The Neuroscience of Reading: Using Research to Understand Reading Development and Difficulties

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Reading Development & Disabilities

Perspectives on the brain’s role in learning
1. Zealous excitement
2. Resolute acceptance
3. Uncertainty
4. Indifference
5. Limited to no potential
6. Incredulous opposition
Interpretation of fMRI images

What do the colored areas of brain images show?

1. Brain activations
2. Blood flow
3. Activation of neurons
4. Radioactivity in the brain
5. Statistical map
6. My confusion

Can neuroscience help us understand how to maximize success and minimize difficulty with reading?

Potential Contributions of Neuroscience

<table>
<thead>
<tr>
<th>Definition</th>
<th>Identification</th>
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</thead>
<tbody>
<tr>
<td>What is it?</td>
<td>How do we find it?</td>
</tr>
<tr>
<td>Can it get better?</td>
<td>What will it take?</td>
</tr>
</tbody>
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Neuro

Prediction | Intervention
Overview of methods

Most commonly used tools for questions in Education Neuroscience: MEG, ERP, fMRI

fMRI Use in Research

- High quality images
- Radio waves & magnetic field
- No radiation

Functional Magnetic Resonance Imaging

Varma et al., 2007
How does fMRI work?

1. Ask a question suitable for fMRI use
   – What are the neural correlates of reading?
2. Isolate the area of interest
   – Must be operationally defined
3. Design an fMRI paradigm
   – Intermix experimental and control trials of the paradigm
4. Identify activations unique to the experimental trials

Common fMRI Index of Reading

- crane brain > feet feet

Unit of Measurement

- The brain is not the unit of measurement in fMRI
- Meet the Voxel

• The brain is not the unit of measurement in fMRI
• Meet the Voxel
**How does fMRI work?**

- BOLD • Blood Oxygen Level Dependent
- Task
- Blood flow changes
- Decrease of oxygenated blood
- Compensated by increase in oxygenated blood flow to those same brain regions
- Measured in each "voxel"

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**After data collection, before analysis**

- Artifact detection • Identify outliers in the data
- Realignment • Correct for participant’s motion
- Normalization • Adjust individual brain images to fit a template
- Smoothing • Increases signal to noise ratio
Normalisation

Avants, Epstein, Grossman; Gee, 2008

fMRI Images

- Statistical map
- Group average
- Comparison: Experimental vs. Control

Understanding fMRI Images

<table>
<thead>
<tr>
<th>What do they tell us</th>
<th>What do they not tell us</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas recruited for a particular task</td>
<td>A dynamic story</td>
</tr>
<tr>
<td>Group averages</td>
<td>Timing of activations</td>
</tr>
<tr>
<td>Group differences</td>
<td>Individual differences</td>
</tr>
<tr>
<td>Activations for aspects of reading</td>
<td>Activation for reading as a holistic experience</td>
</tr>
<tr>
<td>Areas most involved</td>
<td>Every area active</td>
</tr>
</tbody>
</table>
Magnetic Resonance Imaging

- MRI vs fMRI
- Functional Magnetic Resonance Imaging (fMRI)
  - Measures blood flow changes
  - Blood Oxygenation Level Dependent (BOLD)
  - Based on magnetic field detection

Applications of MRI Technology

Brain Development

(reviewed in Marsh et al 2008)
Consider the following:

- Dyslexia does not exist.
- Reading difficulties are actually just laziness.
- If a child tries hard enough, he can read.
- Difficulties are all in the mind, and excuses are an easy way out of trying.
- The brain isn’t relevant for education.
- What does the brain have to do with learning?
- Should my school be buying a brain scanner?
Why it Matters

• Teacher and parent understanding matters for student achievement
• The brain’s structure and function dictate our behavior
• Reading difficulties are rooted in different brain networks than typical readers
• Brain imaging has predicted who benefits from reading instruction
• Effective instruction can rewire the reading brain
• Brain imaging has revealed why students have struggled

What educators think matters for influencing:

— Student performance
— Parental perceptions
— Colleagues and teachers-in-training

Parent and Teacher Surveys

• Educators and parents confuse the definition and causes of learning disabilities
• 1 in 2 agree that learning disabilities are often just laziness
  — Parents and members of the general public
• Teacher attitudes predict achievement of students with dyslexia
  — Implicit only, not explicit

(Hornstra et al., 2010; Tremaine Foundation Report, 2010)
Peter Effect & Teacher Development

