

Cognitive neuroscience of reading: Core Knowledge

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Reading Development & Disabilities

Definitions & Labels



Identification



Intervention

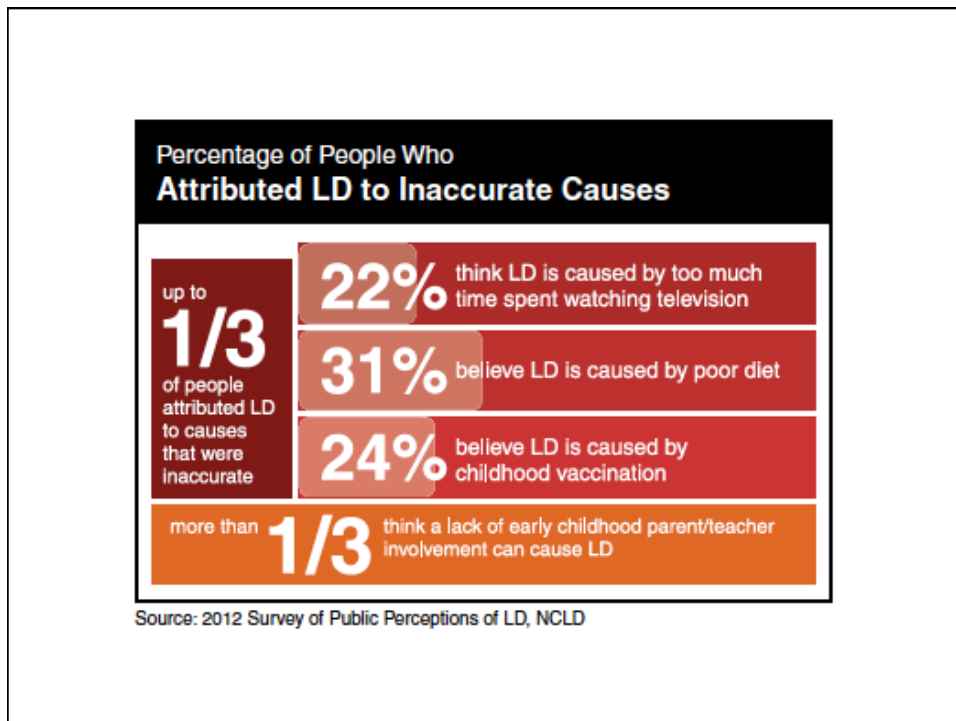
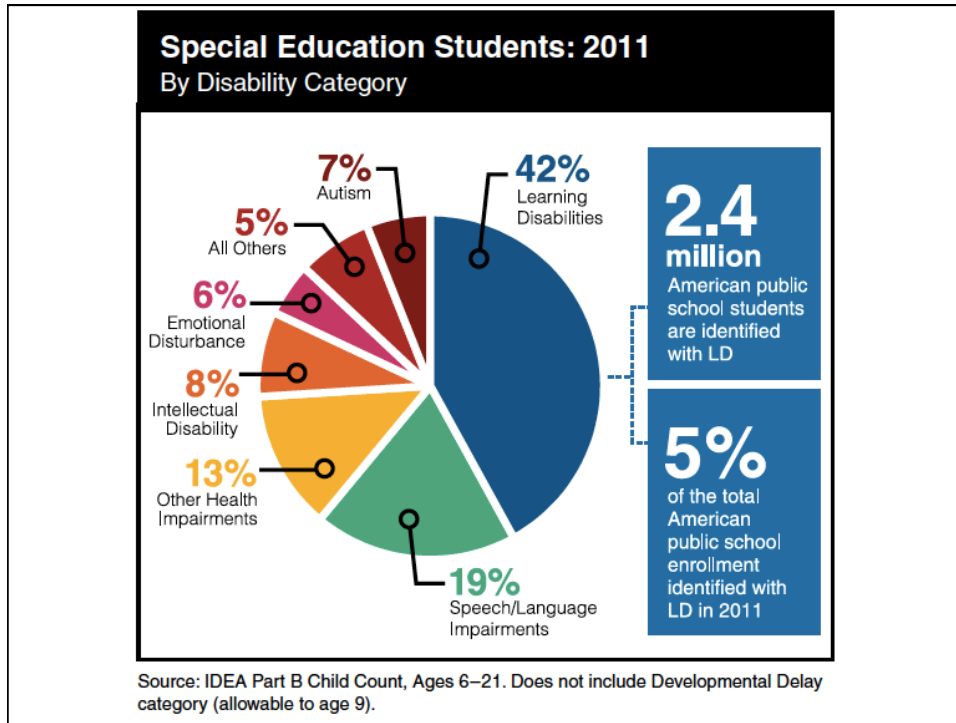


