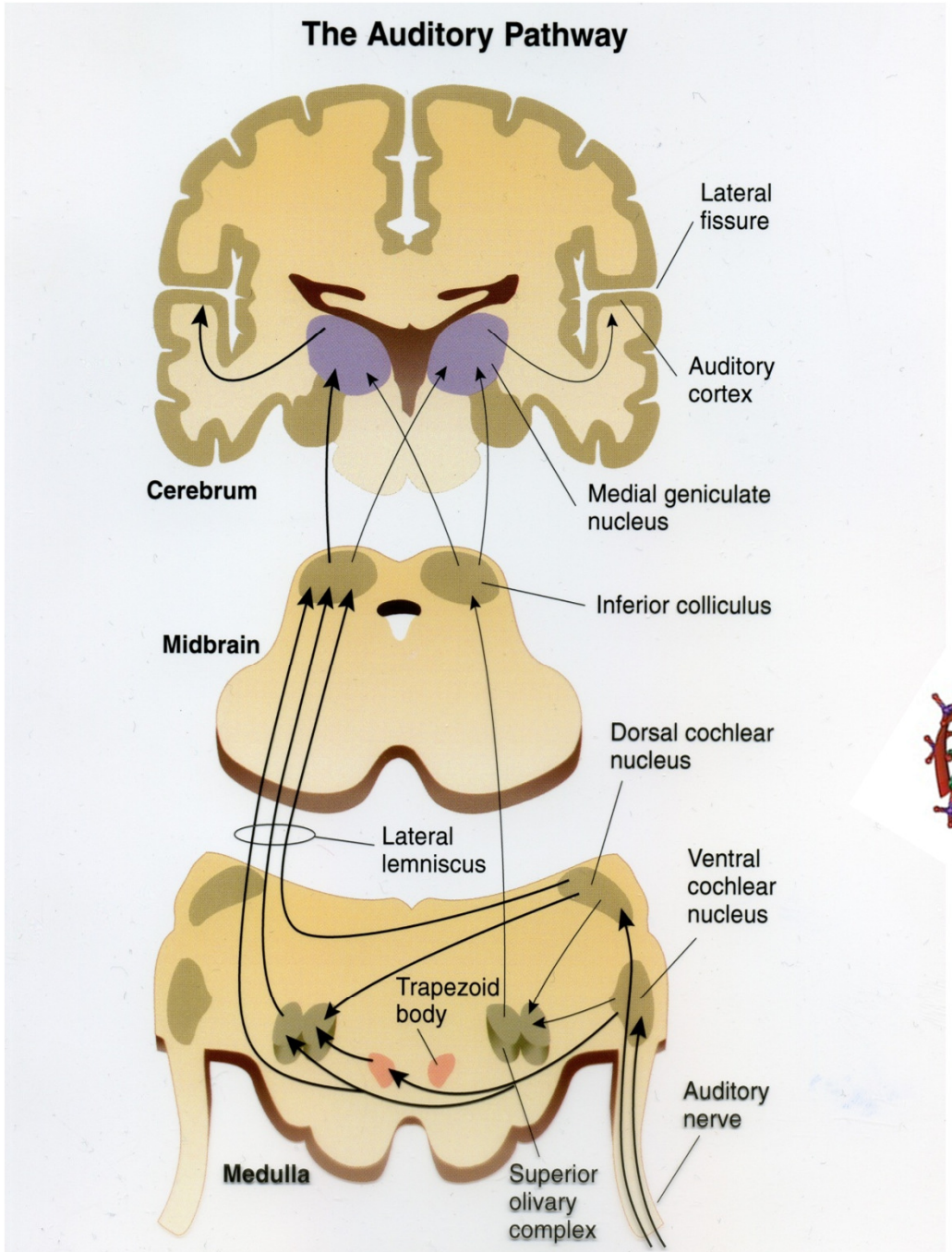





Ossicles
Pinna
Auditory nerve
Ear canal
Cochlea
Ear drum
Eustachian Tube







The pathway of the auditory system. The major pathways are indicated by heavy arrows.

Copyright © 2005 Allyn and Bacon



Research Goal

- To understand the **basic** mechanisms of central auditory processing from molecule to behavior, in order to:
  - Have a comprehensive understanding of pathophysiology of disorders
  - Enhance treatments
  - Optimize learning for everyone

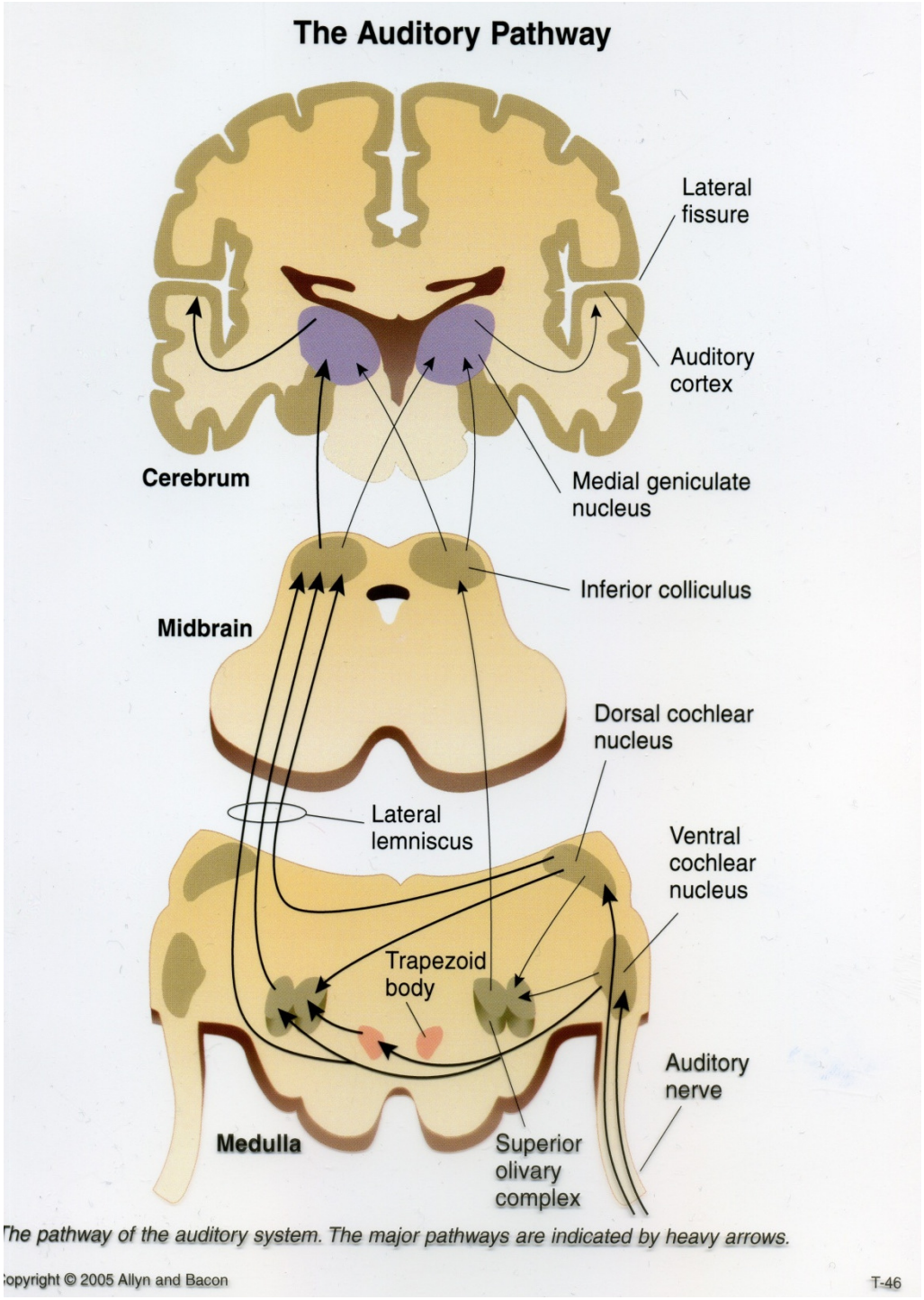
Three Strategies
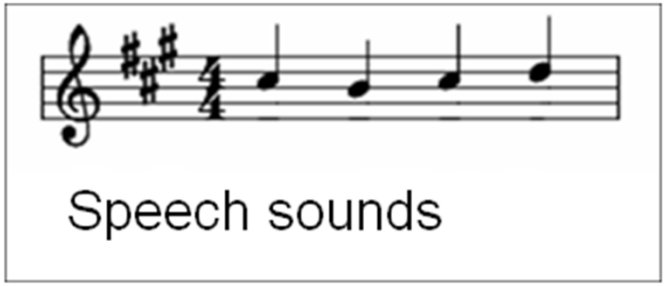
- #1. Examine stages of neural processing along the auditory pathway to delineate domain-general and –specific properties of the CNS

- #2. Capitalize on our knowledge of the cellular and molecular characteristics of the brain, to develop and test hypotheses about the genetic basis of complex auditory functions (spoken language)

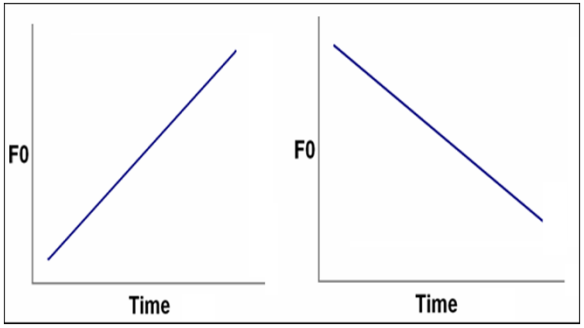
- #3. Through looking at the CNS as a network, we hope to gain a fuller understanding of spoken language processing problems and treatments.

#1. Stages of Neural Processing

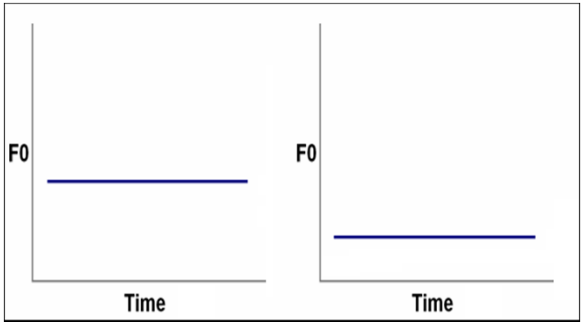




IBE Combo

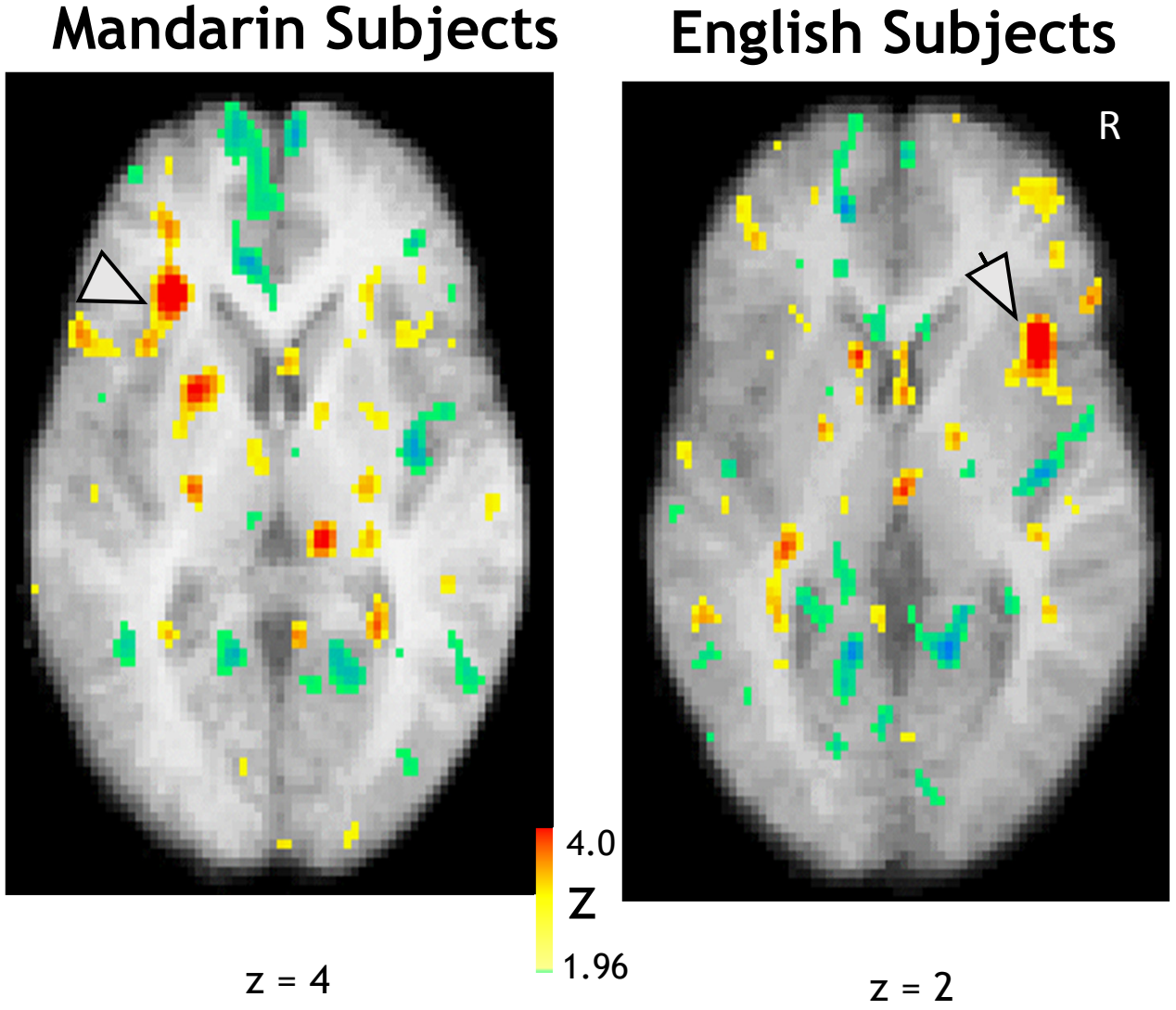


IBEs



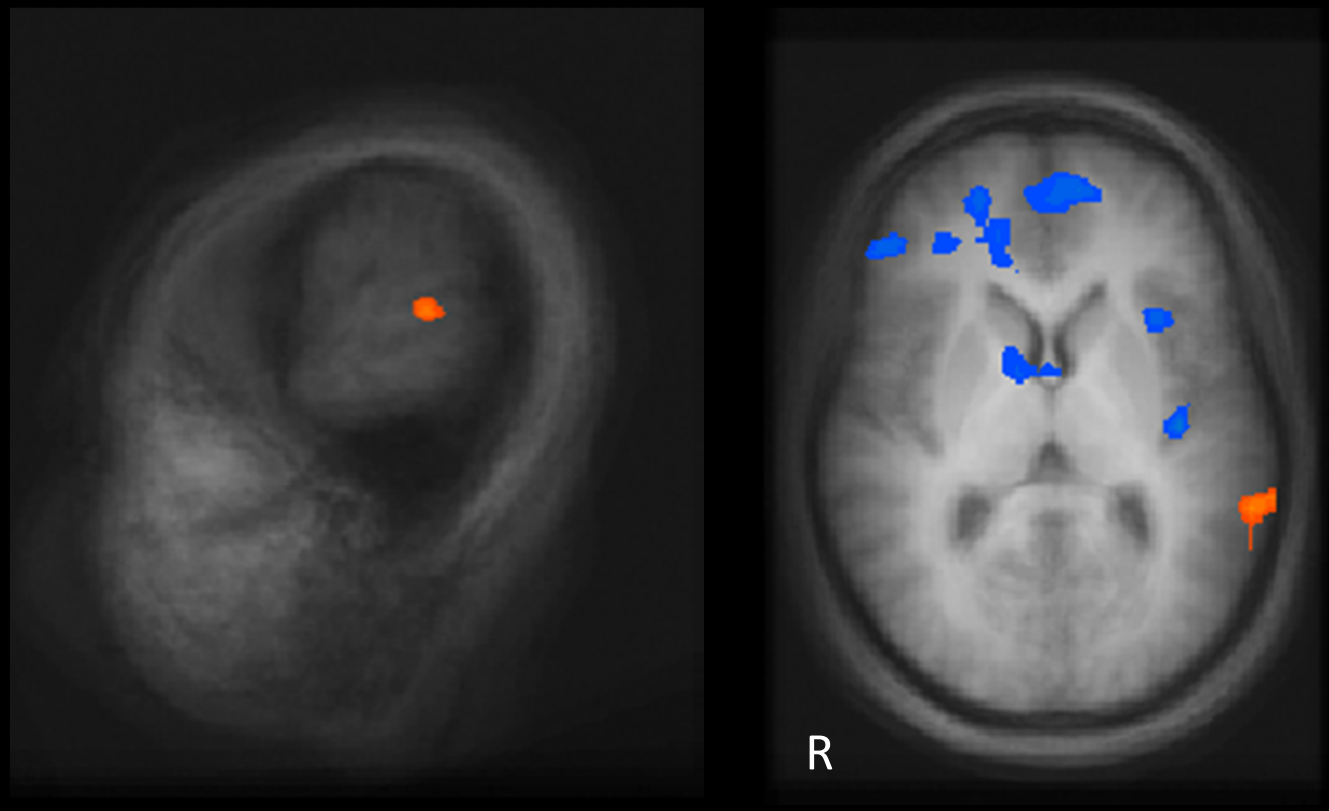
Suga et al.