• Can you teach what you don’t know or like?
  – 54.3% of 195 teacher candidates were classified as unenthusiastic about reading
  – “Teacher educators who lack a thorough understanding of basic language constructs were unable to give this knowledge to their teacher candidates”
  – “Teacher educators with a higher understanding were more likely to pass on this understanding to their teacher candidates”

(Applegate and Applegate, 2004; Binks-Cantrell et al., 2012)

Developmental Disabilities

• Describe sets of abilities or characteristics that vary from the norm in the limitations they impose on independent participation and acceptance in society (Odom, Horner, & Snell, 2009)

• 17% of the school-age population (US Centers for Disease Control & Prevention)

• Students struggle to develop the skills required for success in academic settings (and beyond)

• Students face challenges in and out of the classroom, and typically across the life span

DSM Proposed Revision: Dyslexia

A. Difficulties in accuracy or fluency of reading that are not consistent with the person’s chronological age, educational opportunities, or intellectual abilities.

B. Significantly interferes with academic achievement or activities of daily living
**DSM IV-V: Rationale for changes**

- Learning disorders interfere with the acquisition and use of one or more of the following academic skills: oral language, reading, written language, mathematics.
- Learning disorders are distinct from intellectual disability.
- Discrepancy from IQ no longer required.

**DSM-V: Neurodevelopmental Disorders**

- Intellectual Developmental Disorder
- Communication Disorders
- Autism Spectrum Disorder
- Motor Disorders
- ADHD
- Specific Learning Disorder

**DSM-V**

- Specific Learning Disorder
  A. Difficulties learning and using academic skills based on the presence of at least 1 of the following for at least 6 months despite provision of interventions to target those difficulties:
  1. Inaccurate or slow and effortful word reading
  2. Difficulty understanding the meaning of what is read
  3. Difficulties with spelling
  4. Difficulties with written expression
  5. Difficulties mastering number sense, number facts, or calculation
  6. Difficulties with mathematical reasoning
DSM-V

B. Affected academic skills are substantially and quantifiably below those expected given age and cause significant interference with academic or occupational performance, or daily living, as indicated by standardized test scores and clinical evaluation.

C. Learning challenges began during school-age years but may not manifest until demands for affected academic skills exceed individual’s capacities.

DSM-V

D. Learning difficulties are not better accounted for by intellectual disabilities, uncorrected visual or auditory acuity, or other mental or neurological disorders, psychosocial adversity, lack of proficiency in language of academic instruction, or inadequate educational instruction.

DSM-V

• Evidence required:
  – Student’s history
  – School reports
  – Psychoeducational assessment
Diagnostic codes

• 315.00 SLD with impairment in reading (i.e., Dyslexia)
  – Word reading accuracy
  – Reading rate or fluency
  – Reading comprehension
• 315.2 SLD with impairment in written expression
  – Spelling accuracy
  – Grammar and punctuation accuracy
  – Clarity or organization of written expression
• 315.1 SLD with impairment in mathematics (i.e., dyscalculia)

Severity

• Required to specify current severity
  – Mild: some difficulties learning skills in 1 or 2 academic domains but may be able to compensate or function well with accommodations
  – Moderate: marked difficulties learning skills in 1 or more academic domains and unlikely to become proficient without intervals of intensive and specialized teaching during school years
  – Severe: severe difficulties learning skills, affecting several academic domains; the individuals is unlikely to learn those skills without ongoing intensive individualized and specialized teaching

Specific learning disability

• U.S. Office of Special Education and Rehabilitative Services
  – Individuals with Disabilities Education Act (IDEA)
  – Governs how states and public agencies provide early intervention, special education, and related services to children with disabilities (ages 18 or 21)
• Having a disorder in one or more of the basic psychological processes involved in understanding or in using spoken or written language, which may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations.
• The term includes such conditions as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia.
• The term does not include children who have learning problems which are primarily the result of visual, hearing, or environmental, cultural, or economic disadvantage.
Developmental Disability Categories

- Intellectual Disabilities/Mental Retardation
- Hearing Impairments
- Speech or Language Impairments
- Visual Impairments
- Emotional Disturbance
- Orthopedic Impairments
- Other Health Impairments
- Specific Learning Disabilities
  - Deaf-Blindness
  - Multiple Disabilities
  - Autism
  - Traumatic Brain Injury
  - Developmental Delay
- 4.4% of US school-age children
- 40.6% of Developmental Disabilities

