Central Auditory Processing: From Molecule to Behavior

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“The Auditory System”
The pathway of the auditory system. The major pathways are indicated by heavy arrows.
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
Mandarin Tone – Mandarin Passive

Mandarin Subjects

English Subjects

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
The Auditory Pathway

- Lateral fissure
- Auditory cortex
- Medial geniculate nucleus
- Inferior colliculus
- Dorsal cochlear nucleus
- Lateral lemniscus
- Trapezoid body
- Auditory nerve

Speech sounds

IBEs 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)
Grammar Learning

- Grammar learning
  - Procedural memory
    - Fronto-striatal System
      - Dopaminergic System
        - DA Receptor Genes
**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)
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

<table>
<thead>
<tr>
<th></th>
<th>Singular</th>
<th>Plural</th>
<th>Dim</th>
<th>Dim. Pl</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘dog’</td>
<td>vib</td>
<td>vib-il</td>
<td>ki-vib</td>
<td>ki-vib-il</td>
</tr>
<tr>
<td>‘cat’</td>
<td>pesh</td>
<td>pesh-el</td>
<td>ki-phinx</td>
<td>ki-phinxel</td>
</tr>
</tbody>
</table>

Transparent and opaque items are mixed during training.
Individual Differences
Memory & Language Learning

- Significant positive correlation between sound learning & procedural memory

\[
r(21) = 0.745, \quad p < 0.001
\]
Frontostriatal Pathway & Success

Ettlinger, Novis, Wang, & Wong (submitted)
Network Differences
Network Differences

The chart illustrates differences in network activity across various pathways (BR->RMTG, Hipp->BG, LMTG->BR, MTG->BG) for different groups:
- **Learners - Complex**
- **Learners - Simple**
- **Non-learners - Complex**
- **Non-learners - Simple**

The chart shows quantitative measures with error bars indicating the variability of the data.
Neuroanatomy

$r = .58, p = .002$
$r = .47, p = .02$
**DRD2 and Phenotype**

Procedural Memory

Grammar Learning

Model Goodness-of-Fit Statistics

Grammar Learning: $\chi^2 = 0.11, \text{DF}=2, p=0.95$ (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

QSIN Performance

% Acc in Repeating Words in Noise

Old (Normal)  Old (Peripheral Loss)  Young

Internal unpublished data
• Decline in hearing (presbycusis)
• Do neurocognitive factors explain differences in speech perception in noise in younger and older adults?
fMRI Experiment

12 sec Stimulus Presentation
(3 sec Trials)

Quiet Quiet Quiet Quiet

SNR-5 SNR-5 SNR-5 SNR-5

"axe"
(SNR-5)

IR = 14 sec

2 sec Scanning
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 vs. Younger

% Correct (QuickSIN 0 dB SNR condition)

Left Pars Triangularis (fractional hemispheric volume)

r(13) = .601
p = .018

r(12) = -.478
p = .084

Left Superior Frontal Gyrus (mm thickness)

r(13) = .688
p = .005

r(12) = .378
p = .183
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
Speech in Noise Improvement
Children with Cochlear Implants

• Auditory, cognitive, and language abilities better than hearing impaired but worse than their normal hearing peers
Working Memory in CI Children

Pisoni & Cleary, 2003
Phonological Awareness in CI Children

Spencer & Tomblin, 2009
# Child CI Users

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

Testing and Training Schedule

Expressive Vocabulary
Receptive Vocabulary
Oral Language
IQ

Earobics Training
150 minutes/week
4 weeks

Normal Classroom Activities
4 weeks

Expressive Vocabulary
Receptive Vocabulary
Oral Language

Earobics Training
150 minutes/week
4 weeks
Training
OWALS: Trained Group Improved
Research Goal

• To understand the basic mechanisms of auditory processing from molecule to behavior, in order to:
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  — 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.
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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.

Bootstrap consensus for all variants
Log likelihood = -588981.51
Bootstrap consensus for non-common variants
Log likelihood = -62798.53
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