Mandarin Tone – Mandarin Passive



Wong et al. (2004). *J Neuroscience*

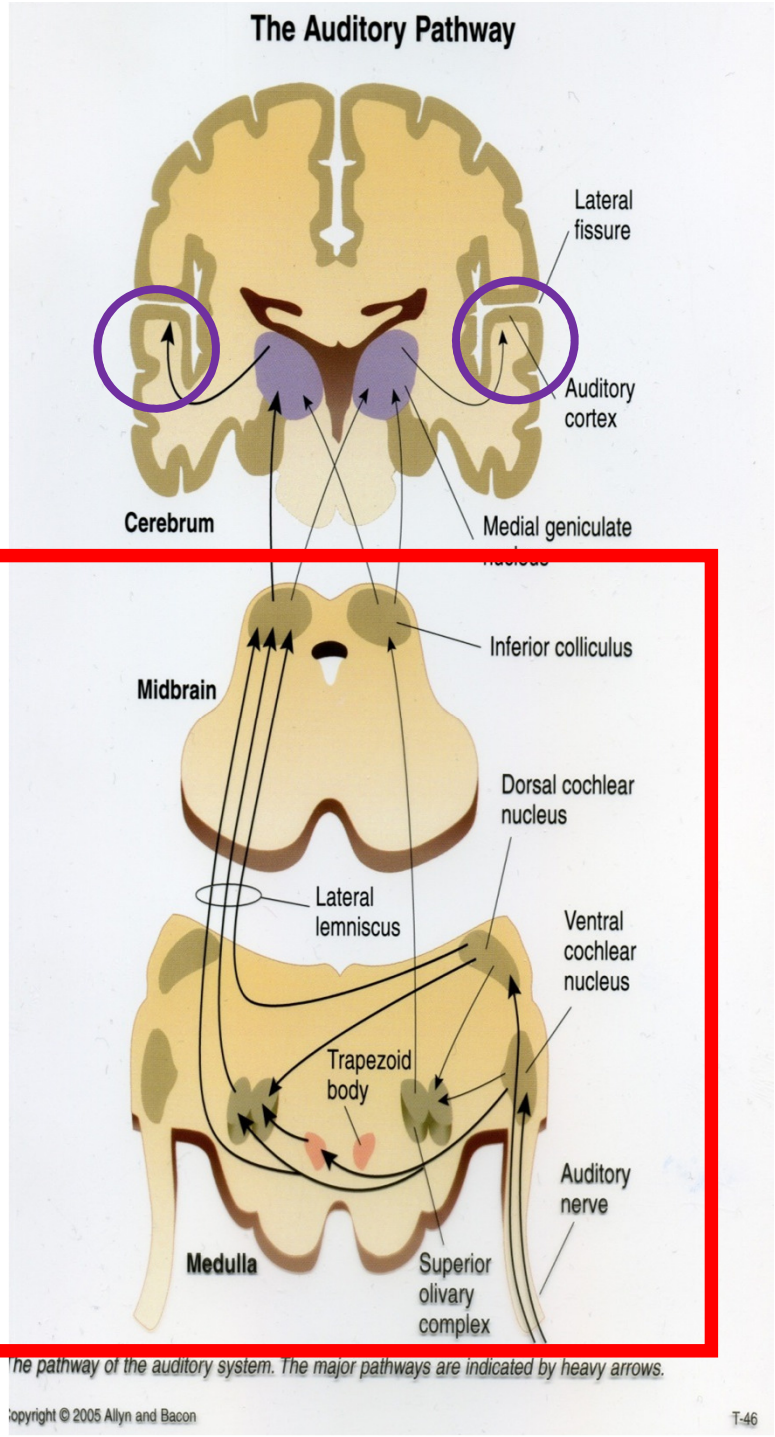
Successful vs. Less Successful (Post-Training)
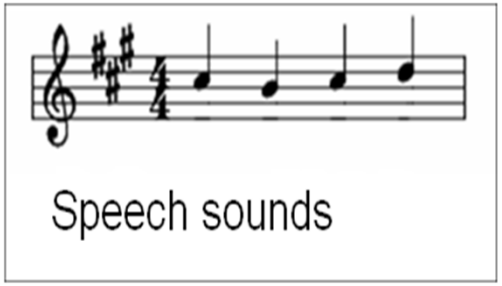


= Successful > Less Successful Learners

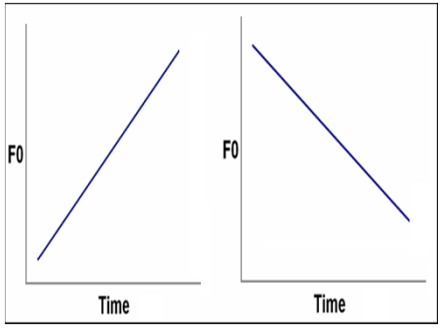
= Less Successful > Successful Learners

Wong et al. (2007). *Human Brain Mapping*

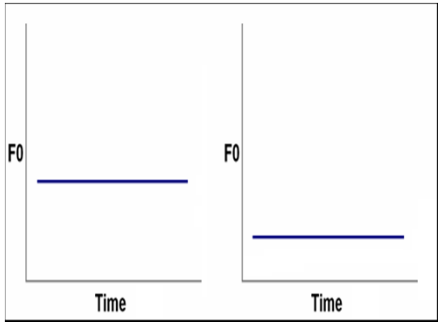




IBE Combo



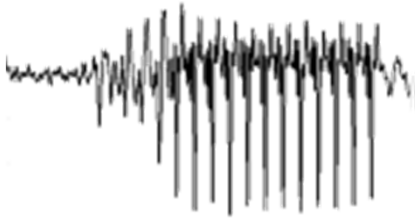
IBEs



Suga et al.

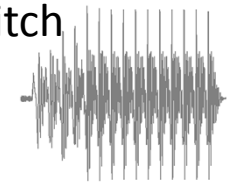
Soundwave to Brainwave

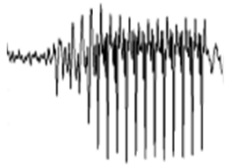
SOUNDWAVE



BRAINWAVE

Low pitch





High pitch

da



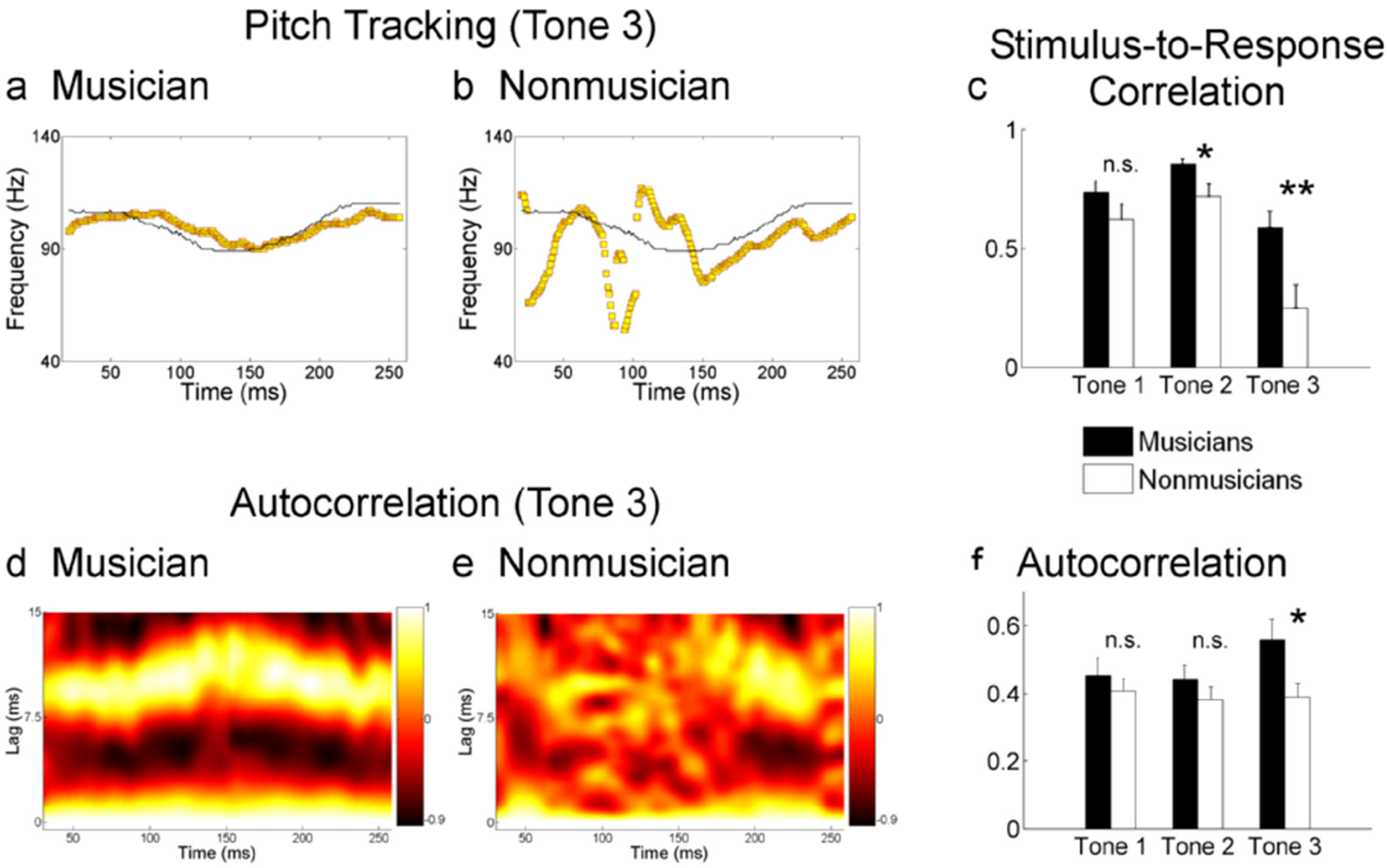




SOUNDWAVE



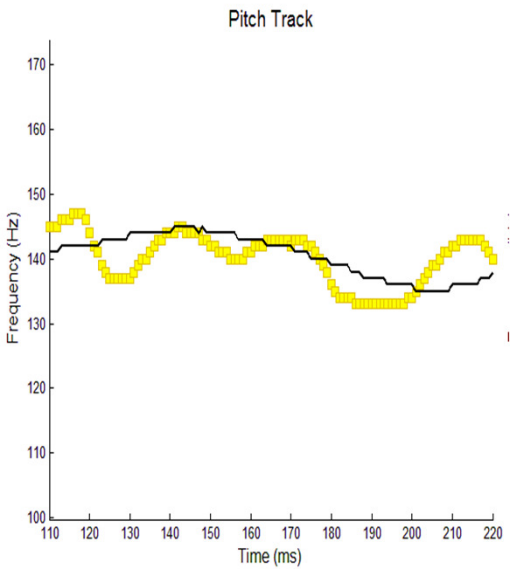
BRAINWAVE

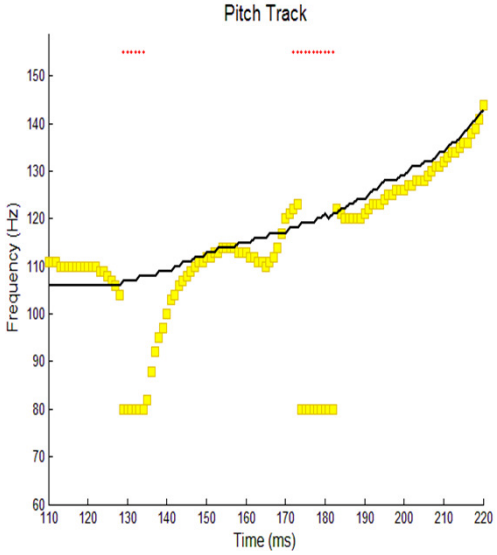


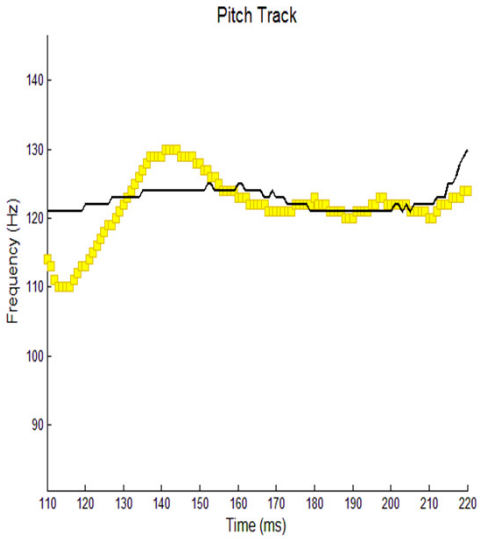
Wong et al. (2007). *Nature Neuroscience*

