The role of the auditory cortex in speech sound processing and literacy acquisition

CHRISTINE BRENNAN, PHD CCC-SLP
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Abstract
The auditory cortex is a critical part of the language network and serves to support phonological processes that underlie both speech processing and reading. The role of phonological awareness is implicated in reading impairment and is also implicated in both language and math disabilities. This presentation will review research that sheds light on the organization of the auditory cortex and how this cortical region supports the development of phonological, reading, and language skills. Differences in the organization of the auditory cortex in language-based learning disabilities will be discussed. Implications for testing and intervention will be addressed.

Recommended Readings
Learner outcomes

1. Explain how the organization of the auditory cortex supports speech processing.
2. Explain the role of the phonological network in reading development and disability.
3. Identify how testing and intervention can integrate principles of the neural organization of the auditory cortex as it relates to reading and language.

How the organization of the auditory cortex supports speech processing

The Speech Chain
A Brief Review of the Auditory System

Two functional sub-systems

- **Peripheral Auditory System**
  - Conduction and Transduction
  - Sound Reception

- **Central Auditory System**
  - Transmission and Decoding
  - Sound Perception

The Auditory Pathway

A complex neural pathway
- Originates at the cochlea, passes through the auditory nerve
- Travels through the brainstem and midbrain
- Arrives at the cortex

Numerous synapses along the way
- No single neuron goes from the auditory nerve to the cortex—all are interrupted along the way

The Auditory Nerve (portion of the 8th CN)

Auditory fibers originate at the hair cells of the cochlea
Fibers from the hair cells first synapse with special neurons called spiral ganglion
The "spiral fibers" (fibers from the spiral ganglion) form the auditory nerve
The Auditory Nerve

Key distinction in auditory nerve fibers
- **Afferent fibers**
  - Send sensory signals away from cochlea, to the brain
- **Efferent fibers**
  - Send information from the brain, back down to cochlea
- Latin “ad-” means “to”; “-fer-” means “carry”
- Latin “ex-” means “from”; “-fer-” means “carry”

Auditory Brainstem & Midbrain

The auditory brainstem and midbrain are primarily responsible for decoding “low-level” information about the sound

For example, the brainstem helps to figure out about sound localization

Auditory Brainstem Implant

Some patients don’t benefit from a CI

ABI stimulates the cochlear nucleus

In US, only approved for adults with NF2
In Europe, they have been used in children, and in patients with other disorders

Interesting video on ABI → [http://www.youtube.com/watch?v=Y3Woq6nInRo](http://www.youtube.com/watch?v=Y3Woq6nInRo)
The Auditory Cortex

The auditory cortex (just like all sensory cortices) has six layers. Each layer contains different cell types and fiber types that encode and transmit different information to different parts of the brain.

Tonotopic organization is maintained in auditory cortex (and at all levels).
What aspects of signal need to be conveyed to brain about speech sound?

- **Frequency**
- **Intensity**
- **Timing**

**Frequency**

Tonotopic organization is preserved throughout the entire AS, from the cochlea to the auditory cortex.

Frequencies detection is determined by *where* in the CAS neurons are firing.

**Intensity**

Intensity/amplitude is encoded by the number of neurons that fire and by the rate at which those neurons fire.

Relative amplitude is determined by *how many* neurons fire and *how fast* they fire.
Timing

Timing information is conveyed by *when* neurons fire.

Timing is very important for separating detailed information about a sound, e.g., voice onset time, or *when* the vocal folds vibrate during speech.

Hierarchical organization

Low level acoustic features

- A1 → belt/parabelt
- Frequency selectivity
- Pure tones → complex signals

Grain Size Theory

"Grain size" = the number of phonemes/graphemes in a word or a segment of a word.
Why Does Grain Size Matter?

Phonological Skill
- Reading development
- Implicated in dyslexia

Speech processing
- Critical for cross-modal integration

Structure of the auditory cortex
- Grain size selectivity (STG)

Linguistic Experience & Skill
- Reading instruction
- Decoding skill

Hierarchical Organization of the Auditory Cortex

Meta-Analysis (DiWitt & Rauschecker, 2012)
- Phonemes (2)
- Real words (3-10 phonemes)
- Suggests gradient of selectivity
  - Mid-STG = phonemes
  - A-STG = words

Limitations
- No direct testing of grain size
- Did not control for
  - Low level features
  - Meaning/Syllable structure

Design & Methods

fMRI (20 typical adults)
- High resolution scanning of auditory cortex

Stimuli: Synthetic speech and noise
- Pseudowords: CVCV structure
- Noise: spectral and temporal complexity
- Grain size manipulation
  - Large = 4 phones
  - Medium = 2 phones
  - Small = 1 phone

Contrasts
- Grain size
- Syllable structure
Grain Size Effects: There is grain size selectivity in the auditory cortex

Brain-behavior correlation for phonological decoding skill and STG activation

Interpretation of the effect of grain size and the brain-behavior correlation

Typical adults activate the auditory cortex differently for 1-2 speech sounds verses stimuli with more speech sounds (i.e., 4).

