Cognitive and Neurobiological Correlates of Decoding and Reading Comprehension: Classroom Implications

Laurie E. Cutting, Ph.D.
Vanderbilt University
Haskins Laboratories

MTSU 2015
**Multi-Faceted Approach**

- Combined cognitive neuroscience and education approach
- Multiple patterns of reading problems
  - Difficulty acquiring early and/or basic reading skills
  - Reading comprehension
  - Later emerging reading difficulties
- Multiple complementary techniques
  - Experimental and “paper-pencil” tasks
  - fMRI, DTI, structural MRI
Overview

PART I: Components of reading, and major practice issues

PART II: Importance of word-level findings

PART III: Findings “beyond” word-level: comprehension

- Behavioral
- Neurobiological

PART IV: Implications for practice and current and future directions
PART I: COMPONENTS OF READING, AND MAJOR PRACTICE ISSUES
A Common Developmental Framework for Reading: The Simple View (but expanded)

**LANGUAGE COMPREHENSION**
- Background knowledge
- Vocabulary
- Language Structures
- Verbal Reasoning
- Literacy Knowledge

**WORD RECOGNITION**
- Phono Awareness
- Decoding
- Sight Recognition (of Words)

Skilled Reading

Adapted from Scarborough, 2001
Behaviorally, We Know Many of the Characteristics of Skilled Readers

- Recognize words accurately and fluently
  - In and out of context
- Strong vocabularies
- Knowledge/understanding of syntactic construction
- Good verbal (and spatial?) working memory
- Make inferences, integrate into existing background knowledge
- Employ strategies (visualization, organizing/summarizing what has been read, etc)
- Wide background knowledge
How do children get to be skilled readers? And what can go wrong?
Early Reading Development and Reading Difficulty

- A lot is known about *early* reading development / word recognition

- Significant amount research has focused on the characteristics, prevalence, identification, and treatment of reading difficulties in young children

- Less is known about reading in older children, particularly comprehension, despite significant underachievement (NAEP)
Major Practice Issues I will *(try)* to Address!

- Better identification
- Different ways individuals respond to intervention
- Role of higher level abilities
  - Type of text
PART II: IMPORTANCE OF WORD-LEVEL FINDINGS
A Common Developmental Framework for Reading: The Simple View (but expanded)

**LANGUAGE COMPREHENSION**
- Background knowledge
- Vocabulary
- Language Structures
- Verbal Reasoning
- Literacy Knowledge

**WORD RECOGNITION**
- Phono Awareness
- Decoding
- Sight Recognition (of Words)

Difficulties at this level cascade to poor reading comprehension “Dyslexia”

Adapted from Scarborough, 2001
What Word-Level Processing Generally Looks Like in the Brain

Adapted from Pugh et al., 2000
Left Occipitotemporal Area:
Well Established Finding of Lower Activation in Dyslexia

Cutting et al., 2013, Brain Connectivity, and many others.

TD>DYS, p = .028
White Matter Connections from Left Occipito-Temporal Region

Fan et al., 2014

Participants
17 Typically Developing (TD; 11.8 ± 0.7 year old, 9F/8M)
24 Dyslexia (DYS; 12.0 ± 0.6 year old, 11F/13M)

* Picture adapted from: Yeatman et al., 2012
What Makes the Difference?

<table>
<thead>
<tr>
<th></th>
<th>TD&gt;DYS Coefficient</th>
<th>DYS&gt;TD Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>L middle temporal</td>
<td>1.056555</td>
<td>L lateral occipital</td>
</tr>
<tr>
<td>L inferior temporal</td>
<td>1.018094</td>
<td>L para hippocampal</td>
</tr>
<tr>
<td>L superior temporal</td>
<td>0.455544</td>
<td>L entorhinal</td>
</tr>
<tr>
<td>L fusiform</td>
<td>0.378173</td>
<td>L superior parietal</td>
</tr>
<tr>
<td>L superior parietal</td>
<td>0.169229</td>
<td></td>
</tr>
<tr>
<td>pseudo-F</td>
<td>4.694; p(pr&gt;pseudo-F) = .029</td>
<td></td>
</tr>
</tbody>
</table>

TD = Typically Developing  
DYS = Dyslexia

- Typically Developing (TD) – connectivity pattern of *relatively* more connections to left fusiform and left inferior temporal, as well as left middle and superior temporal gyri and left inferior parietal
- Dyslexia (DYS) - connectivity pattern of *relatively* more connections to bilateral occipital

Fan, Anderson, Davis, & Cutting, 2014
Left Occipitotemporal Area: Some Poor Readers Don’t Show Anomalies!

