Early Auditory Deprivation: Auditory Neuroscience and Listening and Spoken Language Outcomes

Jace Wolfe, Ph.D.

March 19th, 2024

Road Map

- **<u>Primary Objective:</u>** Discuss the impact of early auditory deprivation on auditory brain development and listening and spoken language outcomes

- Brief overview of anatomy and physiology of the auditory brain

- Auditory neuroscience
  - Effects of hearing loss on auditory brain physiology
  - Andrej Kral's research on auditory deprivation
  - Listening and spoken language and beyond

- Shoot for the moon!

Back in Time..

2000

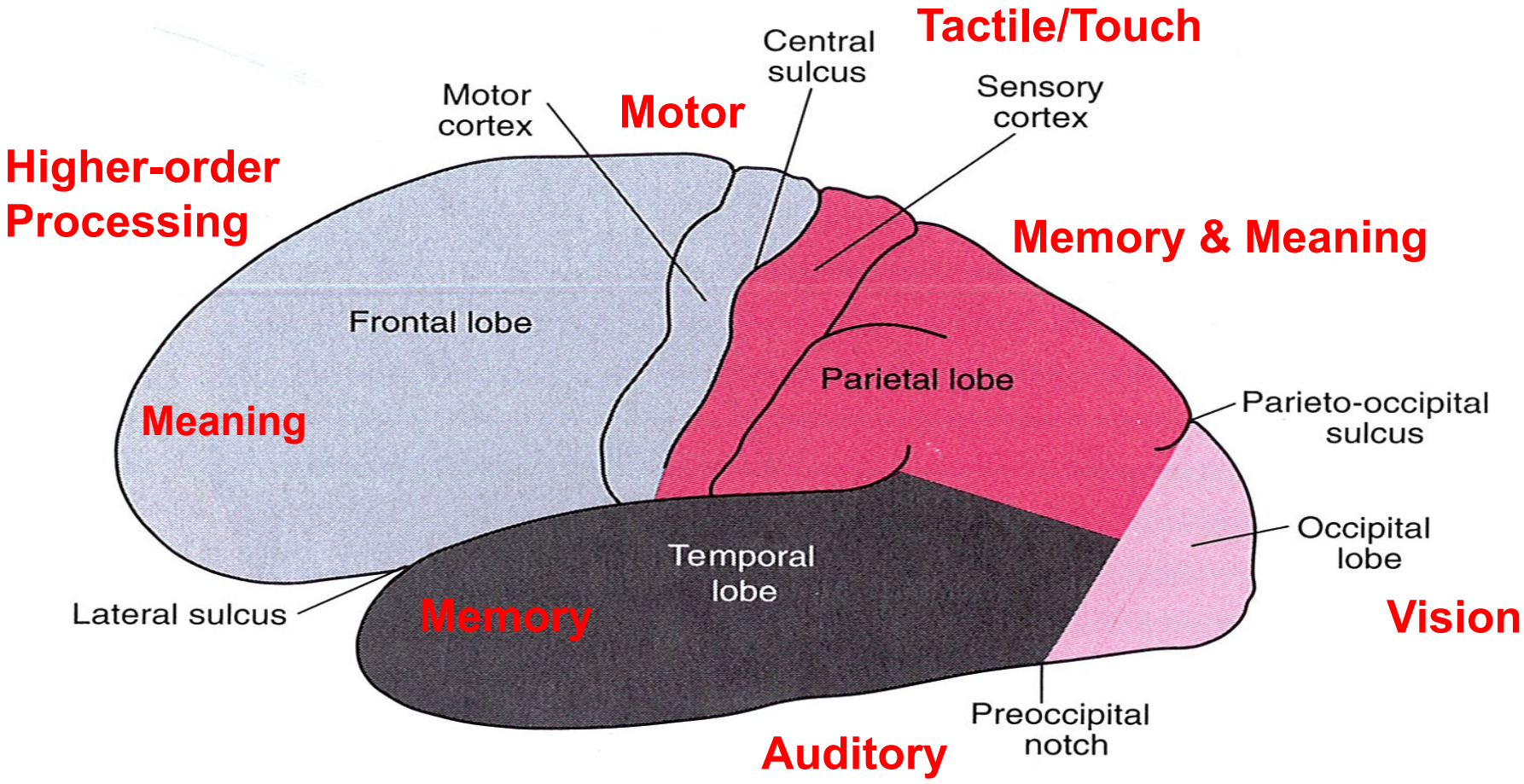
Audiologist: Jace Wolfe Circa 2000

Peter's Story

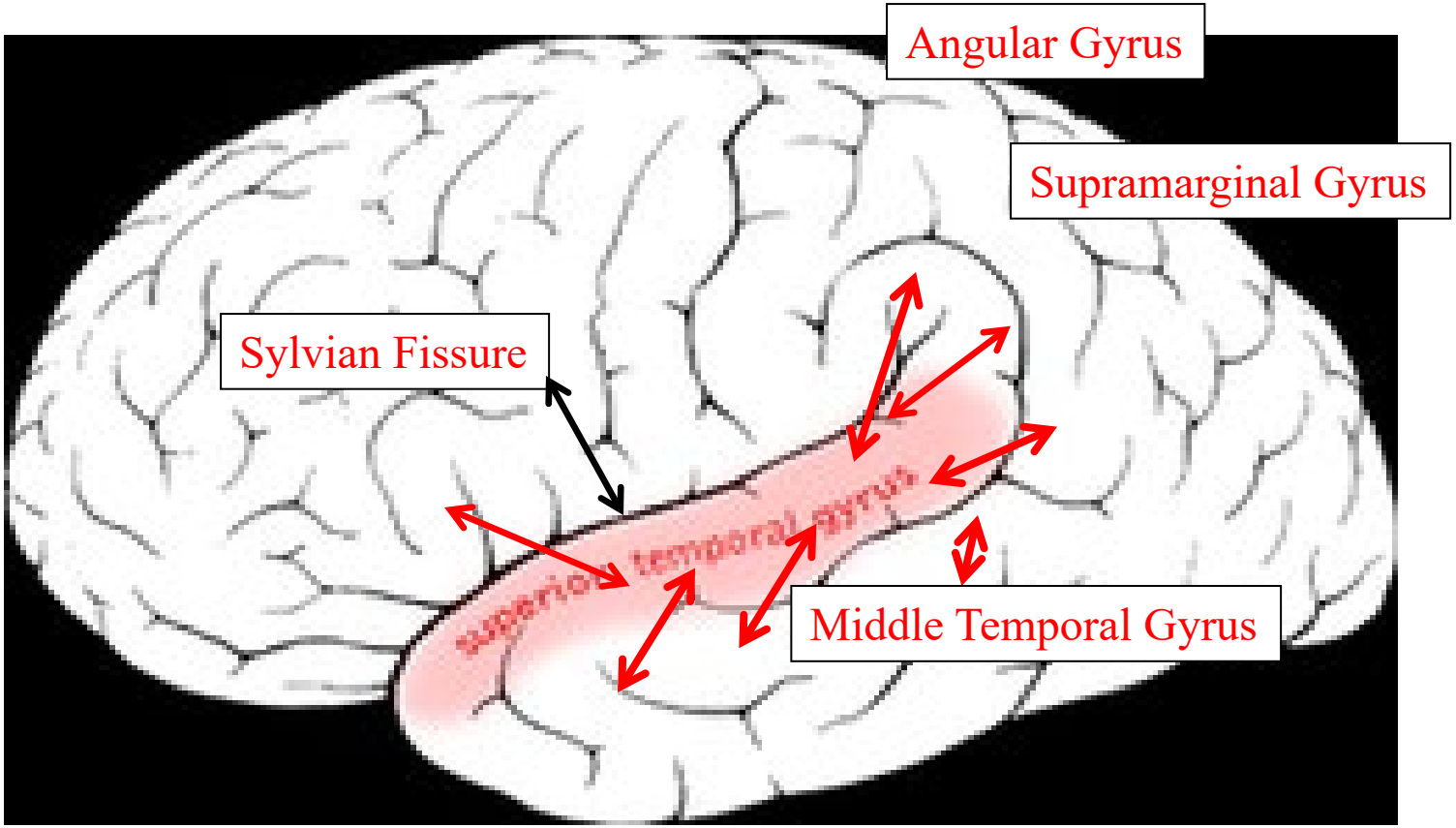
Shooting for the Moon!

Early auditory deprivation places excellent listening and spoken language outcomes at risk!

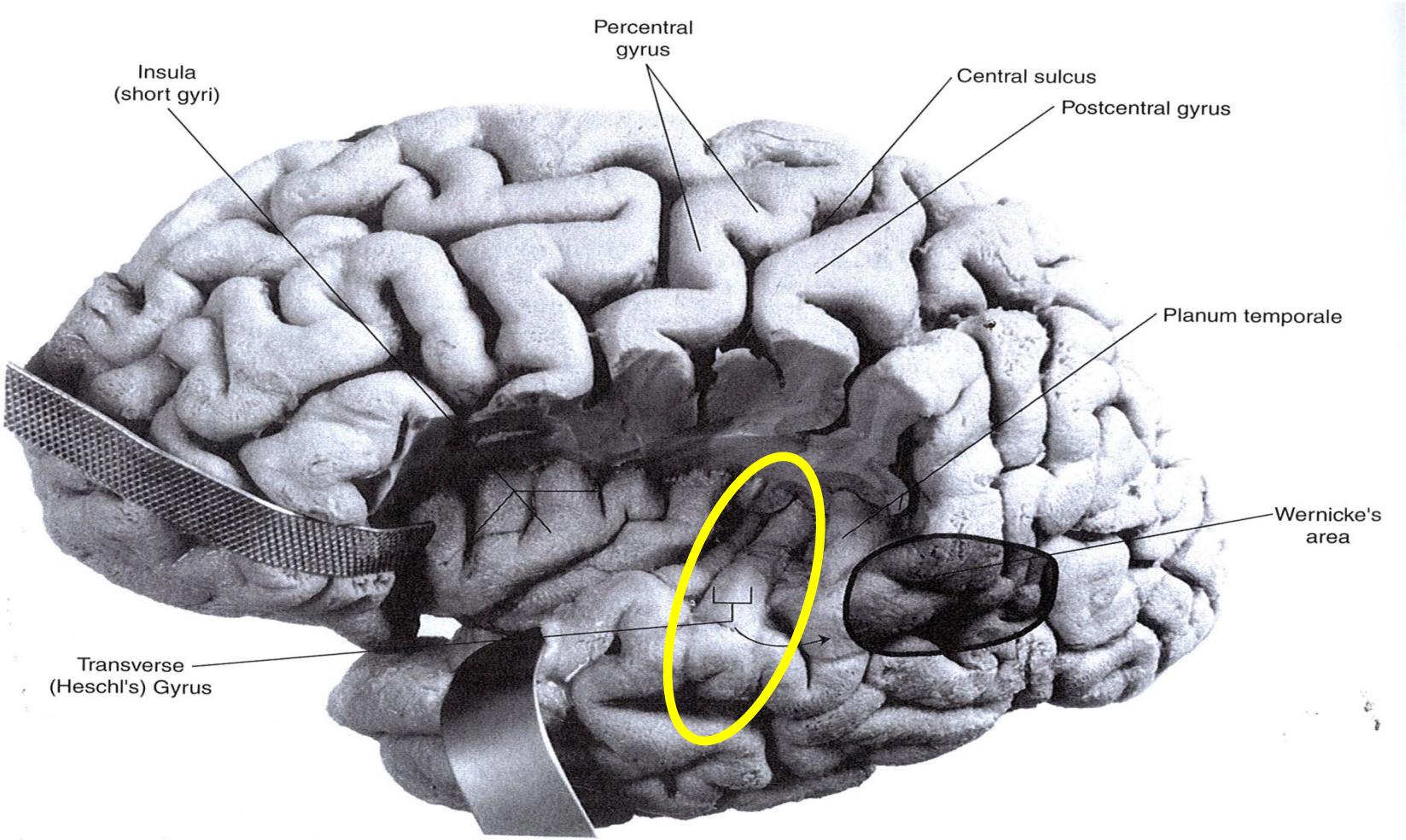
The Lobes of the Brain



The Auditory Brain

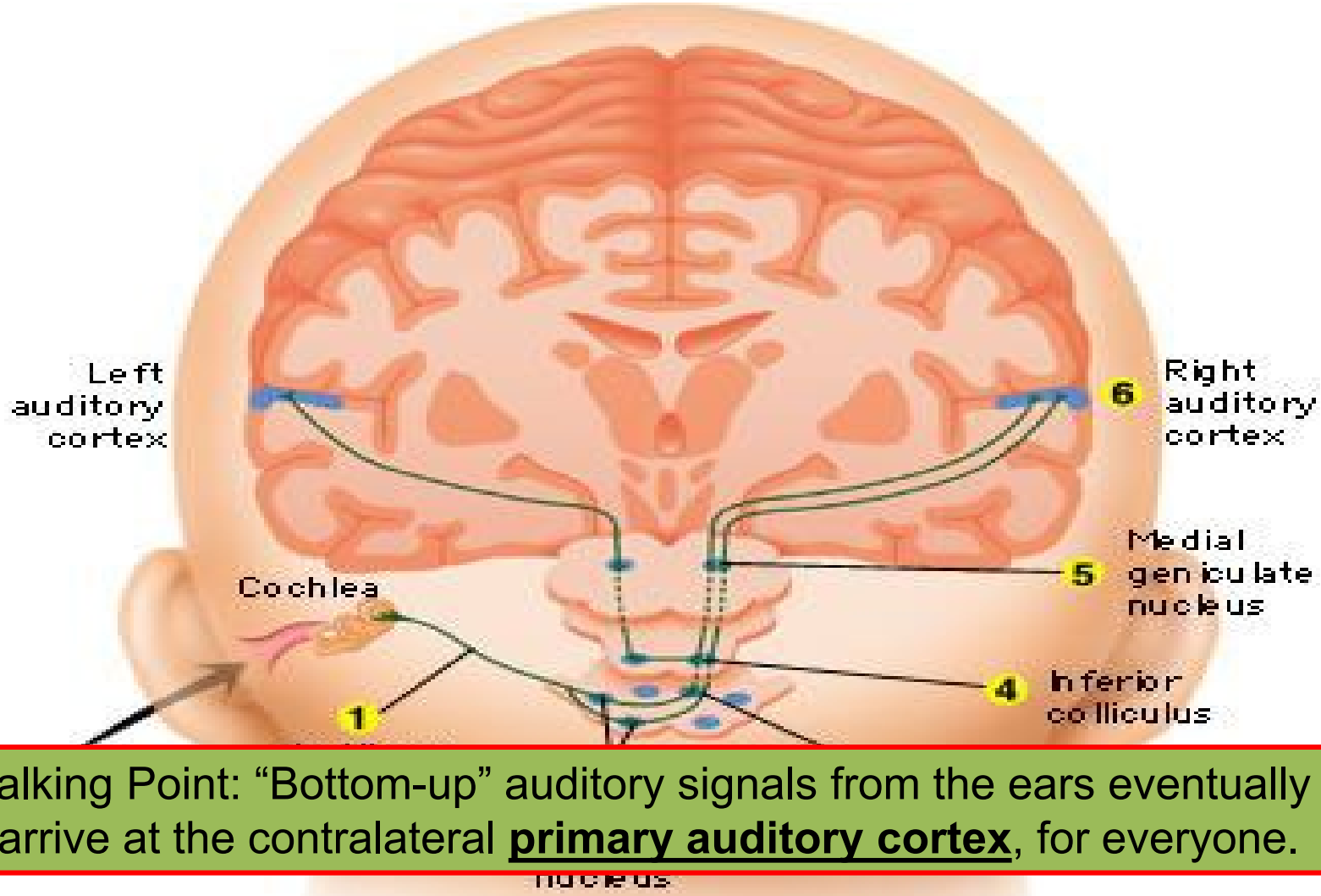


Primary Auditory Cortex



Subhash Bhatnagar

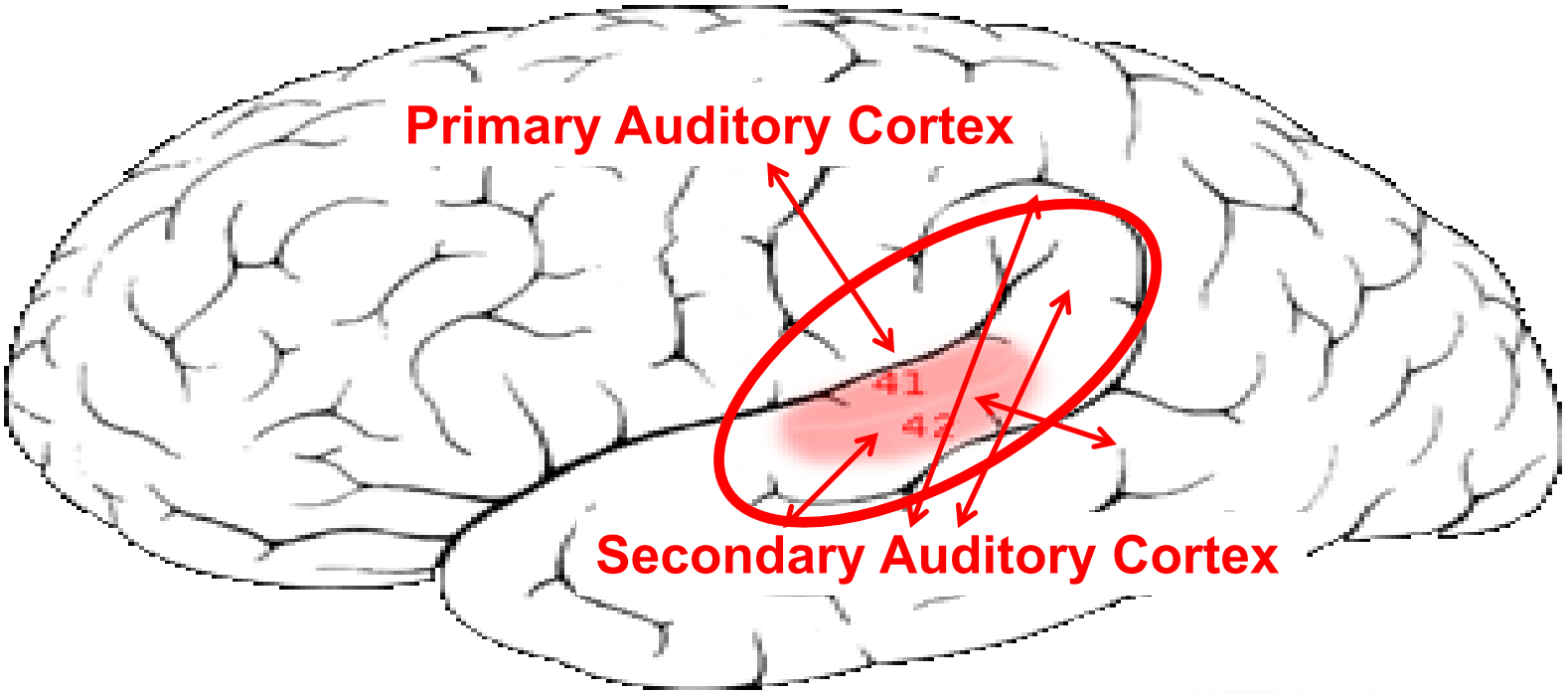
Auditory Nervous System



Talking Point: "Bottom-up" auditory signals from the ears eventually arrive at the contralateral **primary auditory cortex**, for everyone.

