

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

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Reading Development & Disabilities

Definitions & Labels      Identification      Intervention

Classroom

Clinic      ?      Lab

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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

Zealous excitement

Resolute acceptance

Uncertainty

Indifference

Limited to no potential

Incredulous opposition

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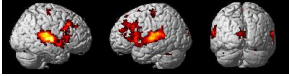
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**Interpretation of fMRI images**

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

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



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**Potential Contributions of Neuroscience**

Definition <i>What is it?</i>	Identification <i>How do we find it?</i>
<b>Neuro</b>	
<i>Can it get better?</i>	<i>What will it take?</i>
Prediction	Intervention

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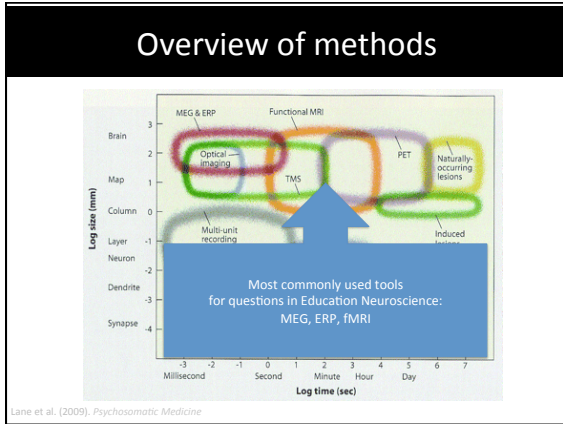
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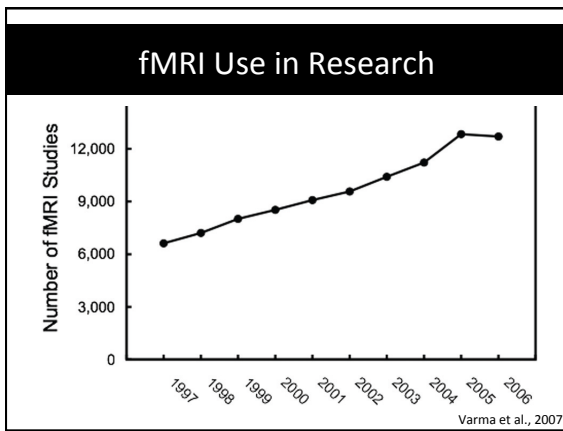
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### Functional Magnetic Resonance Imaging

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

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### 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

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### Common fMRI Index of Reading

<p>crane brain</p> <p style="font-size: small;">yes    rhyme?    no</p>	>	<p>feet feet</p> <p style="font-size: small;">yes    same?    no</p>
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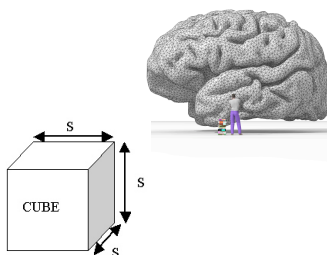
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### Unit of Measurement

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



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### How does fMRI work?

- BOLD
- Task
- Blood flow changes
- Measured in each "voxel"

- Blood Oxygen Level Dependent
- Decrease in blood flow for a task
- Compare oxygenated blood flow to those in the same brain regions

crane  
brain  
rhyme?  
yes no

CUBE  
x y z

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crane  
brain  
rhyme?  
yes no

feet  
feet  
same?  
no

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### After data collection, before analysis

- **Artifact detection**
- **Realignment**
- **Normalization**
- **Smoothing**

- Identify outliers in the data
- Correct for participant's motion
- Adjust individual brain images to fit a template
- Increases signal to noise ratio

