Center for the Study of Learning

Gallaudet University
Georgetown University
Wake Forest University

Supported by the National Institutes for Child Health and Human Development
First use of alphabet - 1800 B.C.
- Typical Reading
- Precocious Reading
- Reading Disability
Learning to Read

• Phases of reading acquisition (Ehri, 1992)
  – Pre-alphabetic- visual
  – Partial alphabetic- phonological cues
  – Full alphabetic- decoding
  – Consolidated Alphabetic- chunking, analogy

• Phonological processing abilities are critical (Wagner and Torgesen, 1987)
Research Questions

• What is the neural basis of visual word processing in healthy children?
• How does the neural basis of word processing change during schooling?
• What is the relationship between these neural systems and phonological skills?
The neural basis of reading

- Left inferior frontal gyrus
- Left temporo-parietal cortex
- Left infero-temporal cortex
The neural basis of reading

- Left inferior frontal gyrus
- Left temporo-parietal cortex
- Left infero-temporal cortex

Orthography
Direct Lexical Access
The neural basis of reading

- Left inferior frontal gyrus
- Left temporo-parietal cortex
- Left infero-temporal cortex

Cross-modal integration
Phonological assembly
Semantics
The neural basis of reading

- Left inferior frontal gyrus
- Left temporo-parietal cortex
- Left infero-temporal cortex
I told you not to read this, didn’t I?
Implicit Word Processing

adapted from Price et al, 1996

41 normal subjects

Male Female
Implicit Reading Activity

6-9.4 y
n=13

9.4-18 y
n=13

20-23 y
n=15

Developmental Changes in Activity

p < .001, peak p < .0001

Reading Composite fMRI
“In the process of early visual education... the storage of memory images of letters and words occurs in both hemispheres.... the process of learning to read entails the elision from the focus of attention of the confusing memory images of the nondominant hemisphere”
Phonological Processing and Reading

• Types of phonological processing (Wagner & Torgesen, 1987)
  – Phonemic Awareness (LAC)
  – Phonological Naming (RAN)
  – Working Memory (Digit Span)
• Subtypes of dyslexia are associated with these types of functions
• Are these abilities associated with different brain regions?
Phonemic Awareness

Lindamood Auditory Conceptualization Test (LAC)

“Show me /p/ /t/ /p/”

“If this says ‘eth’, show me ‘ith’
Phonological Naming
Rapid Automatized Naming Test (RAN)

s a o d o p a p d o
s d a o a p s p d s
o p s p d o s a o p
a d o p s p a s d s
p o s d s p o a o d
Working Memory

Digit Span

“3 8 2 4”
“7 4 6 2 5”
“9 2 3 6 1 8”
“5 3 8 2 7 4 6”
“2 5 4 3 2 8 9 4”
Correlations with Phonological Processing

Phonemic Awareness
Phonological Naming
Working Memory

p< .005, peak p< .0005

Young readers activate left temporoparietal cortex, related to phonological awareness.
Conclusions

Young readers activate temporoparietal cortex, related to phonological awareness.

Reading acquisition = Right posterior cortex (nonlinguistic visual) Left frontal & temporal (phonology, semantics)
The neural basis of precocious reading acquisition: fMRI case study of hyperlexic reading
Hyperlexia

• Developmental disorder of communication (usually autism spectrum)
• Extremely precocious reading learned very early without explicit instruction
• Reading scores above expectation, with comprehension commensurate with verbal ability
• Incidence ≈ 2 / 10,000 (Burd et al., 1985, Yeargin-Allsopp, 2003)
Ethan

• 10-year-old boy
• Disordered
  – expressive/receptive language (first word at 3.5y)
  – social interaction
  – motor coordination
• Pervasive Developmental Disorder- Not Otherwise Specified
• Early intense interest in text
• Precocious reading
# Ethan’s Reading Scores

<table>
<thead>
<tr>
<th>Age</th>
<th>Word I.D. Age eq.</th>
<th>Word Attack Age eq.</th>
<th>GORT Passage Age eq.</th>
<th>GORT Comp. Age eq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5y-11m</td>
<td>8y-10m</td>
<td>9y-4m</td>
<td>10.3</td>
<td>&lt;7.9</td>
</tr>
<tr>
<td>9y-9m</td>
<td>15y-1m</td>
<td>16y-11m</td>
<td>14.9</td>
<td>12.1</td>
</tr>
</tbody>
</table>
Hyperlexia Hypotheses