FFR from Infants









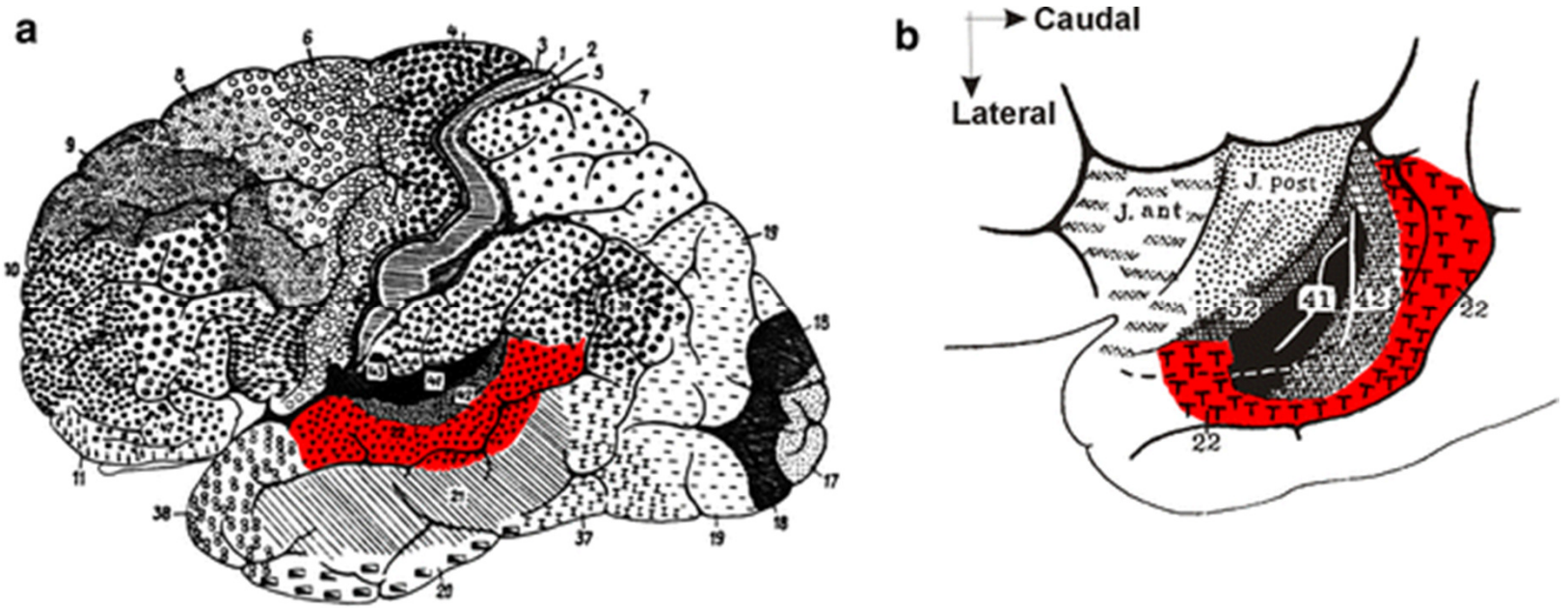




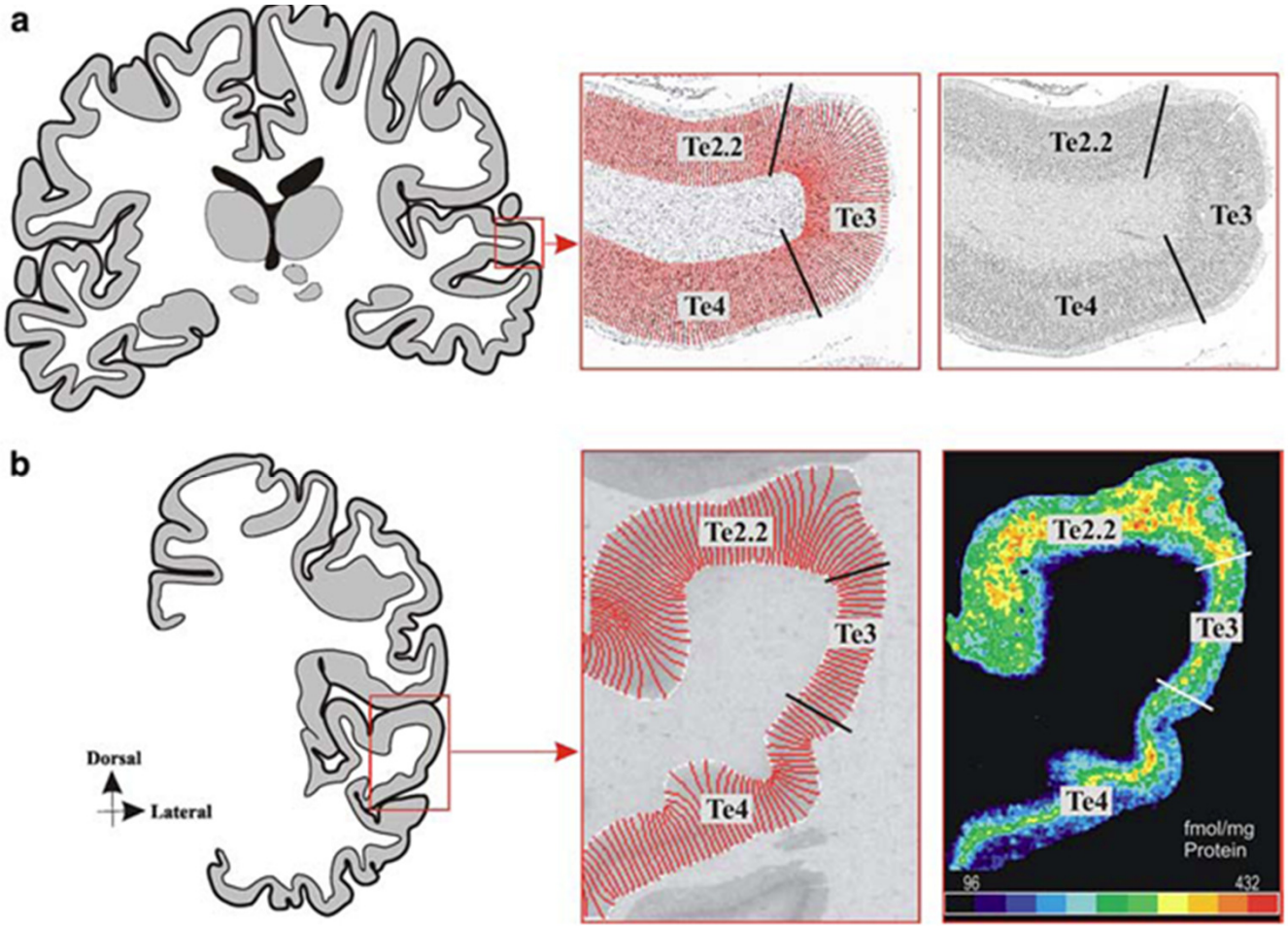


#2. Genetic Basis of Complex Auditory Behavior

Brodmann (1909)
Superior Temporal Region



(a) Cyto- vs. (b) Receptor-



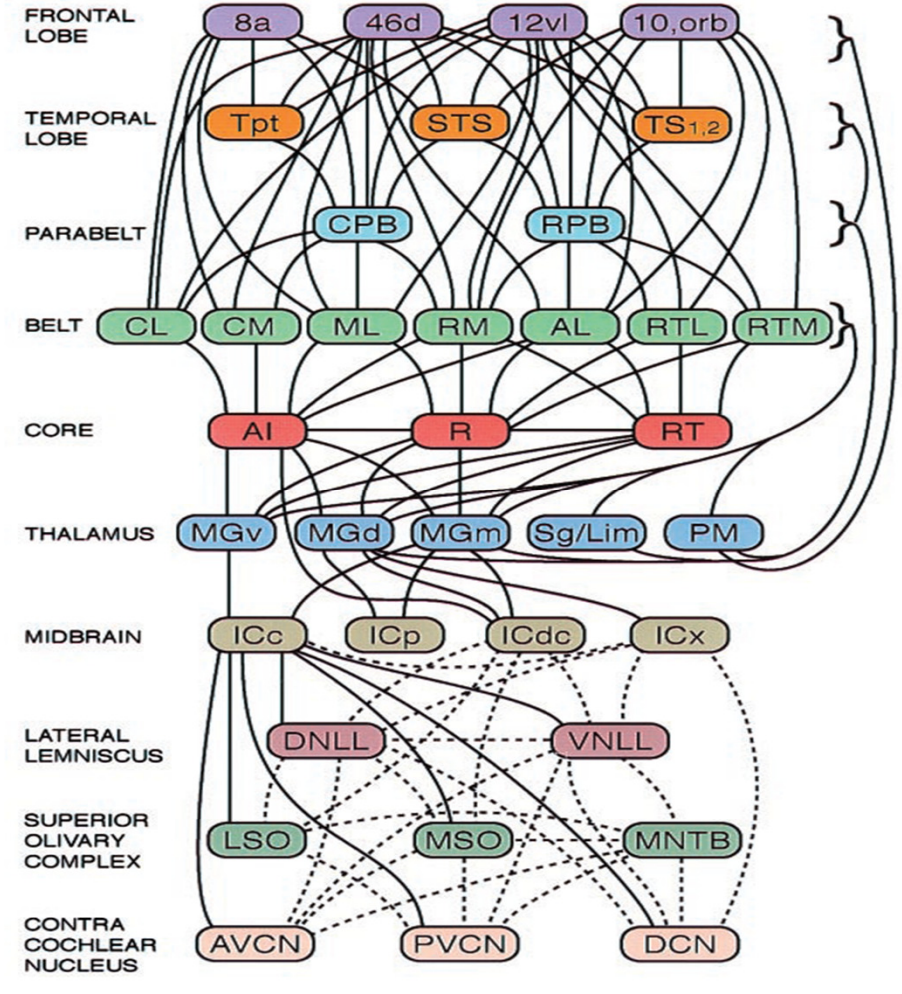
Morosan et al. 2005

“Auditory” Network

Non-Auditory

Temporal Cortex (Auditory)

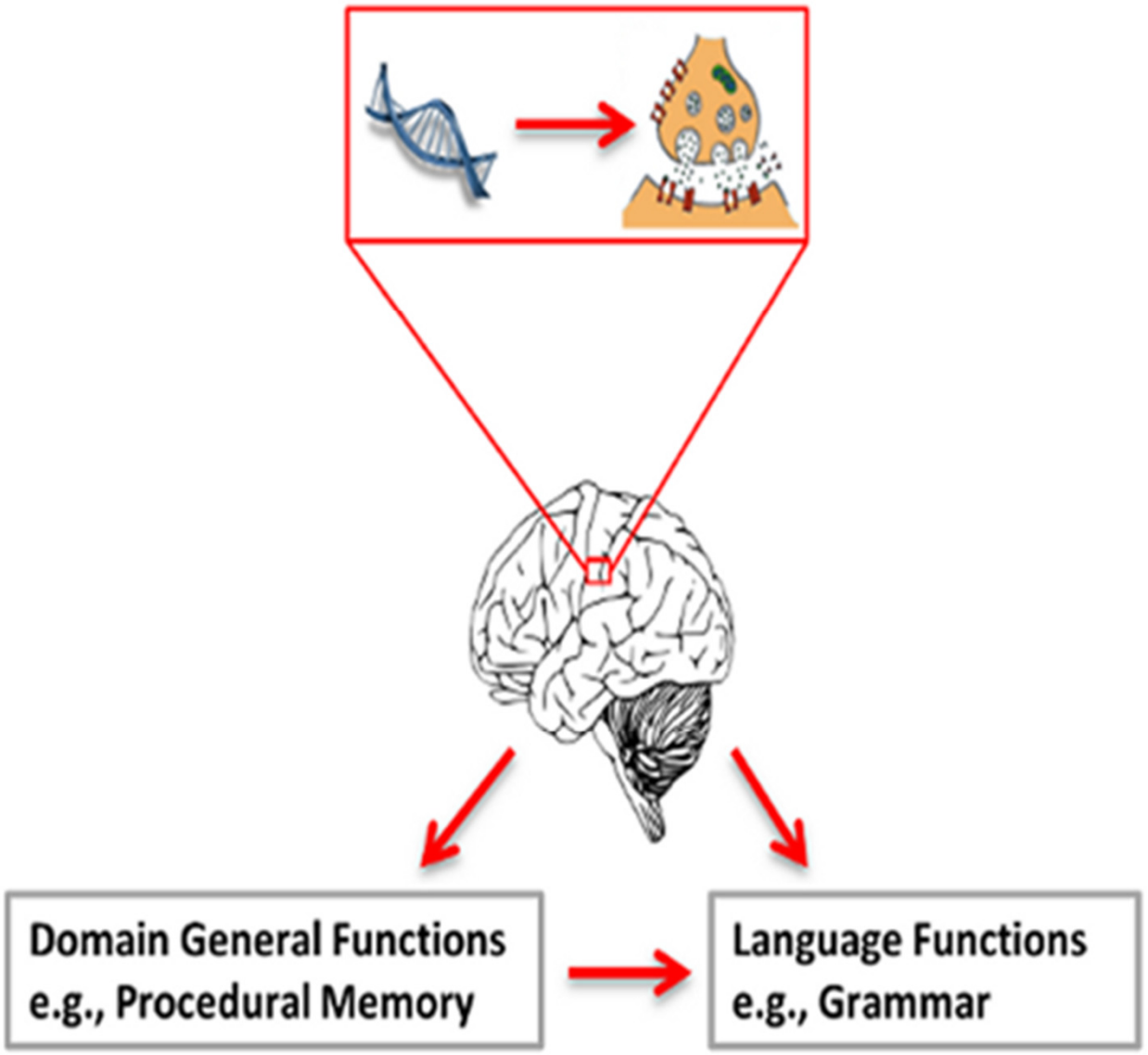
Sub-cortical (Auditory)



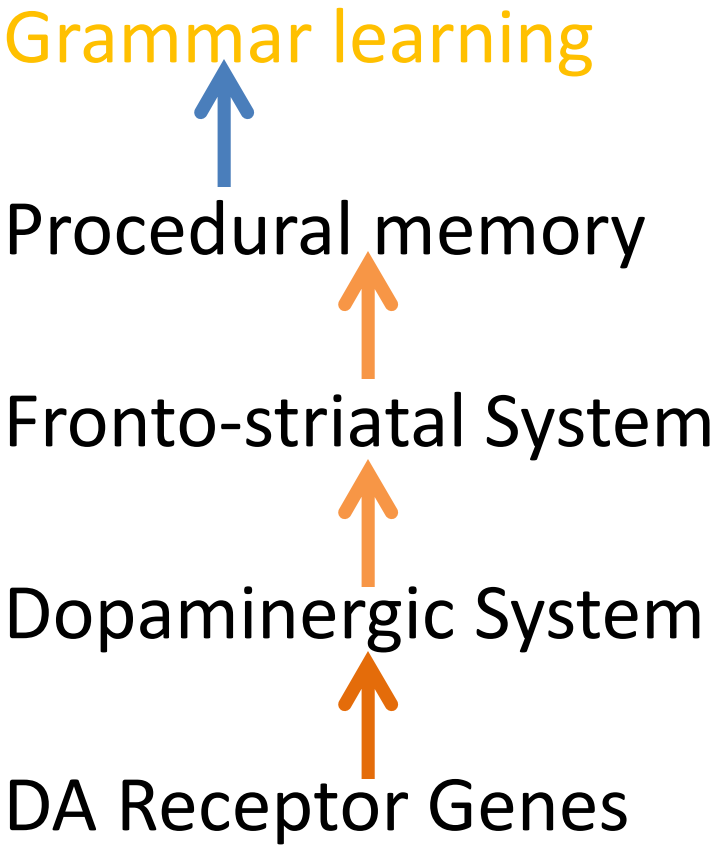
Kaas & Hackett (2000), *PNAS*

- Genes -> **Neurons (e.g., receptors)** -> Systems -> Behaviors (e.g., language)

a)


Domain General Functions
e.g., Procedural Memory
Language Functions
e.g., Grammar

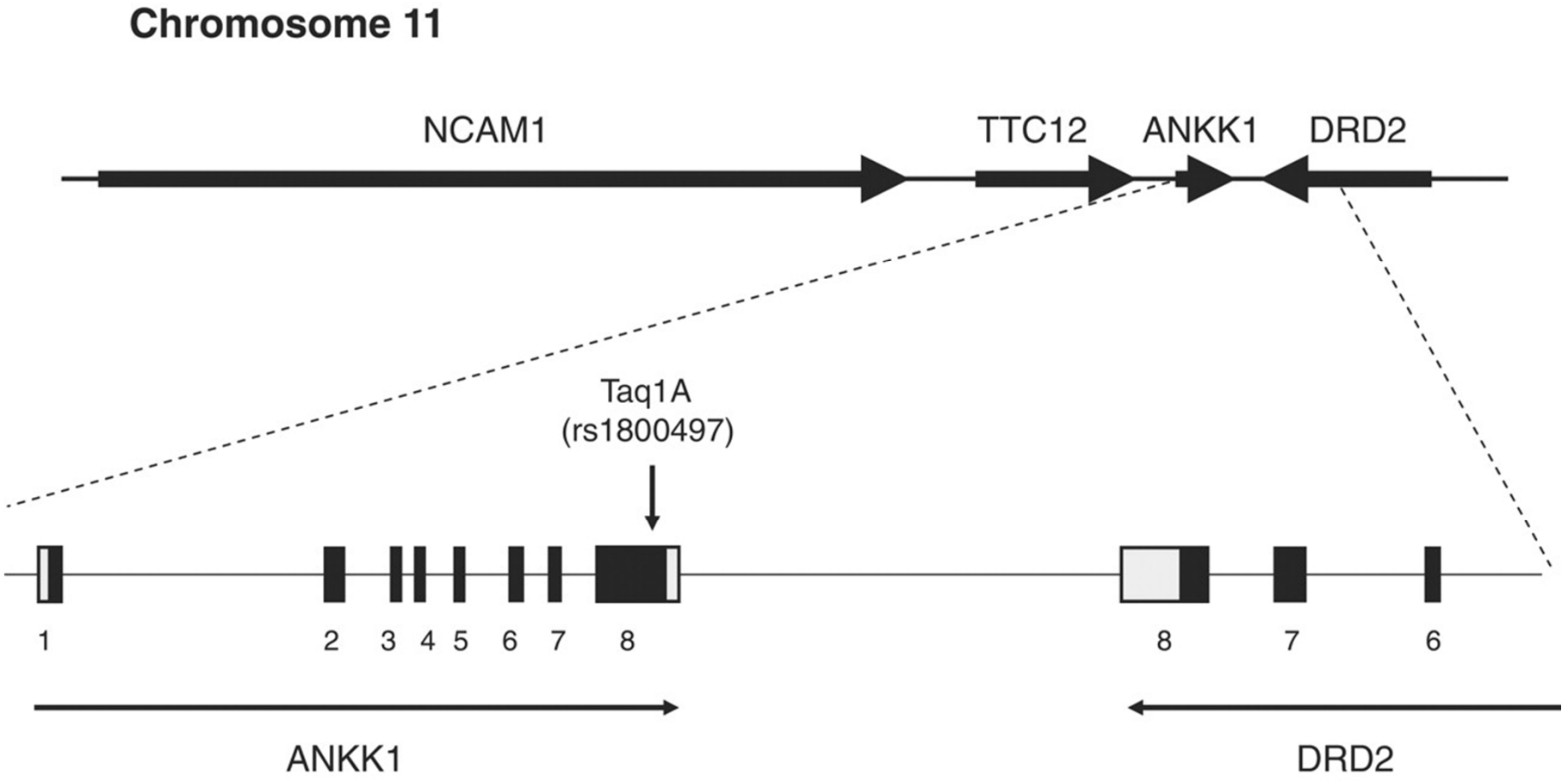
Grammar Learning



DRD2 Polymorphism

- A1A1, A1A2, or A2A2
  - Presence of A1 allele is associated with reduced D2 receptor binding in basal ganglia (Thompson et al. , 1997)
    - BUT might be consequential to ANKK1 signaling and indicative of more general neural function

DRD2 Taq1A


Chromosome 11
NCAM1
TTC12
ANKK1
DRD2
Taq1A
(rs1800497)
1
2
3
4
5
6
7
8
8
7
6
ANKK1
DRD2

Morpho-Phonology Learning

- Learning Opaque phonological rules involving combining morphemes and performing phonological transformations
  - Generalization to Untrained Stimuli
    - Simple phonology Condition
    - Complex phonology Condition
- Learners & Non-Learners (all adults)

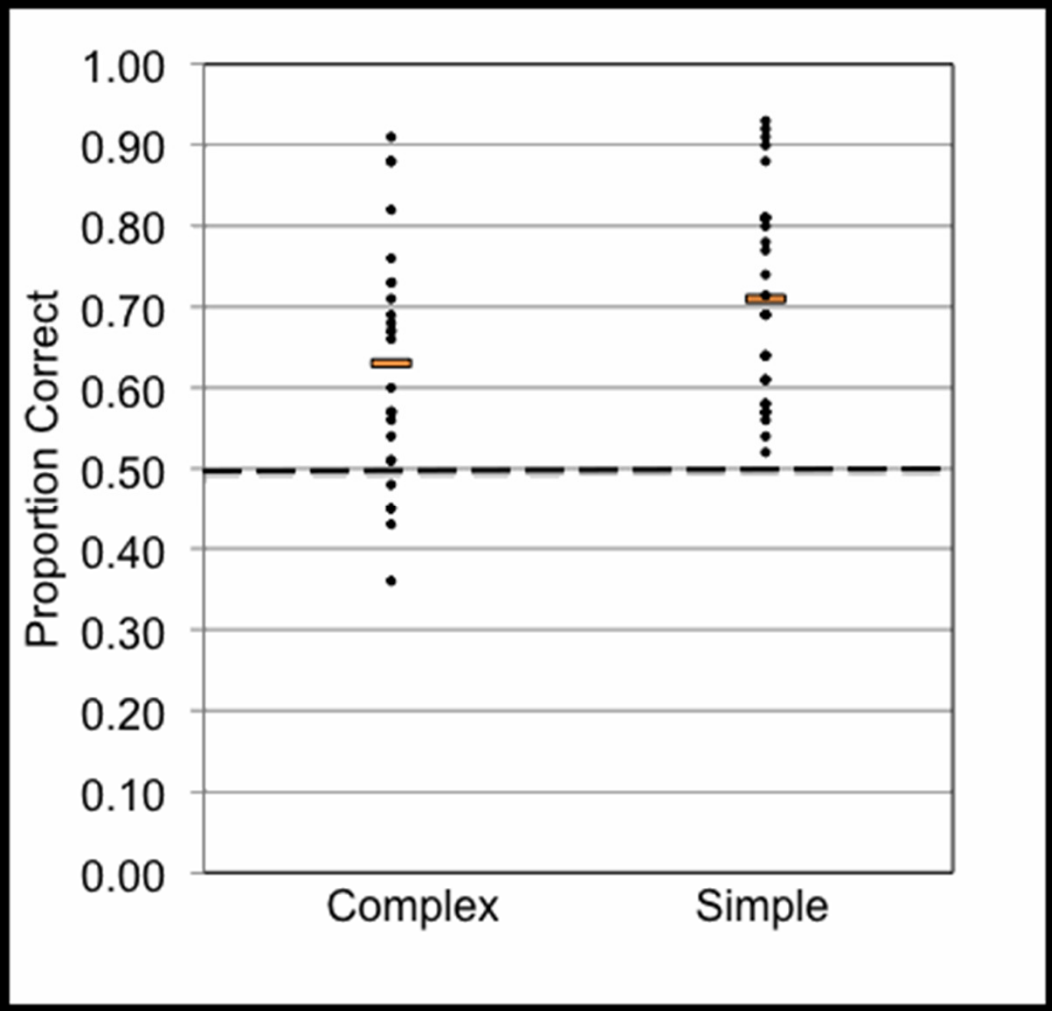
Ettlinger, Bradlow, & Wong (2014). *Appl Psych*

Transparent (simple) & Opaque (complex) Grammar

	Singular	Plural	Dim	Dim. Pl
'dog'	vib	vib-il	ki-vib	ki-vib-il
'cat'	pesh	pesh-el	ki-pish	ki-pish-el