Individuals with higher decoding skill recruit the “small” region less for larger stimuli

- But those with lower skill recruited this region more
- Perhaps they continue to rely on this region to help with more demanding processing tasks
- The STG is sensitive to phonological skill and this can be detected in listening tasks
- Previous research shows the STG is also sensitive to reading skill
The role of the phonological network in reading development and disability

Typical Semantic Processing

Semantic knowledge represented by distributed networks
- Involves large portions of the left temporal lobe and left ventral prefrontal cortex, and parietal and occipital areas (Martin and Chao, 2001; Binder and Desai, 2011)
- Commonly involving regions of the right hemisphere as well (Martin and Chao, 2001; Binder and Desai, 2011; Donnelly et al., 2011)

Encoding word and object meanings shows a left hemisphere prominence (Martin, 1999)

Left hemisphere prominence is present even during infancy (Travis et al., 2011)

Structural differences in SLI

Abnormal gyri
(Carl and Plante, 1998; Cohen et al., 1989; Gauger, Lombardino, & Leonard, 1997)

Reduced volume
(Gauger, Lombardino, & Leonard, 1997)

Atypical rightward asymmetry
(De Fossé et al., 2004)
Rightward asymmetry in SLI

Atypical rightward asymmetry is also observed in the posterior language cortex (Herbert et al., 2003 and Jernigan et al., 1991)
- Posterior peri-sylvian areas (Plante, Swisher, Vance, & Rapcsak, 1991)
- Planum temporale (Gauger et al., 1997; Preis, Jäncke, Schittler, Huang, & Steinmetz, 1998)

Suggests that abnormal brain development, possibly of a genetic etiology
- Results in atypical structural asymmetries that in turn give rise to abnormal functional organization

Functional Differences in SLI

Functional differences in SLI

Badcock et al., 2012

SLI vs. Sibs and TD
- Reduced activation of left IFG & bilateral superior temporal cortex

Badcock et al., 2012

fMRI: SLI < TYP
left inferior frontal cortex + Superior Temporal Cortex (bilaterally)
Disruption of Posterior Brain Systems for Reading in Children with Developmental Dyslexia

fMRI: 144 children (70 w/ dyslexia)
Examined brain activation patterns in typical children and children with dyslexia
Looked at pseudoword and real-word reading tasks that required phonologic analysis

Skill-Correlation and Age-Correlation Analyses

Shaywitz et al., 2002
Disruption in neural systems in Dyslexia

Children with dyslexia demonstrated a disruption in neural systems for reading involving posterior brain regions, including parieto-temporal sites (IPL) and sites in the occipito-temporal area (FG).

Reading skill was positively correlated with the magnitude of activation in the left occipito-temporal region (FG).

Activation in the left and right IFG (inferior frontal gyri) was greater in older compared with younger dyslexic children.

Shaywitz et al., 2002

Where was the disruption: mostly in Posterior Brain Systems

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Shaywitz et al., 2002
Deficient orthographic and phonological representations in children with dyslexia revealed by brain activation patterns

fMRI visual word rhyming (28 children, 14 w/ dyslexia)
Word pairs w/ conflicting & non-conflicting orthography & phonology

<table>
<thead>
<tr>
<th>Similar phonology (P+)</th>
<th>Dissimilar phonology (P-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar orthography (O+)</td>
<td>Genes-bates</td>
</tr>
<tr>
<td>Different orthography (O-)</td>
<td>Has-jazz</td>
</tr>
</tbody>
</table>

Found no differences on easier non-conflicting trials

Cao et al., 2006

Stronger activation for controls vs. children w/ dyslexia
Regions for conflict vs. null: left inferior frontal gyrus (IFG), left inferior parietal lobule (IPL) and left inferior temporal gyrus/fusiform gyrus (ITG/FG)

Controls > Children w/ dyslexia

pint – mint
jazz - has

Cao et al., 2006

Same effect for Conflict vs. Non-conflict
Regions for conflict vs. non-conflict: left inferior frontal gyrus (IFG) and medial frontal gyrus

Controls > Children w/ dyslexia

Cao et al., 2006
Reduced activation in the reading network of children with dyslexia

Deficient orthographic representations in ventral temporal cortex

Deficits in mapping between orthographic and phonological representations in inferior parietal cortex

Greater activation for the controls in inferior frontal gyrus could reflect more effective top-down modulation of posterior representations

Cao et al., 2006

Foxp2 gene and Altered Brain Activation in Distinct Language-Related Regions

Mutations of the FOXP2 gene cause a severe form of language impairment and orofacial dyspraxia