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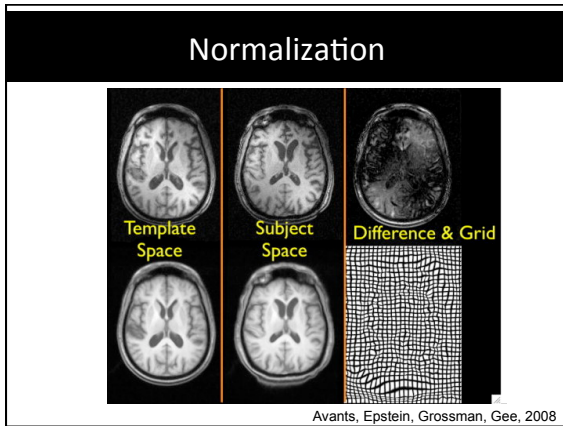
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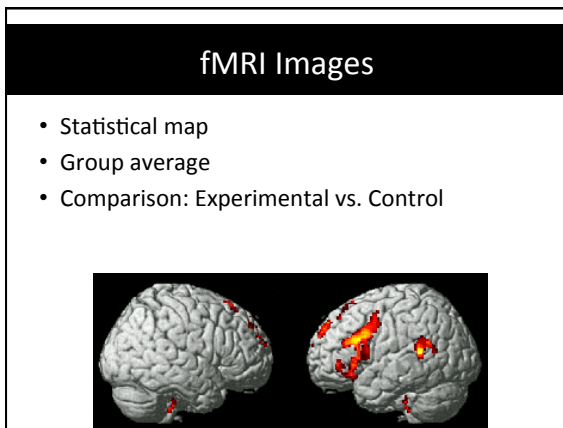
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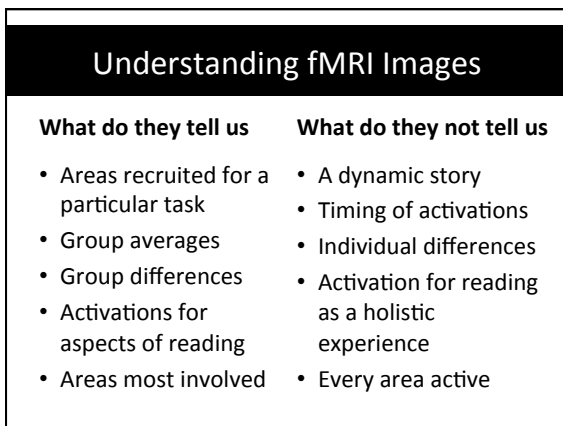
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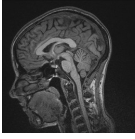

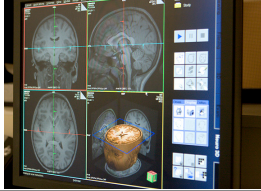
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## Magnetic Resonance Imaging