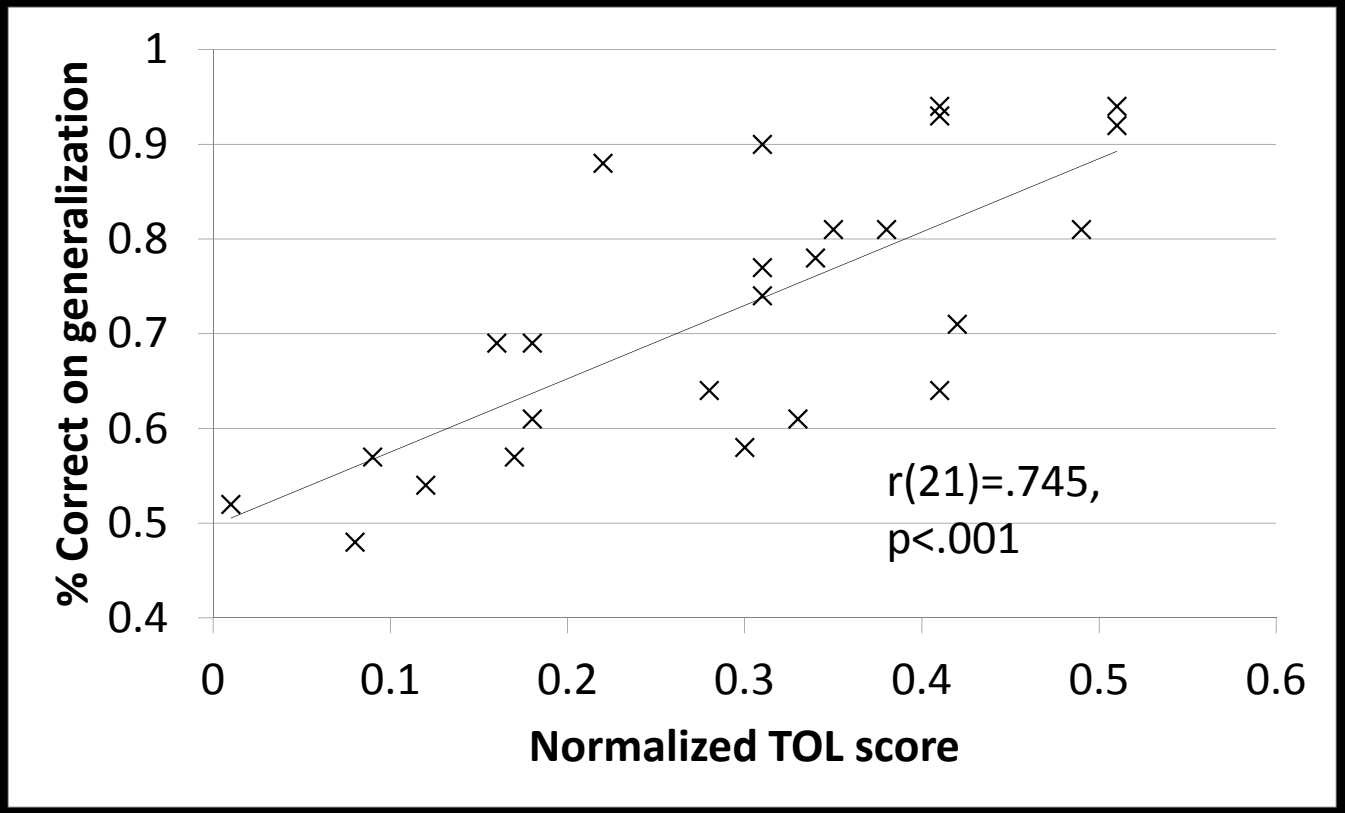
Transparent and opaque items are mixed during training

Individual Differences

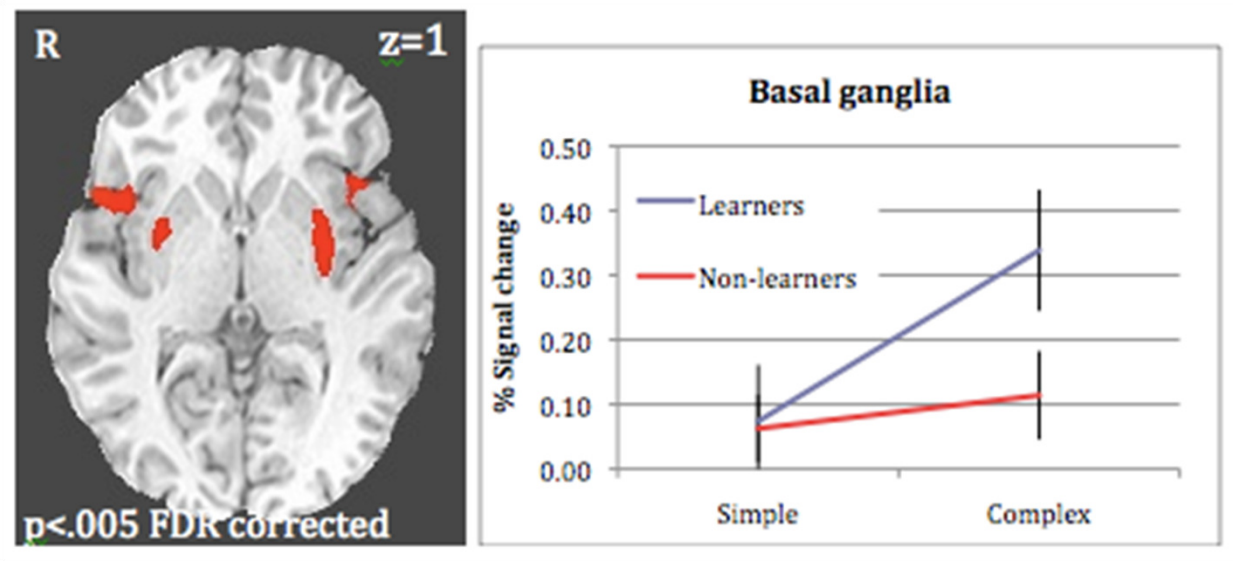


Memory & Language Learning

- Significant positive correlation between sound learning & procedural memory

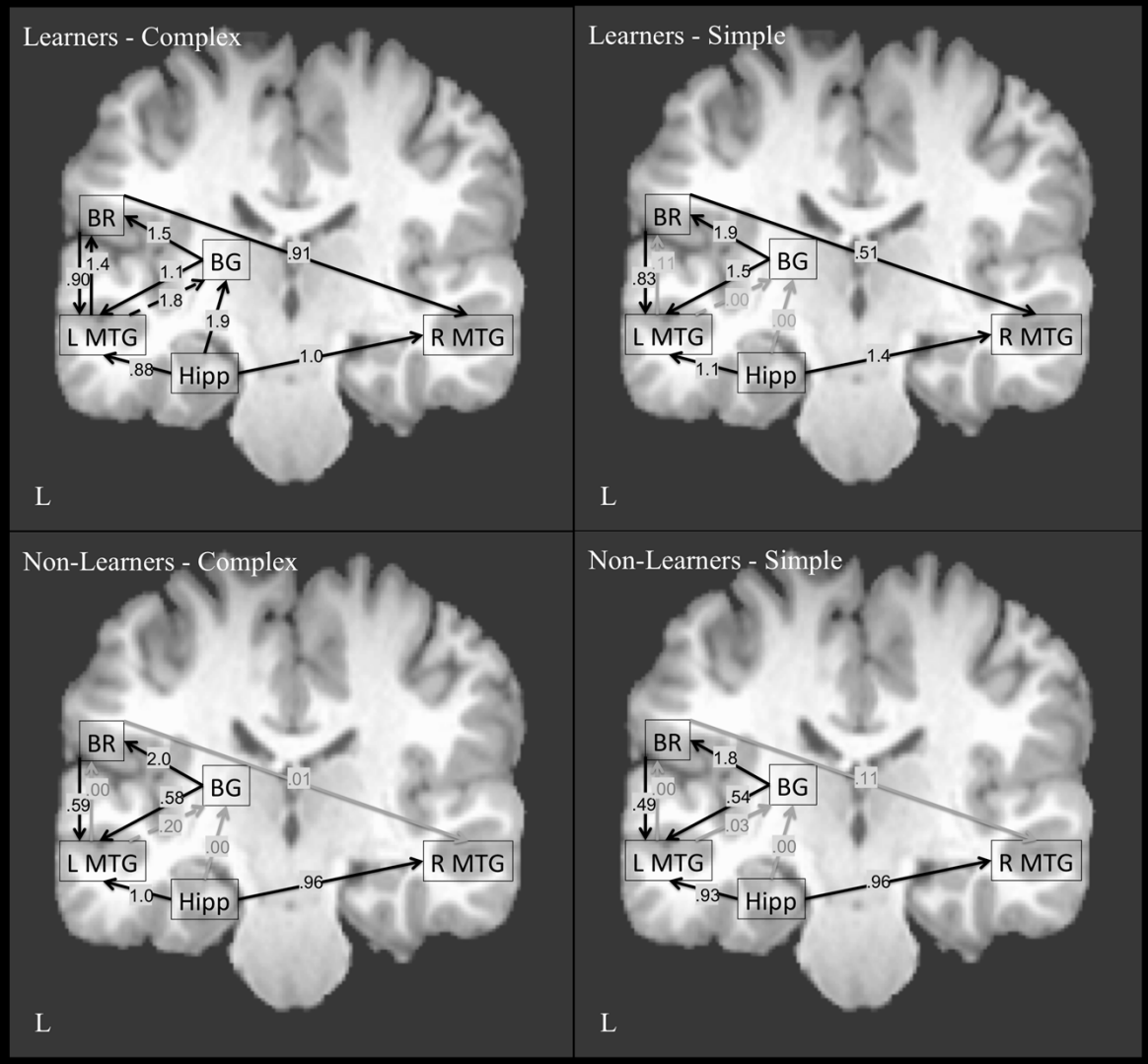


Frontostriatal Pathway & Success

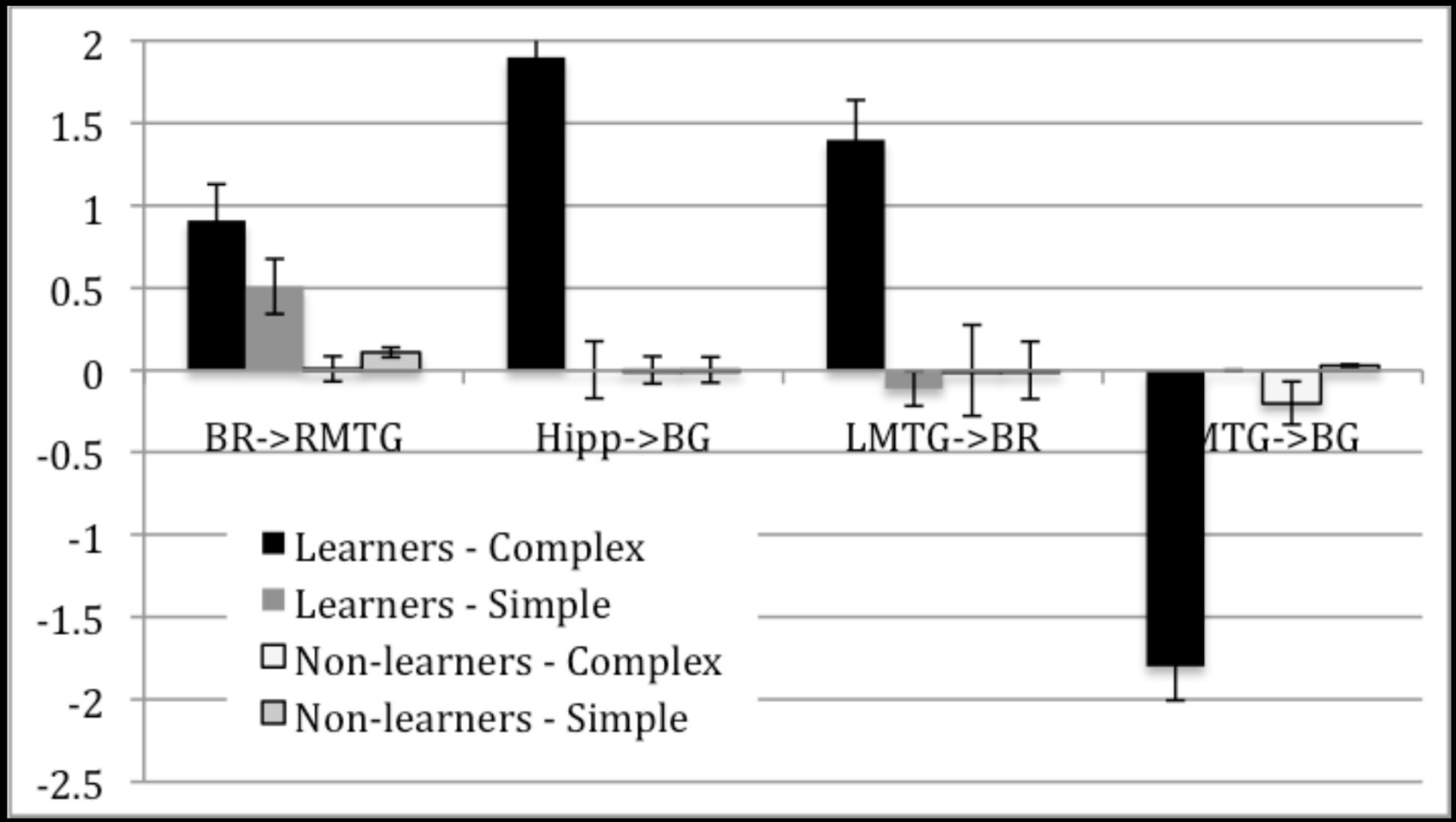


Ettlinger, Novis, Wang, & Wong (submitted)