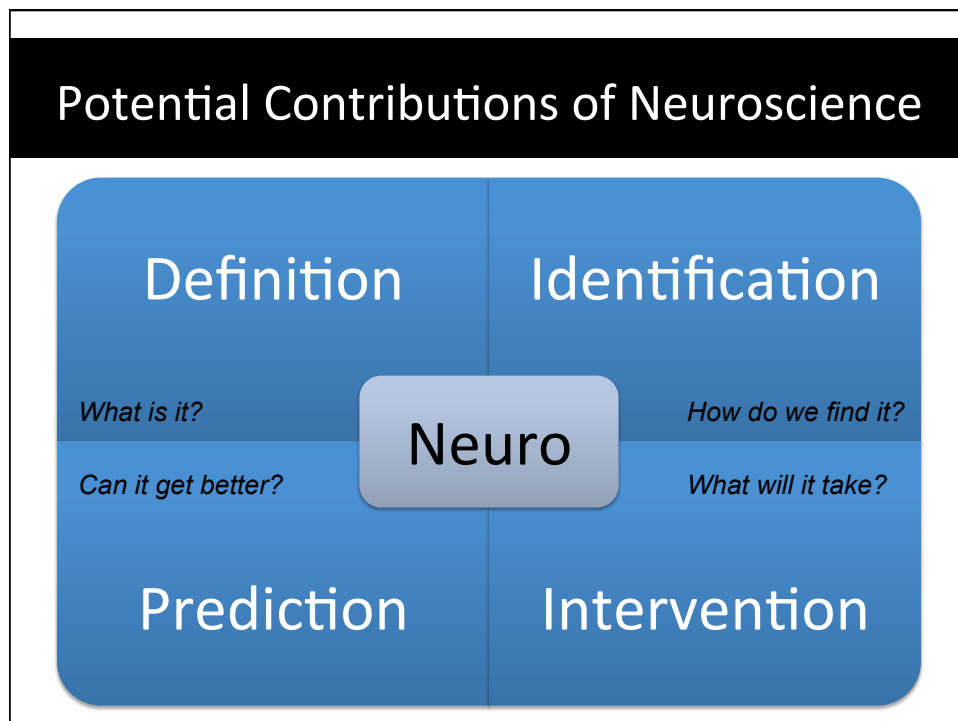
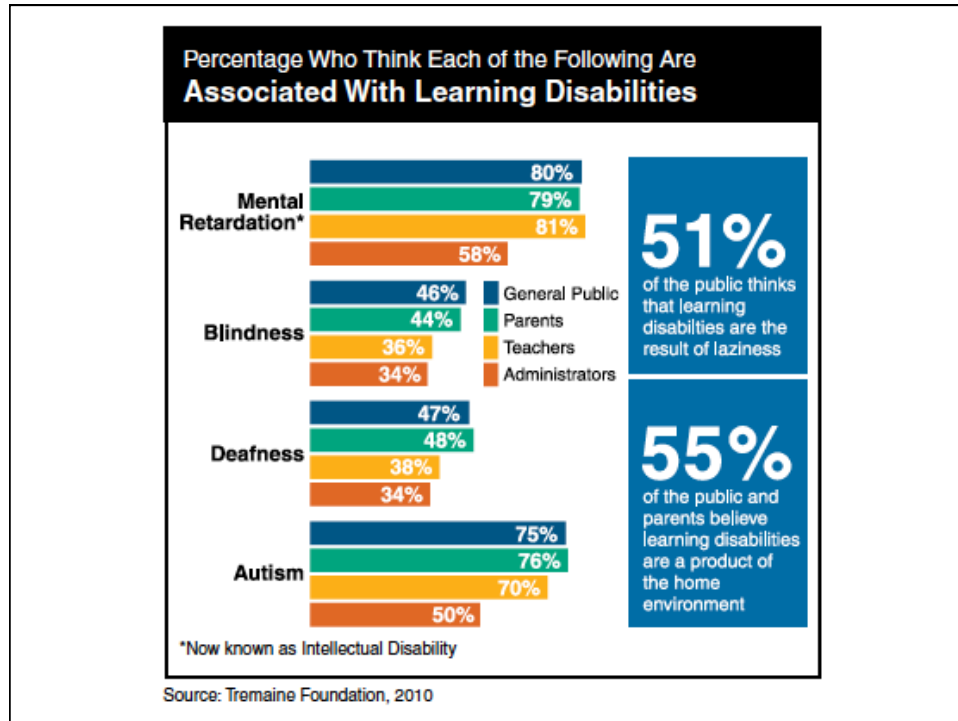
Classroom

Clinic



Lab





Diagnostic Labels

- Education Context: Specific learning **disability**
 - Individuals with Disabilities Education Act (IDEA)
- Clinical Context: Specific learning **disorder**
 - Diagnostic and Statistical Manual of Mental Disorders (DSM-V)
 - International Classification of Diseases (ICD-10)
- Research Context (and other 2): Dyslexia

IDEA definition

Specific learning disability: Definition

*a disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or **written**, which disorder may manifest itself in the imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations.*

(20 U.S.C. § 1401 (30))

Neuroscience data not admissible

IDEA Fall 2015 Update

- U.S. Department of Education released a guidance letter in October, 2015
- Confirmed that schools can use and recognize the terms *dyslexia*, *dysgraphia* and *dyscalculia*
- Countered misconception that these terms were not recognized

Clinical Resources

- Diagnostic and Statistical Manual of Mental Disorders (DSM-V)
 - American Psychiatric Association
 - Provides criteria for diagnosing mental disorders
- International Classification of Diseases (ICD-10)
 - World Health Organization
 - Provides clinical codes for a particular diagnosis
 - No diagnostic criteria or other information

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:

Neuroscience data not admissible

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

Proposed definition of dyslexia for DSM-V

~~1. Difficulties in accuracy or fluency of reading that are not consistent with the person's chronological age, educational opportunities or intellectual abilities.~~

~~2. The disturbance in criterion 1, without accommodations, significantly interferes with academic achievement or activities of daily living that require these reading skills.~~

~~(DSM-5, 2010)~~

Many Paths to Reading Difficulty

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



Goal + Learner + Context

How would you define dyslexia?

Letter Reversals

e



Visual problems

Problems planning, organizing, executing



Reading Comprehension Issues



Speed of Processing



Impairments with linking letters & sounds



Motor Coordination Issues

Seeing
BACKWARDS

"It doesn't exist...kids can be lazy or stupid"



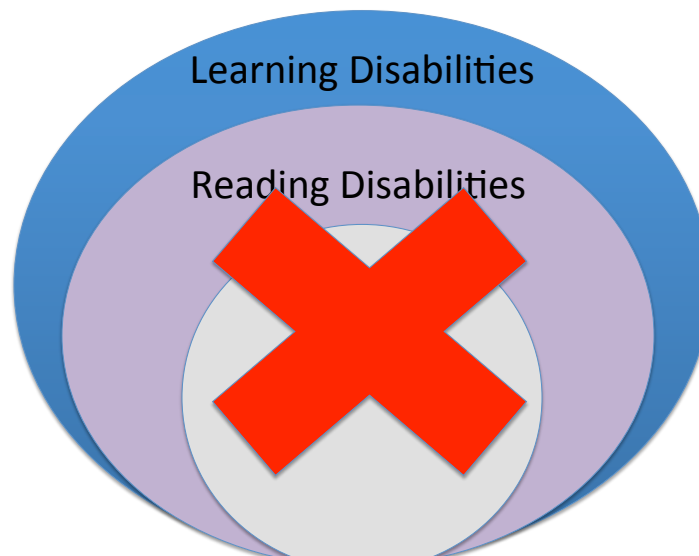
Defining Dyslexia

- 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
- **NOT ADMISSIBLE: brain data**

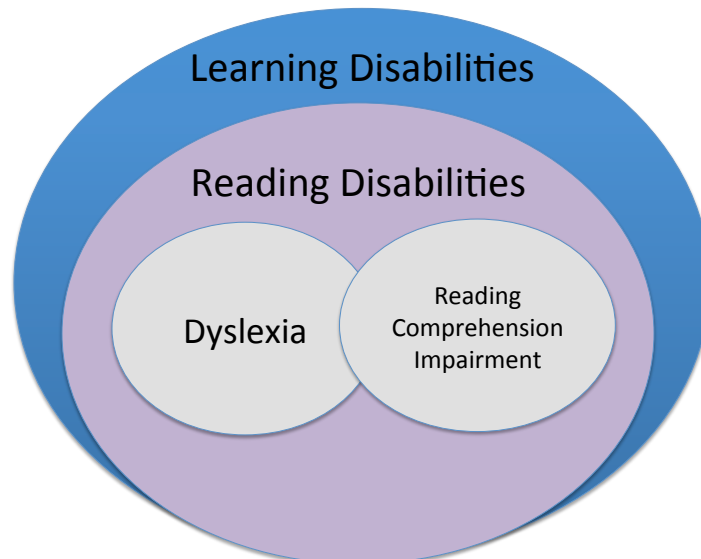
(Lyon et al., 2003)

How do we operationally define “difficulties”?