Hierarchy of Labels

Labels

- Value
  - Educational services
  - Insurance and legal issues
  - Social community
  - Cultural relevance
Normal Curve

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>-3SD</th>
<th>-2SD</th>
<th>-1SD</th>
<th>Mean</th>
<th>+1SD</th>
<th>+2SD</th>
<th>+3SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Score</td>
<td>55</td>
<td>70</td>
<td>85</td>
<td>100</td>
<td>115</td>
<td>130</td>
<td>145</td>
</tr>
<tr>
<td>2% &amp;ile Rank</td>
<td>&lt;2nd</td>
<td>16th</td>
<td>50th</td>
<td>84th</td>
<td>&gt;98</td>
<td></td>
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</tr>
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</table>

Many Paths to Reading Difficulty

- Decoding
- Fluency
- Strategies for comprehension
- Background knowledge
- Multi-Language Learners
- Task demands

Goal + Learner + Context

Equifinality

equal  end

Many Paths to Reading Difficulty
How do we diagnose reading disabilities?

The Many Strands that are Woven into Skilled Reading
(Scarborough, 2001)

Defining Dyslexia

- Neurobiological in origin
- Difficulties in accurate and/or fluent word recognition and by poor spelling and decoding abilities
- Deficit in the phonological component of language
- Unexpected in relation to other cognitive abilities and the provision of effective classroom instruction
- Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge
- Exclusion of cultural, educational, environmental, or other disabilities

(Lyon et al., 2003)
Reading Disabilities: Neuroscience

• Distinct signature of functional brain activations
  – Pre-readers (Espy et al., 2004; Gou et al., 2011; Yamada et al., 2011)
  – School-age/adult readers (Espy & Zeffiro, 1998; Gabrieli, 2009; Papanicolaou et al., 2004; Rumsey et al., 1997; Shaywitz et al., 2006)

• Plasticity of reading brain systems (Aylward et al., 2003; Eden et al., 2004; Odegard et al., 2008; Meyer et al., 2008; Richards et al., 2000, 2001, 2006; Shaywitz et al., 2004; Temple et al., 2003)

Typical Reading Brain Activations

Reading Brain Networks

• Anterior
  – Motor production
    – Processing of low-frequency exception words and nonwords

• Posterior – Dorsal
  – Phonological processing, sound-symbol mapping

• Posterior – Ventral
  – Automatic recognition of printed words

• Developmental shift from:
  – Bilateral to left posterior systems
  – Dorsal to ventral
Characteristics of Developmental Dyslexia

- Anterior hyperactivation
- Posterior hypoactivations
- Right hemisphere recruitment

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
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)

Major Languages Used Internationally

www.fl壮大es/image
Literacy Rates Worldwide

Languages spoken by more people have simpler inflectional morphology

[Image of a world map showing literacy rates.]

[Graph showing the relationship between log frequency and morphological complexity.]

[Image of a brain with a maze, labeled A to F.]

Dr. Joanna Christodoulou,
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Orthographic Transparency

Spectrum of orthographic structures in alphabetic scripts

![Transparent to Opaque]

Spanish, Italian | 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

![Graph showing longitudinal stability across groups]

(Caravolas et al., 2013)

Cross-Linguistic Convergence

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

![Brain images showing activations]

(A Control Group | B Dyslexic Group | C Control-Dyslexic Activation)

(Paulesu, Demonet, Fazio, McCloy, Chavane, Brunswick, et al., 2001)
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

Intervention

- Identification estimates imprecise
  - Current practices over- and under-estimate who struggles to read (Gabrieli, 2009; Torgesen, 2000)
- Prospects for struggling readers vary
  - 88% remained poor readers from grade 1 to 4, Juel, 1988; 50% from Kin were dysfluent in grade 3, Simmons et al., 2008
- Estimates of intervention efficacy vary
  (Snow et al., 1998; Torgesen, 2000)
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

Phonologically-Based Intervention

Control

Dyslexic

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

Neural effects of intervention in dyslexic children

Pre-Intervention

Post-Intervention

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

Task: Word repetition or sound deletion
- Increased activation in parietal and phonological regions
- Increased frontal regions
- Decreased activation in left of the occipitotemporal cortex (shift from visual to phonological strategies)

Dyslexic Intervention Group

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)
Activations Differ in Treatment Responses

- Students who improved word reading skills showed greater activation in right inferior frontal lobe
  - less activation in right middle temporal lobe

(Odegard et al., 2008)

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

Reading Development & Disabilities