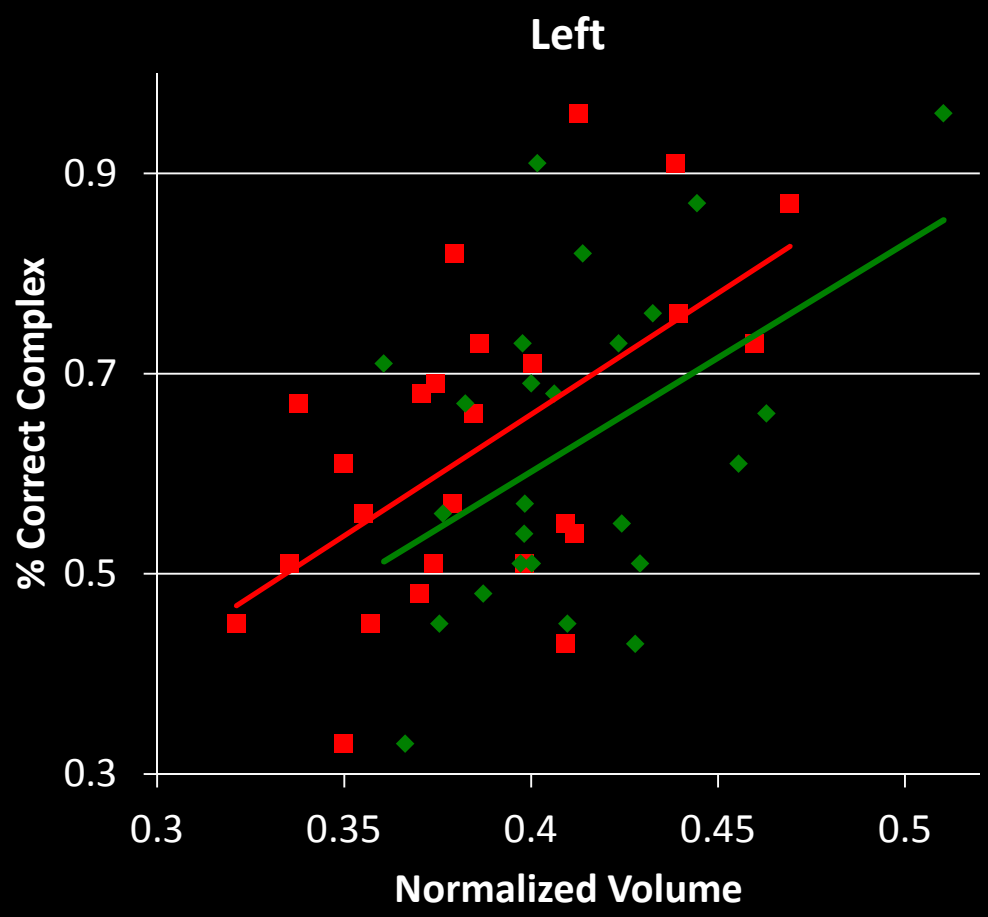
Network Differences



Network Differences



Neuroanatomy

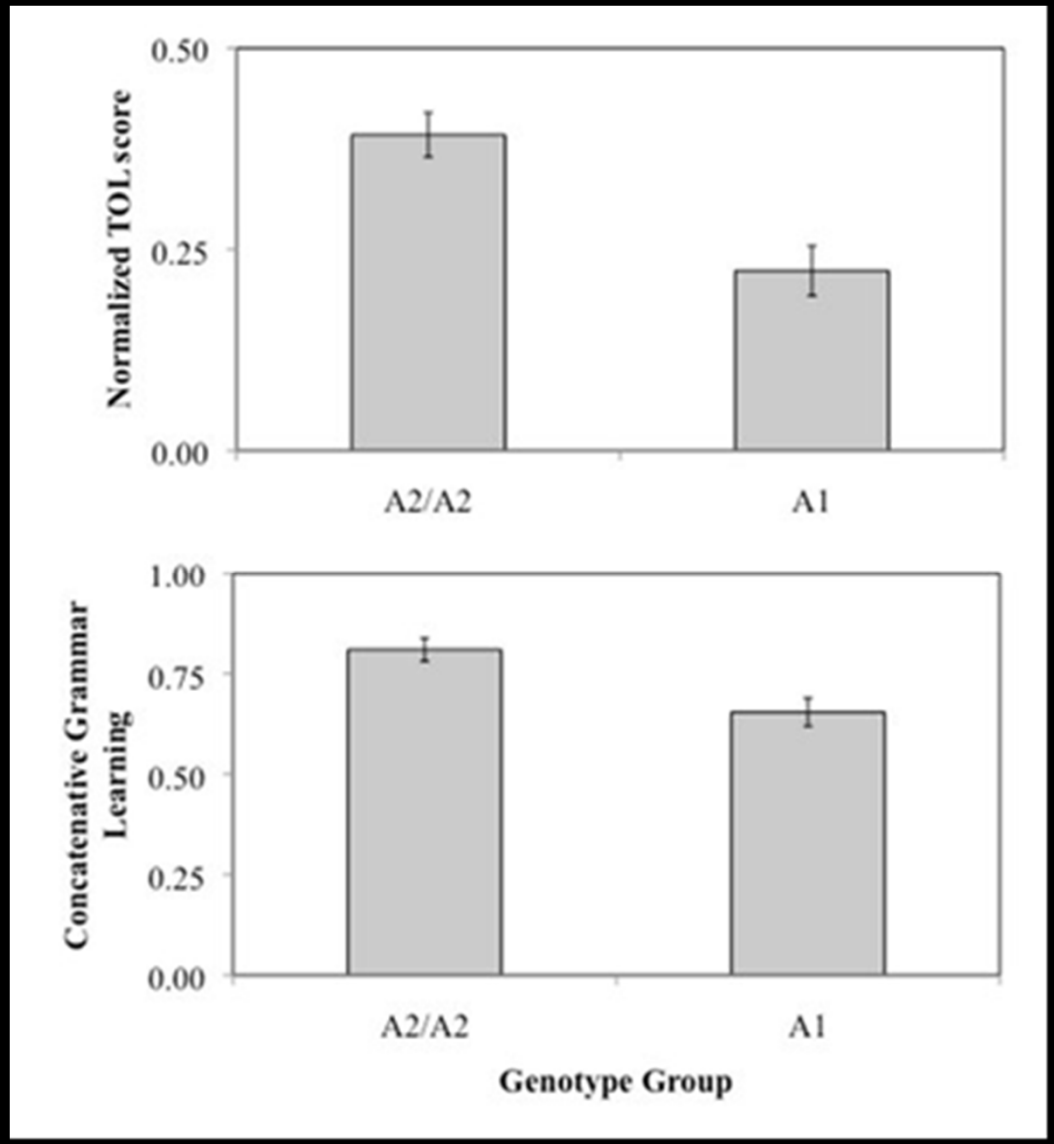


r = .58, p = .002
r = .47, p = .02

ITG

IFG

DRD2 and Phenotype

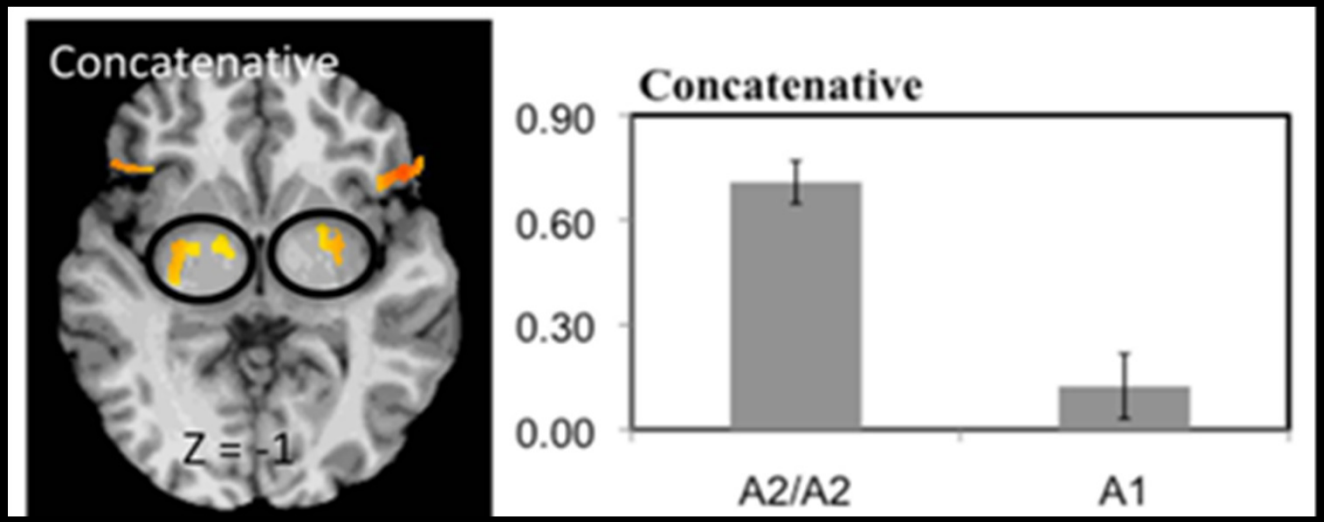


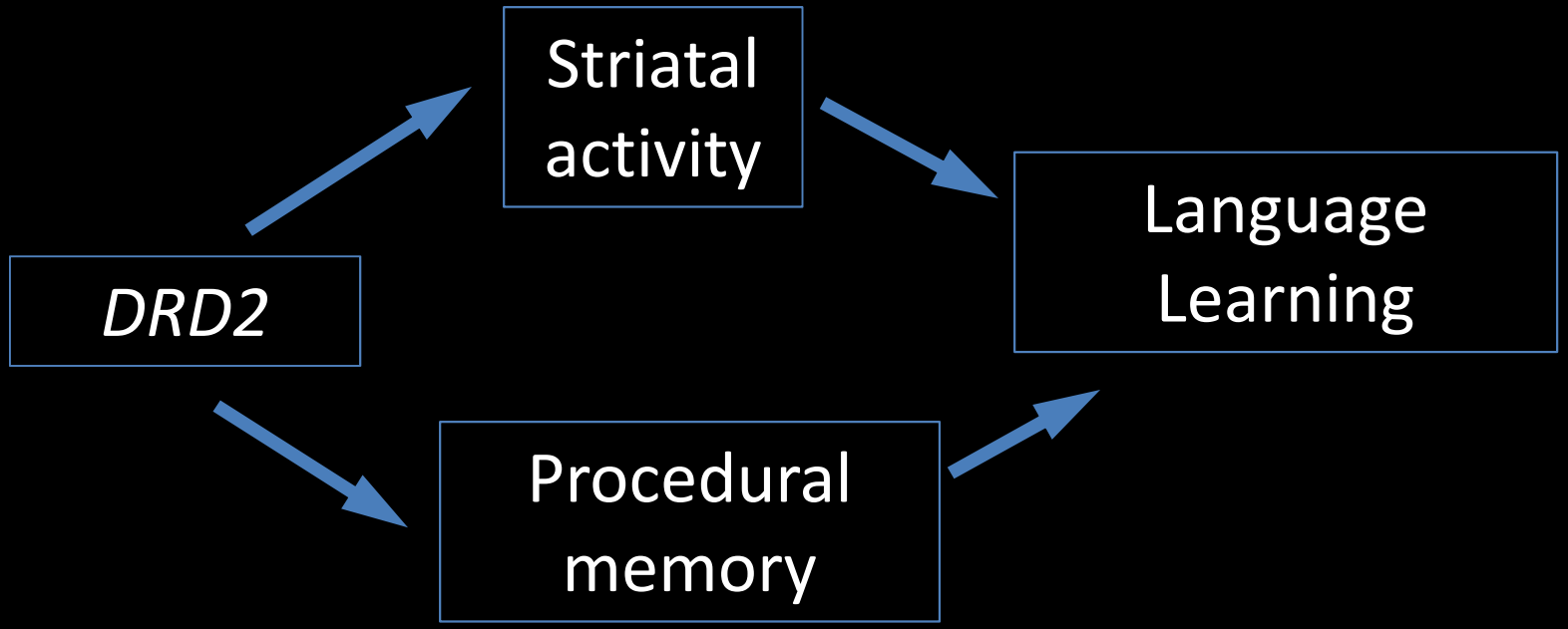
Procedural Memory

Grammar Learning

Wong, Ettlinger, & Zheng (2013). *PLoS One*

DRD2 and Brain





Model Goodness-of-Fit Statistics

Grammar Learning: $\chi^2 = 0.11$, DF=2, p=0.95 (good fit)

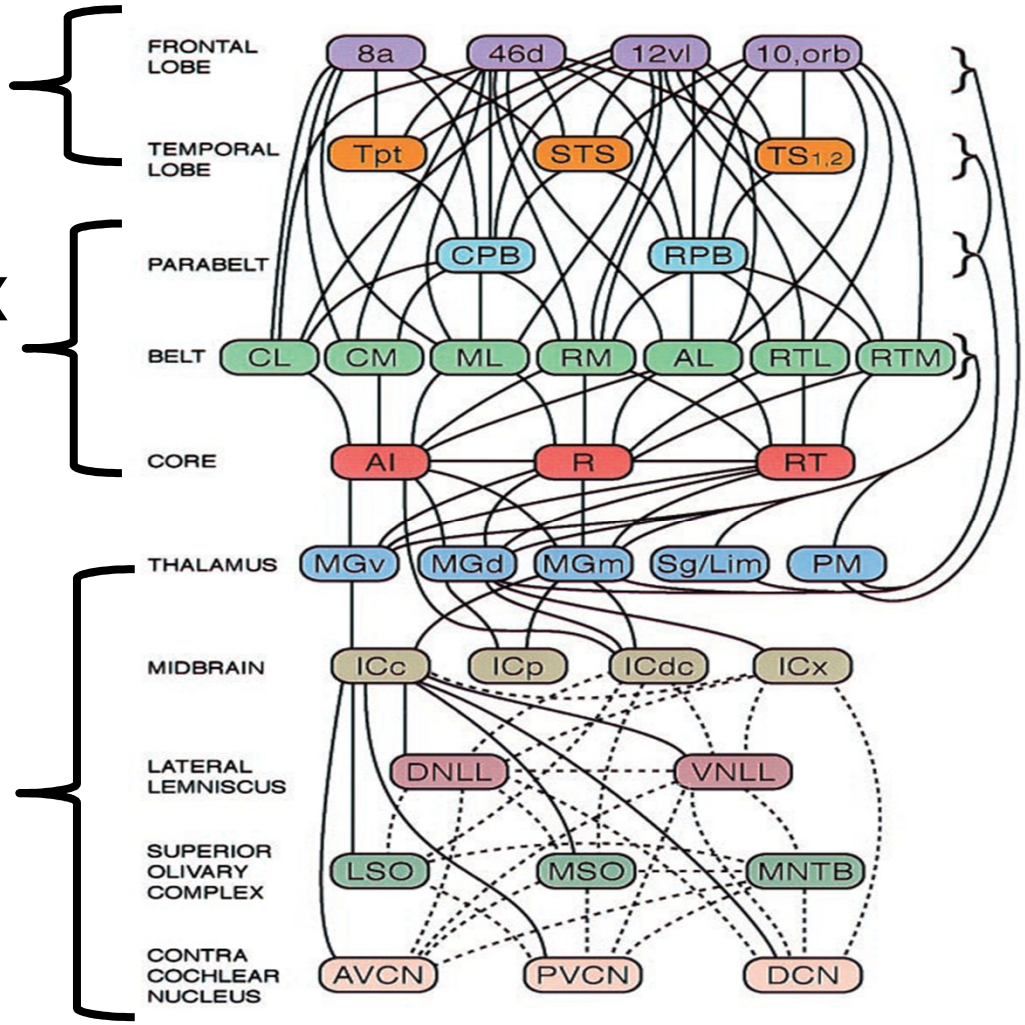
#3. Auditory System as a Network

“Auditory” Network

Non-Auditory

Temporal Cortex (Auditory)

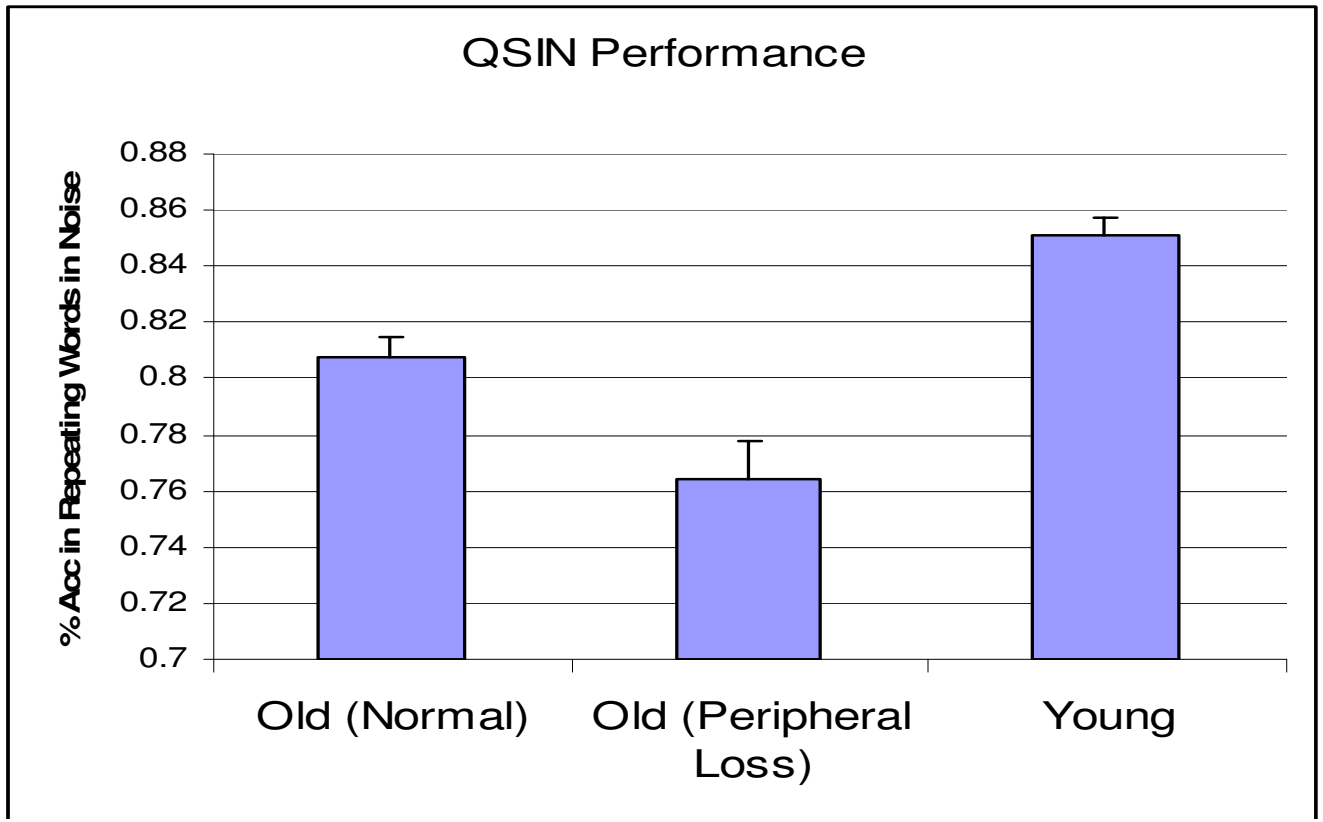
Sub-cortical (Auditory)



Kaas & Hackett (2000), *PNAS*

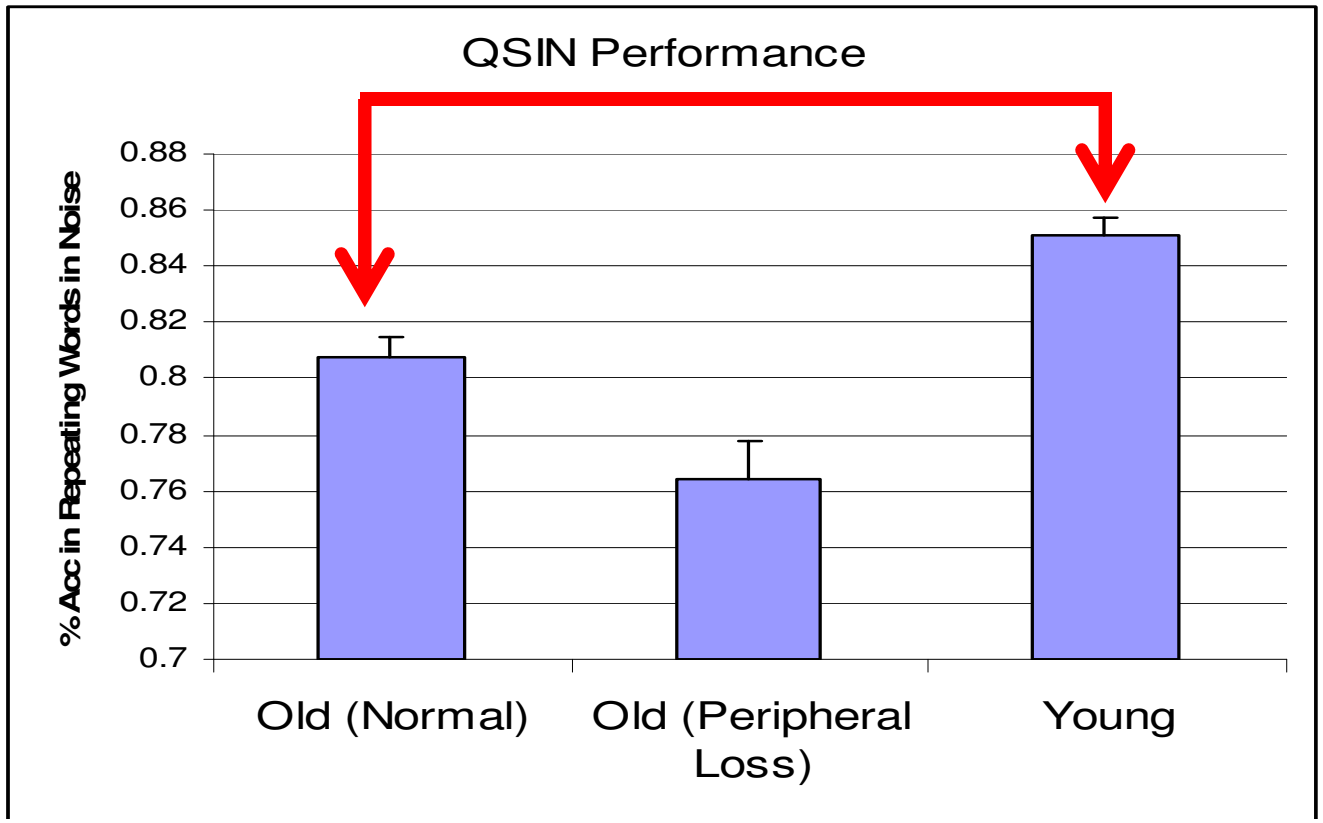
- Short- and long-distance neural connections reflect complex auditory functions
  - Frontotemporal anatomical connectivity reflects cognitive-auditory functional connection
  - Treatments of complex auditory behaviors cannot rely on amplification alone