Contextualizing Reading Difficulties



Contextualizing Reading Difficulties



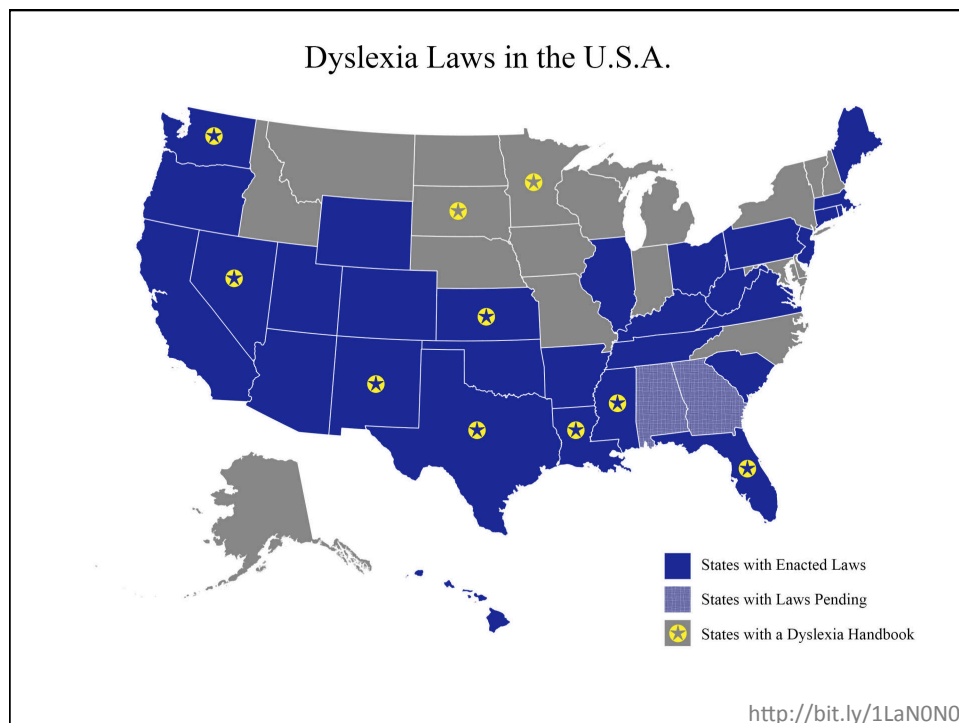
Simple View of Reading

- Decoding x Listening Comprehension = Reading Comprehension
- Link between reading comprehension and decoding decrease over time
- Link between reading comprehension and listening comprehension increase over time
- Why?

Label Comparisons

- **Dyslexia**
 - Common parlance
 - Research term
 - Specific to word level difficulties
- **Specific Learning Disability**
 - National and state level in US (IDEA)
 - Legally defined and acknowledged
 - Not specific to type of reading issue
 - Includes the term 'dyslexia' as a type of SLD
- **Specific Learning Disorder**
 - Clinically-based DSM-V/ICD-10
 - Not specific to type of reading issue

Role of Neuroscience?

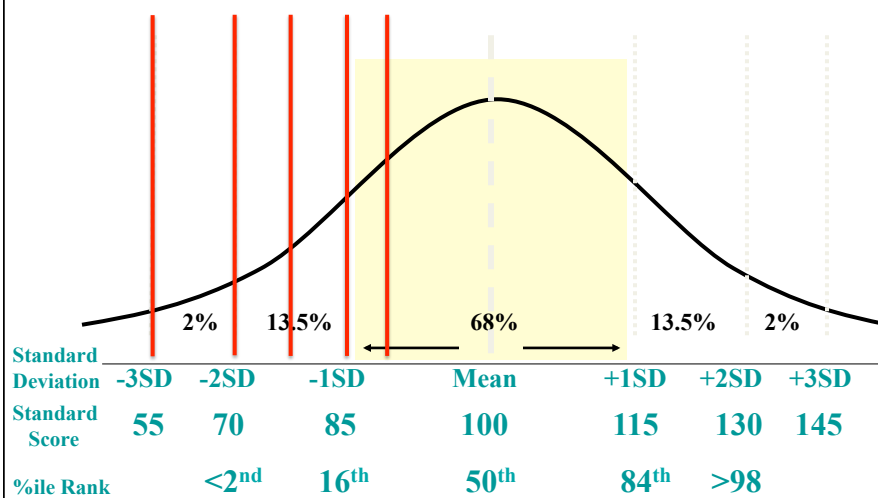


Labels

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

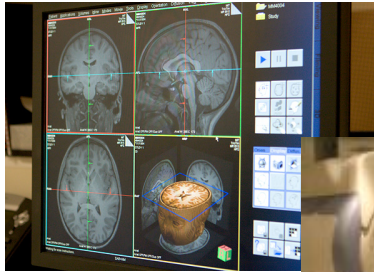


Standardized Assessments



Functional Magnetic Resonance Imaging

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

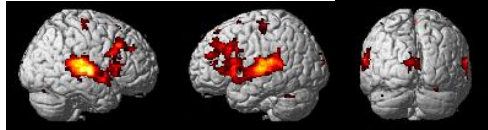


How does fMRI work?