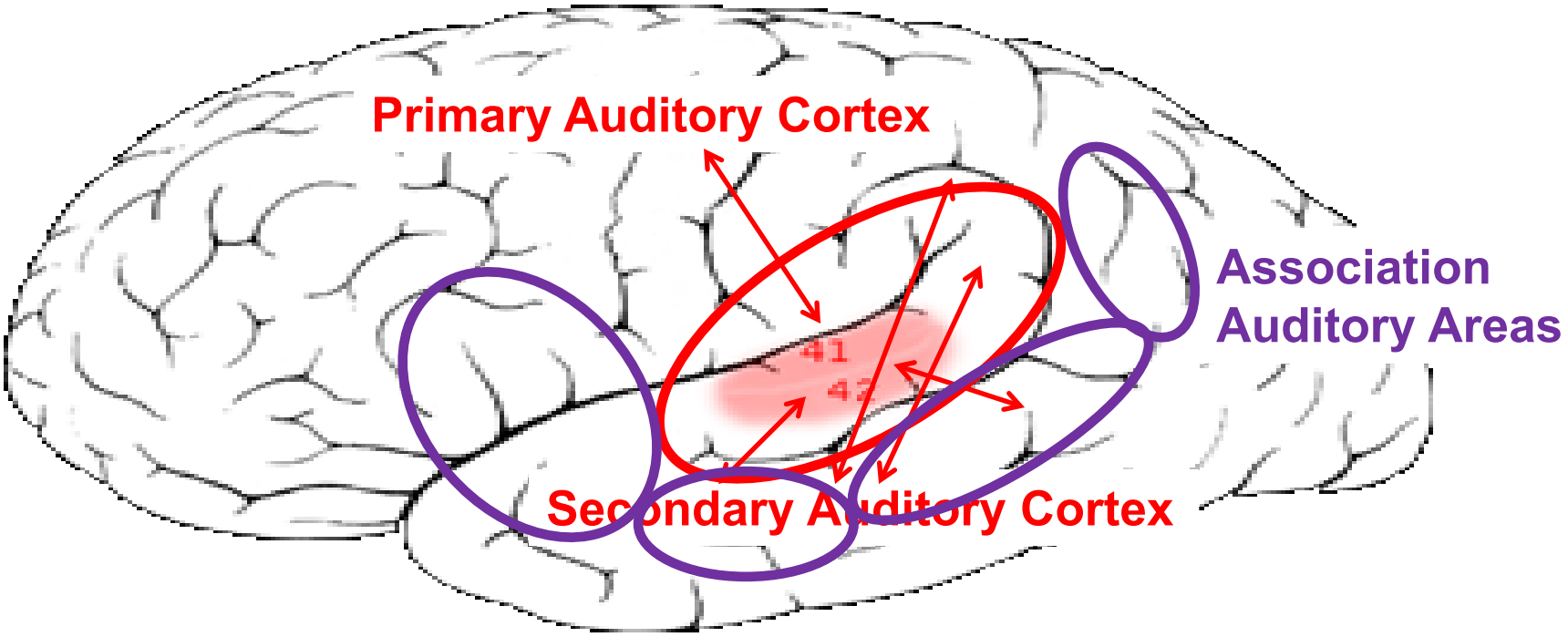
The Auditory Brain
Secondary Auditory Cortex

Secondary auditory cortex is like a "belt" around primary auditory cortex

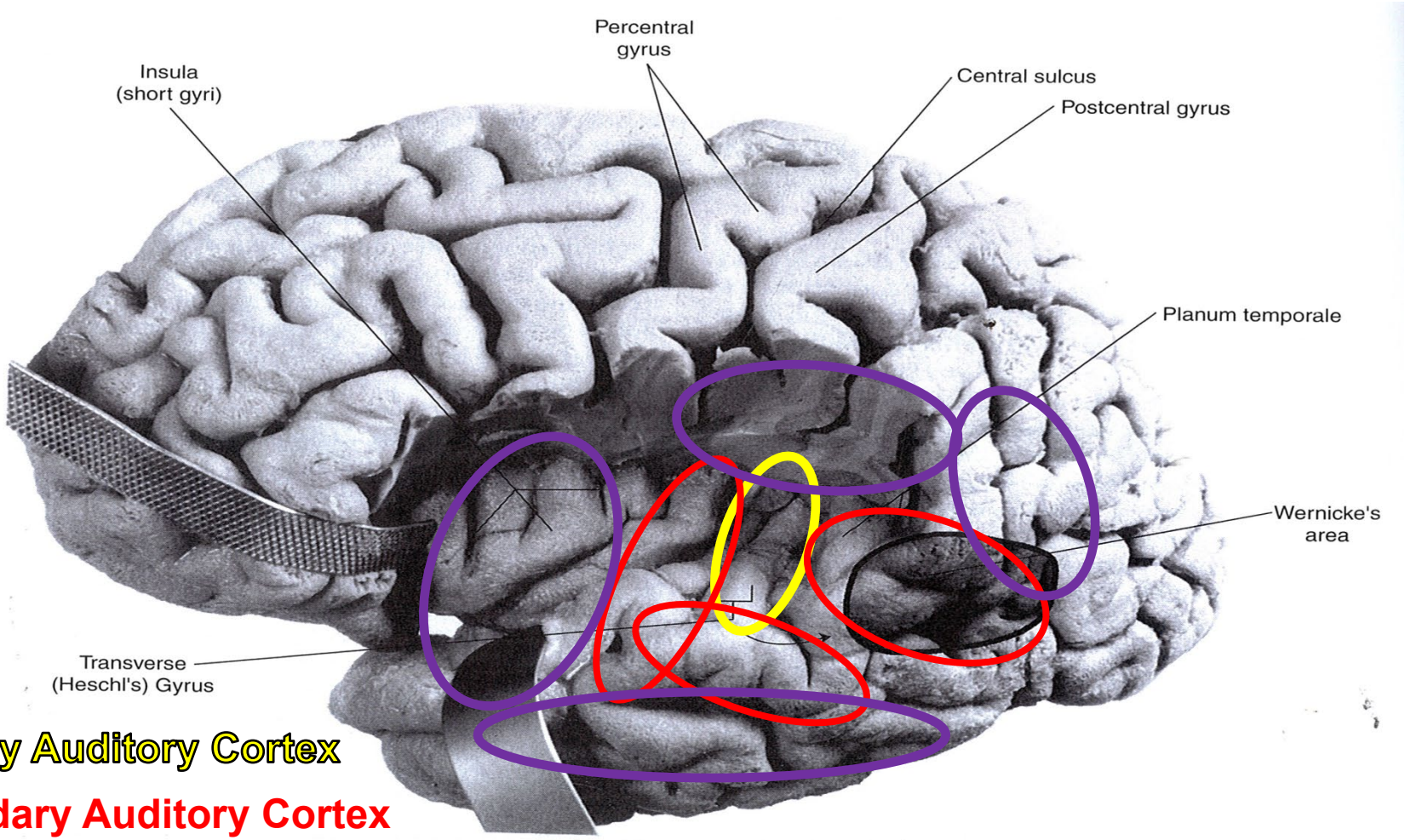


The Auditory Brain

Association Auditory Areas



The Auditory Brain



Primary Auditory Cortex

Secondary Auditory Cortex

Association Auditory Areas

Subhash Bhatnagar

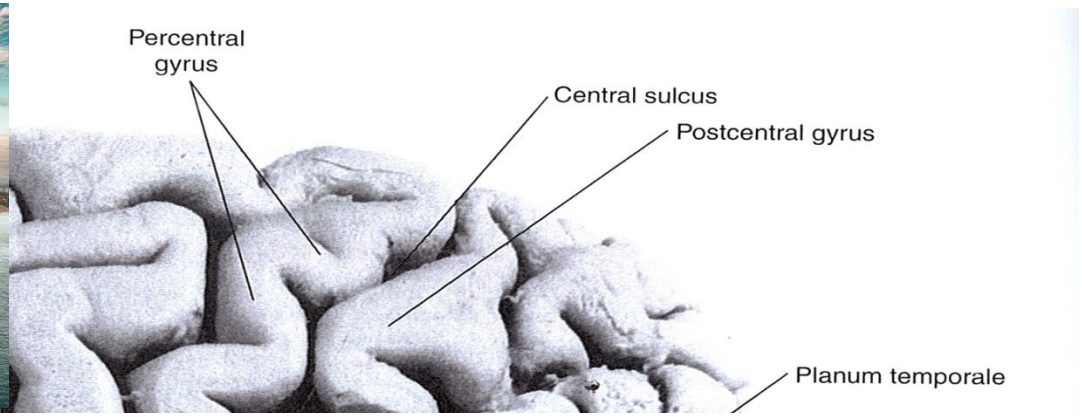
Auditory Cortex

Secondary Auditory Cortex = Bridge to Higher Order Processing

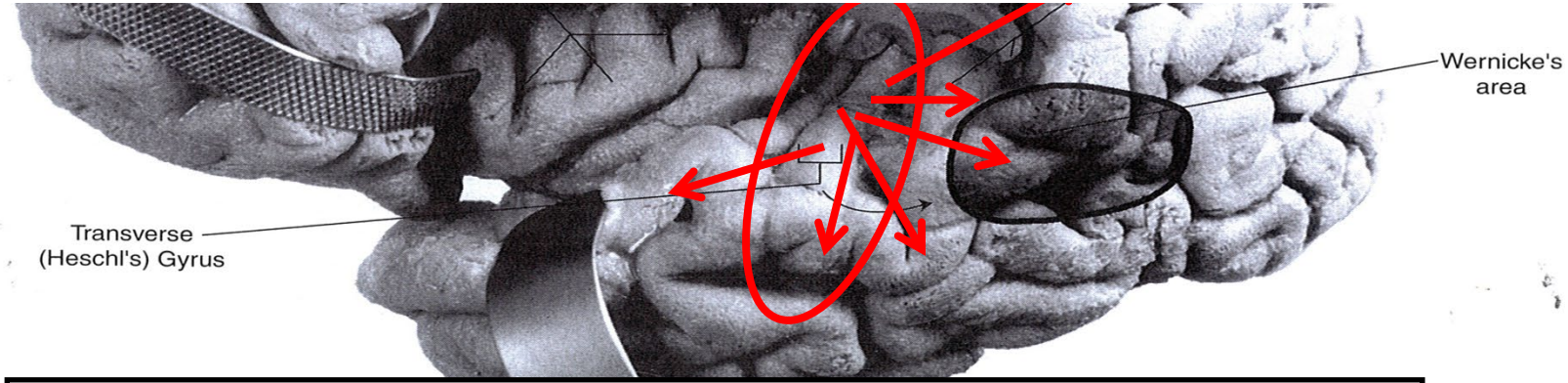
Talking Point: Secondary auditory cortex serves as the **bridge** for sound to be **shared and integrated** with the rest of the brain.

Auditory Cortex

Secondary Auditory Cortex = Bridge to Higher Order Processing

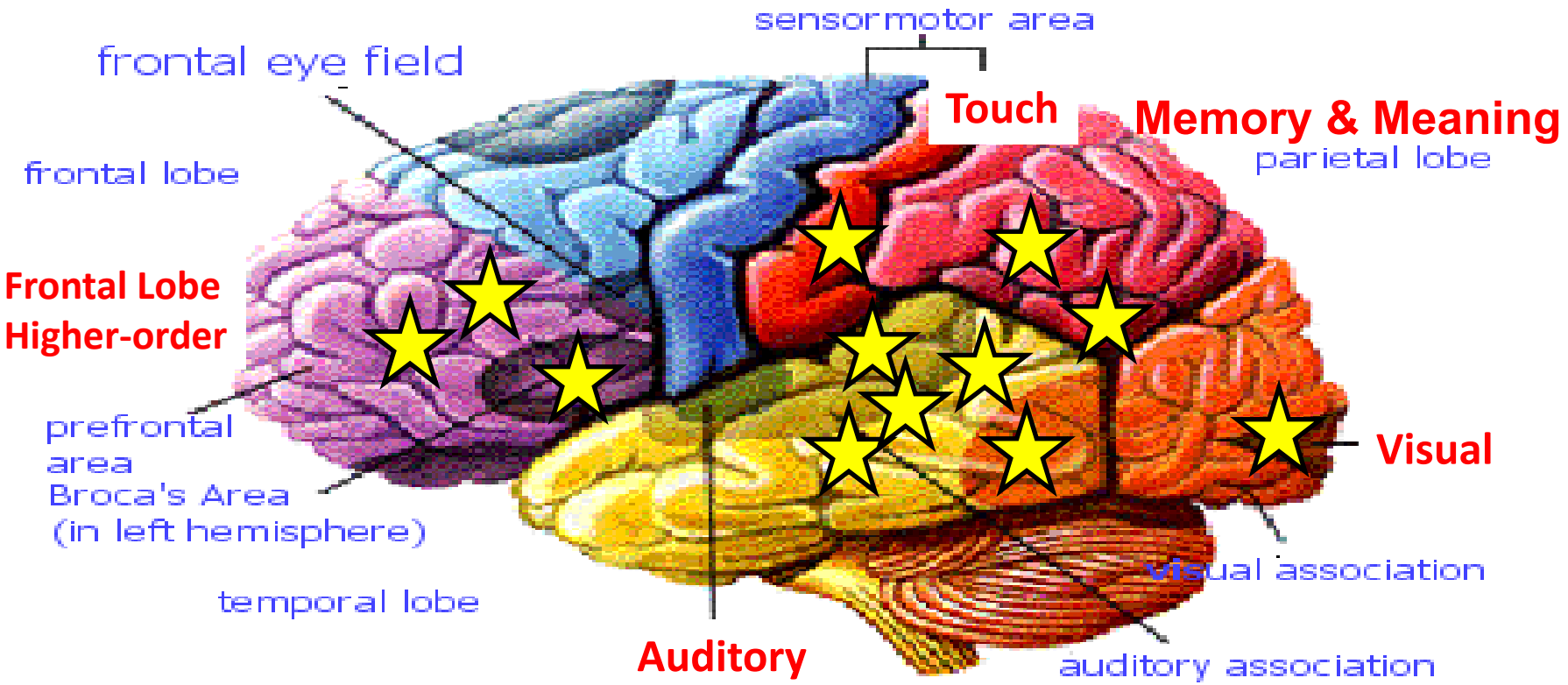


Secondary and association auditory areas possesses pluripotent neurons, which are capable of processing multi-modal stimuli



Talking Point: Secondary auditory cortex serves as the **bridge** for sound to be **shared and integrated** with the rest of the brain.

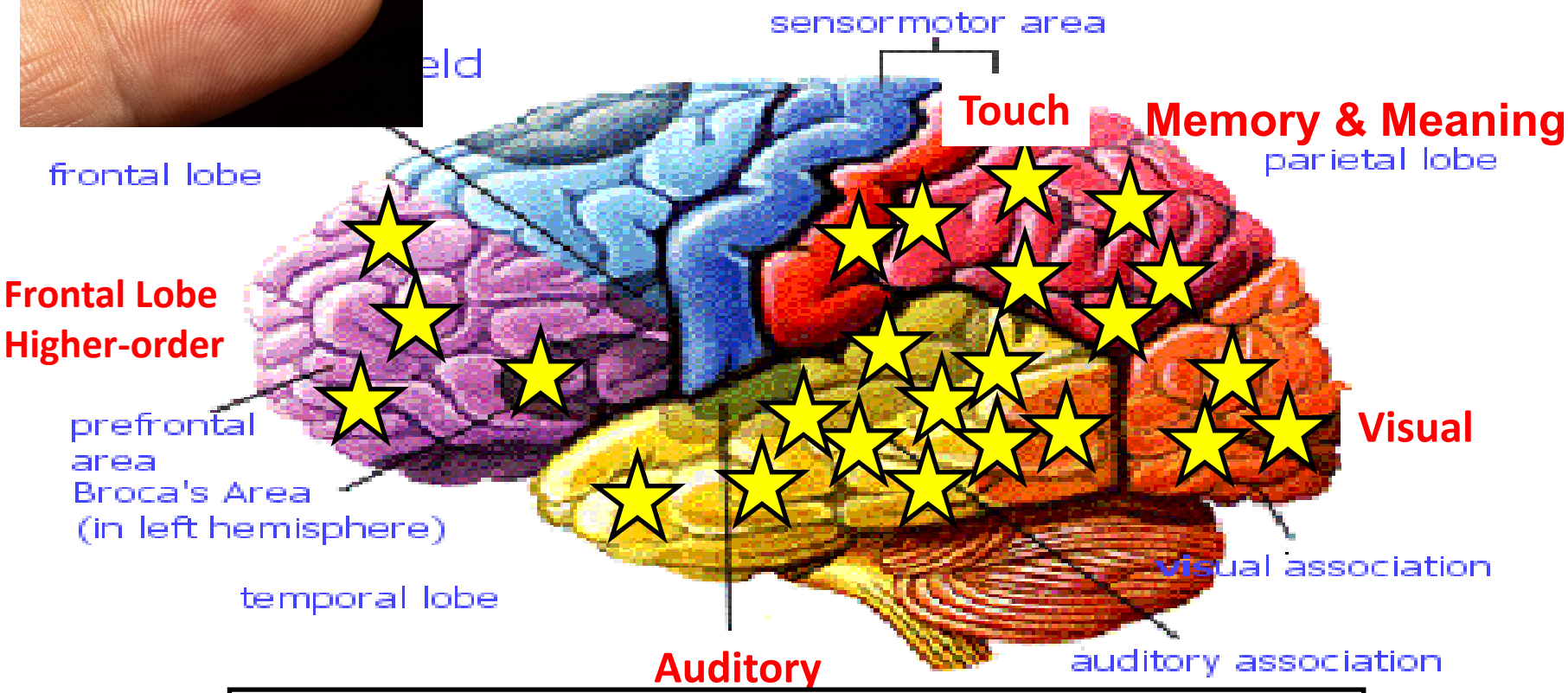
The Listening Brain



Talking Point: Fundamentally, everything that comes into our minds is reduced to **patterns of neural activities.**