Single-nucleotide polymorphisms (SNPs) located within a KIAA0319/TTRAP/THEM2 gene cluster and affecting the KIAA0319 gene expression are associated with reading disability

This study:
- Genotyped and scanned 94 healthy subjects and
- fMRI during a reading task

Pinel et al., 2012

Foxp2 gene and Altered Brain Activation in Distinct Language-Related Regions

FOXP2

- Variations of activation in the left frontal cortex

Pinel et al., 2012
Genes and Altered Brain Activation for Reading

KIAA0319/TTRAP/THEM2 locus, rs17243157
- Asymmetry in activation of the superior temporal sulcus (STS)

Interestingly, healthy subjects bearing the KIAA0319/TTRAP/THEM2 variants were previously identified as having an enhanced risk of dyslexia
- AND... they did show a reduced left-hemispheric asymmetry of the STS

These findings are consistent with the previous fMRI results in SLI and reading disorders
Suggests a continuum between these pathologies and normal inter-individual variability

Arcuate fasciculus is important for reading
White matter density in the Arcuate fasciculus is predictive of reading growth

FA (density) along the direct segment was uniquely predictive of reading growth
This effect was consistent in both younger and older children
The direct segment’s structure may support reading across development

Gullick and Booth, 2015
Integrating principles of auditory cortex organization into intervention: Literacy

Is literacy something SLPs should be involved in?

ASHA (2006, 2010) advocates several roles of the SLP in literacy instruction.

Catts et al., (2002) – children with oral language impairment are 6x more likely to have difficulty in learning to read.

Reading is a language-based skill and SLPs are experts on language and communication.

Reasons for low test scores on comprehension

- Insufficient time for slower readers
- Decoding or word recognition may be difficult
- There may be limited working memory
- A child may lack background knowledge
- Vocabulary or language skills may be limited
What do good readers do?
Use their background knowledge
Self question what they know and don’t know
Integrate information across text
Monitor their reading using prediction and reread and look for more evidence when they detect something doesn’t make sense

Children with language-learning disability...
Use less diverse vocabulary
Have more over and under extensions
Have greater difficulty with lexical ambiguity
Have poorer labeling and usage of diverse vocabulary
And may have/know faulty definitions

The National Reading Panel (experts in reading) provided recommendations for literacy training

Recommendations of the NRP:
1. Phonemic awareness
2. Phonics
3. Vocabulary
4. Fluency
5. Comprehension
Approaches to Reading Instruction

Code emphasis – trains phonetics (phonics)
◦ Letter sound matching, text to sound conversion
Meaning emphasis – trains word meanings
◦ Emphasis on context and meaning of text
Instruction can combine these approaches

Adams et al., 1998

Phonemic Awareness precedes decoding skill and deficits are associated with poor decoding

Implicit instruction
◦ Poems, rhymes, songs, games with similar sounds (alliteration)

Explicit instruction (oral and pictures)
◦ Initial sounds in words (matching and identification)
◦ Rhyming
◦ Final sounds in words (matching and identification)

Phonics: phoneme and grapheme training

Match letters with sounds
Manipulation of letter tiles/slides/cards to make words or change words
Say it and move it (say a word as written then move a letter and say it again)

Decoding: Analytic & Synthetic
◦ Analytic: whole to part, separate syllables
◦ Synthetic: part to whole, link letters to sounds and blend, word on syllable types and mapping to sounds
Approaches for phonics

Synthetic phonics (also called blended phonics)
- First teaches the letter sounds and then builds up to blending these sounds together to achieve full pronunciation of whole words

Analytic phonics
- Phonemes are associated with particular graphemes are not pronounced in isolation but are identified in sets of words (i.e., word families)

Implications for Intervention

Adapt intervention not just to remediate deficits, but also to capitalize on strengths
- If a method is not working, consider alternatives
- Skill-based approaches
  - Build sight word vocabulary, reading natural text
  - Strategy-based / top-down approaches
    - context, prediction, text structure, question asking

Reading skill is more than just word recognition

Fluency – speed and accuracy of word recognition
- How to train this – word on familiar content

Comprehension – understanding the meaning of the text
- How to train this – emphasize from early stages of learning, build vocabulary, sentence and text comprehension, oral language skills
Building vocabulary

Build oral vocabulary (expressive and receptive)
Label pictures
Practice definitions, learn definitions
Building variability of word use (type token ratio)
Increase usage in sentences

Summary and Conclusions

Summary & Conclusions

Auditory cortex is organized in a way that facilitates speech perception, language processing, and reading.
This organization is dependent upon experience and is sensitive to skill.
There are detectible differences in the auditory cortex in individuals with disabilities.
Intervention can target deficits in phonological processing and improve cortical activation patterns.
Intervention can also compensate for underlying deficits in phonological processing – leading to improved outcomes.