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


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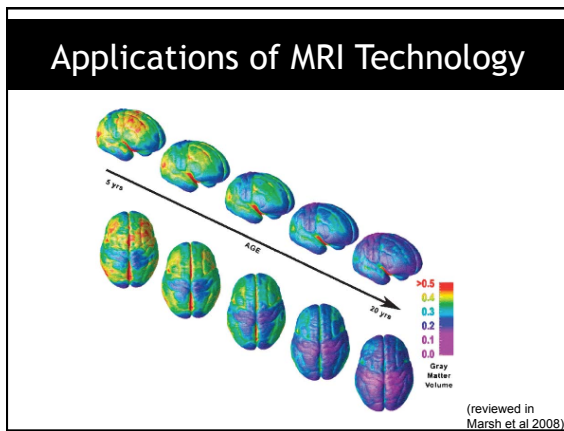
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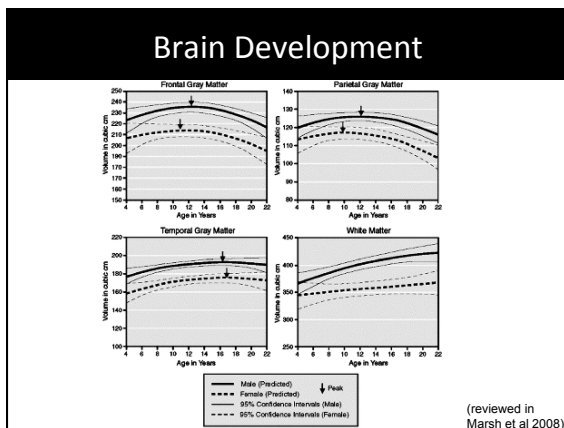
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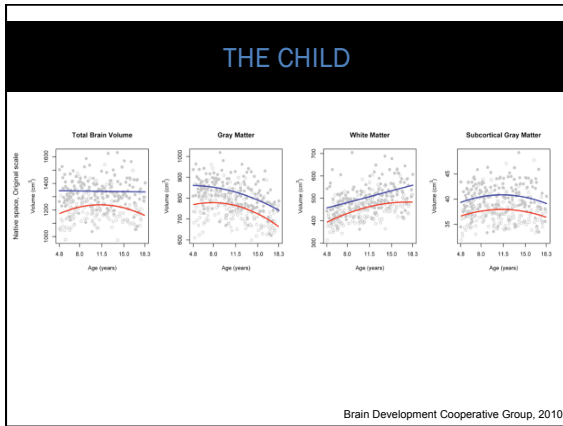
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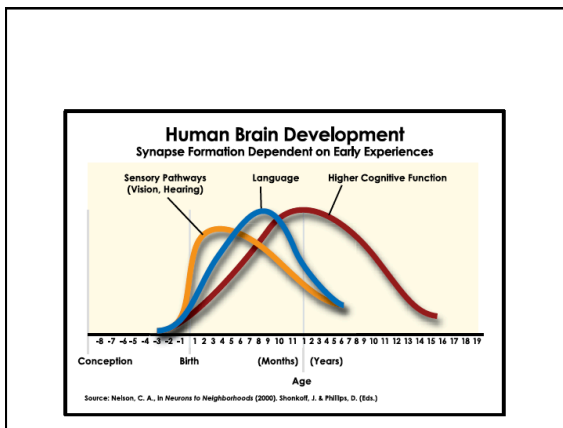
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### Consider the following:

- *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?*

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### 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

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### What educators think matters for influencing:

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



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### 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)

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**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)

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**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

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**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

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**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

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**DSM-V: Neurodevelopmental Disorders**

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

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**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

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**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.

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**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.

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**DSM-V** 

- Evidence required:
  - Student's history
  - School reports
  - Psychoeducational assessment

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### Diagnostic codes

- 315.00 SLD with impairment in reading (i.e., Dyslexia)
  - Word reading accuracy Alternative term: Dyslexia
  - 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) Alternative term: Dyscalculia

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### 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

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### 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.

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### Developmental Disability Categories

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

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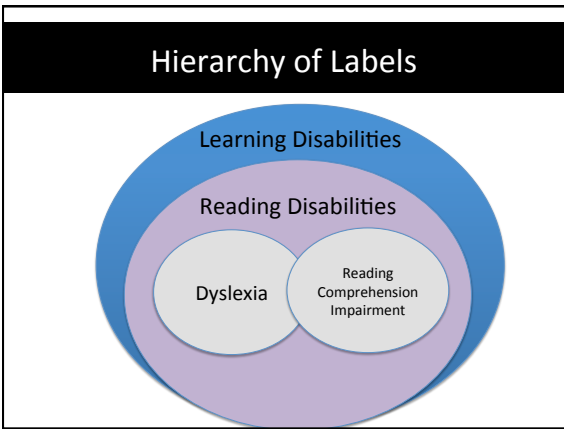
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### Labels

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

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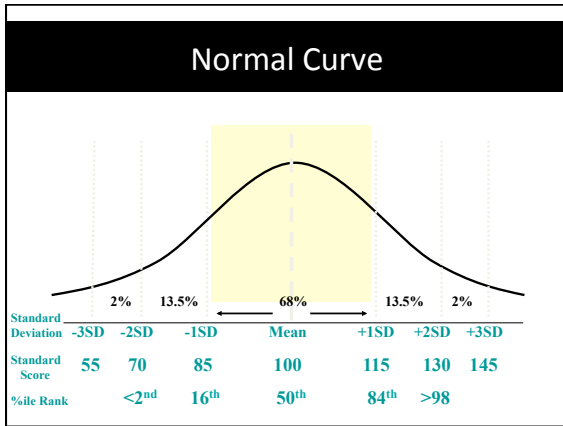
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### Many Paths to Reading Difficulty

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

Goal + Learner + Context

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### Equifinality

equal end

### Many Paths to Reading Difficulty

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### How do we diagnose reading disabilities?