-- Kai-How Farh

The Listening Brain



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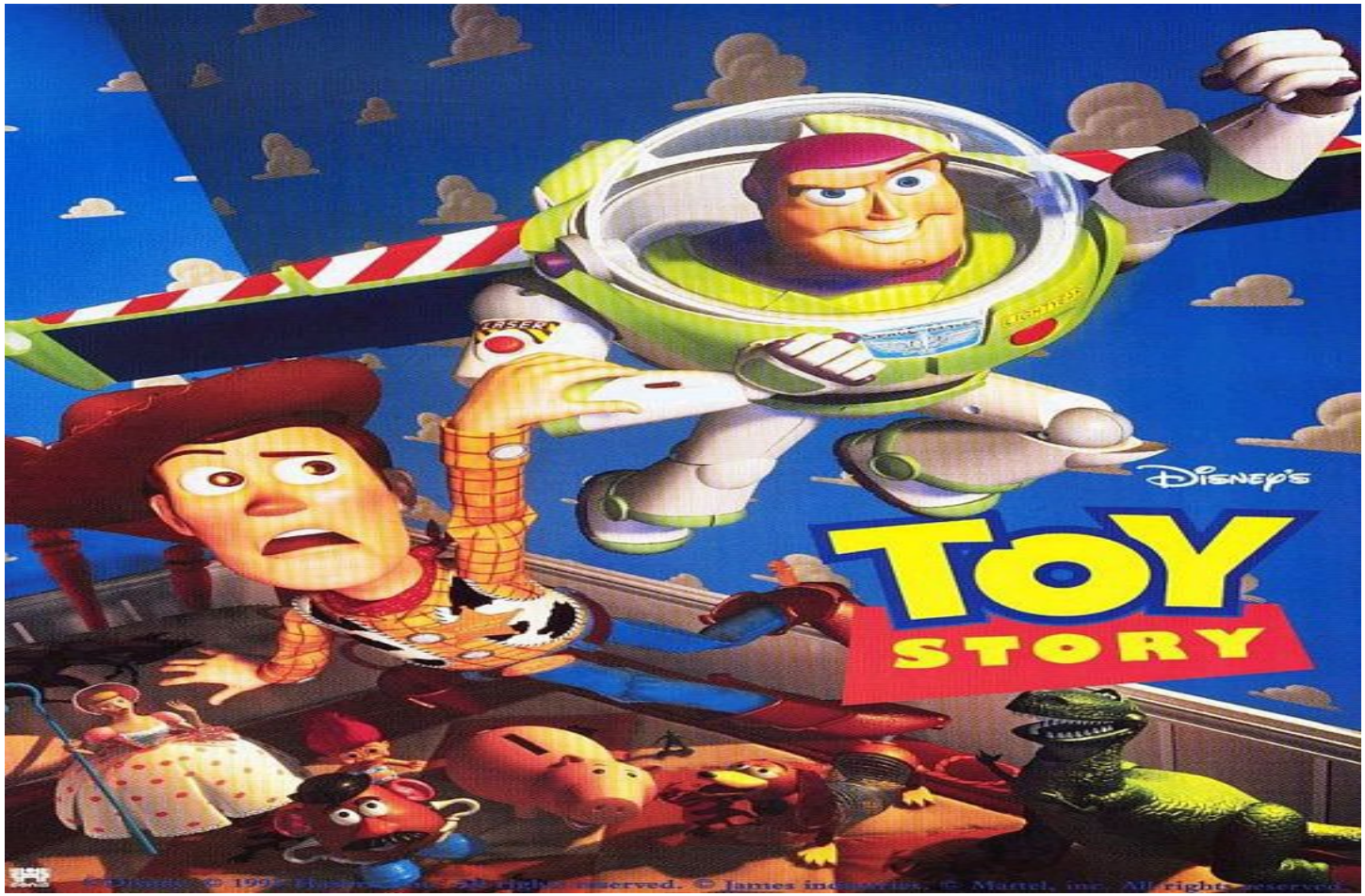
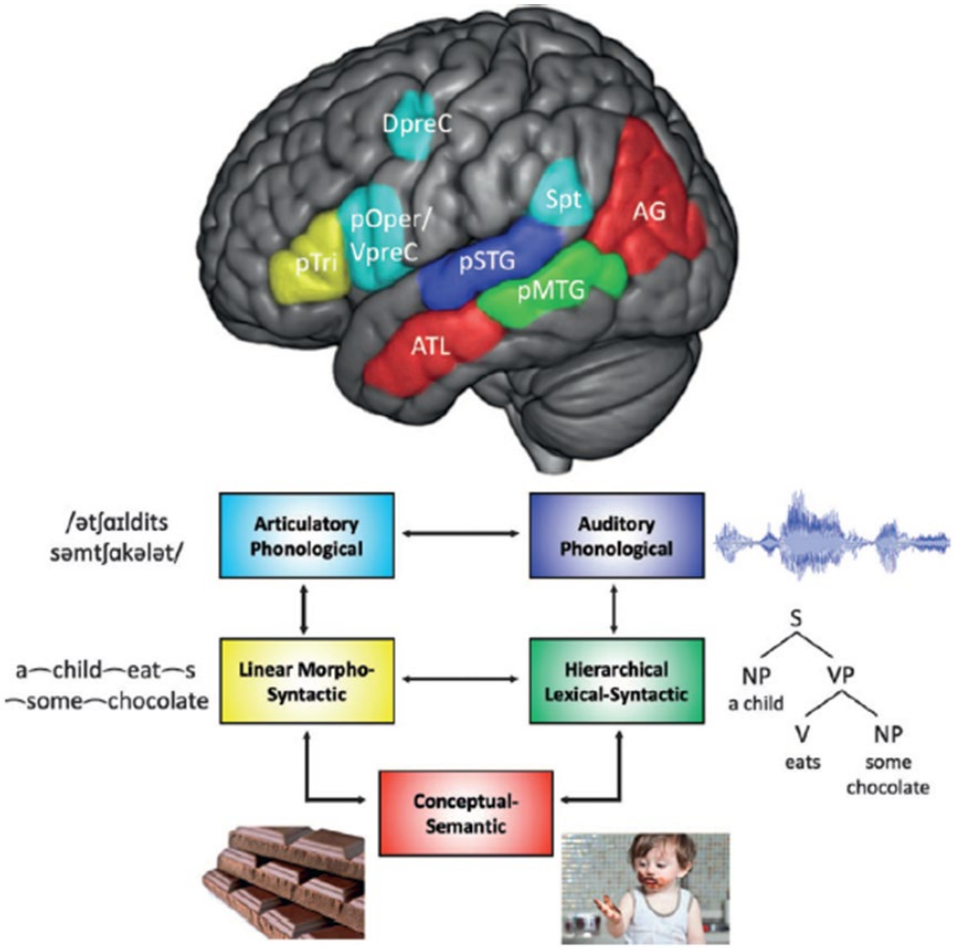
Exploring the World Through Listening



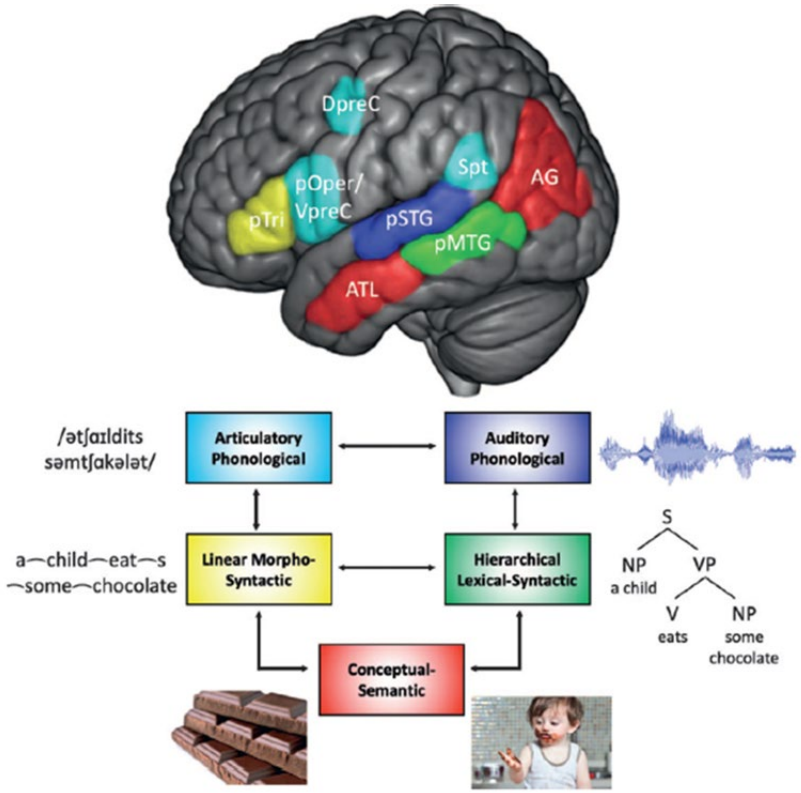
Exploring the World Through Listening

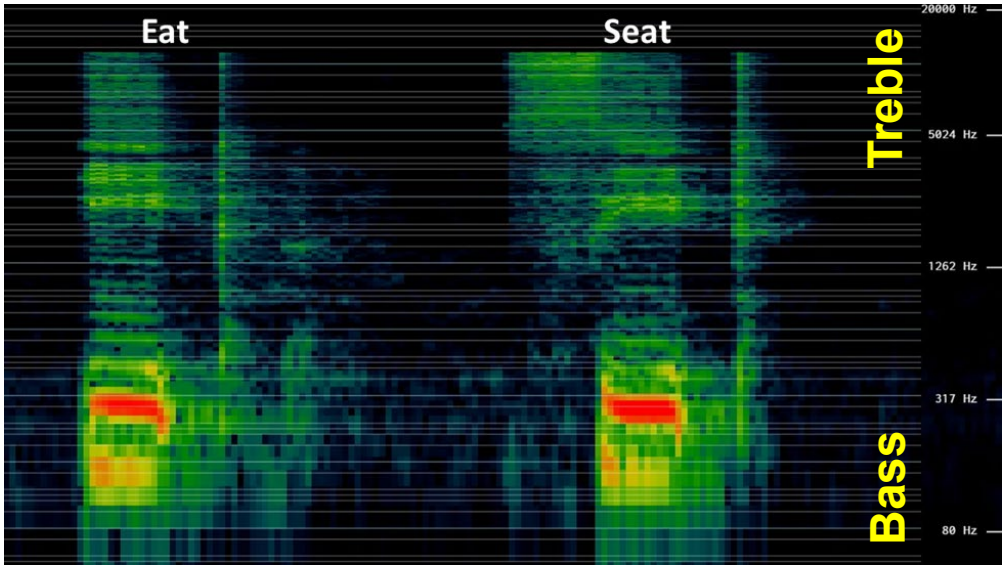
Hierarchical Processing



Matchin & Hickok, 2020

Hierarchical Processing in the Auditory System





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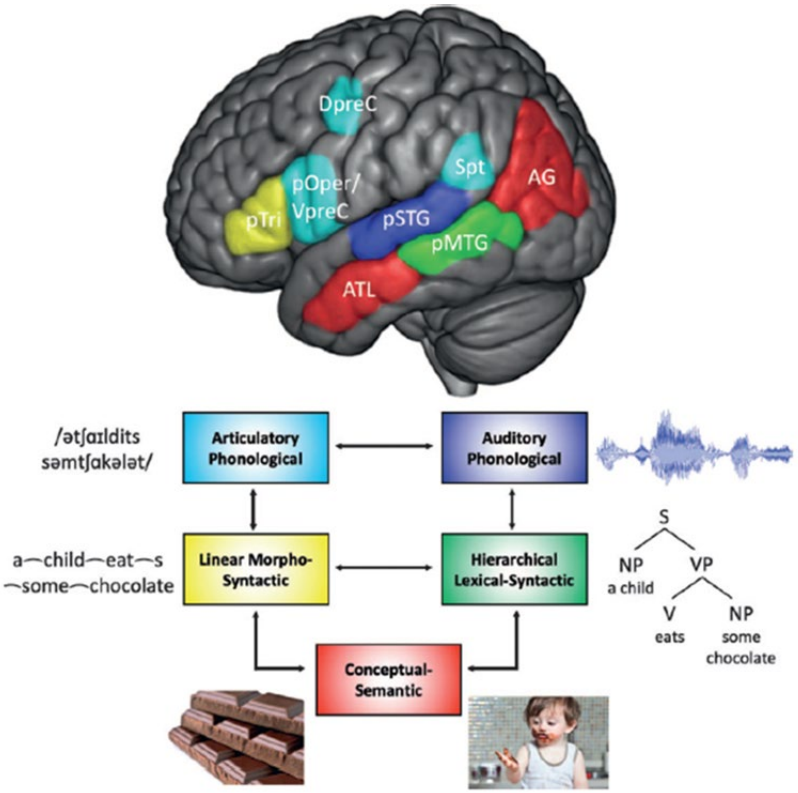

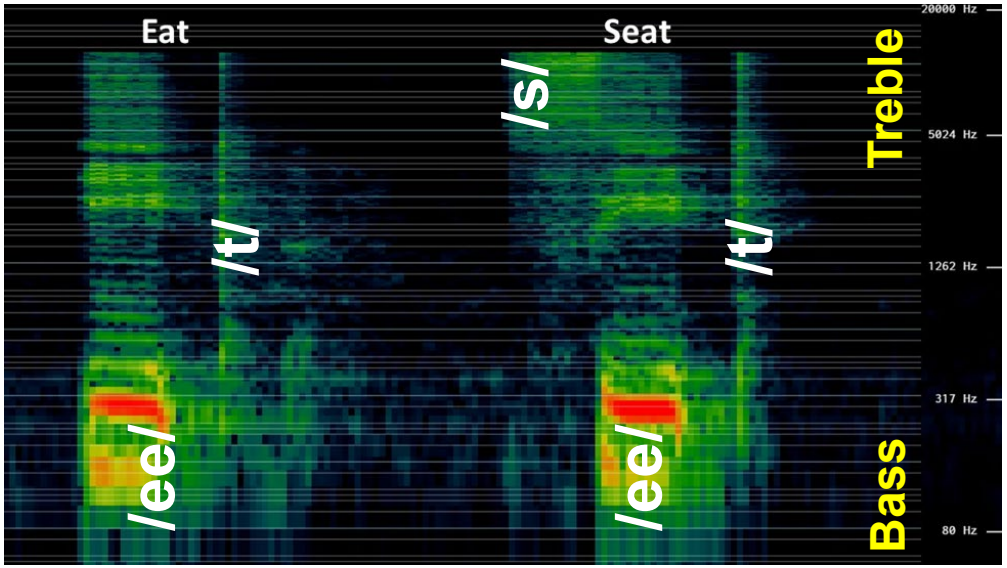

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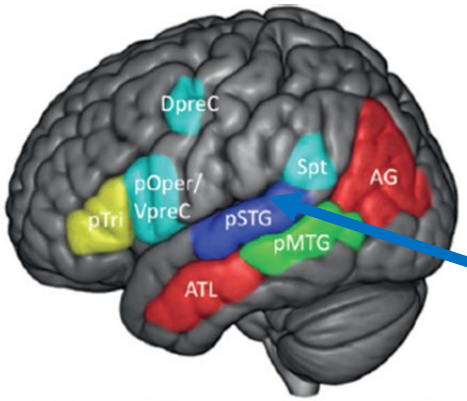

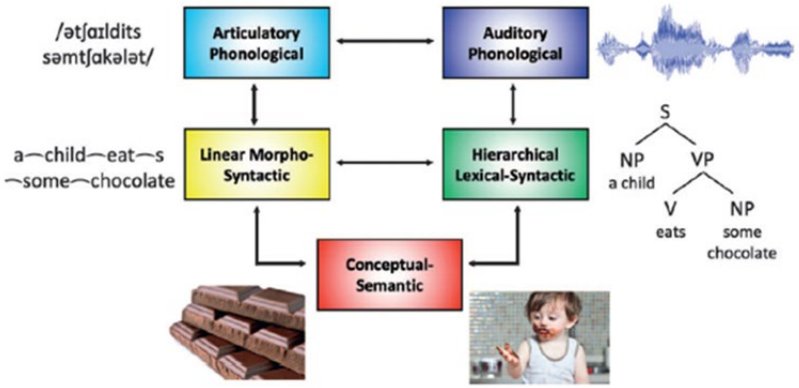

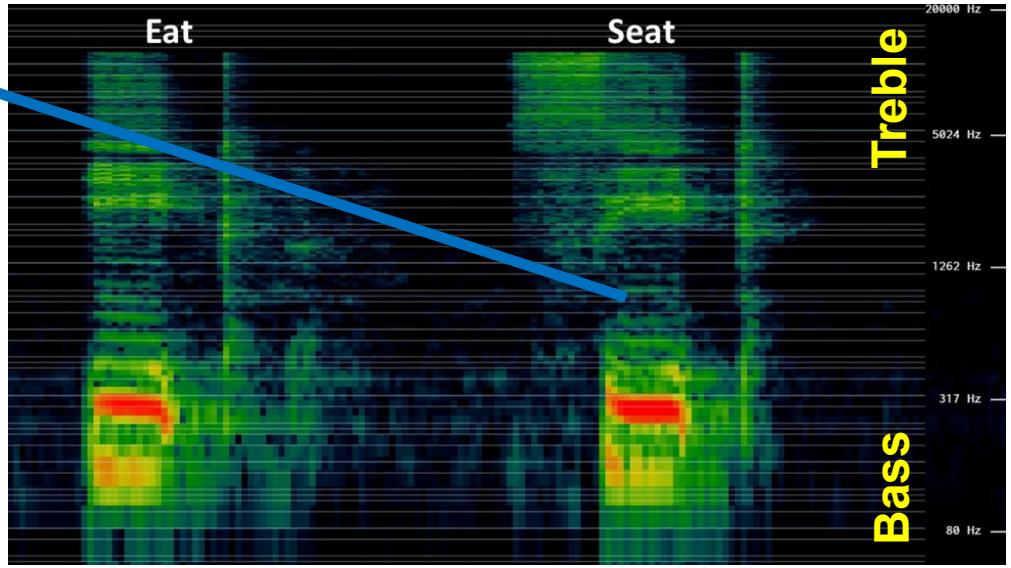

Low Frequency ⟶ High Frequency

Matchin & Hickok, 2020

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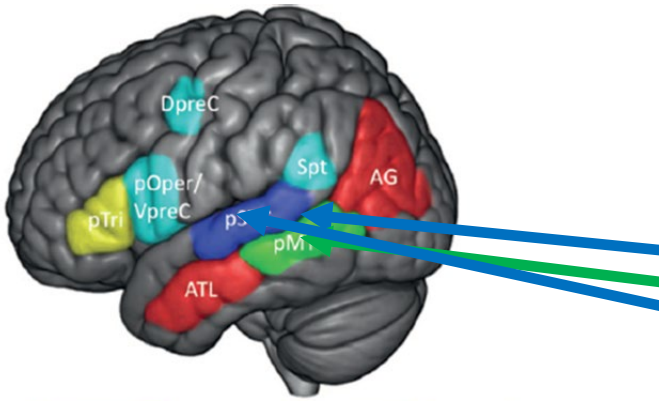

