Cognitive neuroscience of reading development and difficulties

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Topics in the Cognitive Neuroscience of Reading

• Becoming a reader
• Reading with dyslexia
• Reading intervention
• Socioeconomic status and reading

The Reading Brain

Figure 7.1: Cerebral Dyslexia Hypothesis
Cortical Networks for Reading

Reading Requires Reorganization

3 Core Reading Brain Networks
Developmental Differences

- Shift from:
  - Bilateral to Left
  - Dorsal to Ventral
  - Reliance on phonological processing networks to automatic recognition

Increase in frontal activations
- Greater access to metalinguistic abilities

Differences in Emerging Reading Systems

- Typically Developing Readers
  - Initial recruitment and subsequent disengagement of right hemisphere
- At-Risk Developing Readers
  - Compensatory recruitment of frontal regions
Topics in the Cognitive Neuroscience of Reading

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- Reading intervention
- Socioeconomic status and reading

Defining Dyslexia

- **What is the basis?** Neurobiological in origin
- **What are the main features?** Difficulties in accurate and/or fluent word recognition and by poor spelling and decoding abilities
- **Why?** Difficulty with the sounds of language (phonology)
- **What else?** Average or higher cognitive skills
- **What else?** Reading comprehension, reduced reading experience
- **What else can contribute to reading issues?** Exclusion of cultural, educational, environmental, or other disabilities

Characteristics of Developmental Dyslexia

- Relatively *more* activation in the frontal/anterior system
- Relatively *less* activation in back/posterior systems
- Activation of similar regions in the right hemisphere

*Brunswick, 1999; Castles et al., 2001; Remedios et al., 1992, 1997; Shaywitz et al., 1998, 2000; Shaywitz, Breier, Fletcher, Bergman, & Papanicolaou, 2000; Shaywitz et al., 2002; Shaywitz, Shaywitz, et al., 2000*
Typical Readers

Readers with Dyslexia

<table>
<thead>
<tr>
<th>Visual Recognition</th>
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Dyslexia: Specific Activations vs. Developmental Differences

- Posterior network activations specific to dyslexia
  - Dyslexic Group < Typical Age-Matched Readers
  - Dyslexic Group < Typical Reading-Matched Readers

- Frontal network activations not unique to dyslexia
  - Dyslexic Group = Typical Reading-Matched Readers
  - Dyslexic Group > Typical Age-Matched Readers

Hoeft et al. (2007)

Dyslexia and IQ

Similar processing patterns across struggling readers

<table>
<thead>
<tr>
<th>IQ</th>
<th>Reading</th>
<th>DMTE</th>
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<tr>
<td>Low Avg</td>
<td>Low/below avg</td>
<td>Hypo-activation in Posterior Dorsal</td>
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<td>Avg</td>
<td>Low/below avg (discrepant)</td>
<td>Hypo-activation in Posterior Dorsal</td>
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Tanaka et al., 2011

IQ Reading fMRI

Low Avg Low/below avg (discrepant)

Hypo-activation in Posterior Dorsal
**Dyslexia and IQ**

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<th>IQ</th>
<th>Reading</th>
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(Hancock, Gabrieli, Hoeft, 2016)

**Orthographic Transparency**

Spectrum of orthographic structures in alphabetic scripts

- **Transparent**
  - Spanish, Italian
- **Opaque**
  - French, Greek
  - English

Language structure matters for reading demands

**Longitudinal stability in typical reading development across languages**

Consistent predictors across alphabetic scripts:
- Phoneme awareness
- Letter knowledge
- RAN

(Caravolas et al., 2013)
Word-Level Phonological Awareness Developmental Continuum

- Rhyming (age 3)
- Word Awareness
- Syllable: segmentation & blending (age 4 – 5yrs; age 5 – 6yrs)
- Onset-rime: segmentation & blending (age 6)
- Phoneme: segmentation & blending (kindergarten)
- Phoneme: deletion & manipulation (kindergarten)

(Modified from O’Connor, 1998)

Reading Across Languages: Similar Task, Different Learning Pace

![Percentage correct word reading across languages](Seymour et al., 2003)

Reading Across Languages: Similar Task, Overlapping Brain Networks

[(Ruedel et al., 2015)]
Cross-Linguistic Convergence

- Strong similarity across French, Italian, and English readers
- Universal features: lower activations in posterior networks