Left Hemisphere
Phonological Advantage
Welsh et al., 1987

Right Hemisphere
Visual Advantage
Cobrinik, 1982
Methods

• Same fMRI methods as cross sectional study

• Compared Ethan to two control groups
  – Age Matched (n=9)
  – Reading Matched (n=8)
Ethan- Implicit Reading

Turkeltaub et al., Neuron 2004

P< .005
Ethan vs. Controls
Left Hemisphere

Age Matched (n=9)

Reading Matched (n=8)

Correlations with Phonological Awareness

p< .005, peak p< .0005
Ethan vs. Controls
Right Hemisphere

Age Matched (n=9)

Reading Acquisition

Reading Matched (n=8)
Hyperlexia Hypotheses

Left Hemisphere
Phonological Advantage
Welsh et al., 1987

Right Hemisphere
Visual Advantage
Cobrinik, 1982
Conclusions

• In contrast to single hemisphere theories, Ethan demonstrated both
  – Hyper-activity in left hemisphere phonological areas
  – Increased activity in right hemisphere visual areas
• Left temporoparietal cortex is hyper-active in hyperlexia
The International Dyslexia Association / NICHD Research Definition of Dyslexia

• a specific learning disability, neurological in origin

• characterized by difficulties with accurate/ fluent word recognition, spelling and decoding abilities and the phonological components of language

• unexpected in relation to other cognitive abilities and the provision of effective instructions
How Do You Know It’s Dyslexia?

Measurement:

- Single Word Reading
- Phonemic Awareness
- Automatic Naming Speed
- Verbal Working Memory
Malformations

Galaburda et al. 1985
Neurobiological Basis of Dyslexia

Typical Readers

Dyslexic Readers
Dyslexia across cultures: same or different?

Same brain region less active in dyslexics during reading tasks in all countries

Controls > Dyslexics

Paulesu et al., 2001
Phonemic Awareness

• Awareness that language is composed of small sounds

• Hearing how sounds and sound patterns work in our language system
Phonemic Awareness

Measurement with deletion tasks:

• Say cowboy without saying boy = “cow”
• Say pink without the /p/ = “ink”
• Say robe without the /b/ = “row”
• Say blend without the /l/ = “bend”
Phoneme Deletion

<table>
<thead>
<tr>
<th>Task</th>
<th>fixate</th>
<th>repeat</th>
<th>delete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulus</td>
<td>+</td>
<td>rat</td>
<td>rat</td>
</tr>
<tr>
<td>Response</td>
<td>rat</td>
<td>at</td>
<td></td>
</tr>
<tr>
<td>Processes</td>
<td>fixation</td>
<td>vocalization</td>
<td>vocalization + phonological manipulation</td>
</tr>
</tbody>
</table>
Typical Readers:
Deletion versus Repetition
Dyslexic Readers: Deletion versus Repetition
Group Comparison: Controls > Dyslexics

Eden et al., Neuron 2004
After Intervention

Before Intervention

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Study Design

- Assignment of individuals into different interventions
- Groups are equal in reading measures prior to the intervention
- Compare the two groups after intervention

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre intervention</td>
<td>A</td>
</tr>
<tr>
<td>Post intervention</td>
<td></td>
</tr>
</tbody>
</table>
June and Samuel Orton
Adult Phonological Intervention Study

Subjects:
• 20 Adults from Orton Center, recruited through Wake Forest University

Intervention:
• 112.5 hours of Lindamood-Bell (over 8 weeks)

Before and after measures:
• Behavior: reading, phonological awareness
• Physiology (fMRI): phonemic segmentation
Skills Targeted by Intervention

- Visual Imagery (SI)
- Phonemic Awareness (TAAS)

Percent Changes

- Non-Intervention Group
- Intervention Group

*p < .05
Skills Supporting Reading

Non-Word Reading (WJWASS)  Phonemic Transfer Index (DST)

* p < .005
Oral Reading Skills

Real Word Reading (WRAT)  Reading Accuracy (GORT)  Reading Rate (GORT)  Reading Comprehension (GORT)

* p < .05
ANOVA Group x Day: Increases in Activity Following Intervention

Eden et al., Neuron 2004
Conclusion

• After phonological intervention adults with dyslexia show increased activation in the left and right hemispheres.

• The right hemisphere areas are similar to those in the left hemisphere involved in phonological processing in good readers.
• Regions known to be involved in the processing of information from multiple sensory modalities are also involved in PA.

• The neurobiological representation of these regions is established early on.
Overall Summary

• Dyslexic individuals show anomalous activity in these regions, especially parietal cortex.
• This activity becomes established following intensive remediation.