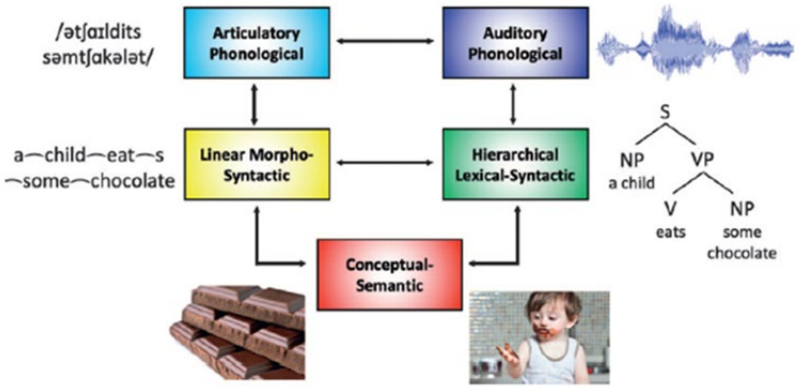

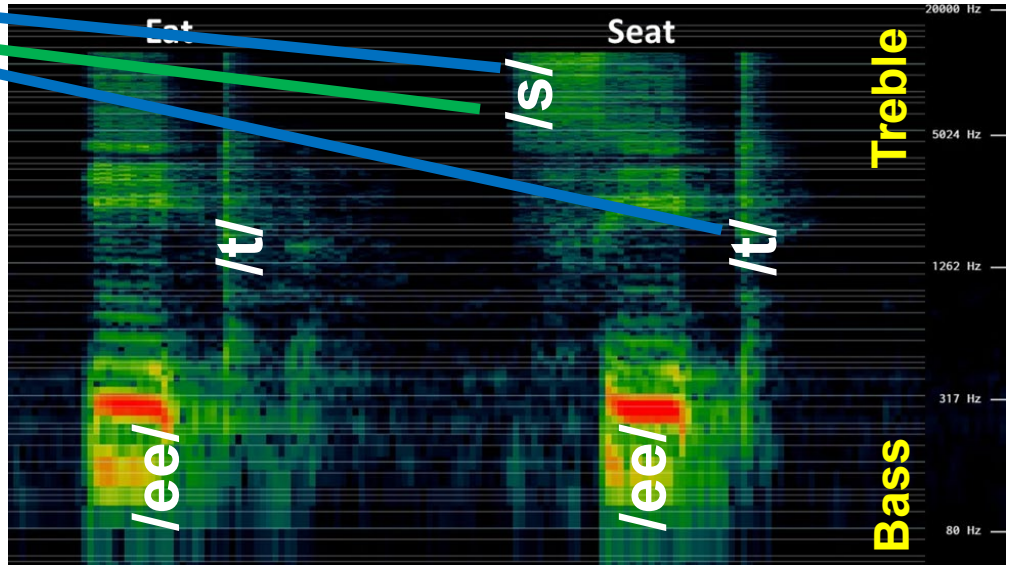

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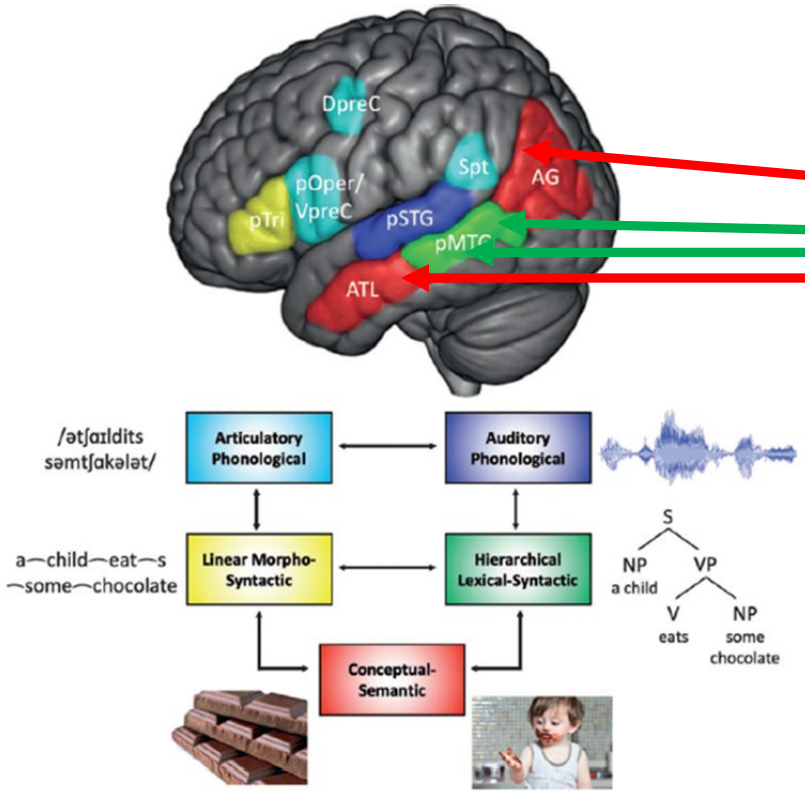
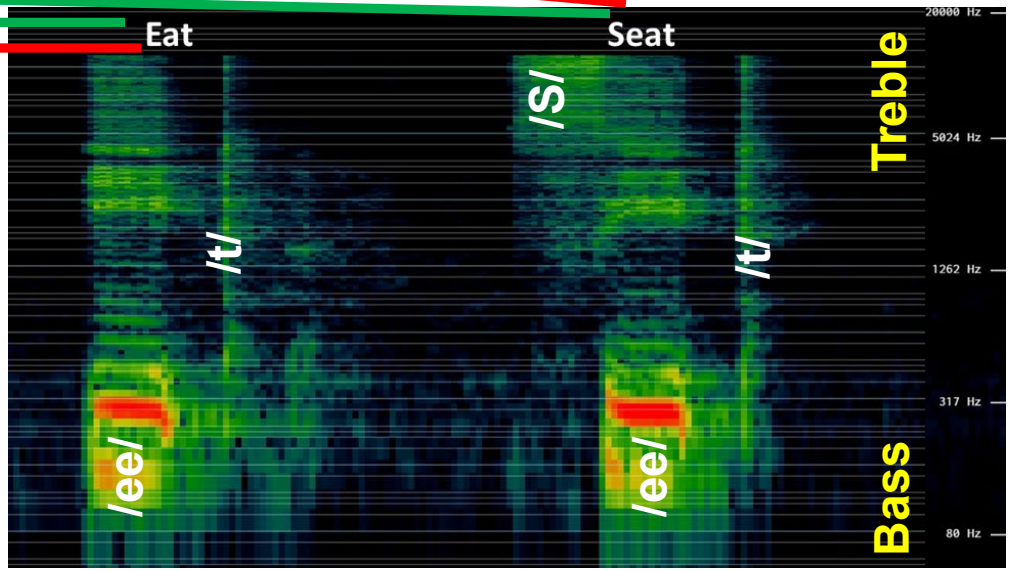
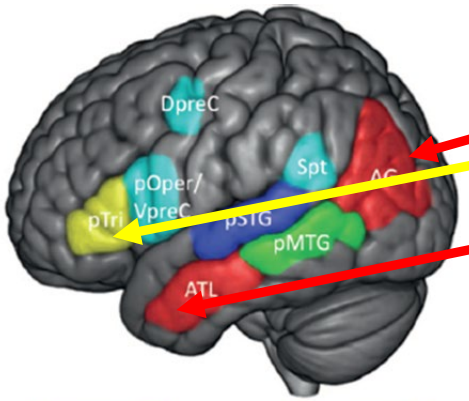


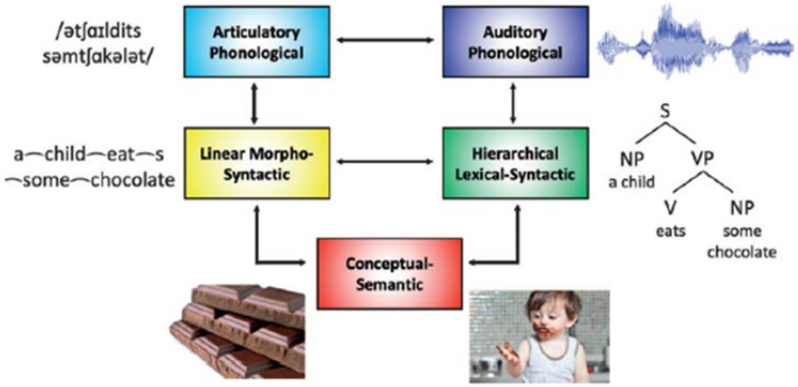


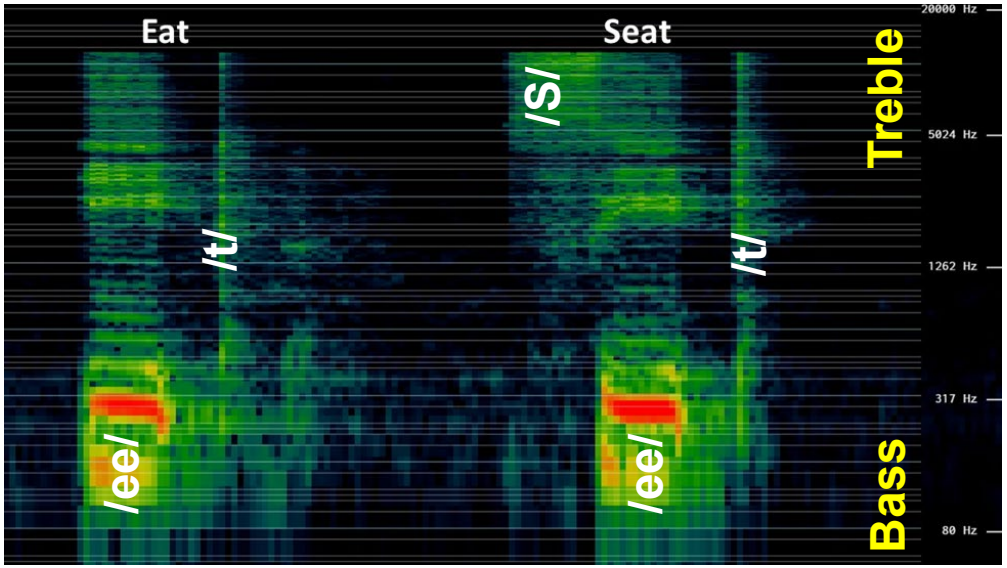
Matchin & Hickok, 2020

Hierarchical Processing in the Auditory System

Sit in your seat and eat!







Low Frequency ⟶ High Frequency

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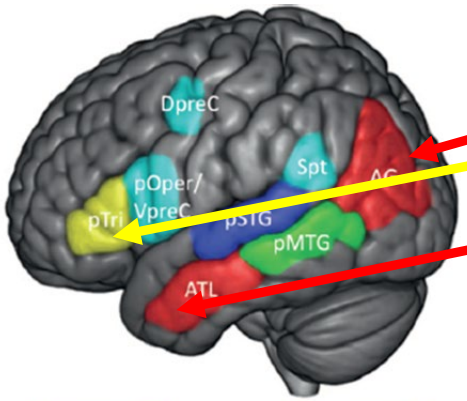
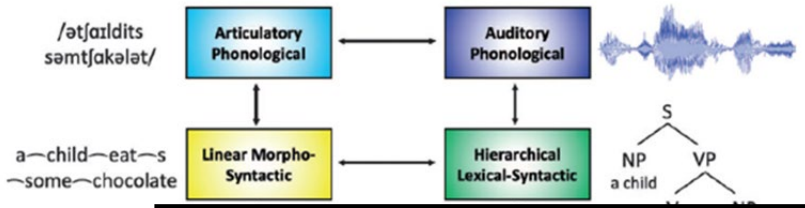
Hierarchical Processing in the Auditory System

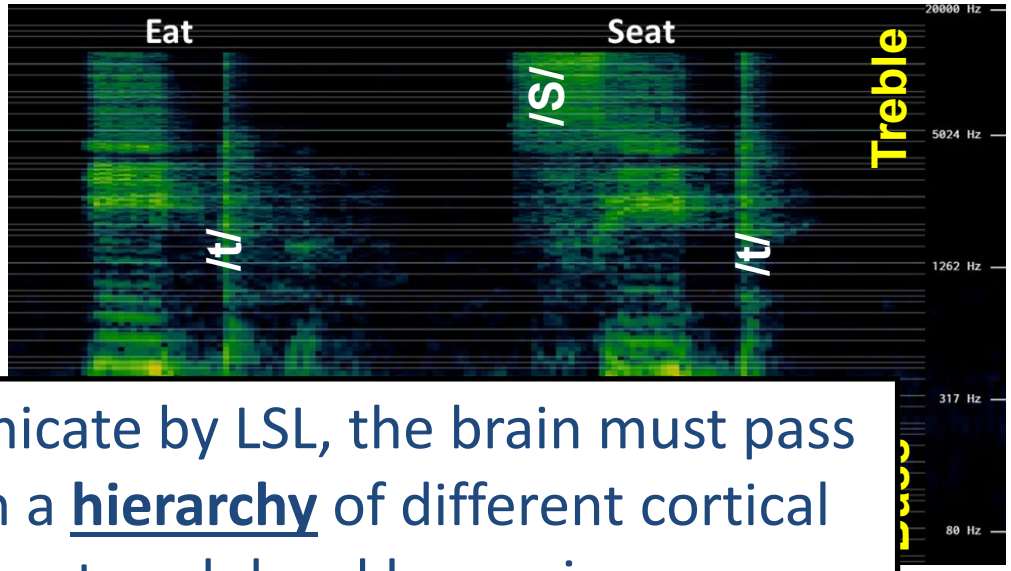
OBERKOTTER foundation

HEARING FIRST Powering Potential

Sit in your seat and eat!



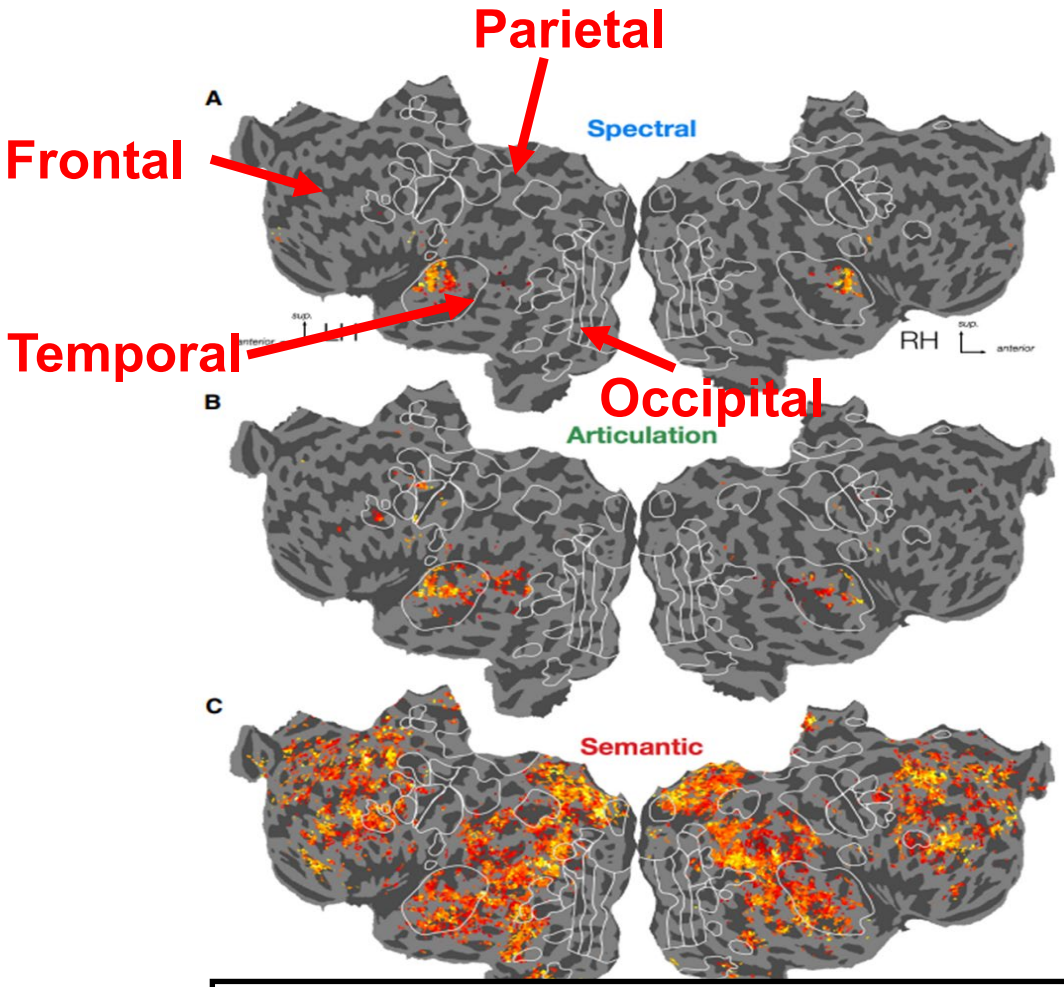




Low Frequency ⟶ High Frequency

Talking Point: To communicate by LSL, the brain must pass auditory signals through a **hierarchy** of different cortical regions with processing at each level becoming more complex to culminate in **comprehension and meaning**.

Hierarchical Processing



Acoustics

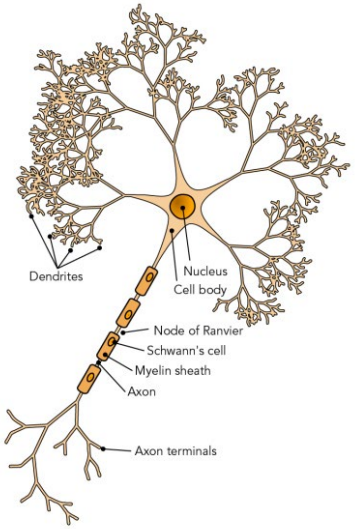
Phonemes/ Syllables

Semantics/ Meaning

Fundamentally, everything that comes into our minds is reduced to **patterns** of **neural activities**.

de Heer et al., 2017

Neurons and Synapses



- **A newborn infant has 100 billion neurons**
  - The same number as the adult brain
- **At birth, the brain weighs about 300 grams**
- **At one year of age, the brain weighs about 1000 gram**
  - The adult brain weighs about 1200-1400 grams
- **At birth, each neuron has about 2500 synapses (250 trillion synapses)**
  - Between 2-3 years of age, each neuron has 15,000-20,000 synapses
    - 1.5 to 2 quadrillion neurons
  - Older children & adults have about 10,000 synapses per neuron
    - 1 quadrillion neurons

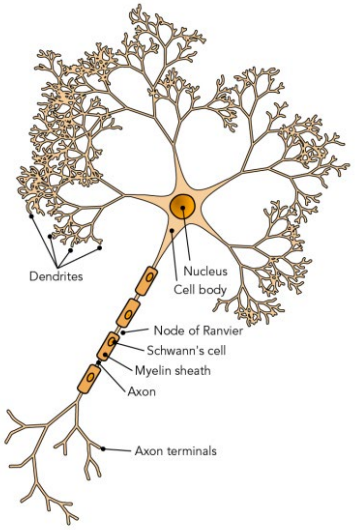
Synaptogenesis and Pruning

Synaptogenesis and Pruning

- Cells that fire together, wire together
- Cells that fire out of sync, lose their link
  - Use it or lose it!

Talking Point: Synaptogenesis refers to the process by which a neuron develops new and stronger synapses, whereas **pruning** refers to the elimination of neuronal processes that are not being stimulated in **synchrony** with nearby neurons.

Neurons and Synapses



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Million:	**1,000,000**
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Quadrillion:	**1,000,000,000,000,000**

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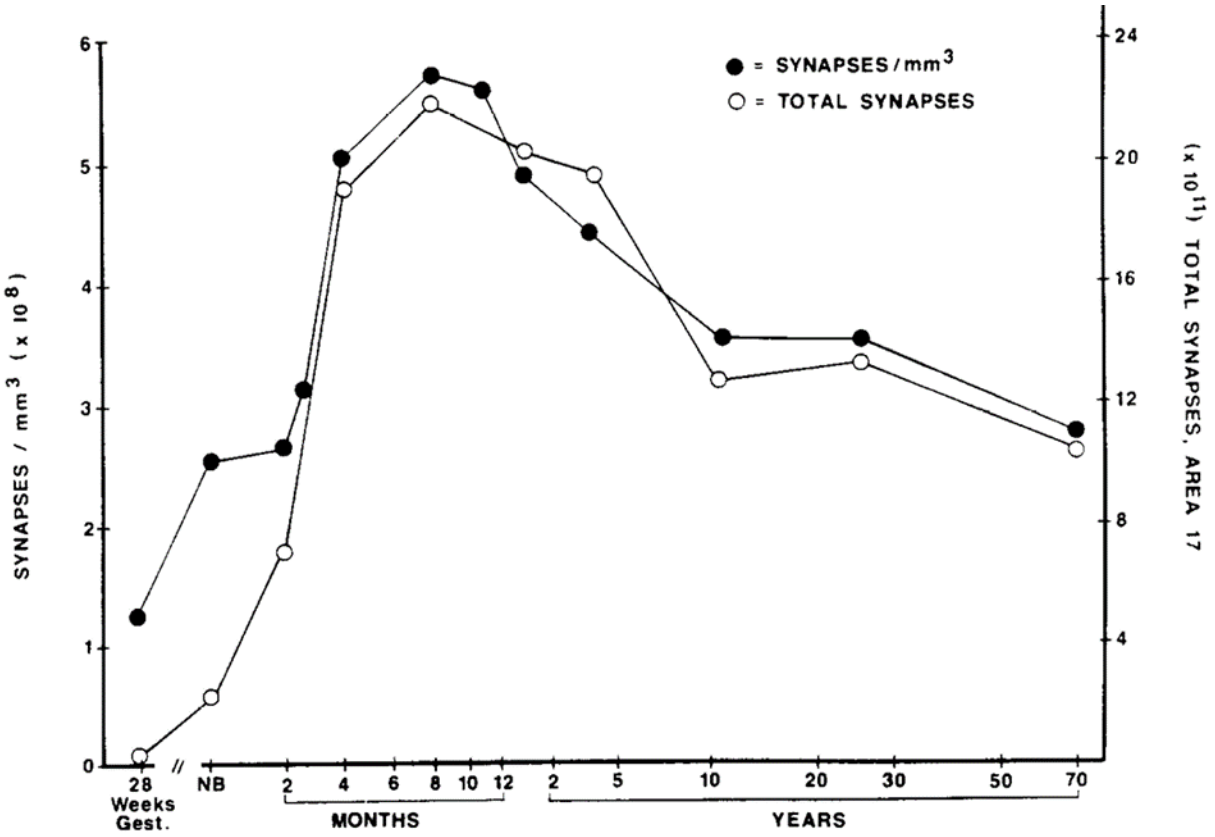
Synaptogenesis and Pruning