Chinese Characters

- Morphosyllabic
- 3,000-4,000 minimum requirement for literacy
- >10,000’s

Language Specific Features: Chinese & Dyslexia

- Demands of the language:
  - Chinese logographic system maps graphic forms (characters) onto morphemes (meanings)
- Left Middle Frontal Gyrus
  - Integrates visual-orthographic and semantic (and phonological) processes in verbal and spatial working memory
- Right mid-inferior frontal regions
  - Fluent Chinese reading
Language Specific Features: Chinese & Dyslexia

- Orthography-to-phonology mapping task
- Frontal regions serve as a unique neuroanatomical marker of Chinese reading difficulty
- Dorsal hypoactivation is a consistent marker of dyslexia

How Learning to Read Changes the Cortical Networks for Vision & Language

Behavioral comparison:
- Adult literates and illiterates from Portugal & Brazil (10 were illiterate, 22 became literate as adults, and 31 were literate in childhood)

- Literacy enhances visual areas while inducing competition with face processing
- Literacy enhanced processing of speech sounds allowing for top-down access to orthography

(Dehaene et al., 2010)
Predicting Reading Outcomes with Neuroimaging

- Neuroimaging (70-90%) vs. Behavioral (@ chance, 50%)
  - Greater activation at time 1 in the right frontal region predicted reading improvement 2.5 years later
- More activation of Right IFG at time 1 predicted better reading outcomes

Topics in the Cognitive Neuroscience of Reading

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- Reading intervention
- Socioeconomic status and reading

Brain structure changes induced by a short intervention

- Increased density of the grey matter in the jugglers compared to the non-juggler controls.
  - 3 months training in juggling
Phonologically-Based Intervention

Control

Dyslexic

Frontal AND Temporo-parietal

Dyslexic

Frontal but NOT Temporo-parietal

Example:
B: D = Rhyme
B: K = Do Not Rhyme

Neural effects of intervention in dyslexic children

Pre-Intervention

Post-Intervention

Increased activity in Frontal AND Temporo-parietal

After training, metabolic brain activity in dyslexics more closely resembles that of normal readers.

Multisensory Reading Intervention
Targeting Reading via Phonological Processing

• fMRI intervention study
• Lindamood program
• Children

Temple et al. (2003) PNAS
Task: Word repetition or sound deletion

Intervention Changes Brain Connections

- Diffusion tensor imaging (DTI)
- 8- to 10-year-old poor readers
- Change in white matter, suggesting an increase in myelination
- Correlated with improvement in phonological decoding ability
  - (Keller & Just, 2009)

Intervention: Brain & Behavior Changes

- Brain networks recruited for reading are adaptable during development and modifiable in struggling readers
- Plasticity of the reading brain across reader ages
- Next steps
  - Compensation vs remediation
  - Differentiate by intervention type
  - Determine dosage needed per case
Summer Reading: Current Status

- Every student experiences summer vacation
- Many communities offer summer reading activities and programs
- Summer slide is often assumed to occur; research on the topic has been generalized to all students
  - Research has explored this among students with specific characteristics

What is summer slump?

- On average, students lose the equivalent of one month during the summer in academic performance (Cooper, Nye, Charlton, Lindsay, & Greathouse, 1996)
  
- Depends on academic area, SES, reading habits, grade, etc. (Cooper, Nye, et al., 1996; Hill et al., 2007)

Summer Slump: Evidence

- Students from low socioeconomic backgrounds
  - Low SES students lose ground while middle- and high-SES peers advance during the summer (Alexander, Entwisle, & Miller, 2001; Alexander, Entwisle, & Olson, 2007; Burkam et al., 2004; Kim & Quinn, 2013)

- Outcomes
  - Achievement Gap: ~80% of the achievement difference between high-income and low-income students may be attributable to summer reading loss (Hill & Quinn, 2008)
  - Dropout rate & attendance of 4-year college differences (Alexander, Entwisle, & Olson, 2007)
Summer Slump: Evidence

- Comparable gains **during the school year** for students of diverse SES backgrounds

![School Year Cumulative Gains](image)

- Significant differences **during the summer** for students of diverse SES backgrounds

![Summer Cumulative Gains](image)

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**General Pattern of Reading Achievement for Students From Different Income Groups**

Cooper et al. conducted a meta-analysis, which is a review and synthesis of multiple research studies. They reviewed 93 evaluations of summer school programs serving grades K through 12, and also reviewed qualitative data from the program evaluations, including interviews with teachers, parents, and administrators.