Speech Perception in Noise in Older Adults



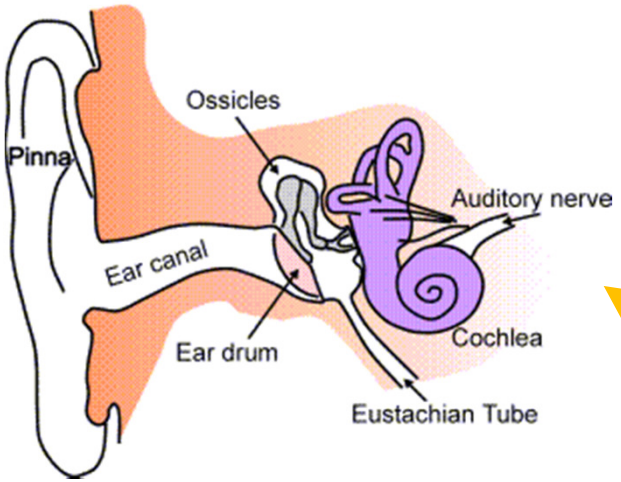
Internal unpublished data

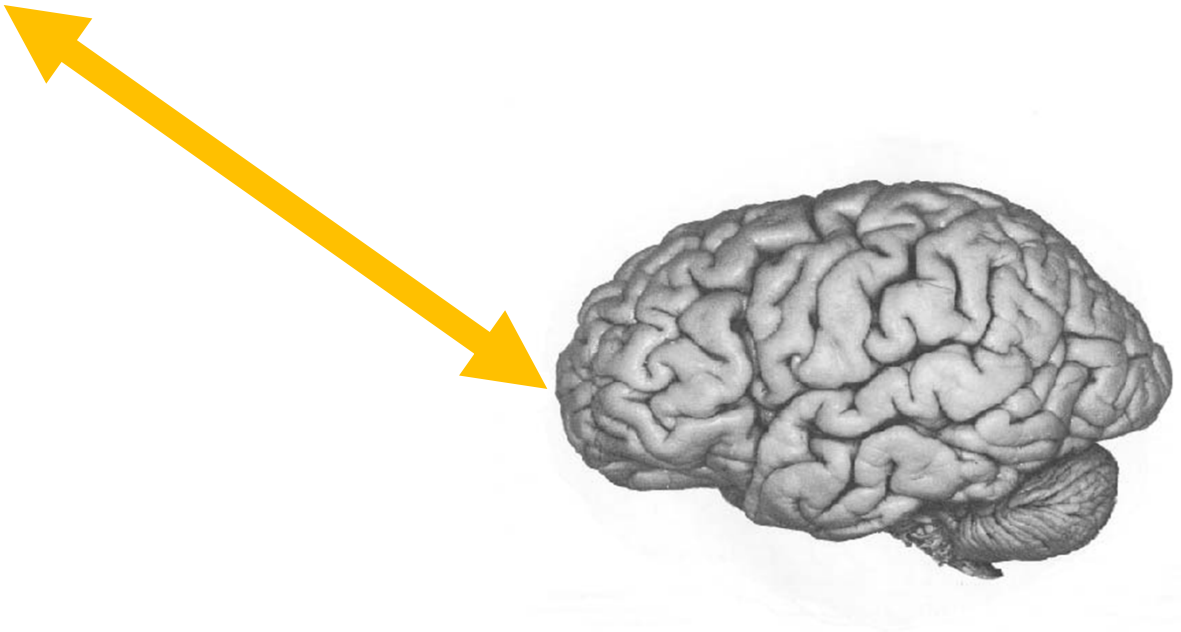
Speech Perception in Noise in Older Adults



Internal unpublished data

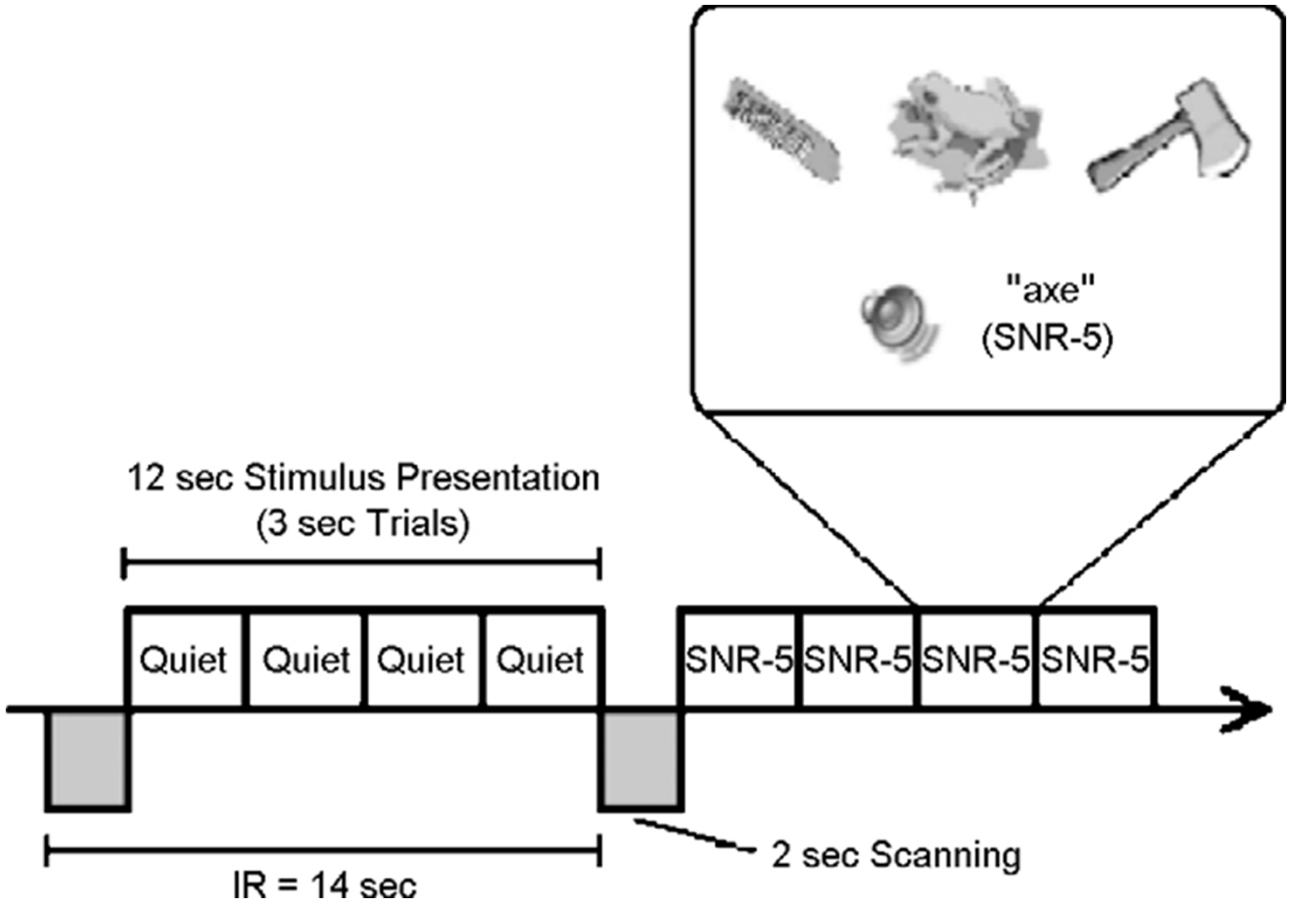
- Decline in hearing (presbycusis)

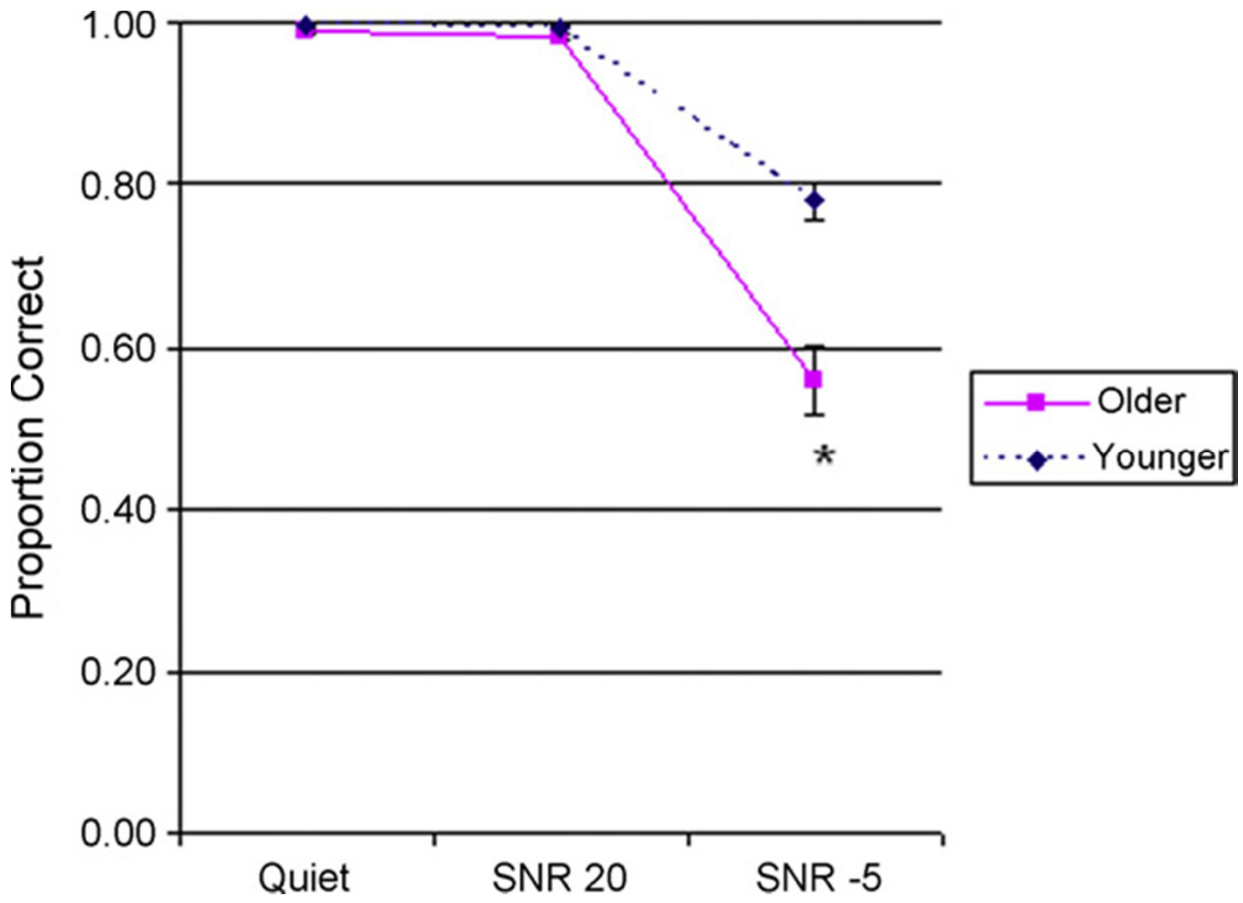




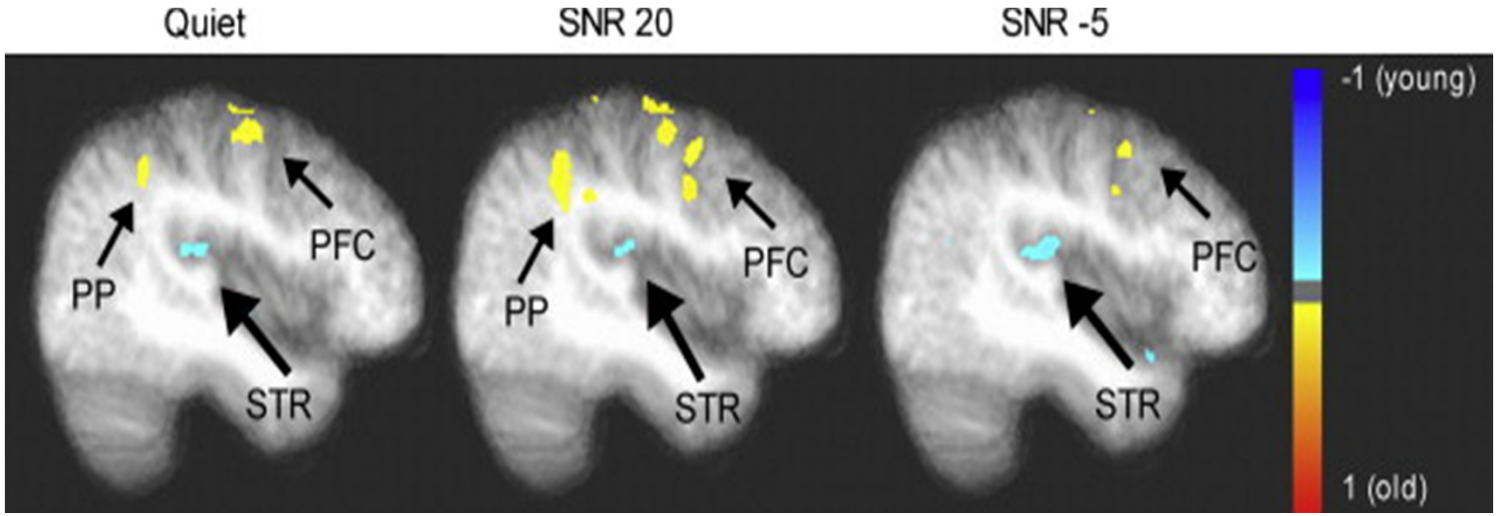
- Do neurocognitive factors explain differences in speech perception in noise in younger and older adults?

fMRI Experiment




1.00
0.80
0.60
0.40
0.20
0.00
Proportion Correct
Quiet
SNR 20
SNR -5
*
Older
Younger

Functional fMRI

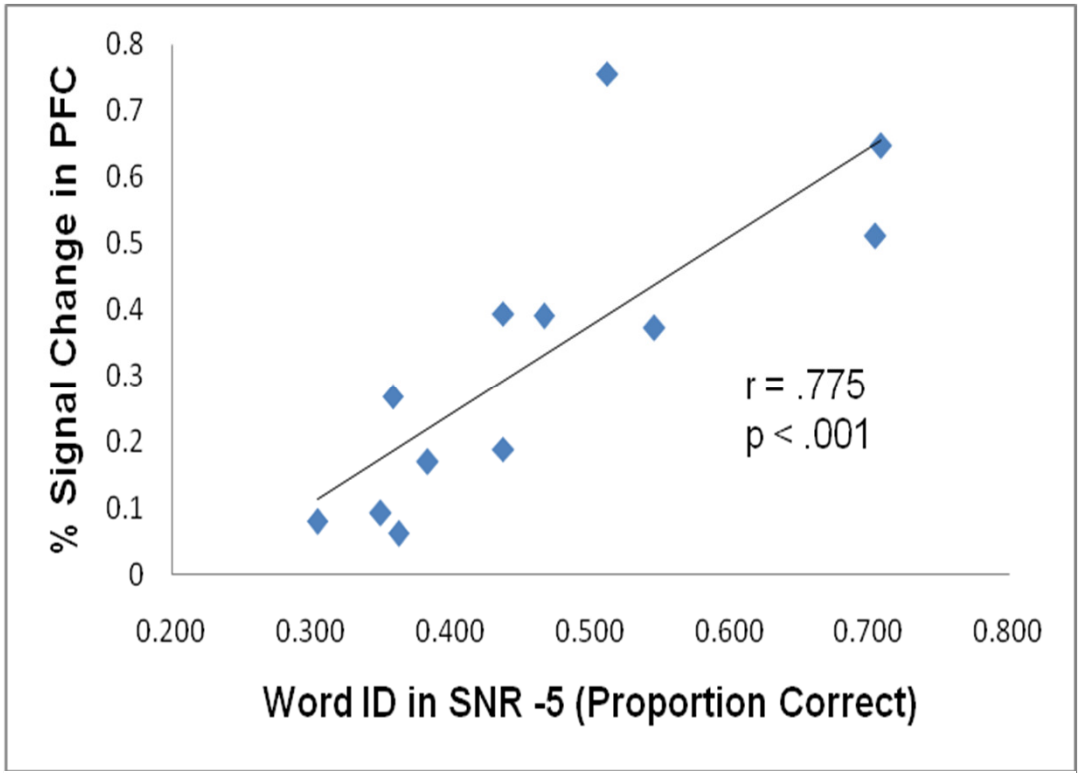


Young > Old: Auditory Cortex (STR)

Old > Young: Cognitive Regions (Prefrontal/PFC & Posterior Parietal/PP)

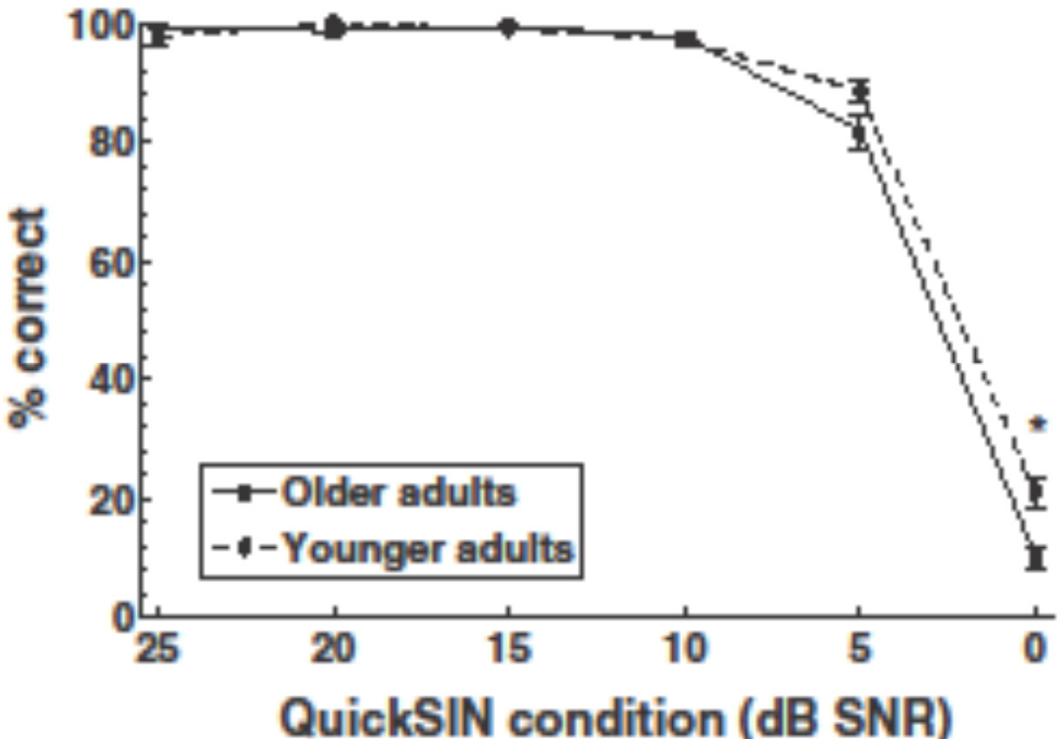
Cognitive "Compensation"