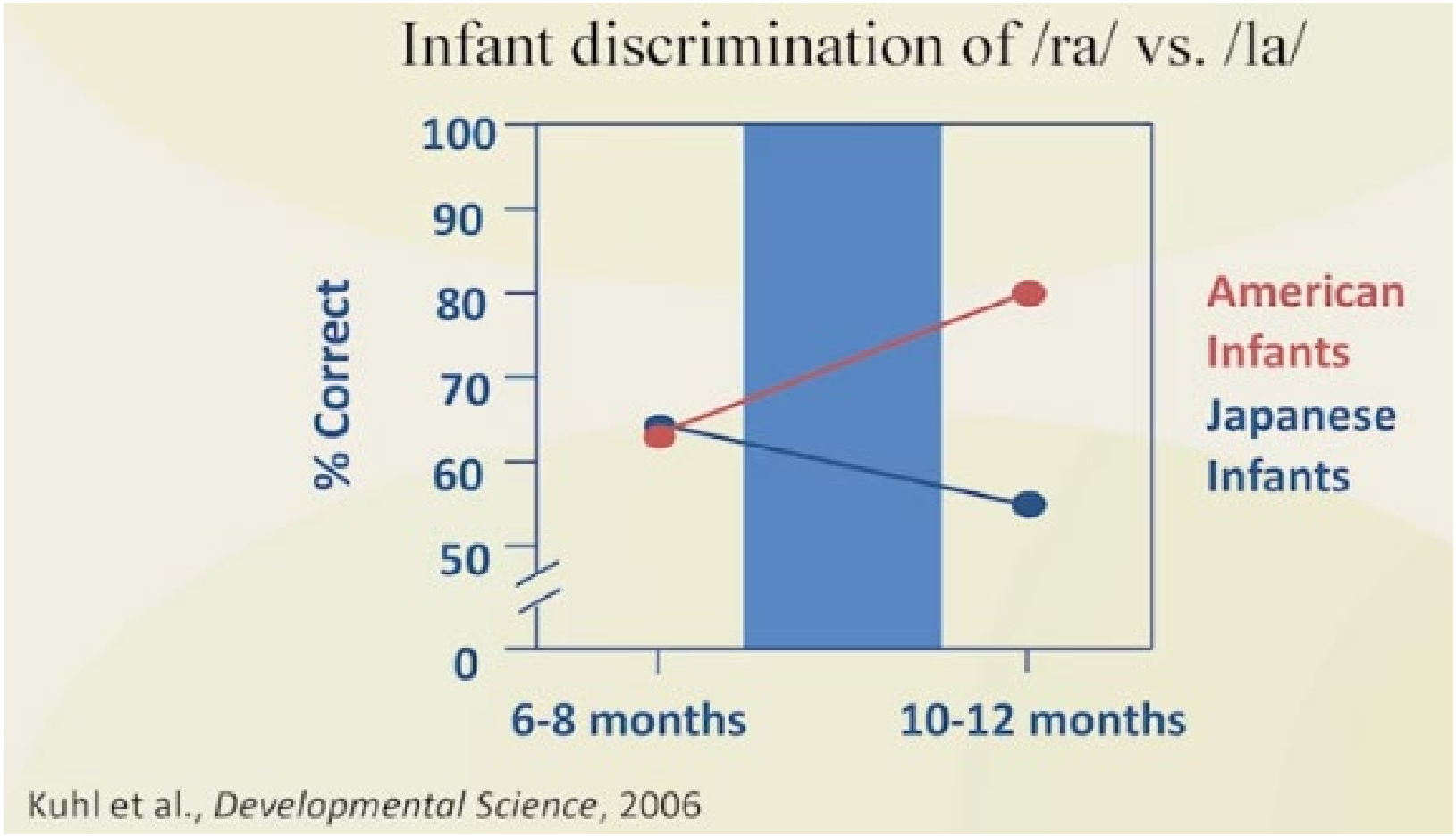
Peter Huttenlocher, 1990

Lego Mania

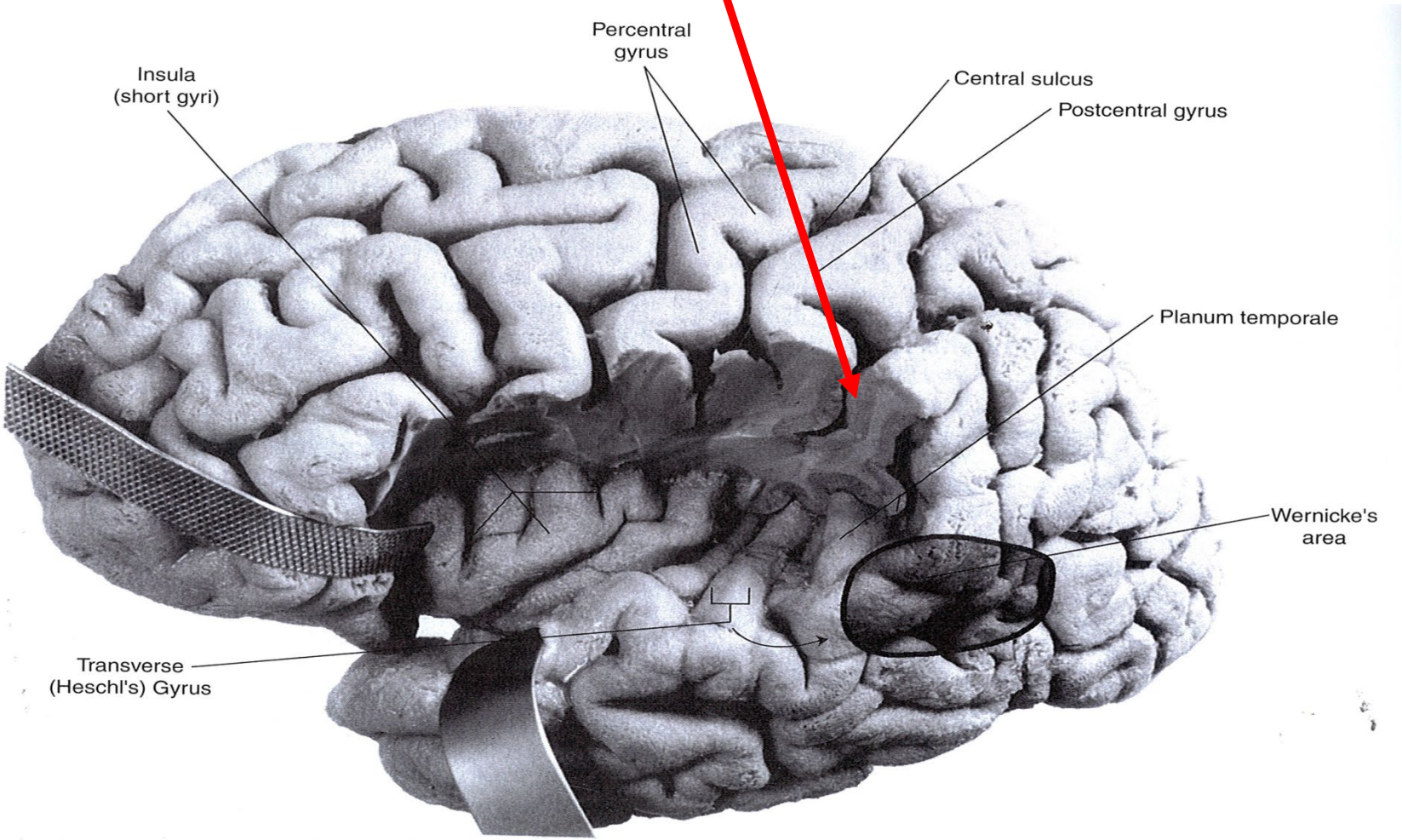
Barbie


MEGA BLOKS
Barbie
Build 'n Style!
129
4+
80226
Beach House ♥ Maison de plage ♥ Casa de playa
Construis avec style ♥ Constrúye con estilo
WARNING:
CHOKING HAZARD - Small parts. Toy contains a small ball. Not for children under 3 years.