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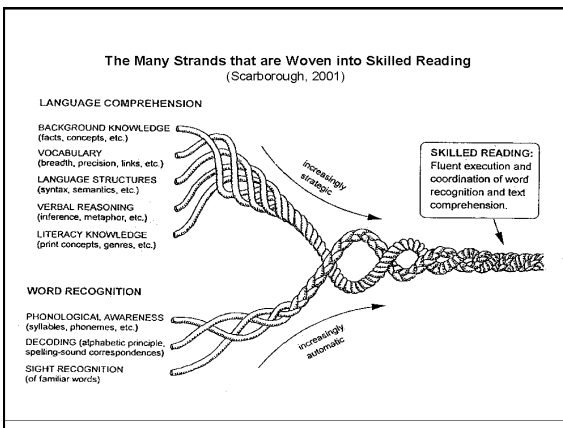
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### Defining Dyslexia

- **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)

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### 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** (Eden & Zeffiro, 1998; Gabrieli, 2009; Papanicolaou et al., 2004; Rumsey et al., 1997; Shaywitz et al., 2000)
- **Plasticity of reading brain systems** (Aylward et al., 2003; Eden et al., 2004; Odegard et al., 2008; Meyler et al., 2008; Richards et al., 2000, 2002, 2006; Shaywitz et al., 2004; Temple et al., 2003)

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### Typical Reading Brain Activations

(Brunswick, 1999; Paulesu et al., 2001; Rumsey et al., 1992, 1997; Shaywitz et al., 1998, 2002; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000; Simos, Papanicolaou, et al., 2000)

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### 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

(Cohen et al., 2000; Fiez et al., 1998; Shaywitz et al., 2002)

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### Characteristics of Developmental Dyslexia

- Anterior *hyper*activation
- Posterior *hypo*activations
- Right hemisphere recruitment

(Brunswick, 1999; Fiez et al., 2002; Rumsey et al., 1992, 1997; Shaywitz et al., 1998, 2002; Simos, Trolier, Fletcher, Bergman, & Papanicolaou, 2000; Simos, Papanicolaou, et al., 2000)

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Typical Readers		Readers with Dyslexia
 <small>VISUAL RECOGNITION 4-100 msec</small>	Visual Recognition	
 <small>WORD-SPECIFIC ACTIVATION 100 msec</small>	Word-Specific Activation	
 <small>PHONOLOGICAL PROCESSING 100-150 msec</small>	Phonological Processing	
 <small>SEMANTIC PROCESSING 200-300 msec</small>	Semantic Processing	

(Wolf, 2007)

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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

(Hoefl et al. 2007)