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

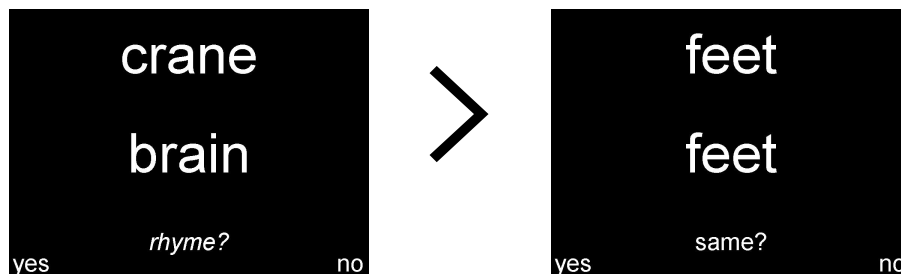
Interpretation of fMRI images

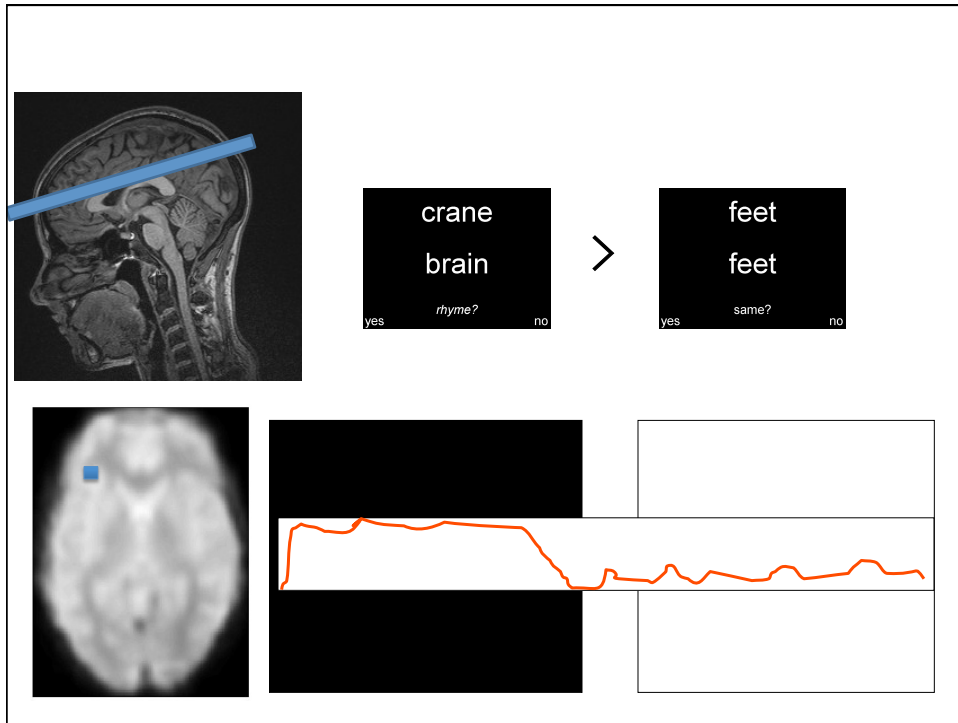
What do the colored areas of brain images show?



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

Common fMRI Index of Reading

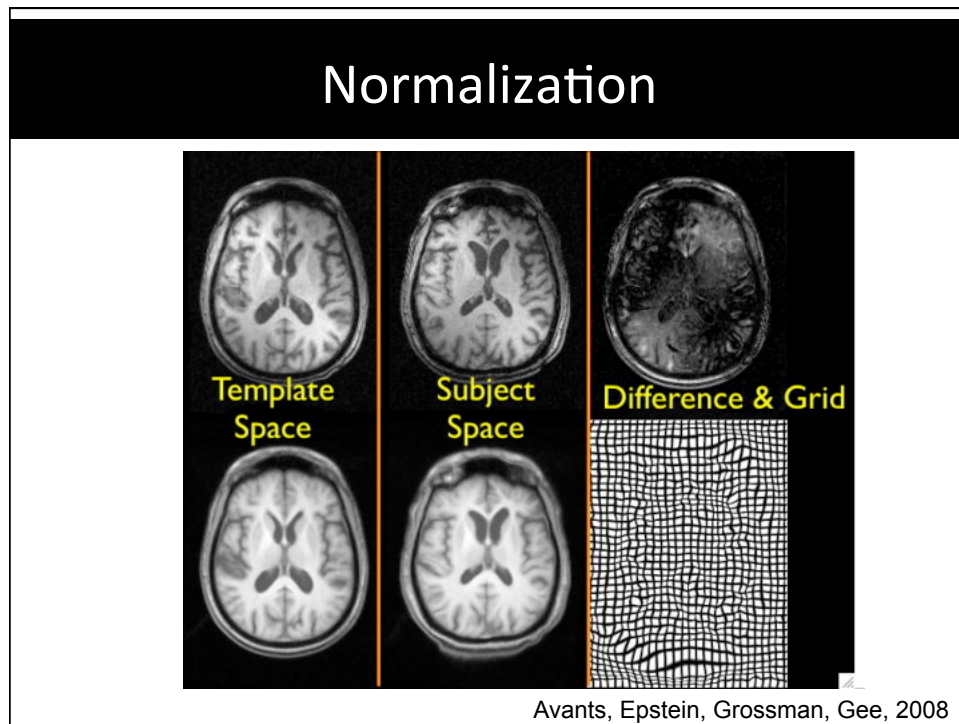




How similar are brains across people?

Individual Image

The figure shows three axial brain slices, each representing an individual. The slices are arranged vertically and show the internal structure of the brain, including the ventricles and white matter tracts. The label 'Individual Image' is positioned above the top slice.