Experience-Dependent Auditory Brain Development

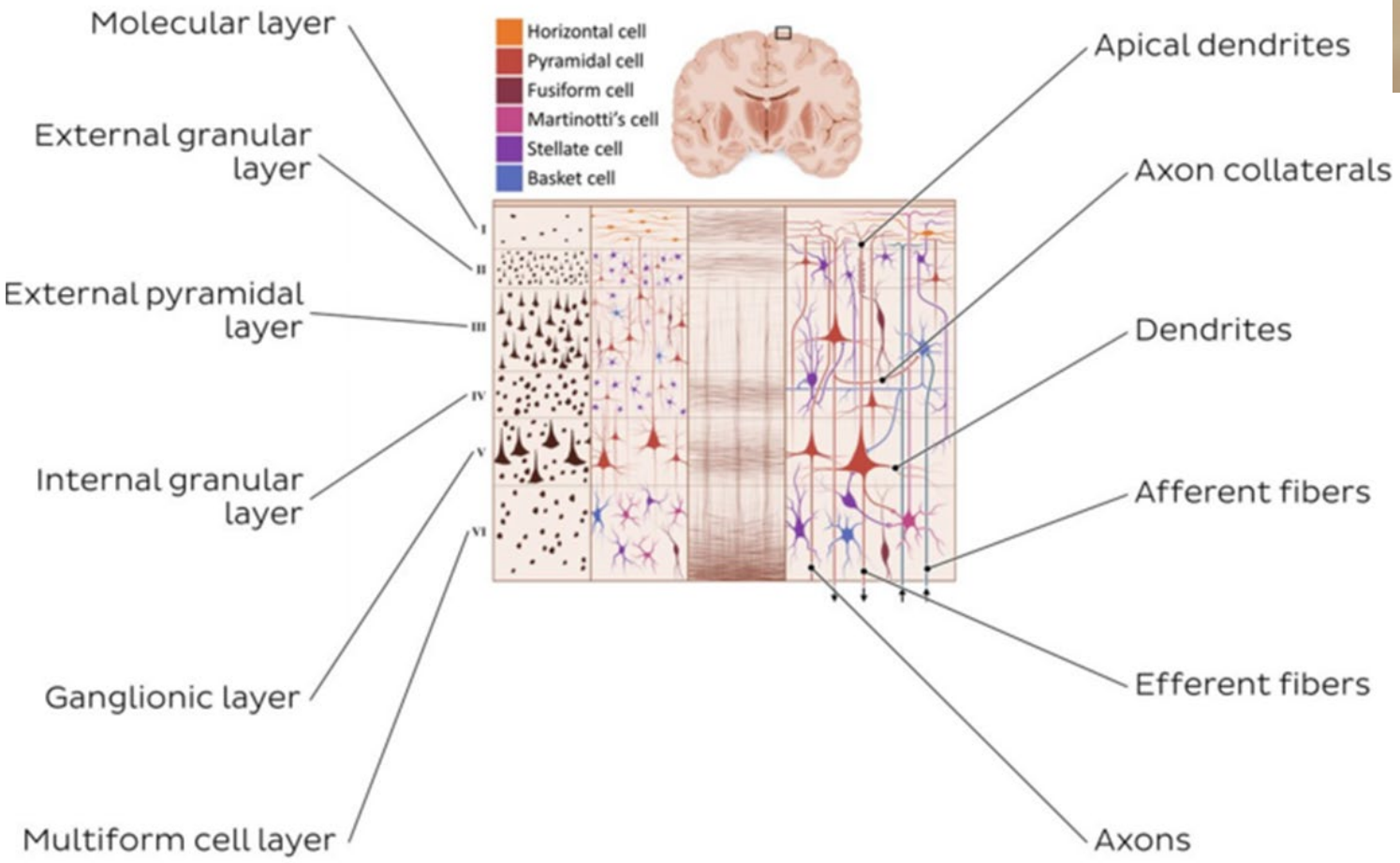


The Neocortex

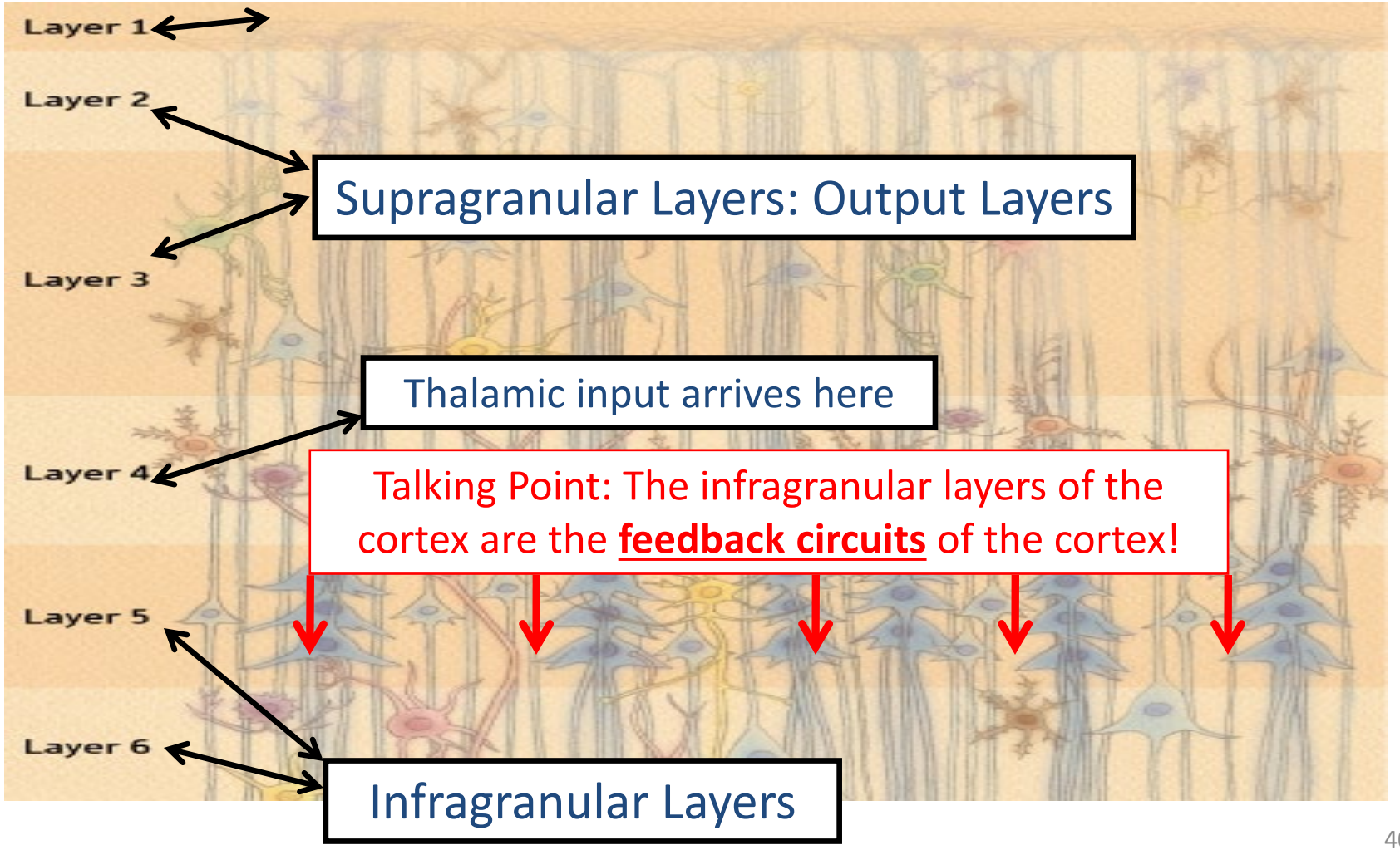


Subhash Bhatnagar

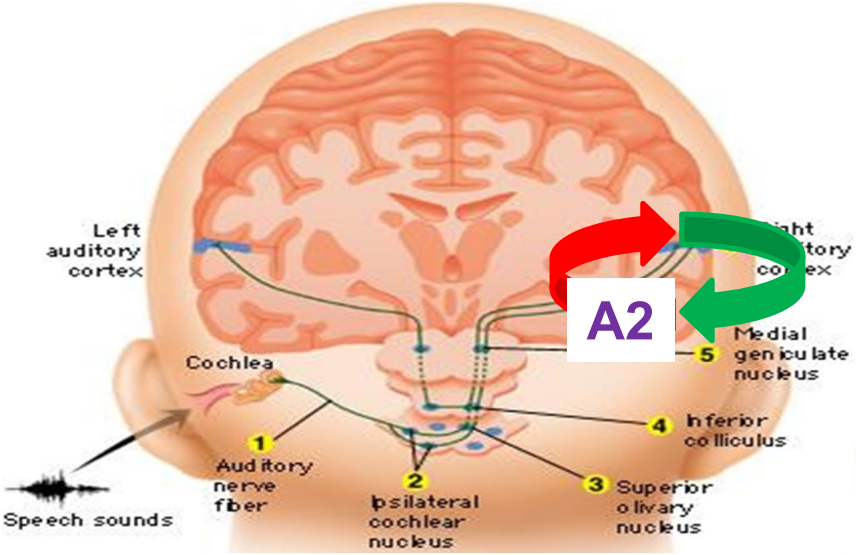
The Neocortex

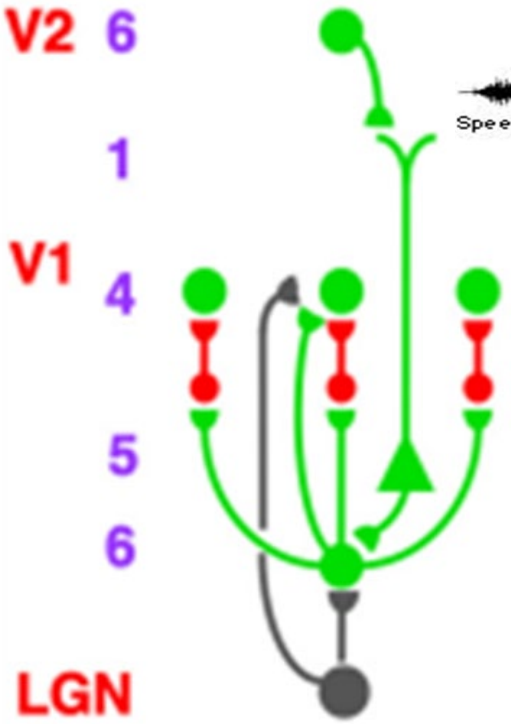


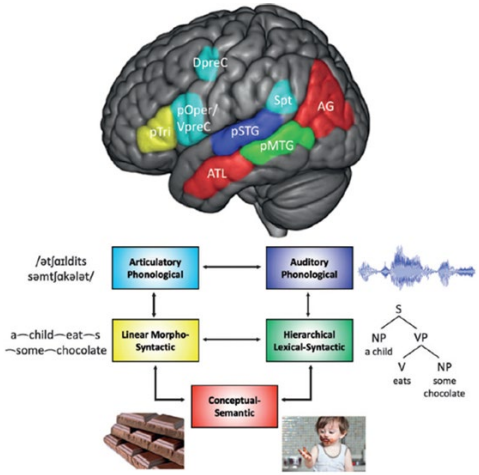
Cortical Layers

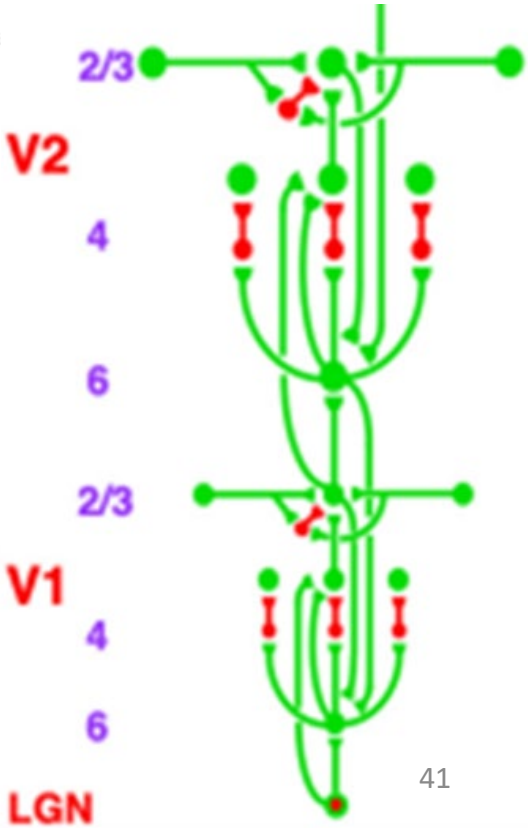


Feedforward and Feedback

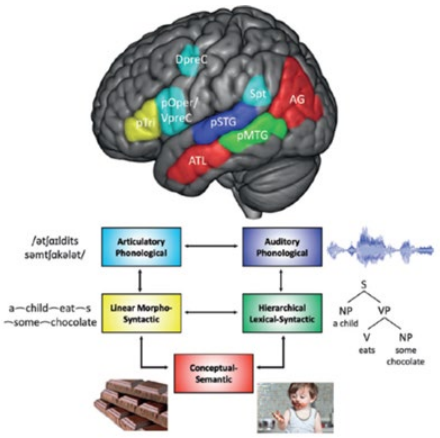


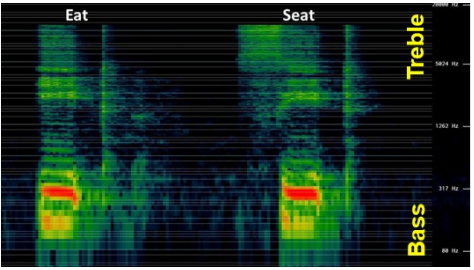






Cortical Layers & Feedback Loops





Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6

/s/ /ee/ /t/

Secondary Auditory Cortex

Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Layer 6

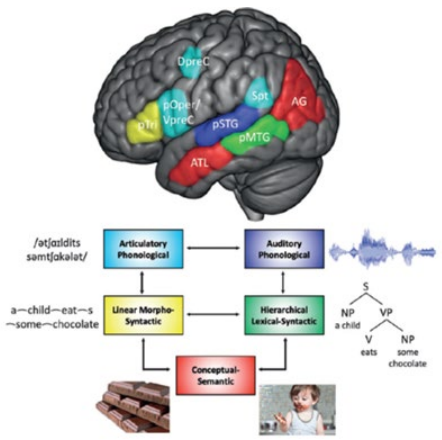
Supragranular Layers: Output Circuits

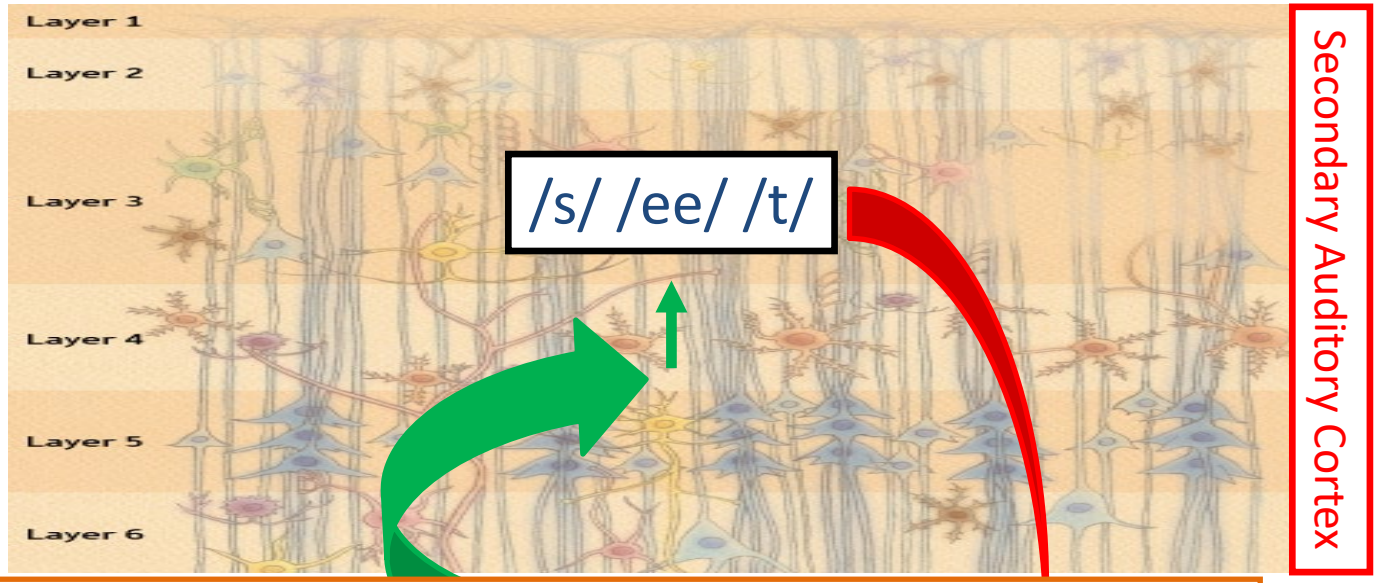
Match = Perception!

Top-down Feedback

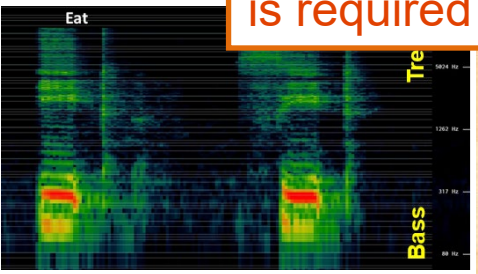
Primary Auditory Cortex

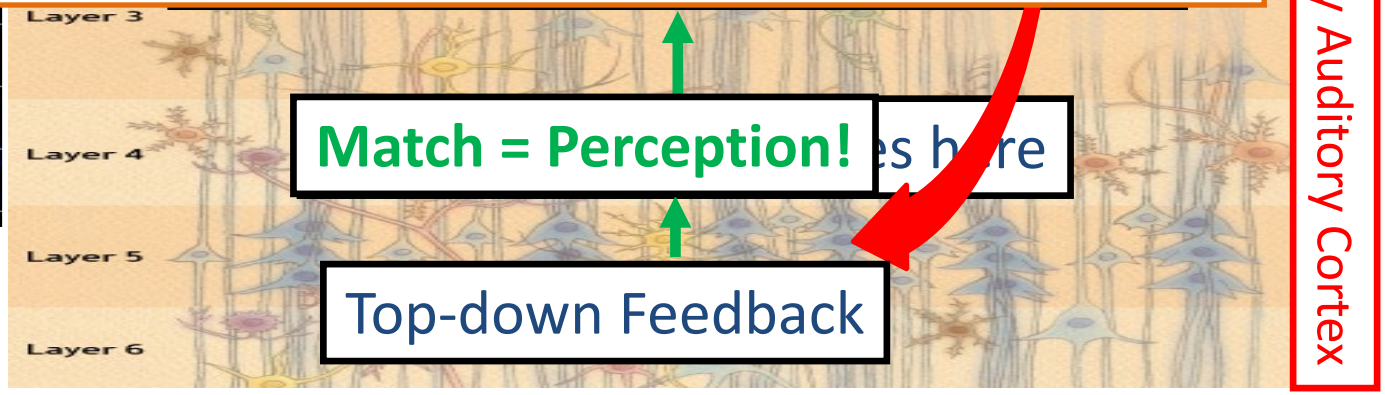
Cortical Layers & Feedback Loops





Talking Point: Higher levels in the hierarchy use a **feedback loop** to match categories to features at lower levels, and a **top/down match** is required for perception.

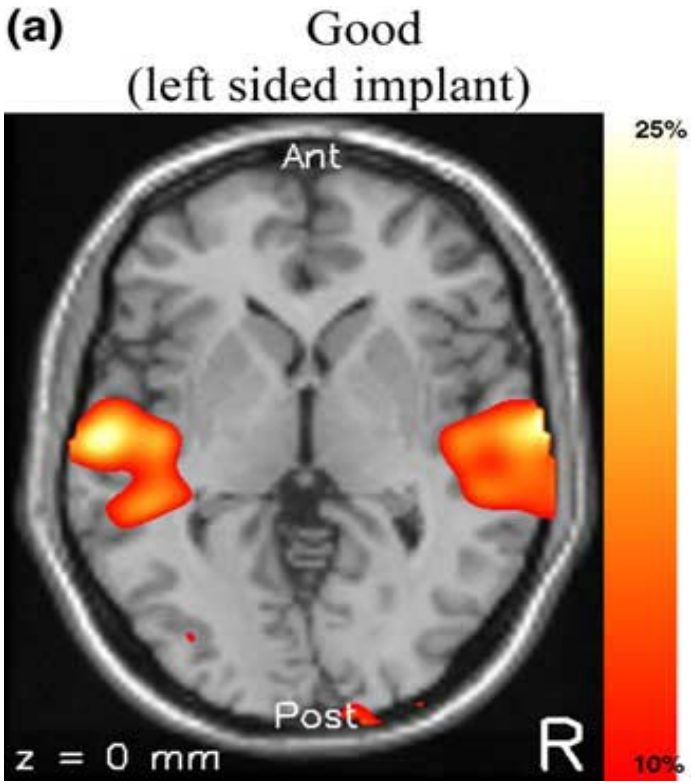




- **Landmark Studies of Auditory Brain Development**

Green et al., 2005

- Measured PET scan while post-lingually deafened adult implant users listened to a story.
- Showed activation of right and left primary and association auditory areas.



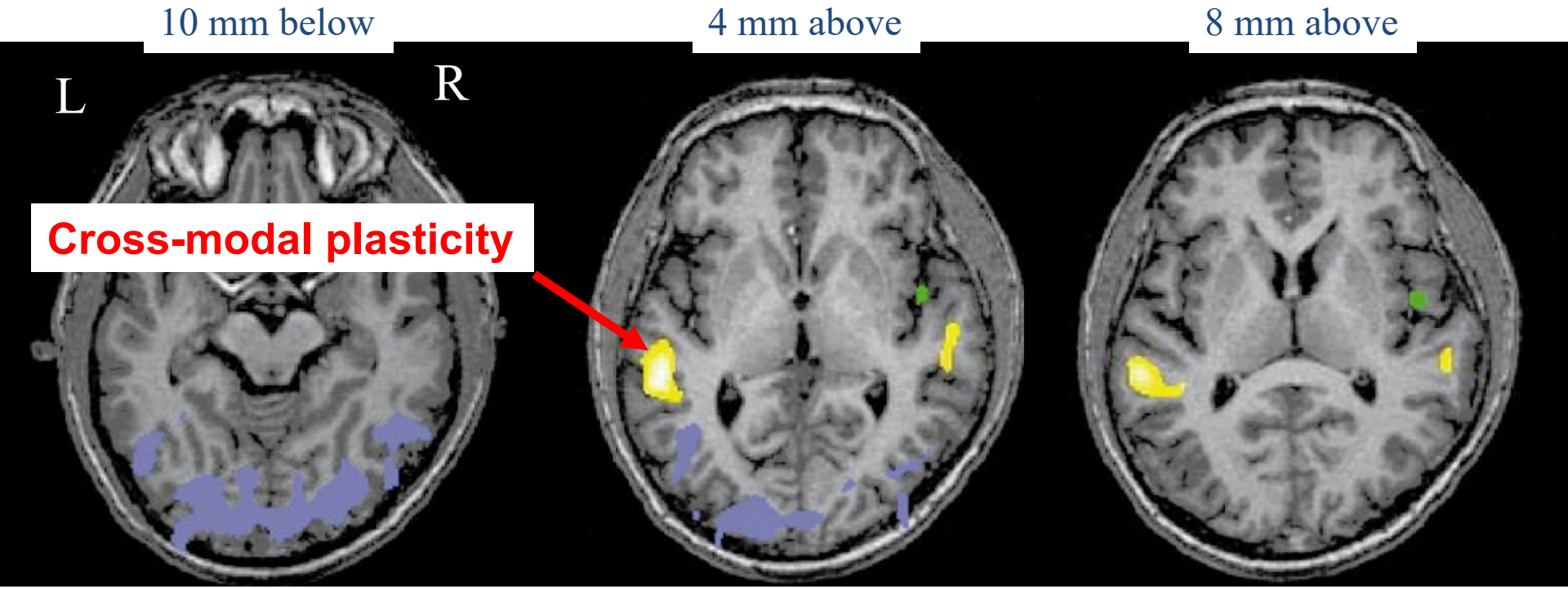
Talking Point: The typical listening brain shows bilateral activation of the **primary** and **secondary auditory cortex**.

Nishimura et al., 1999

- Objective
  - Used PET to evaluate areas of brain that are active in pre-lingually deafened adults who use ASL.
- Two Experiments:
  - Primary: Evaluate PET in response to sign language on video
  - Secondary: Evaluate PET to “meaningless hand movement” and to recorded spoken language after receipt of CI.

Nishimura et al., 1999

Horizontal sections relative to the intercommissural plane:



Blue: Areas activated by visual stimuli (meaningless hand movement)

Yellow: Areas activated by sign language

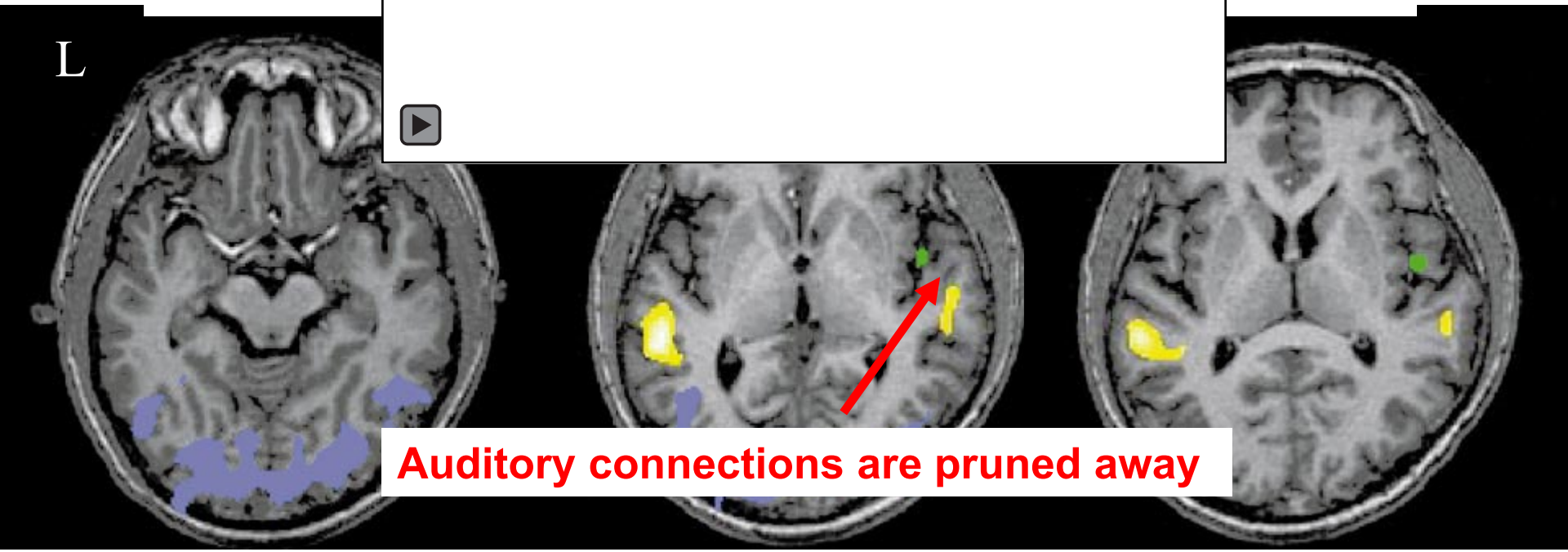
Green: Areas activated by spoken language (CI: Left Ear)

Nish

Horizontal sections rela

10 mm below

mm above



Blue: Areas activated by visual stimuli (meaningless hand movement)

Yellow: Areas activated by sign language

Green: Areas activated by spoken language (CI: Left Ear)

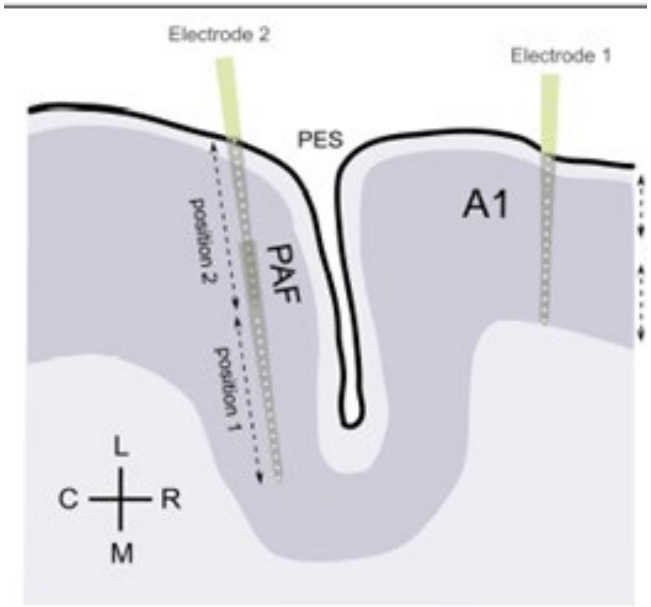
Nishimura et al., 1999

- **Conclusions:**
  - **The primary auditory cortex is reserved for hearing sound**
    → "Cross-modal non-plasticity"

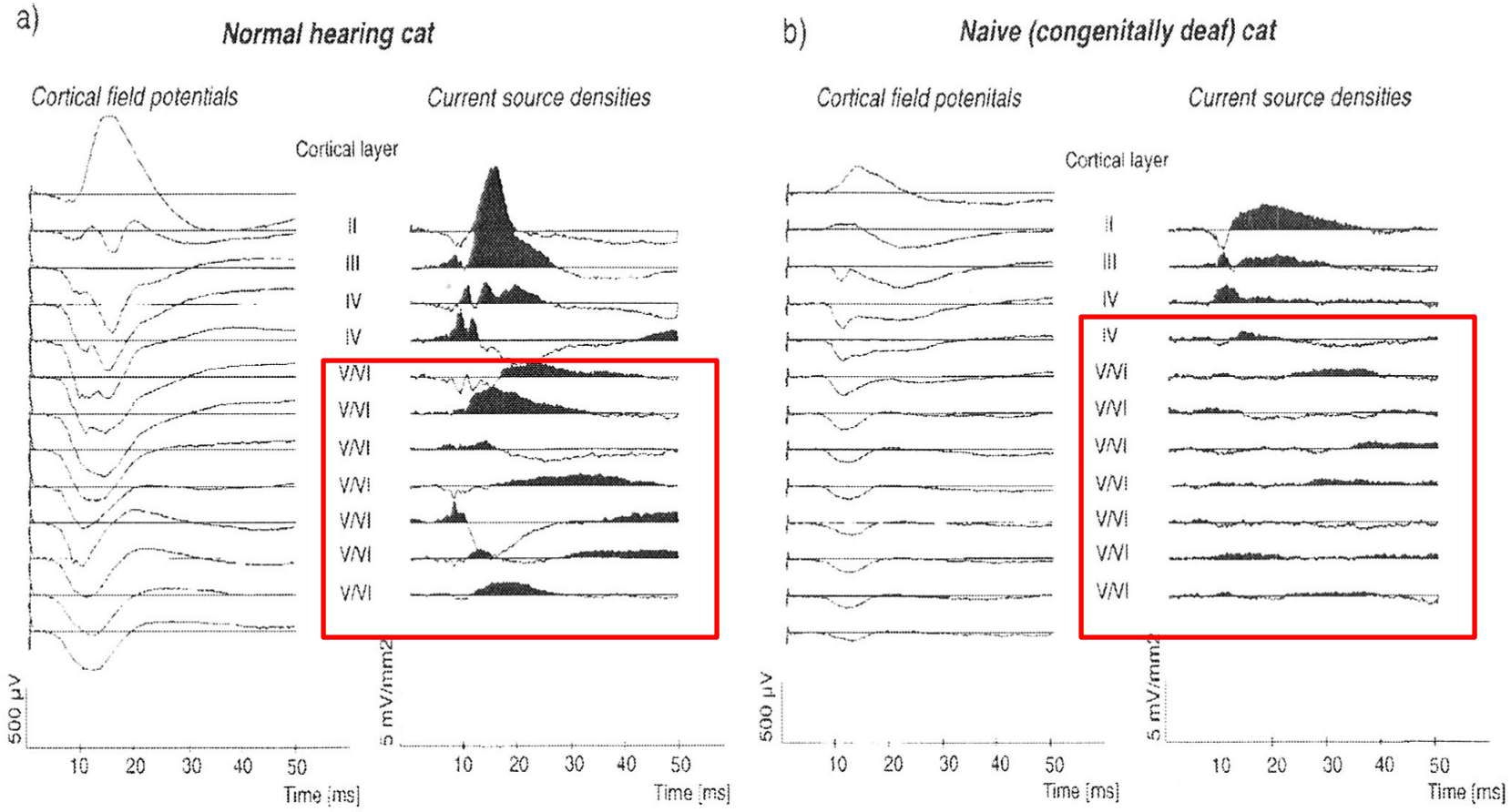
Talking Point: **Auditory deprivation** causes pruning of the synapses between primary auditory cortex and higher order auditory cortical areas.
Sign Language does NOT protect or develop auditory synapses!