- **Left Occipitotemporal Area:**
  - **Anterior Articulatory recoding**
  - **Temporal-Parietal**
    - Mapping of orthographic to phonological representations
  - **Occipitotemporal**
    - Memory-based word identification

**Cutting et al., 2013, Brain Connectivity**

- **TD** = Typically Developing
- **DYS** = Dyslexia
- **S-RCD** = Specific Reading Comprehension Deficits

Bar graph showing:
- **DYS** = 0.081
- **TD** = 0.133
- **S-RCD** = 0.137
So, What Else Is Involved in Reading Comprehension?

PART III: FINDINGS “BEYOND” WORD-LEVEL: COMPREHENSION
Despite the importance of word-level processing, it doesn’t fully explain reading comprehension performance, particularly as children get older.
Language and Executive Function

• Oral Language
  – Vocabulary
  – Syntax

• Executive Function
  – Inhibition,
  – Working memory,
  – Planning/organizing (*Tower of London*)
Word-Level and Language: Predicting Reading Comprehension

**Note:** A large amount of the variance in the simple view is shared.

Sample
- 97 children (65 boys)
- Mean age=9.7+2.1
- Range of reading abilities

Cutting & Scarborough, 2006
Executive Function: Role in Predicting Reading Comprehension

Sample
N=126 (72 boys)
Mean age=11.85±1.32
Range of reading abilities

Eason, Goldberg, Young, Geist, & Cutting, 2012
But, not all texts place same cognitive demands on the reader!
Results

• Measures varied in terms of percentage variance accounted for by oral language (9%-15%) versus word recognition (6%-12%)

• Large amount of overlapping variance (33%-51%)
More Investigation:
Reader x Text Interactions

Eason, Goldberg, Young, Geist, & Cutting, 2012
## Coh-Metrix Analyses

### Text Type

<table>
<thead>
<tr>
<th>Index</th>
<th>Narrative</th>
<th>Expository</th>
<th>p</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sentences</td>
<td>25.90</td>
<td>11.61</td>
<td>.016</td>
<td>1.35</td>
</tr>
<tr>
<td>Number of words</td>
<td>304.90</td>
<td>116.26</td>
<td>.044</td>
<td>1.08</td>
</tr>
<tr>
<td>Words per sentence</td>
<td>12.73</td>
<td>4.15</td>
<td>.417</td>
<td>-0.41</td>
</tr>
<tr>
<td>Syllables per word</td>
<td>1.34</td>
<td>0.07</td>
<td>.147</td>
<td>-0.63</td>
</tr>
<tr>
<td>Flesch Reading Ease</td>
<td>80.88</td>
<td>9.65</td>
<td>.177</td>
<td>0.65</td>
</tr>
<tr>
<td>Celex Word Frequency (Log)</td>
<td>2.23</td>
<td>0.14</td>
<td>.833</td>
<td>0.11</td>
</tr>
<tr>
<td>Content Word Concreteness</td>
<td>420.88</td>
<td>18.09</td>
<td>.162</td>
<td>-0.68</td>
</tr>
<tr>
<td>Connective to Verb Ratio</td>
<td>0.43</td>
<td>0.22</td>
<td>.117</td>
<td>-0.80</td>
</tr>
<tr>
<td>Connectives Incidence</td>
<td>62.45</td>
<td>11.09</td>
<td>.030</td>
<td>-1.11</td>
</tr>
<tr>
<td>Narrativity</td>
<td>72.33</td>
<td>13.39</td>
<td>.017</td>
<td>1.31</td>
</tr>
<tr>
<td>LSA Sentence to Sentence</td>
<td>0.15</td>
<td>0.07</td>
<td>.000</td>
<td>-2.29</td>
</tr>
<tr>
<td>LSA All Sentences</td>
<td>0.14</td>
<td>0.07</td>
<td>.000</td>
<td>-2.79</td>
</tr>
<tr>
<td>LSA Paragraph to Paragraph</td>
<td>0.31</td>
<td>0.11</td>
<td>.005</td>
<td>-1.49</td>
</tr>
</tbody>
</table>

Eason, Goldberg, Young, Geist, & Cutting, 2012
Executive Function

LANGUAGE COMPREHENSION
- Background knowledge
- Vocabulary
- Language Structures
- Verbal Reasoning
- Literacy Knowledge

WORD RECOGNITION
- Phono Awareness
- Decoding
- Sight Recognition (of Words)

Extended and adapted from Scarborough, 2001
What are the neurobiological correlates of reading?

How are language (semantic) and executive function areas involved?
What Language Generally Looks Like in the Brain: Understanding Meaning

Main point: Language regions are multi-functional.