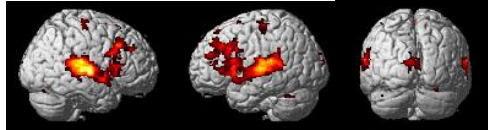


fMRI Images

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

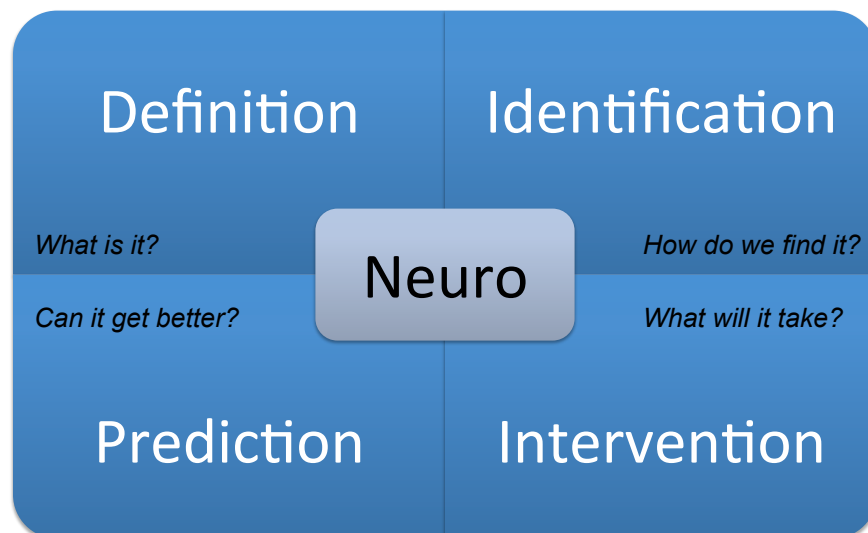
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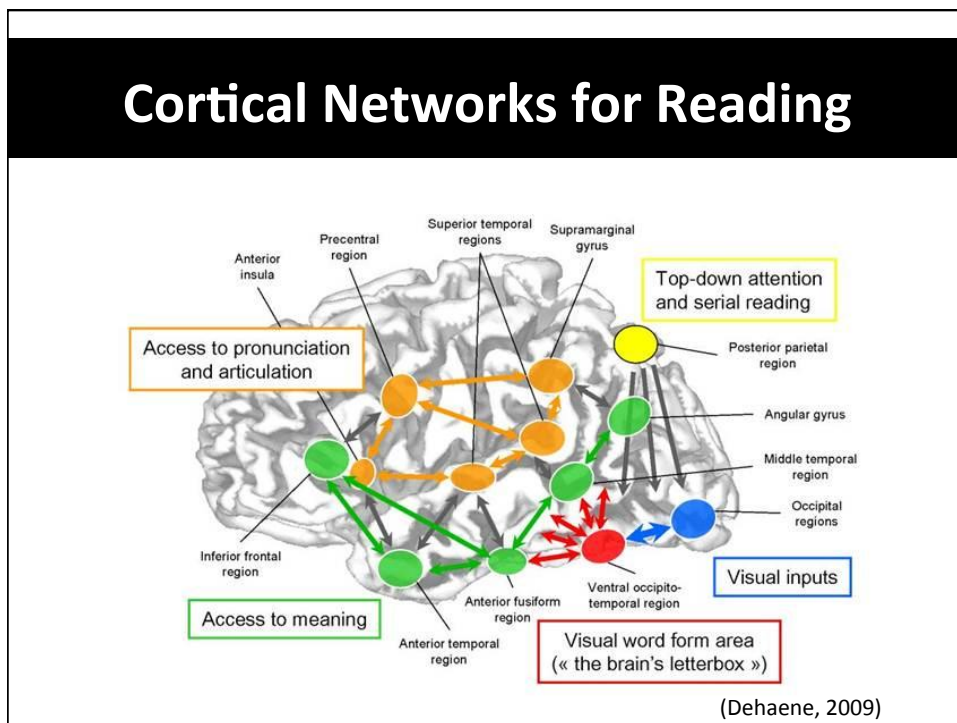
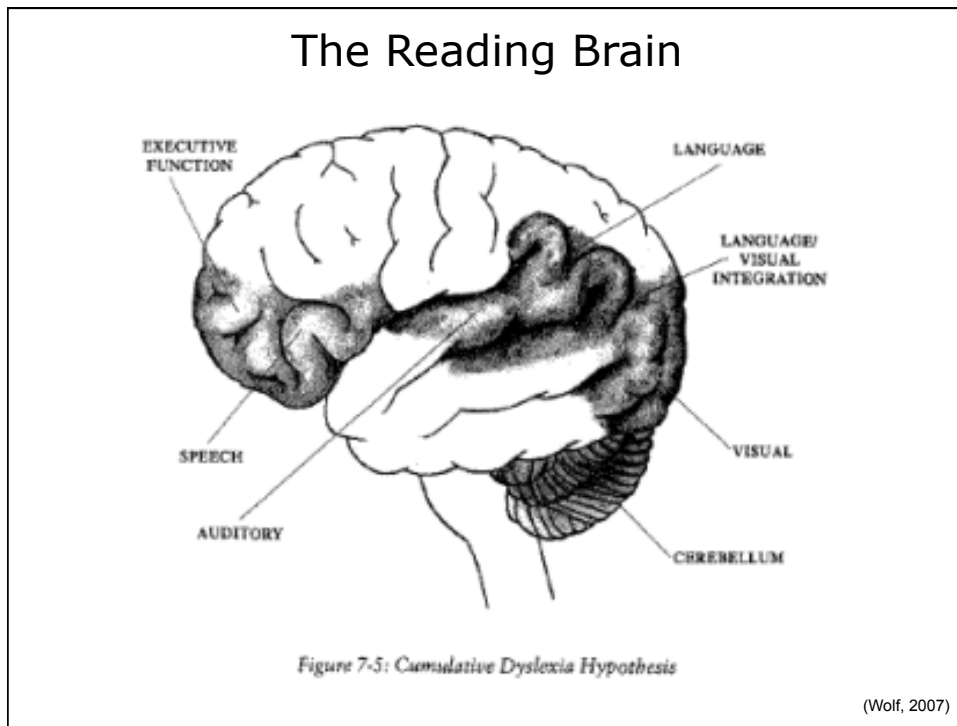
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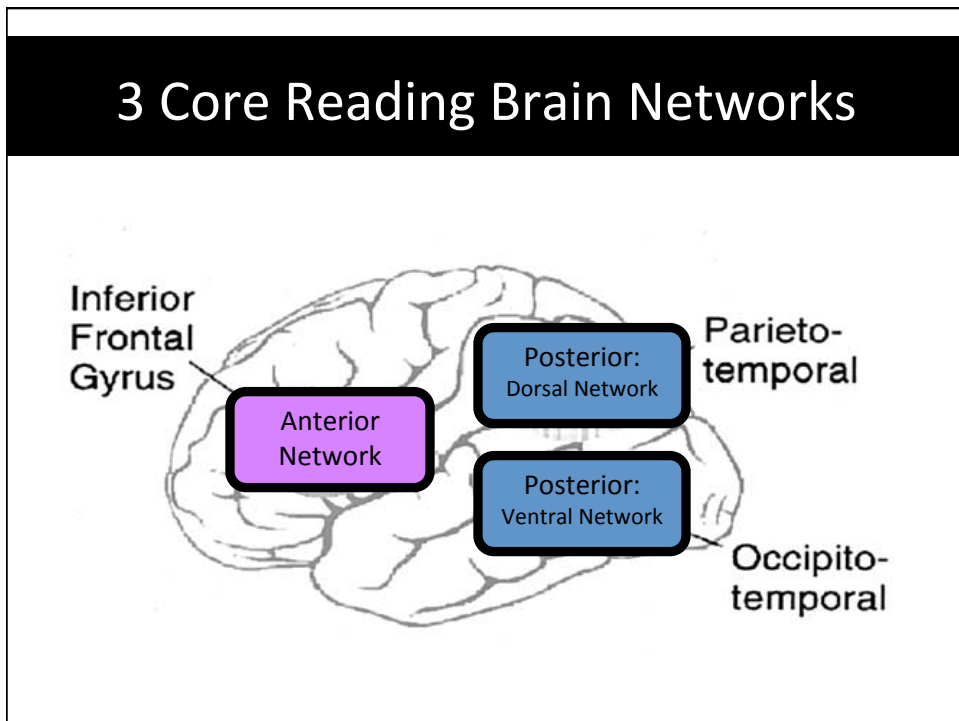
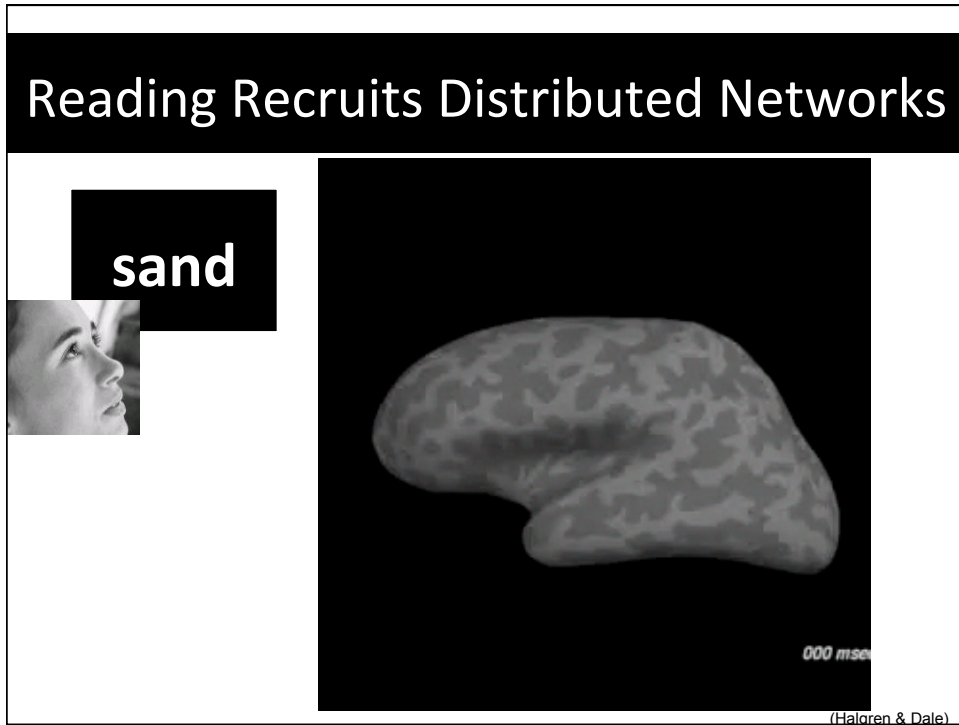