Note: The above is a generalized representation from all studies reviewed. (Cooper, 2004)
Summer Time Adventures in Reading & Teaching (START Study)

- Participants:
  - Ages 6-9
  - Completing grade 1 or 2
- Recruited from community
- Randomized Control Trial (RCT)
- Reader Groups
  - Struggling Readers
    - Treatment Group
    - No-Treatment Group

Summer Time Adventures in Reading & Teaching (START Study)

- Treatment Group
- Instruction: 4 hours x 5 days x 6 weeks
  - Provided at no cost
  - Minimum of 100 hours
  - Academic summer months
  - Groups of 3-5 children
  - Lindamood-Bell teaching staff
- Program: Lindamood-Bell Seeing Stars

Seeing Stars: Symbol Imagery for Fluency, Orthography, Sight Words, and Spelling

- Orthographic and visual processing training, and consequently phonological training
- Visualize:
  - Letters
  - Syllables
  - Words
  - Connected text
    - Semantic information
- Just as the stars are parts of the sky, letters are parts of words

(Christodoulou et al., 2016)
Effect of Remediation Program on Reading Scores

Converging Evidence for Program Efficacy

Previous research: School Year
- Treatment group showed relative word level benefits in:
  - Untimed real word reading
  - Untimed pseudoword reading

Current study: Summer
- Tx group: Increased scores
- No-Tx group: No Change

Previous research: School Year
- Tx group: Increased scores
- No-Tx group: No Change

(Reproduced from Romeo, Christodoulou et al., 2017)

 Intervention Effects Example: School year vs. Summer

Typical Intervention Study Outcomes

Summer Study Outcomes
### Key Findings

- Direct evidence for widening differences between students with reading difficulties who do and do not receive intensive summer reading instruction
- Convergence with studies of other vulnerable student populations for summer reading outcomes

(Christodoulou et al., 2017)

### Effects of Reading Intervention

- Inform our definition of a successful intervention
- Prevention of academic summer regression
- Improvement of outcomes

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Socioeconomic Status (SES)

“An individual’s access to economic and social resources, as well as the benefits and social standing that come from these resources; often measured by educational attainment, income, and/or occupation.”

- Strong predictor of academic achievement and cognitive skill in childhood & throughout life (Bradley & Corwyn, 2002)
  - “Achievement gap” grows with age (Lee & Burkam, 2002)
  - Disproportionate effect on language and literacy skills (Noble et al., 2005; Noble et al., 2012)

SES & Reading Disability

- Low-income students have a disproportionately higher rate of RD diagnosis (Shifter et al., 2010; Fluss et al., 2009)
- Studies of SES & cognition are typically conducted on “typically developing” children with scores in the average range.
- Studies of RD are typically conducted on mid-to-high-SES convenience samples.

“Decreased access to resources may amplify cognitive risk factors for poor decoding” (Noble et al., 2006)

Socioeconomic Status & Language

- Strong predictor of brain structure, with a disproportionate effect on the canonical “language areas” (Raizada et al., 2008; Noble et al., 2012)
  - To date, these studies have largely been done in “typically” developing readers

(Noble et al., 2012)
Hypothesized mechanisms of SES influence

(Noble et al., 2012)

Effect of Remediation Program on Reading Scores

(Romeo, Christodoulou et al., 2017)

Lower Socioeconomic Status Participants

Higher Socioeconomic Status Participants

75% showed improved reading scores

26% showed improved reading scores

(Mrazek, Chivakkodan et al., 2017)
Differences Between Children Who Responded More or Less to Intervention

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<thead>
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<th>Cortical Change</th>
<th>Implication</th>
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<tr>
<td>Intervention Group</td>
<td>No group differences</td>
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Summer Slide, Glide, or Gain: Struggling Reader Outcomes in a High-Stakes Season

- Summers are an opportunity for intervention critical for struggling readers
- Summer intervention efficacy may present as absence of decline rather than presence of growth in reading skills
- Socioeconomic status and severity of reading difficulty are risk factors for summer slide, and predictors of reading benefit from intervention
- Brain and behavior offer converging evidence of treatment response
Contributions of Neuroscience

• Brain imaging can currently:
  – Continue to inform our understanding of brain plasticity in response to intervention
  – Reveal mechanisms underlying behavioral trajectories
  – Demonstrate brain correlates for behavioral changes

• Brain imaging has the potential to:
  – Anticipate who will benefit from which intervention
  – Identify behavioral and brain characteristics predicting response to intervention

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Thank you

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