Adapted from Price et al. 2012
Purpose of Current Study

• Examine neurobiological correlates of word, phrase, and passage comprehension in adolescents

• Ultimate idea is to examine strengths/weaknesses in various subcomponents of reading, and relate them to neurobiological differences
Central Questions

- What are the neural correlates of word vs. reading comprehension in adolescents?
- How does reading ability predict brain activity during reading words vs. passages?
- What are the functional connectivity networks associated with words vs passages in adolescents?
Descriptive Statistics

- 37 right-handed adolescent (21 females) native English speakers
- Mean age 12 years +/- 1.4
- Range of reading ability (TOWRE score 85-115)
Paradigm

(a) Passages
Hydroponics
is a funny word
for plants
growing without soil

(b) Words
era factories
fed task leftover
world bottom
gales water

(c) Baseline

Timing Information
- 550 ms for each content word and 275 ms for each function word
- Presented no more than three content words per slide
- Randomized time between phrases to allow comparison across phrases

Swett, Miller, et al. 2013
& Swett et al., in prep
Hydroponics
is a fancy name
for plants
for plants
Results: Some Unique, Much Overlapping

Overlapping areas: Word Recognition, Semantic, and Domain General

p < .001, k = 57 (ClustSim)
Regions Shared by Passages and Words

One interpretation: shared regions are performing the same function.

But... shared regions may have different functions for word and reading comprehension.
Summary: Semantic Regions

**Connections from Key Nodes:**

- During isolated word processing are to an area thought to be important for rapid and efficient word recognition.

- During passages is to an area where information is combined and integrated.
Summary: Domain General

**Connections from Left DLPFC:**

- **During isolated word processing** are also to the area thought to be important for language.

- **During passages is to an area where information is combined and integrated, as well as default mode network areas.**
Summary

• Much work has been done on word recognition; other work has focused on reading comprehension.

• Our work provides an joint understanding of brain processes underlying these two aspects of reading.

• May have a lot of implications for better understanding reading difficulties and how kids move from learning to read to reading to learn.
Summary

• Executive function and semantic processing hubs have distinguishable functional connectivity patterns for word vs. comprehension-level processing.

• These findings point to flexible network processes within reading “hub” regions. dIPFC may play a role in top-down maintenance of word and comprehension integration.
PART IV: IMPLICATIONS FOR PRACTICE
Major Practice Issues

• Better/earlier identification – can neurobiology play a role? If so, how?
• Those who do not improve with standard intervention protocols – how can we identify them?
• Role of higher level abilities – who might be at risk for reading difficulties caused by impairments in these areas?
  – Type of text – what role does it play?
Better Identification: Predicting Response from Neurobiology

- Children with DYS show different pattern of connectivity strength (indices of white matter) from the critical left OT region to cortical regions as compared to typically developing readers.
  - Consistent with previous functional and structural findings

Connectivity strength may be especially revealing for:
- Responsiveness to intervention
- Predicting reading growth
Response to Treatment

• Do the “overlap regions” play a significant role because they represent key nodes needed to cross word- and passage-level processing?

• Are they more important than the “distinct” regions?
Role of Higher-Level Abilities

• Just as we see behaviorally, there are unique and overlapping areas of activation in the brain associated with reading words and text
  – But, common areas connect to different areas of the brain for word- versus passage-level processing.
• In particular, there appears to be distinct roles for semantic and executive function areas for word- vs passage-level processing.
• Behavioral findings suggest that consideration for different text demands is important.

May help us understand more about successful vs struggling comprehenders
PART V: FUTURE (AND ONGOING) GOALS
Current and Future Directions: Behaviorally

• Further understand the construct of reading comprehension by examining the reader, text, and reader-text interaction
  – Recent use of item response crossed random-effects models
  – Continued passage development – narrative passages

• Role of background knowledge – a large piece of reading comprehension, but thus far in our research we have focused on it less (*but...*)
Current and Future Directions: Neurobiologically

• Understand how these dynamic neurobiological processes of text comprehension vary with reading skill
  – Expository versus narrative text

• How behavioral indices of word-level, language, and executive function correlate with neurobiological correlates of passage comprehension and white matter tracts

• Overlapping vs distinct mechanisms of word-level, language, and executive function and relationship to reading success/failure, and treatment response/nonresponse
VANDERBILT UNIVERSITY

Education and Brain Sciences Research Lab

- NICHD/NIH R01 HD044073
- NICHD/NIH R01 HD044073-S01
- NICHD/NIH R01 HD046130
- NINDS/NIH R01 NS049096
- NICHD/NIH P50HD052121
- NCRR, NIH, under P41 RR15241
- NICHD/NIH P30HD015052
- NCATS/NIH VICTR Resources grant UL1TR000445
- NCRR/NIH Vanderbilt CTSA grant UL1RR024975
- NICHD/NIH R24HD075460
- Johns Hopkins School of Medicine CTSA (NIH M01-RR00052)
- Mental Wellness Foundation
- U.S. Congressionally Directed Materiel and Medical Command (DAMD17-00-1-0548)
Thank you!

Laurie.Cutting@Vanderbilt.Edu