1. Brain activations
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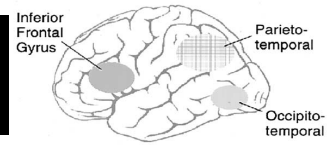
Potential Contributions of Neuroscience





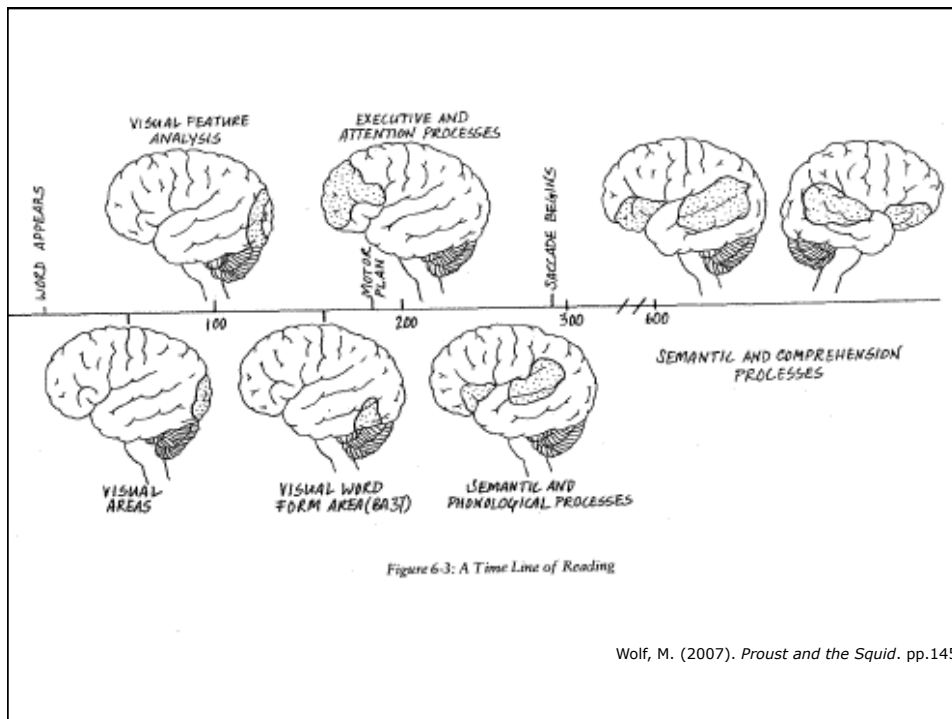


Reading Brain Networks



- **Anterior**
 - Motor production
 - Processing of low-frequency exception words and nonwords
- **Posterior – Dorsal**
 - Efficient word reading & phonological processing
- **Posterior – Ventral**
 - *Automatic* recognition of printed words