- Older Adults – Speech in noise correlated with PFC activation (not true in younger adults)

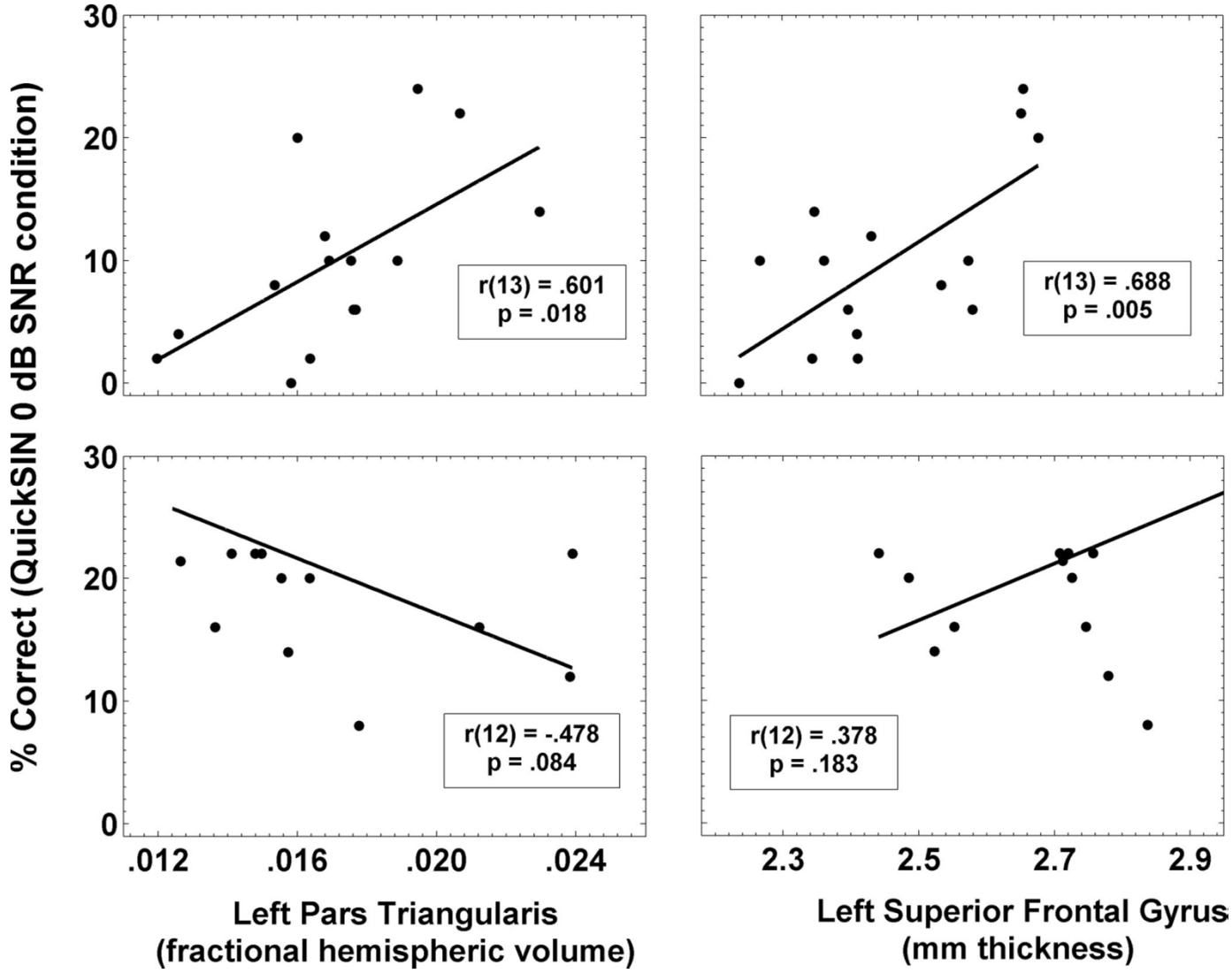


Neuroanatomy

- Older adults show atrophy across brain regions
- Are neuroanatomical differences associated with speech perception in noise?



Wong et al. (2010). *Ear Hearing*



Older

Younger

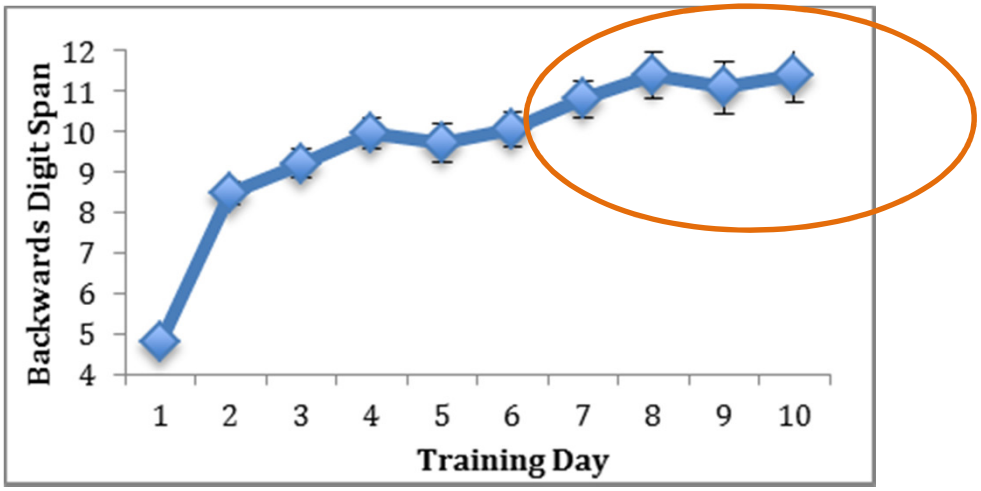
Treatment

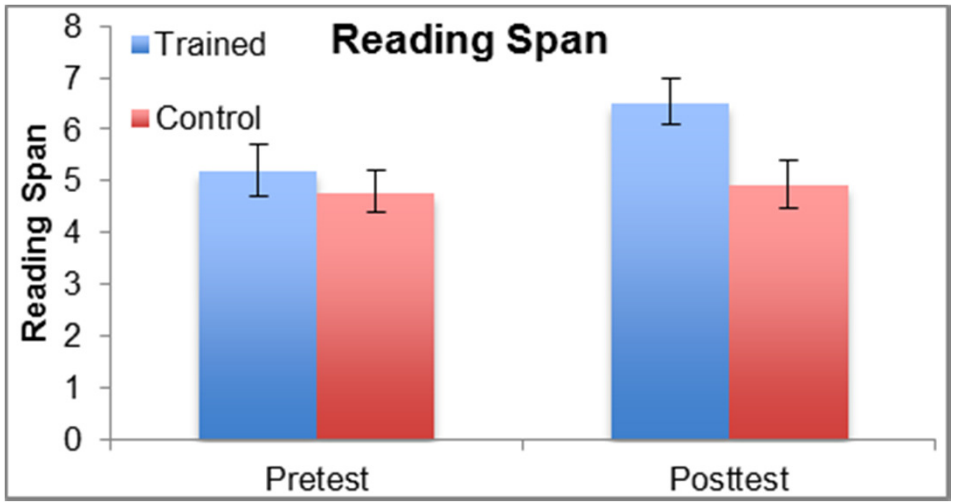
- Cognitive training
  - If neurocognitive factors are associated with speech perception in noise, improving cognitive functions might be effective.
  - What aspects of cognition to train?
  - Do different aspects of cognition interact?
  - Dosage?

Working Memory Training

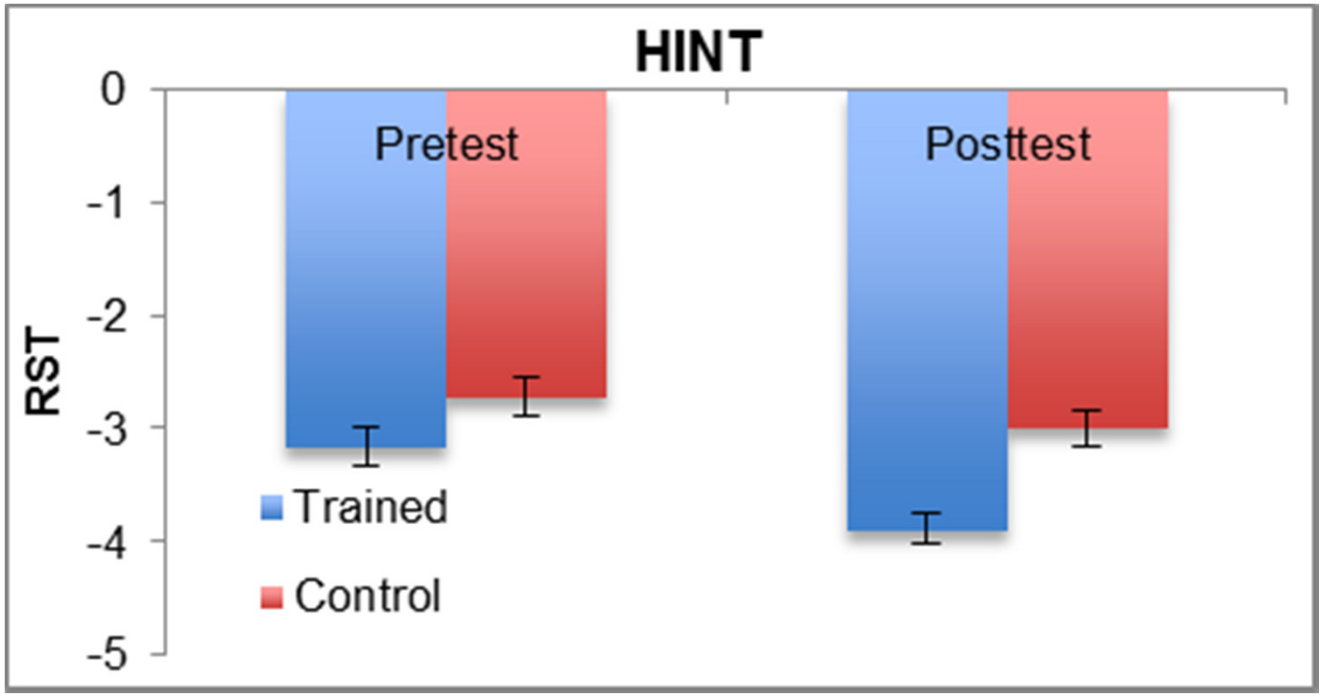
- Ten-session training
- Subjects hear a series of digits (e.g., 3, 5, 1)
- Respond in reverse order (1, 5, 3)
- Number of digits adaptive
- Noise level increased by day

WM Improvement





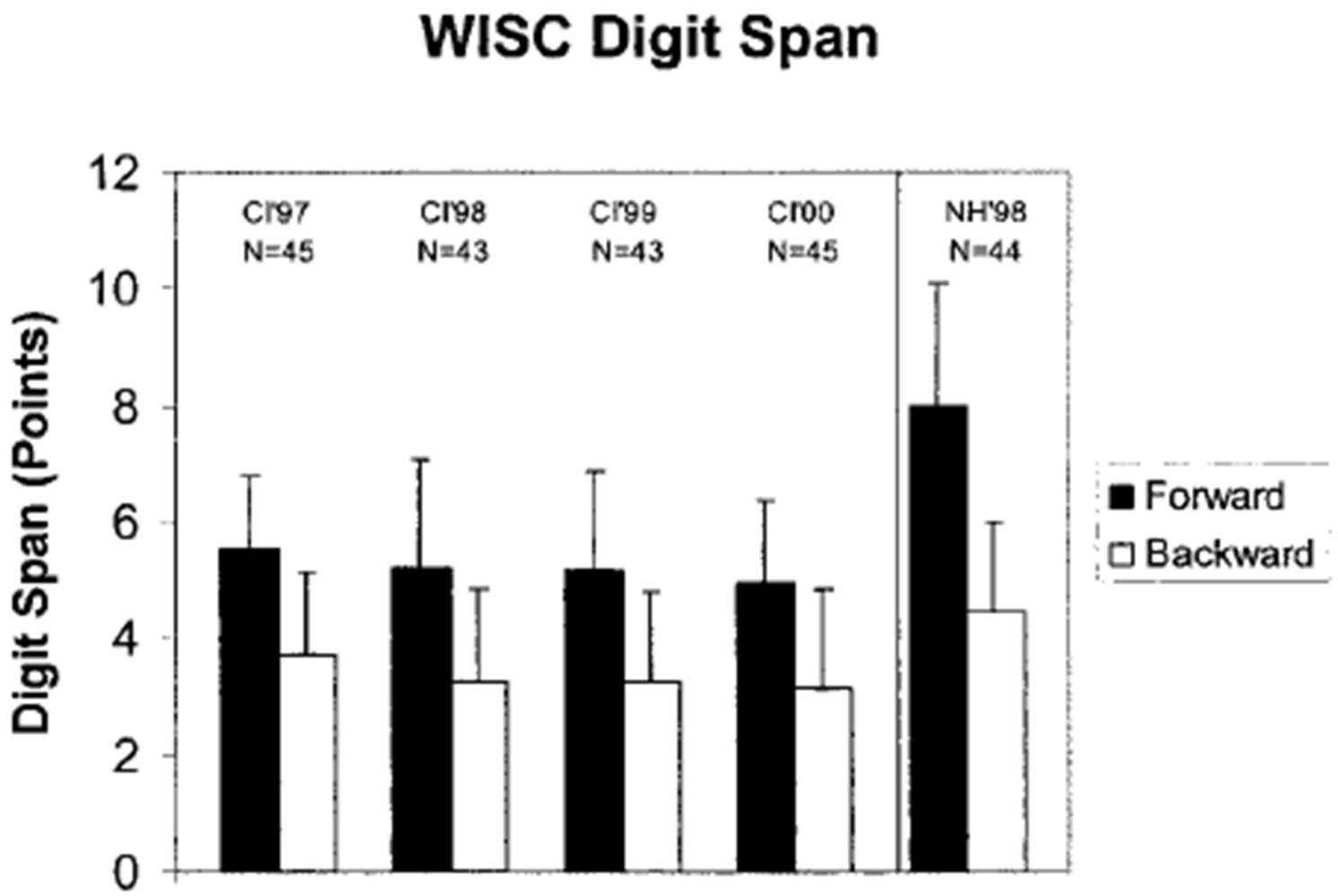
Speech in Noise Improvement



Children with Cochlear Implants

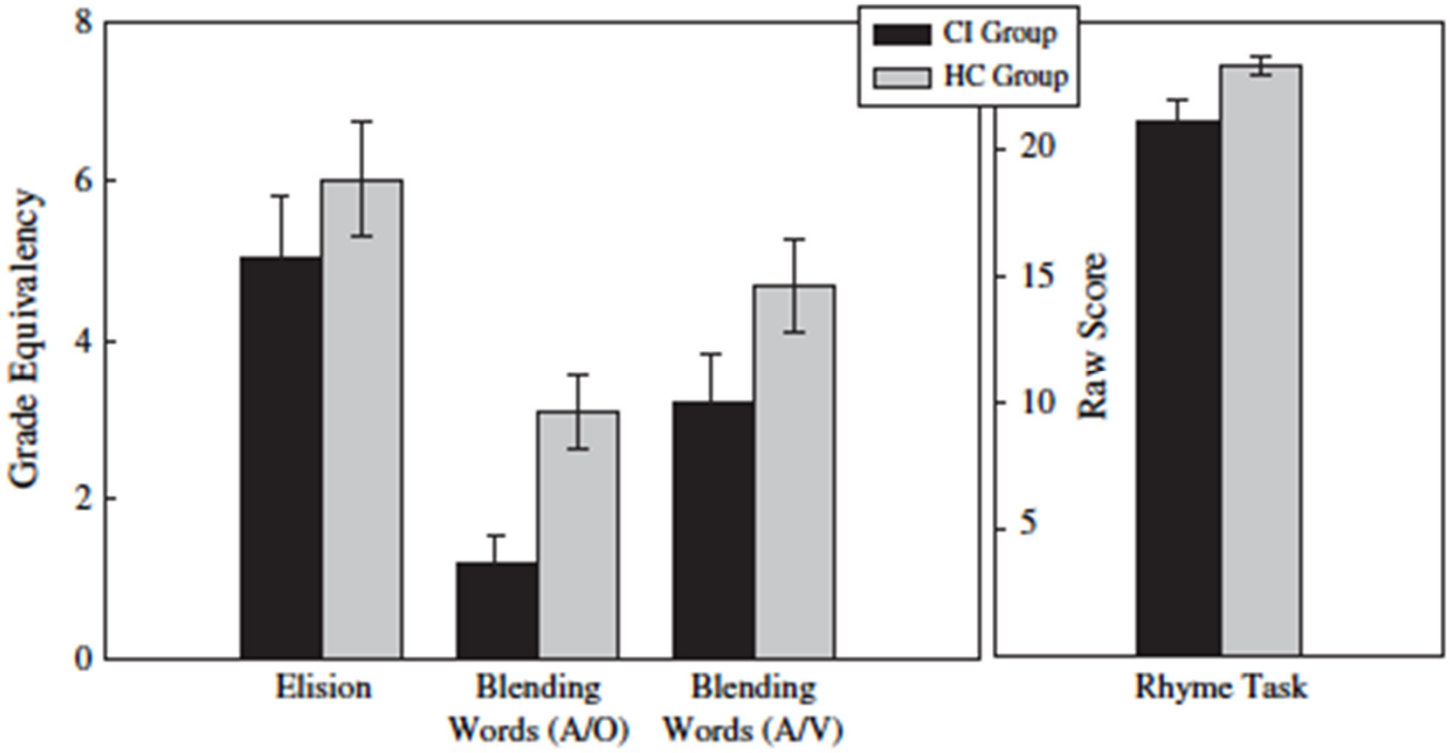
- Auditory, cognitive, and language abilities better than hearing impaired but worse their normal hearing peers