Kral's Cats

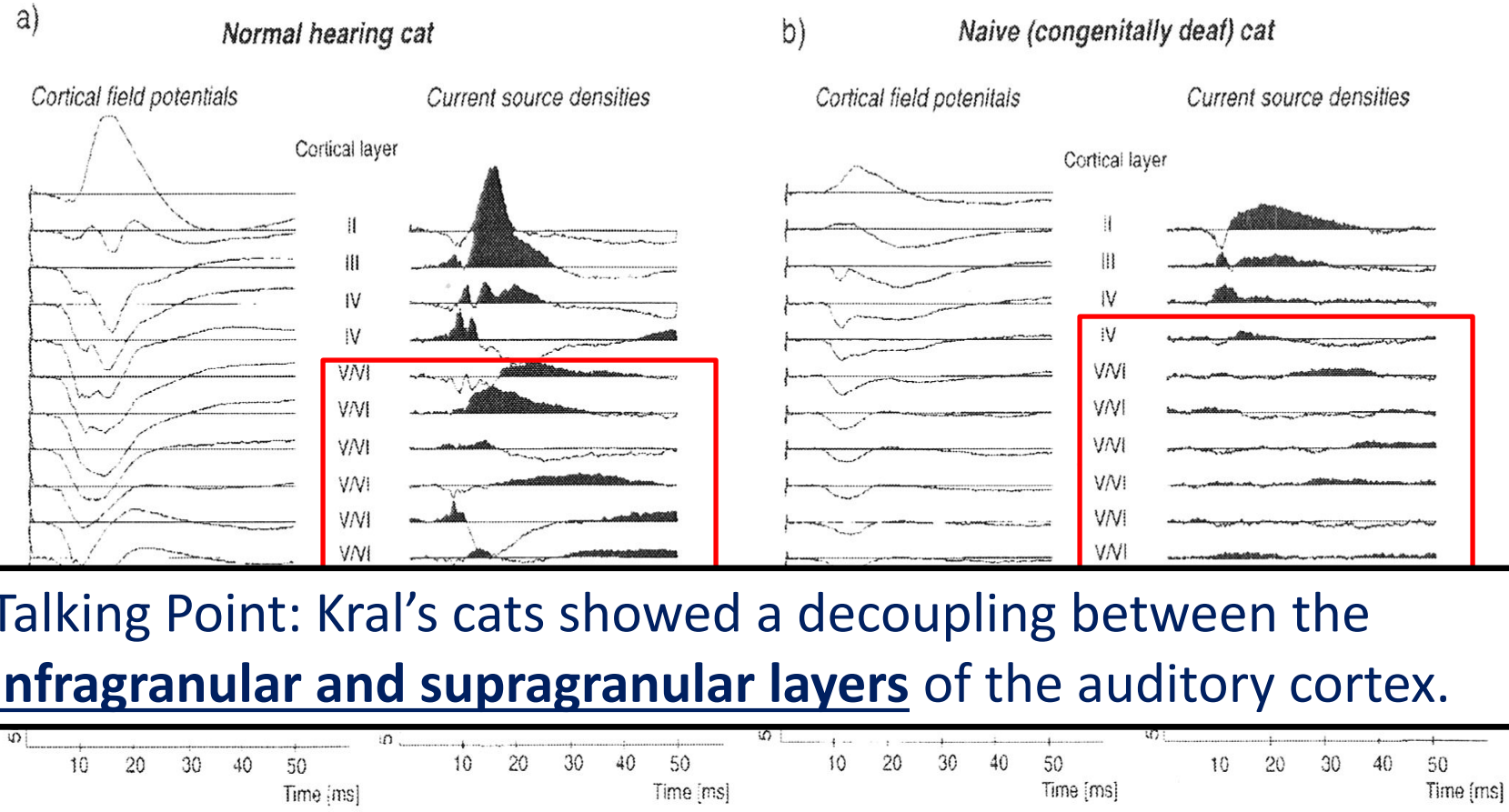
- Used microelectrodes to record local cortical auditory potentials in NH and congenitally deaf cats with and without cochlear implants



Kral et al., 2000

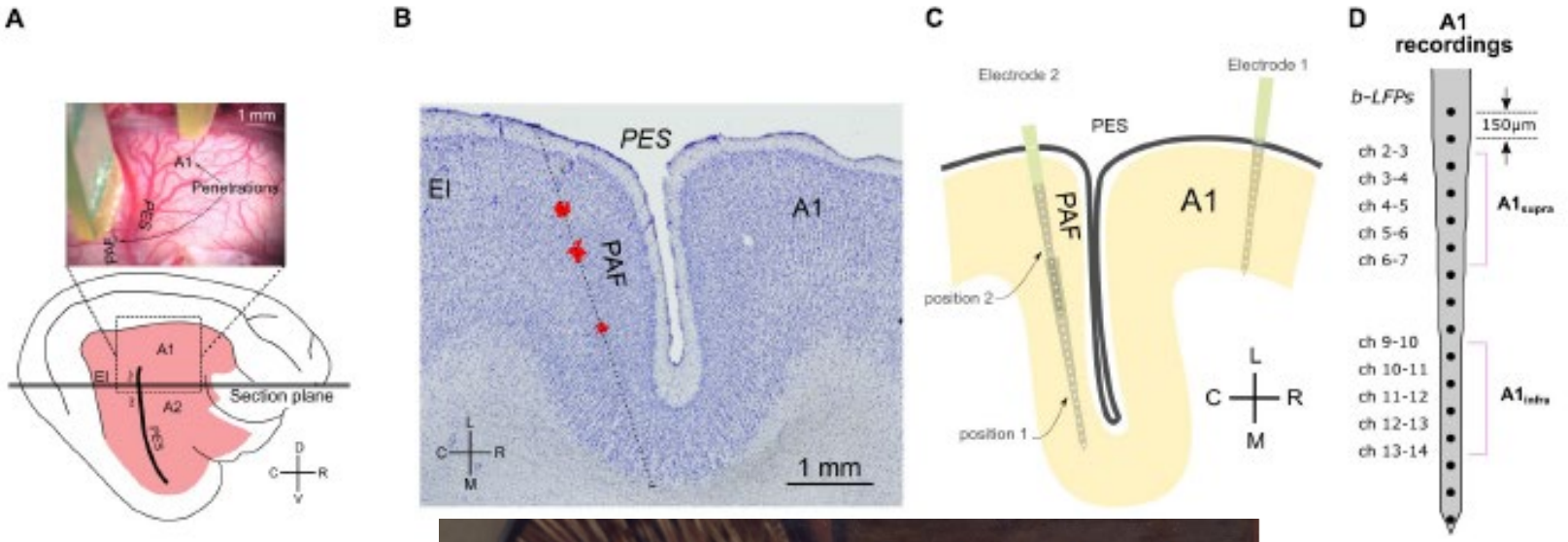


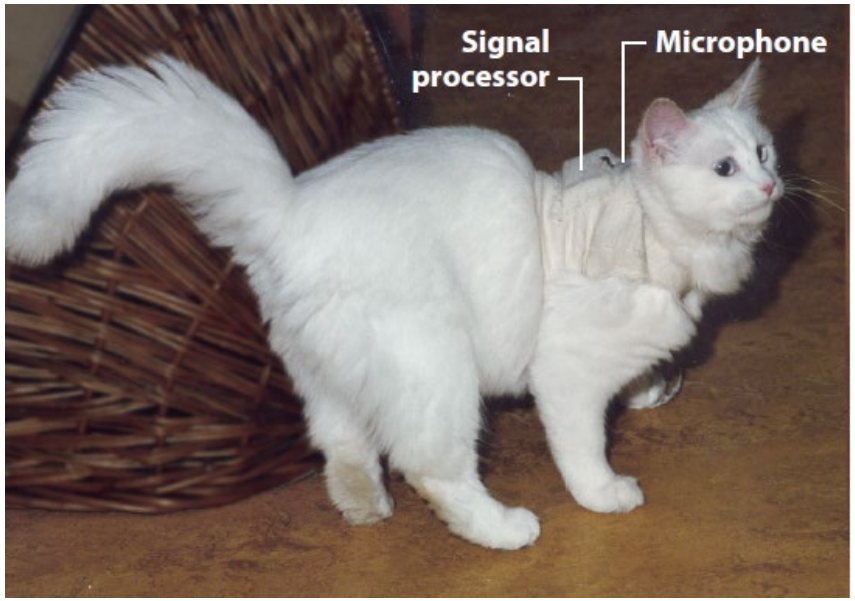
Kral et al., 2000



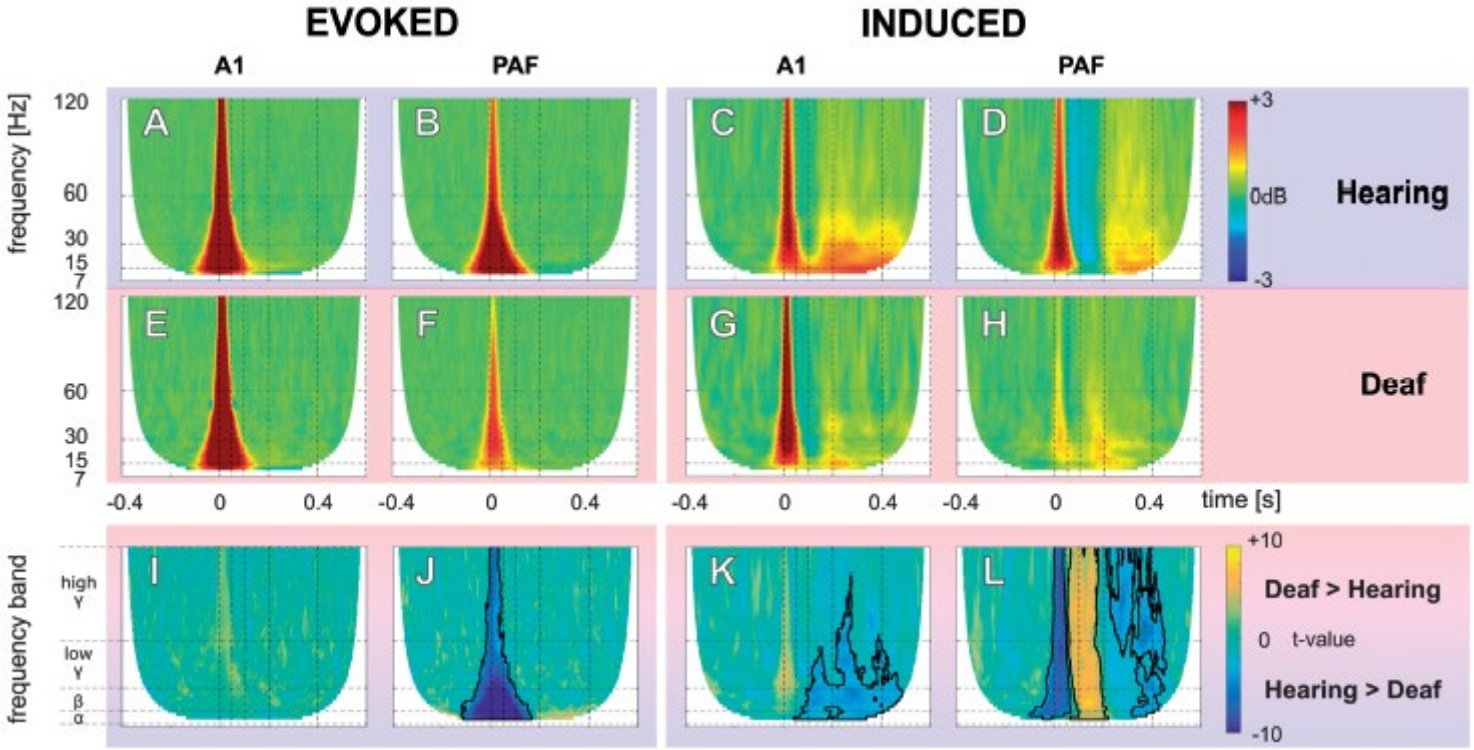
Talking Point: Kral's cats showed a decoupling between the **infragranular and supragranular layers** of the auditory cortex.

Kral's Cats

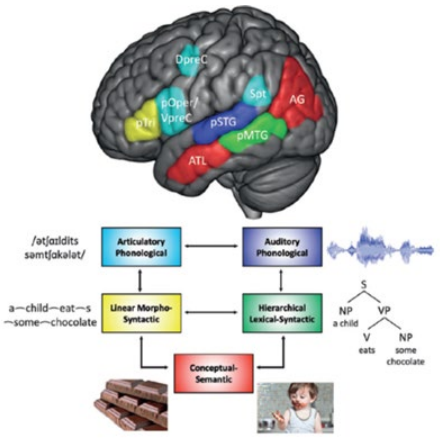

A
1 mm
A1
Penetrations
PES
PAF
A1
EI
A2
PES
Section plane
D
C
R
V
B
PES
EI
A1
PAF
L
C
R
M
1 mm
C
Electrode 2
Electrode 1
PES
PAF
A1
position 2
position 1
L
C
R
M
D
A1 recordings
b-LFPs
150µm
ch 2-3
ch 3-4
ch 4-5
ch 5-6
ch 6-7
A1supra
ch 9-10
ch 10-11
ch 11-12
ch 12-13
ch 13-14
A1infra

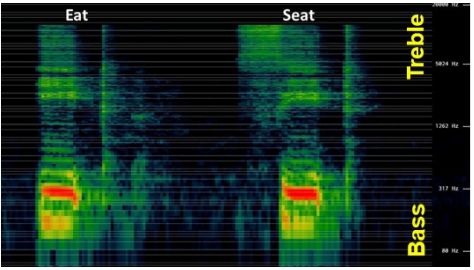

Signal processor
Microphone

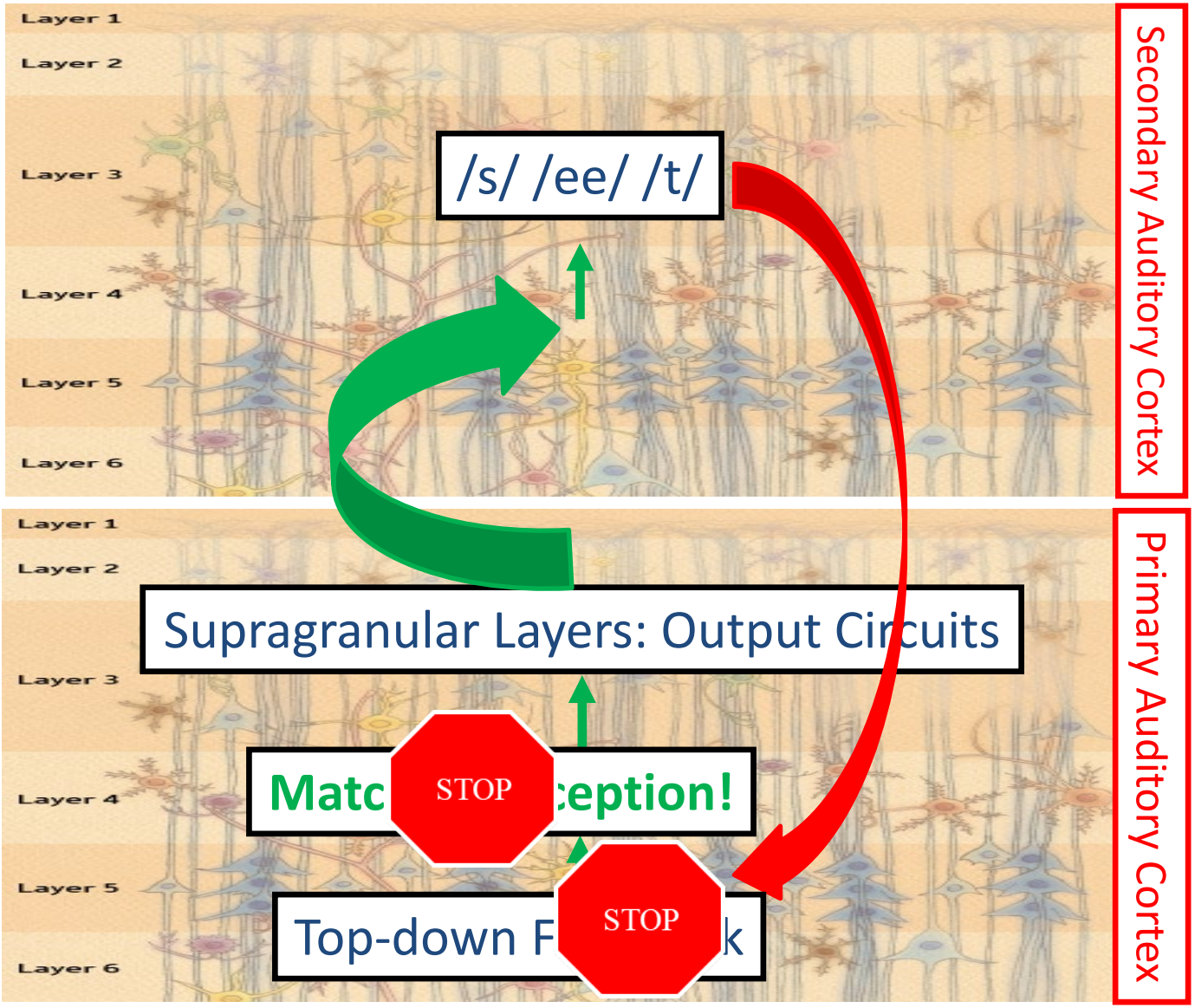
Kral's Cats


EVOKED
INDUCED
A1
PAF
A1
PAF
frequency [Hz]
120
60
30
15
7
A
B
C
D
+3
0dB
-3
Hearing
E
F
G
H
Deaf
-0.4
0
0.4
time [s]
frequency band
high γ
low γ
β
α
I
J
K
L
+10
Deaf > Hearing
0 t-value
Hearing > Deaf
-10