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



Wolf, M. (2007). *Proust and the Squid*. pp.145

Characteristics of Developmental Dyslexia

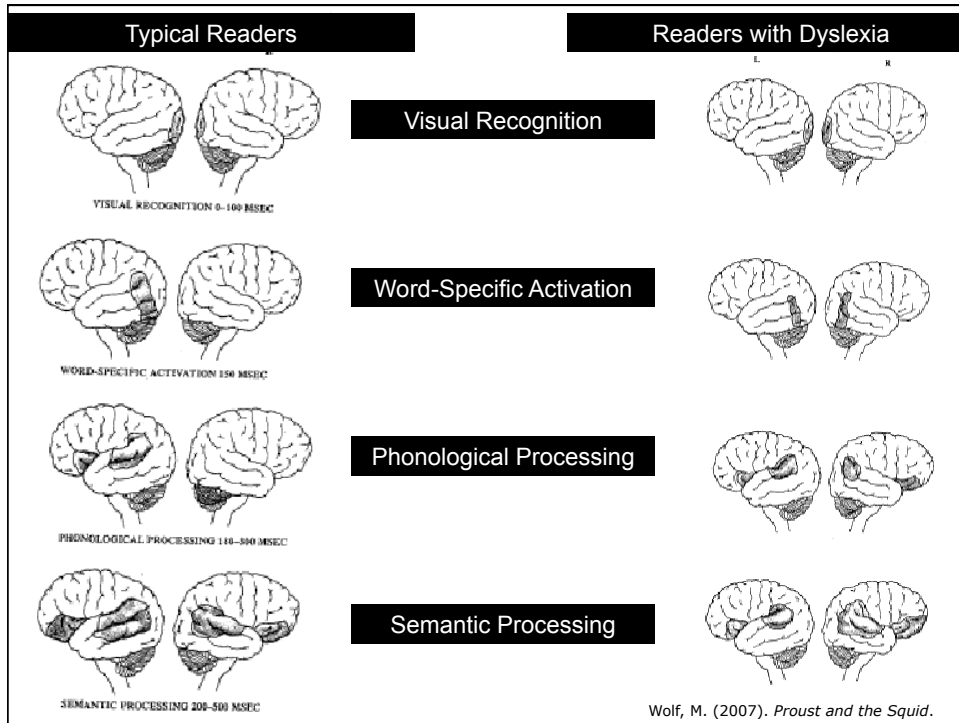
- **Anterior *hyper*activation**
 - (Shaywitz et al., 2002)
- **Posterior *hypo*activations**
- **Right > left hemisphere**
 - (Brunswick, 1999; Paulesu et al. 2001; Rumsey et al., 1992, 1997; Shaywitz et al., 1998, 2002; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000; Simos, Papanicolaou, et al., 2000)

The diagram illustrates the brain's neural networks and activation patterns. A purple box labeled 'Anterior Network' is located in the anterior region. Two blue boxes labeled 'Posterior: Dorsal Network' and 'Posterior: Ventral Network' are located in the posterior region. A blue arrow on the left points upwards towards the 'Inferior Frontal Gyrus'. A blue arrow on the right points downwards towards the 'Occipito-temporal' region. The 'Parieto-temporal' region is also labeled.

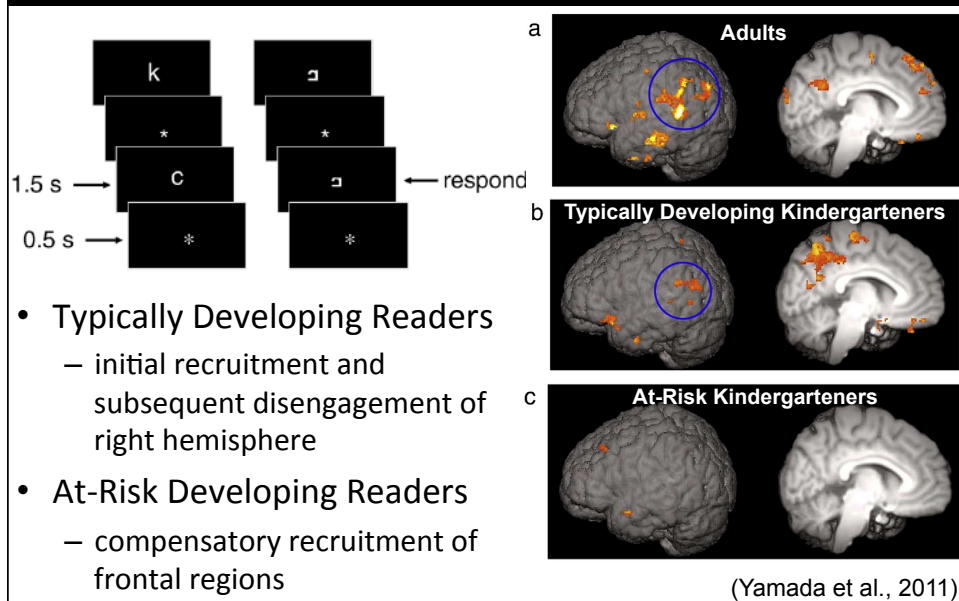
Compensatory Systems in Dyslexia

- Left and right hemisphere anterior regions
- Right hemisphere posterior regions
- Activations in right hemisphere negatively correlated with reading skills
- **Accurate, but not automatic, word reading**

(Shaywitz et al., 2002)

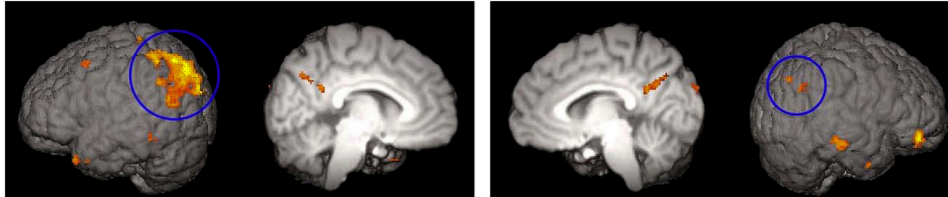


Differences in Emerging Reading Systems

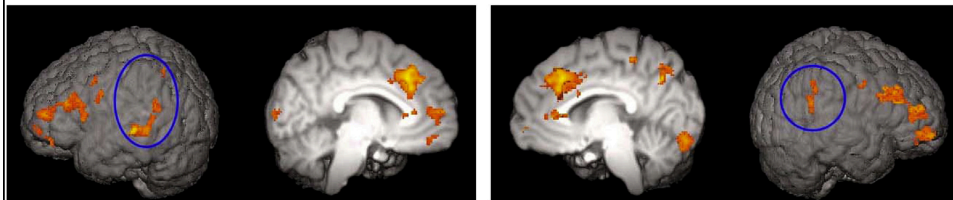


Differences in Emerging Reading Systems

Typically Developing Kindergarten Readers after 3 months

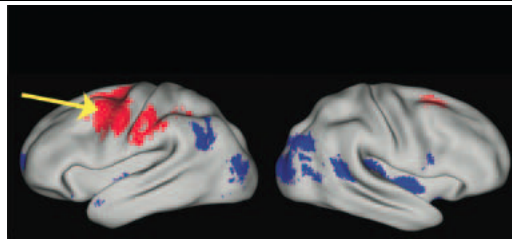


At-Risk Kindergarten Readers after 3 months



(Yamada et al., 2011)