Working Memory in CI Children



Pisoni & Cleary, 2003

Phonological Awareness in CI Children



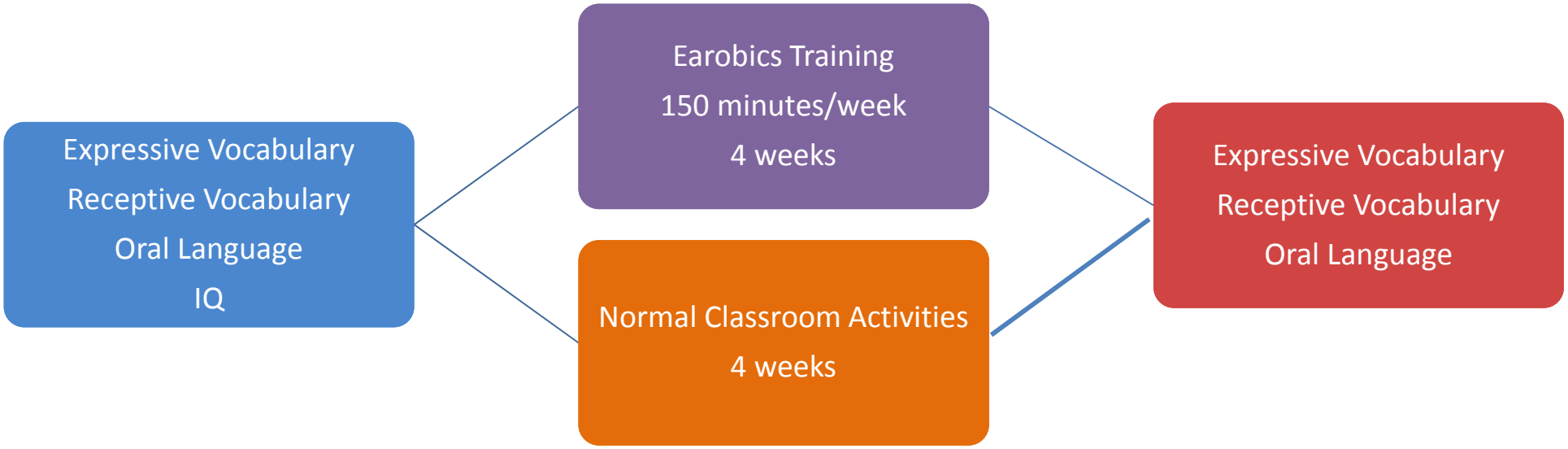
Spencer & Tomblin, 2009

Child CI Users

	Trained		Control	
	M	*SD*	*M*	*SD*
Age	67.6	9.8	62.7	19.2
Age at Implant	21.9	15.4	23.0	10.3
CI Duration	45.7	13.2	39.7	24.8
Pre-Implantation Speech Awareness Threshold	74.5	11.7	74.4	17.9
Speech Awareness Threshold at Pretest	6.5	5.8	6.1	5.5
Performance IQ	100.0	12.7	105.2	16.8

Ingvalson, Young, & Wong (2014). *Int J. Ped. Oto.*

Testing and Training Schedule



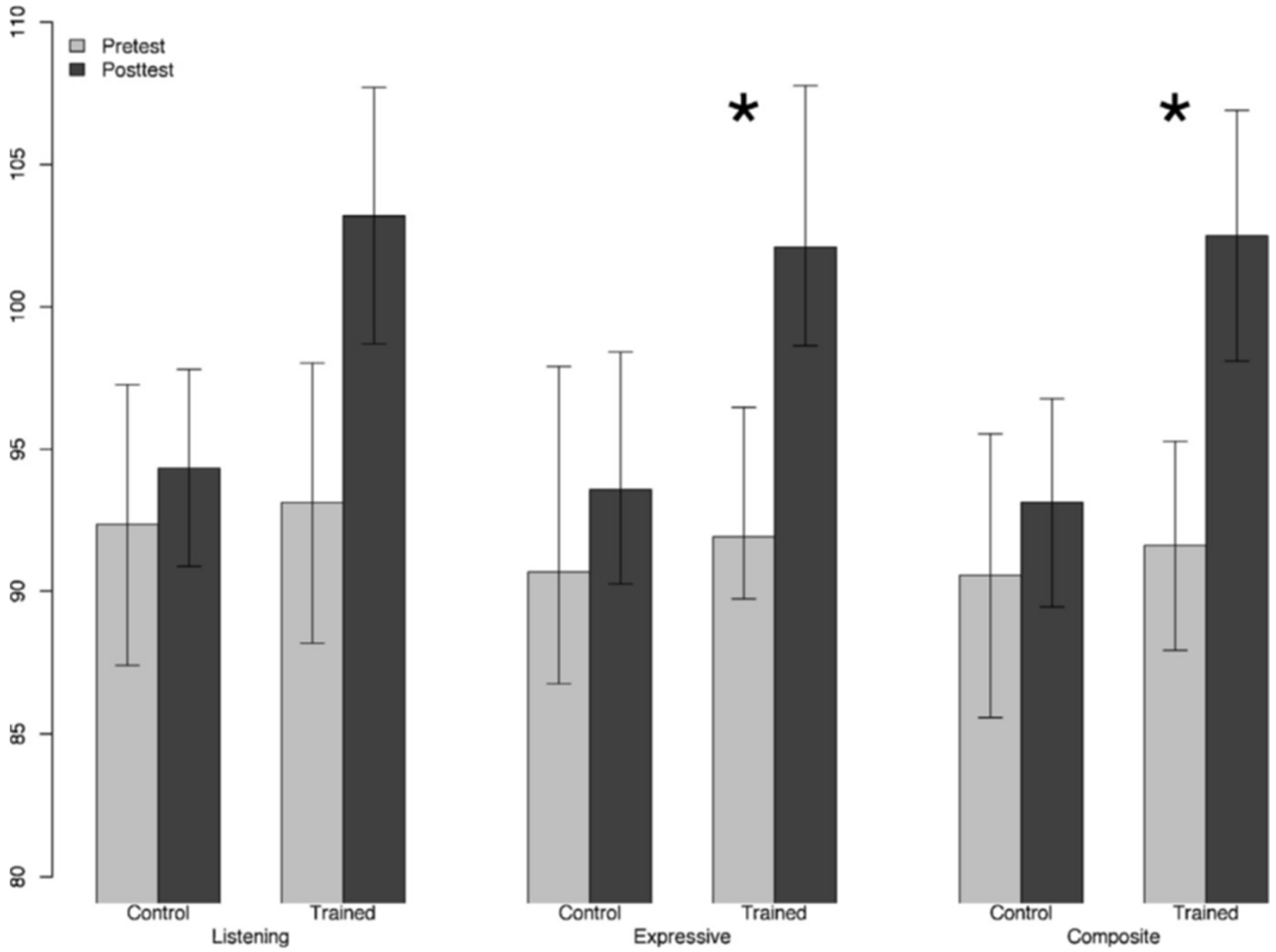
Training







OWALS: Trained Group Improved



Research Goal

- To understand the **basic** mechanisms of auditory processing from molecule to behavior, in order to:
  - Have a comprehensive understanding of pathophysiology of disorders
  - Enhance treatments
  - Optimize learning for everyone

Conclusions

- #1. Stages of neural processing along the auditory pathway can delineate domain-general and – specific properties of the CNS
- #2. Capitalize on our knowledge of the cellular characteristics of the brain, we can develop and test hypotheses about the genetic basis of complex auditory functions
- #3. Through looking at the CNS as a network, we can gain a fuller understanding of spoken language processing problems and treatments.

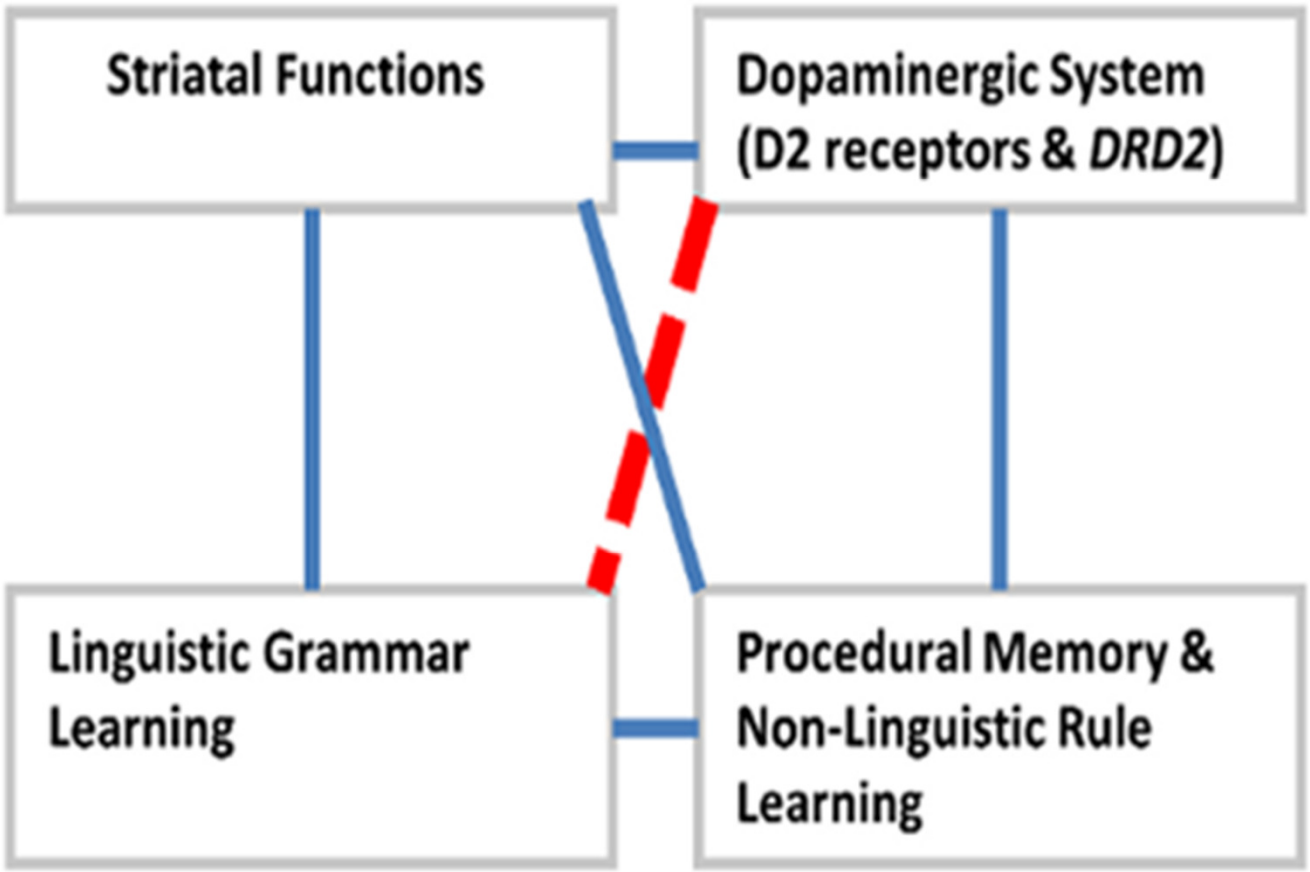
Acknowledgements

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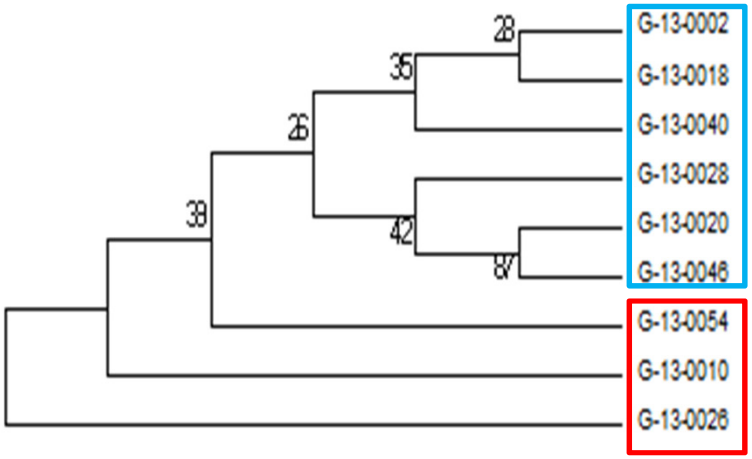
National Institutes of Health (USA) (R01DC008333 & R01DC013315)
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Food and Health Bureau (Hong Kong) (HMRF 01120616)
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Global Parent Child Resource Centre Limited

b)


Striatal Functions
Dopaminergic System (D2 receptors & *DRD2*)
Linguistic Grammar Learning
Procedural Memory & Non-Linguistic Rule Learning

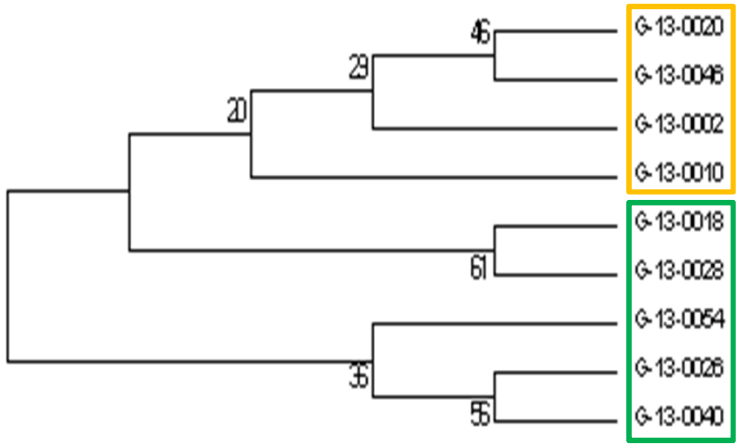
Un-weighted clustering

- Variants (all variants or non-common variants) are aligned across all samples.
- Boxes in the same color indicate the samples are clustered in the original tree.
- In the case for all variants, the clustering is actually not very clear, giving G-13-0026, G-14-0010 and G-13-0054 standing alone. This is likely due to the noisy background of variants.



Log likelihood = -588981.51

Bootstrap consensus for all variants

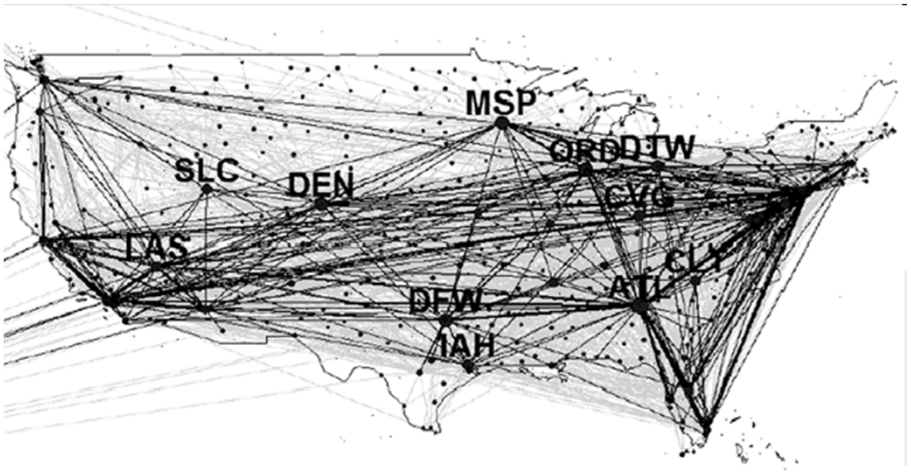


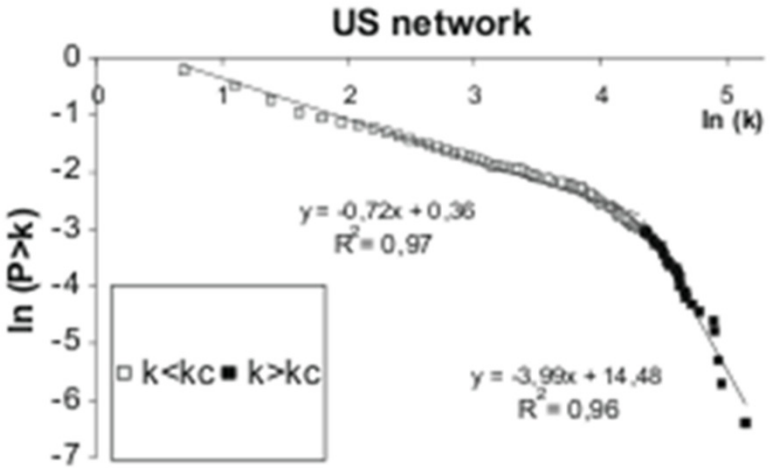
Log likelihood = -62798.53

Bootstrap consensus for non-common variants

Network Efficiency

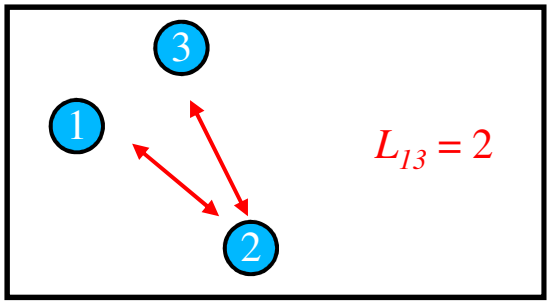
Airport Network





Paleari et al. (2009). *Transportation Research Part E*

Efficiency



-A graph theoretic measure
-Speed of information transfer
-A connection is defined by strength of inter-regional correlation

$$E(i) = \frac{1}{N-1} \sum_{j \in N} \frac{1}{L_{ij}}$$

where N is number of nodes in network

L_{ij} is shortest path between nodes i,j

- Group x Listening condition interaction
- Less efficient for older adults in noisy listening condition
- Cognitive and auditory brain