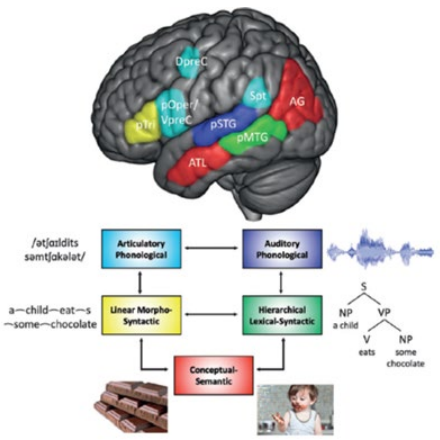
Cortical Layers & Feedback Loops

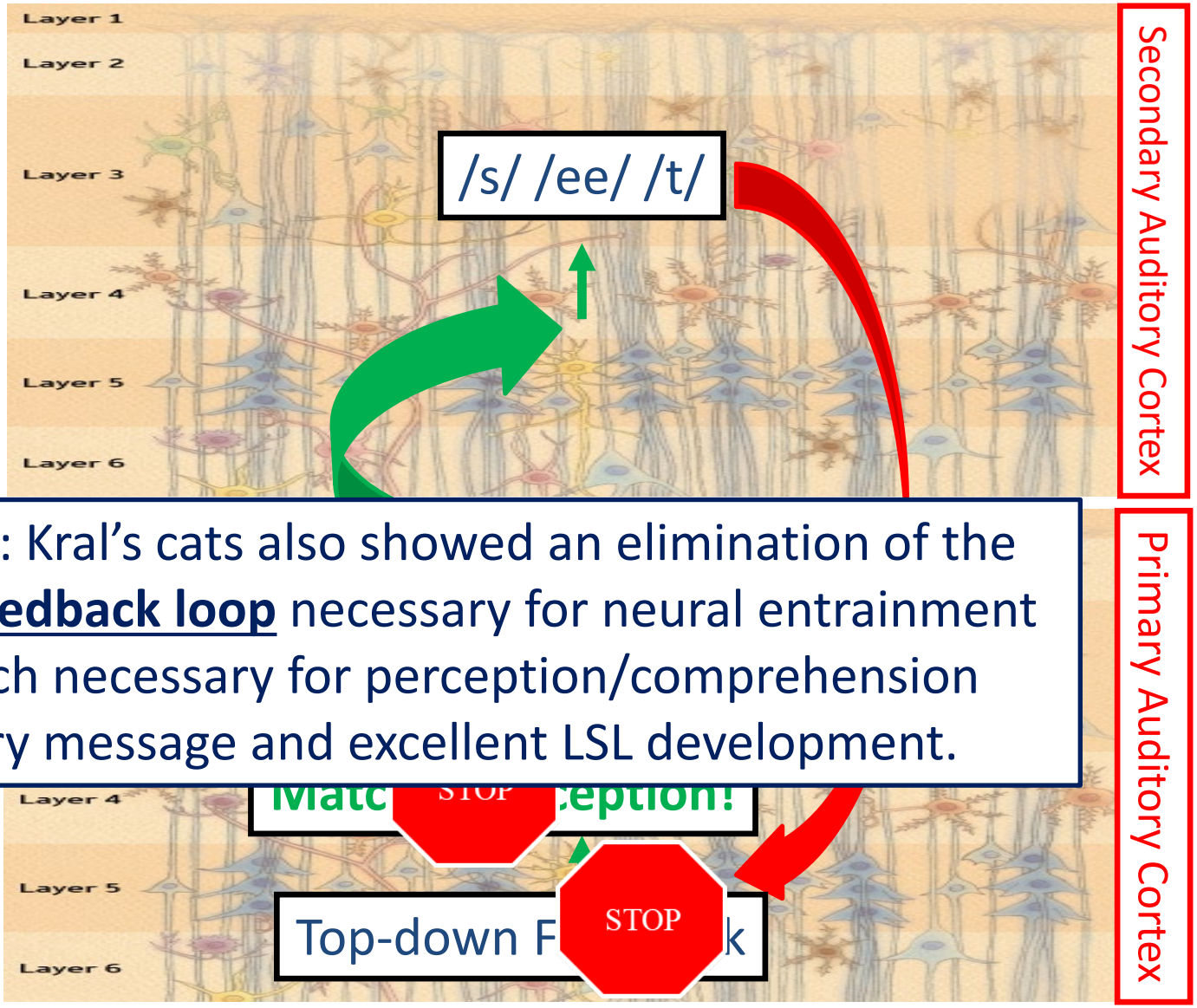






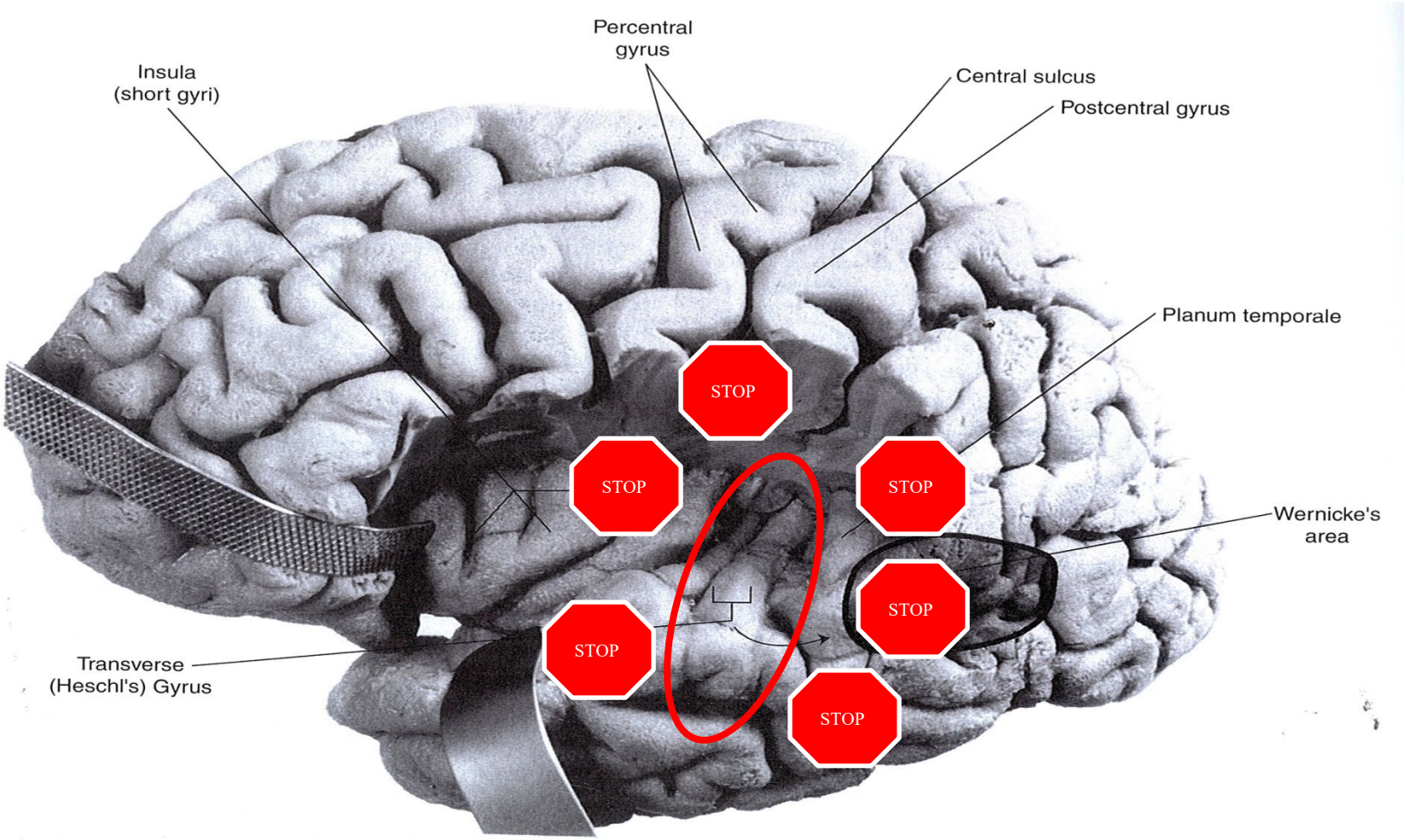
Cortical Layers & Feedback Loops



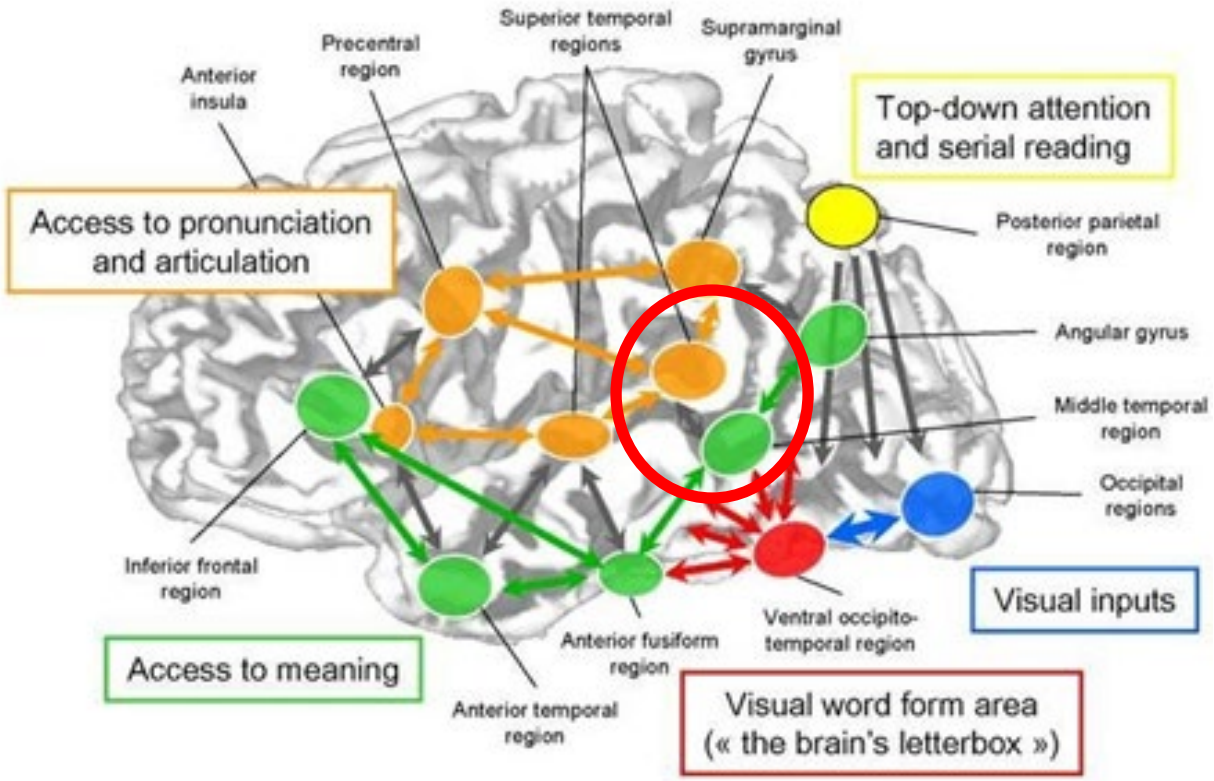


Talking Point: Kral's cats also showed an elimination of the **top-down feedback loop** necessary for neural entrainment and the match necessary for perception/comprehension of an auditory message and excellent LSL development.

The Auditory Brain



Neuroscience of Literacy



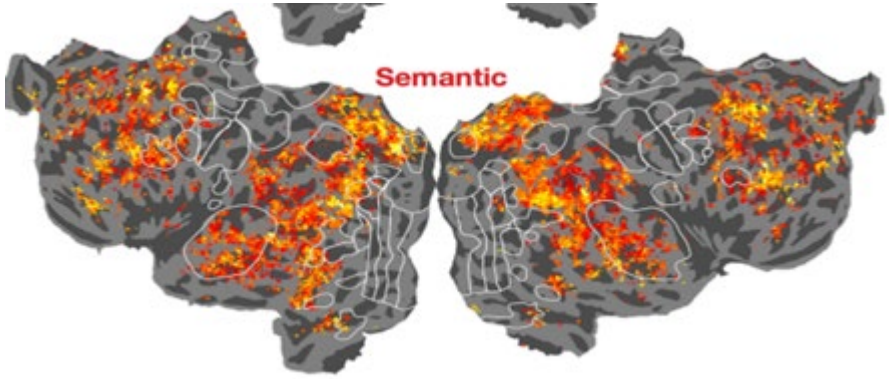
Dehaene, 2009

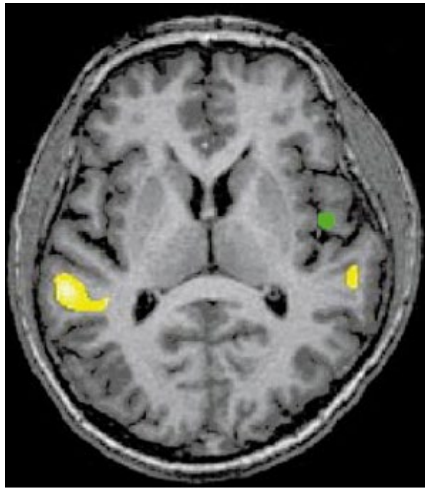
If a Family Wants Their Baby to Listen & Talk:

OBERKOTTER foundation

HEARING FIRST
Powering Potential

Hearing Loss is an Emergency and Every Day is Critical!





Dettman et al., 2016 Otology & Neurotology

Long-term Communication Outcomes for Children Receiving Cochlear Implants Younger Than 12 Months: A Multicenter Study

*Shani Joy Dettman, *Richard Charles Dowell, †Dawn Choo, ‡Wendy Arnott, §Yetta Abrahams, §Aleisha Davis, ‡Dimity Dornan, ||Jaime Leigh, ‡Gabriella Constantinescu, ¶Robert Cowan, and #Robert J. Briggs

TABLE 1. *Demographic details for n = 403 children who received CIs younger than 6 years, divided for age at implant; Group 1 (<12 mo), Group 2 (13–18 mo), Group 3 (19–24 mo), Group 4 (25-42 mo), and Group 5 (43–72 mo)*

Group	No.	Percent/ n = 403	Mean (yrs)	Range (yrs)	SD (yrs)
1. <12 m	151	37.5%	0.70	0.38–1.00	0.15
2. 13–18 m	61	15.1%	1.24	1.02–1.47	0.14
3. 19–24 m	66	16.4%	1.75	1.50–2.00	0.13
4. 25–42 m	82	20.3%	2.60	2.01–3.45	0.43
5. 43–72 m	43	10.7%	4.45	3.58–5.81	0.69

m indicates months; No., number; SD, standard deviation; yrs, years.

Spoken Language Vocabulary

1: <12mths
2: 13-18mths
3: 19-24mths
4: 25-42mths
5: 43-72mths

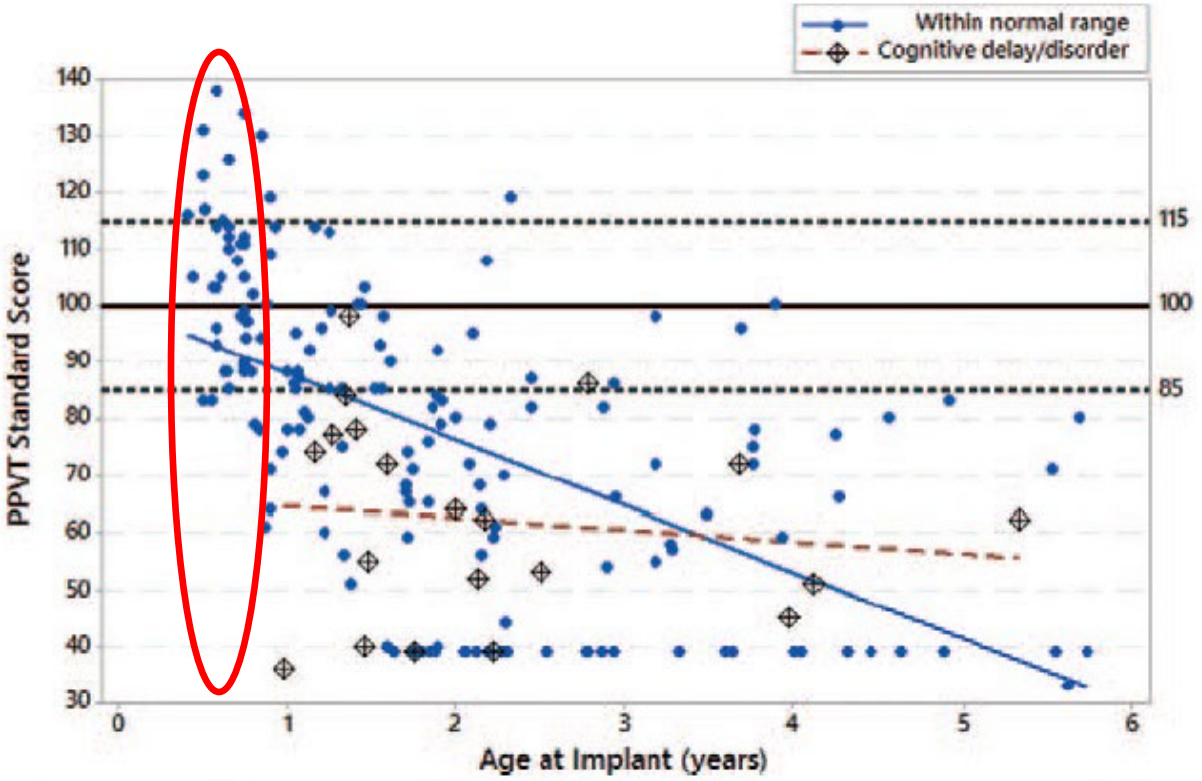


FIG. 5. PPVT standard scores for n = 207 at school entry; children with cognitive skill within the normal range (circles) and children with additional diagnosis of cognitive delay/impairment (diamonds).

Peabody Picture Vocabulary Test 3rd and 4th Editions

Language Rich Listening Environment

OBERKOTTER foundation

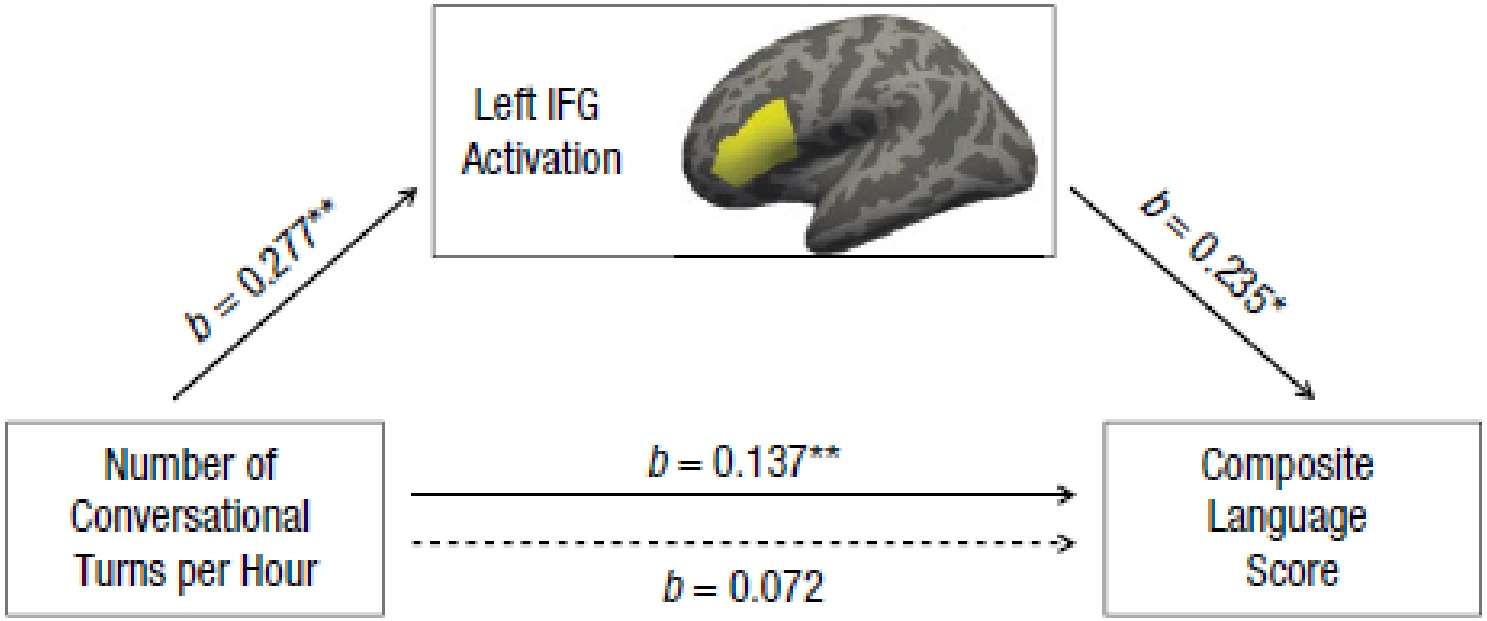
HEARING FIRST
Powering Potential

Beyond the 30-Million-Word Gap: Children's Conversational Exposure Is Associated With Language-Related Brain Function

Psychological Science
2018, Vol. 29(5) 700–710

DOI: 10.1177/0956797617742725
www.psychologicalscience.org/PS
SAGE

Rachel R. Romeo[1,2], Julia A. Leonard[2,3], Sydney T. Robinson[2,3], Martin R. West[4], Allyson P. Mackey[2,3,5], Meredith L. Rowe[4], and



Optimizing Listening, Spoken Language, & Literacy Development

- Provide optimized hearing technology as early as possible!
- Coach and support families to create a language-rich listening environment
  - 46 million words by 4 years of age (Hart & Risley, 1995)
  - 20,000 hours of listening to promote literacy development (Dehaene, 2009)
- Immerse children with hearing loss in least restrictive environment replete with intelligible speech

Talking Point:

Want Great LSL Outcomes?

Prioritize Hearing First!

- **Great outcomes are probable when we do what it takes.**

- **Shoot for the moon!**