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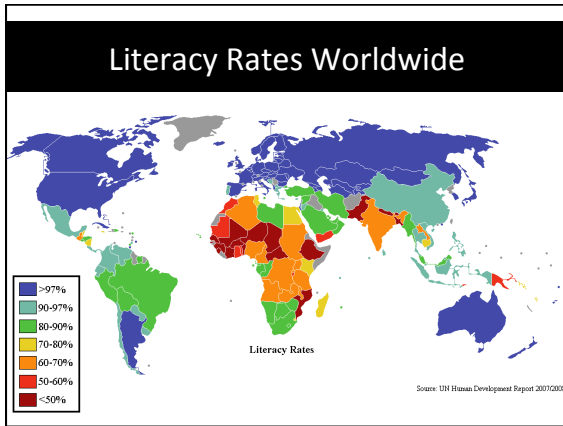
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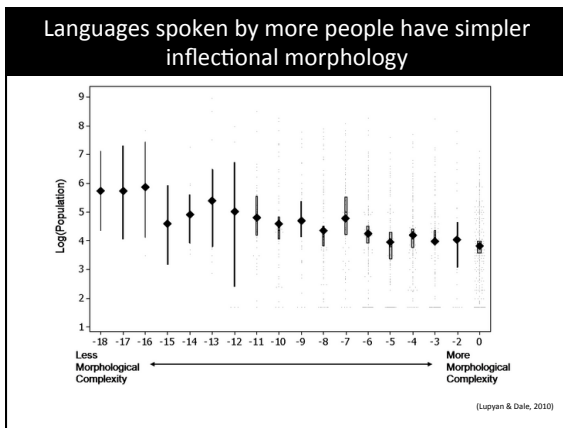
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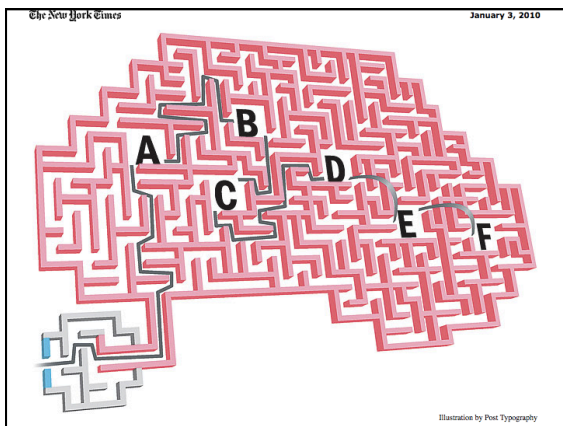
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### Orthographic Transparency

Spectrum of orthographic structures in alphabetic scripts

Transparent Opaque

Spanish, Italian French, Greek English

Language structure matters for reading demands

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### Longitudinal stability in typical reading development across languages

Consistent predictors across alphabetic scripts:

- Phoneme awareness
- Letter knowledge
- RAN

Month	English Group	Spanish Group	Czech Group
0	5	5	5
4	8	8	8
8	12	12	12
12	15	18	18
16	18	22	22
20	22	25	25
24	25	28	28
28	28	32	32
30	30	35	35

(Caravolas et al., 2013)

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### Cross-Linguistic Convergence

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

Country	Control	Dyslexia
France	~1.5	~-0.5
Italy	~1.5	~-0.5
UK	~1.5	~-0.5

(Paulesu, Démonet, Fazio, McCrory, Chanoine, Brunswick, et al., 2001)

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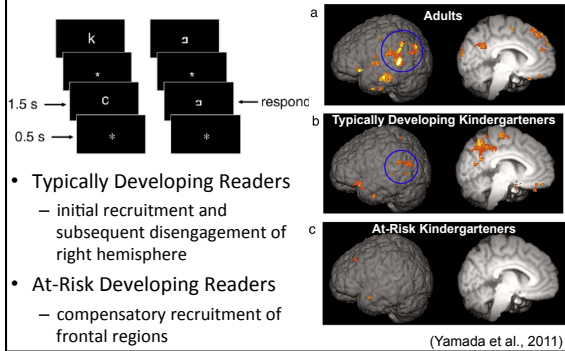
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### Differences in Emerging Reading Systems



The diagram shows a reading task with two columns of letters: 'k', 'a', 'c', 'a' and 'k', 'a', 'c', 'a'. A 1.5 s interval is shown for the first column and a 0.5 s interval for the second. A 'response' arrow points to the right. Below the diagram are three brain activation maps: (a) Adults, (b) Typically Developing Kindergarteners, and (c) At-Risk Kindergarteners. The maps show activation in the right hemisphere for adults and typically developing children, and compensatory activation in frontal regions for at-risk children.

- Typically Developing Readers
  - initial recruitment and subsequent disengagement of right hemisphere
- At-Risk Developing Readers
  - compensatory recruitment of frontal regions

(Yamada et al., 2011)

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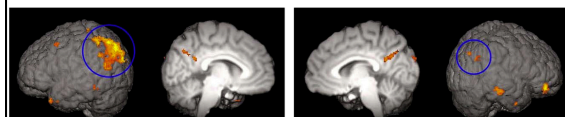
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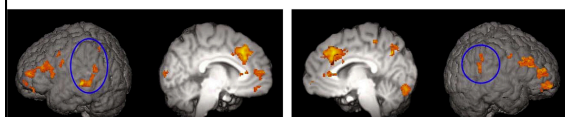
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### Differences in Emerging Reading Systems

#### Typically Developing Kindergarten Readers after 3 months



#### At-Risk Kindergarten Readers after 3 months



The top section shows four brain activation maps for typically developing kindergarten readers after 3 months, with orange activation in the right hemisphere. The bottom section shows four brain activation maps for at-risk kindergarten readers after 3 months, with orange activation in frontal regions. A blue circle highlights the right hemisphere in both sections.

(Yamada et al., 2011)

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### 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)

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### 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

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### Phonologically-Based Intervention

**Control**  
Frontal **AND** Temporo-parietal

**Dyslexic**  
Frontal **but NOT** Temporo-parietal

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

Temple et al. (2003) PNAS

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### Neural effects of intervention in dyslexic children

**Pre-Intervention**  
Frontal **but NOT** Temporo-parietal

**Post-Intervention**  
Increased activity in Frontal **AND** Temporo-parietal

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

Temple et al. (2003) PNAS

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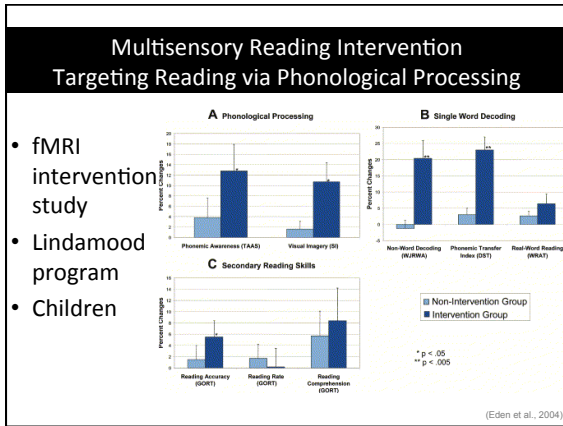
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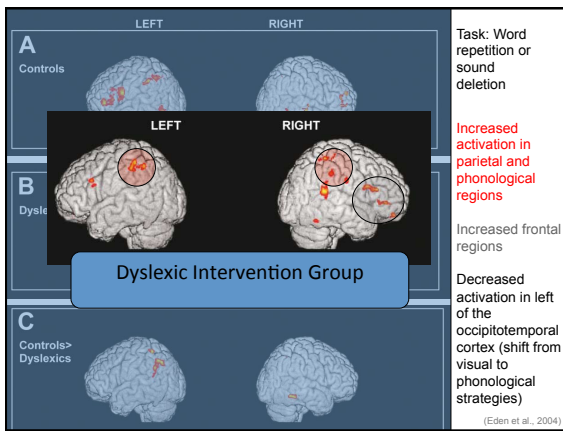
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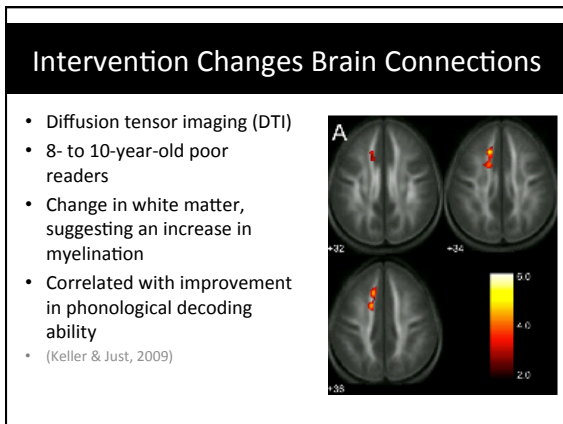
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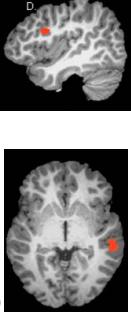
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### Activations Differ in Treatment Responses

- 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)

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### 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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### Reading Development & Disabilities

Definitions & Labels      Identification      Intervention



Classroom

Clinic      ?      Lab

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