Developmental Differences



Red: areas that increase with age
Blue: areas that decrease with age
(Schlaggar & Church, 2009)

Increase in frontal activations

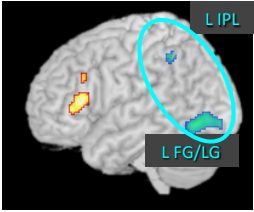
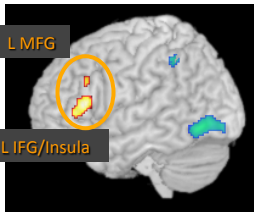
- Greater access to metalinguistic abilities

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

(Church et al., 2008; Schlaggar & Church, 2009)

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

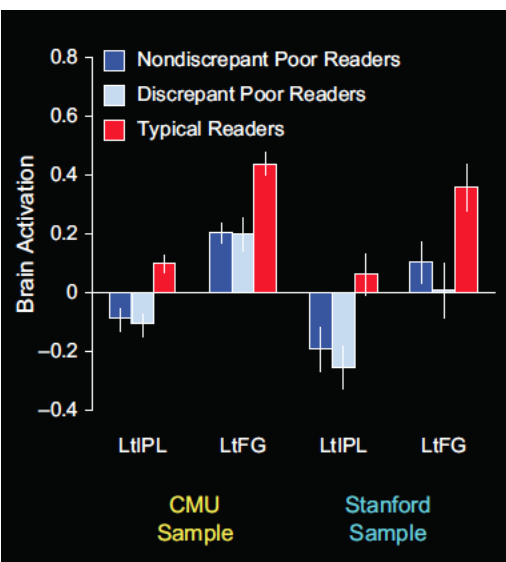



(Hoeft et al. 2007)

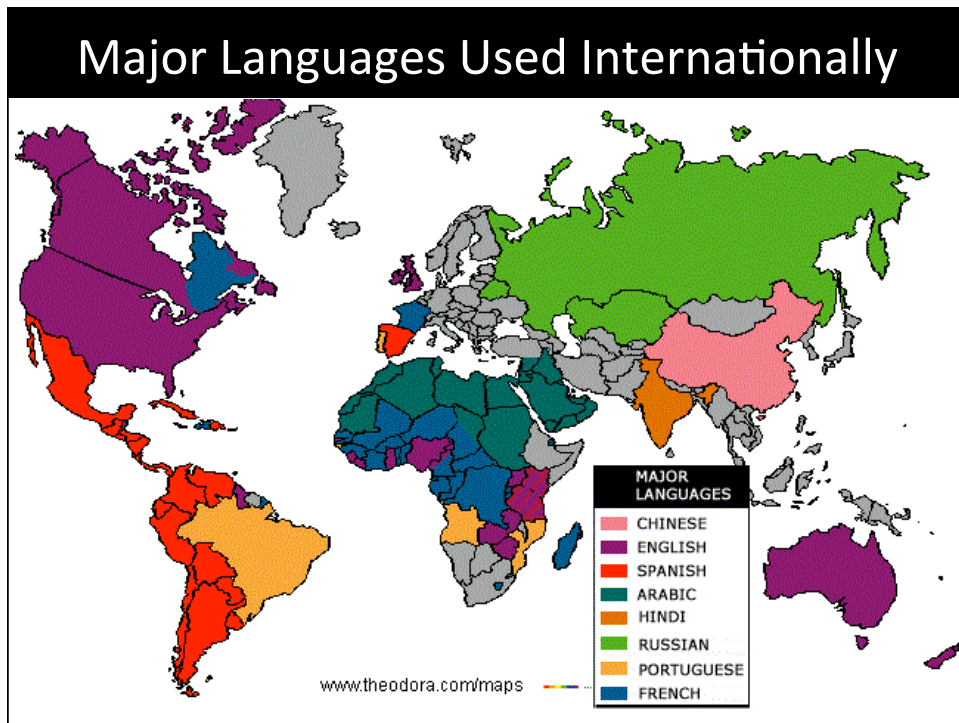
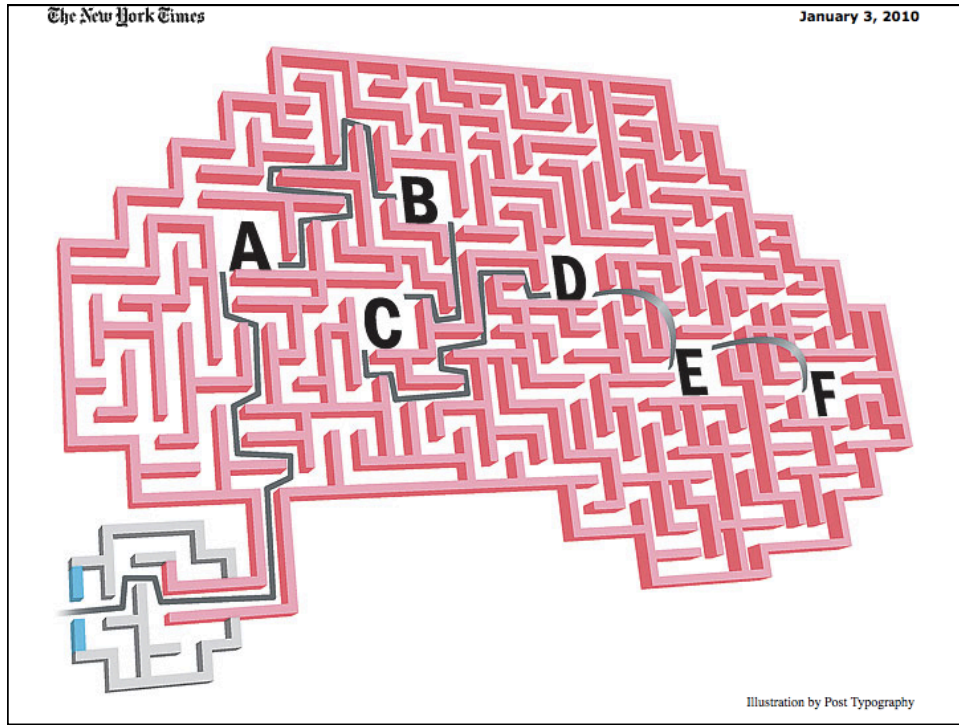
Dyslexia and IQ

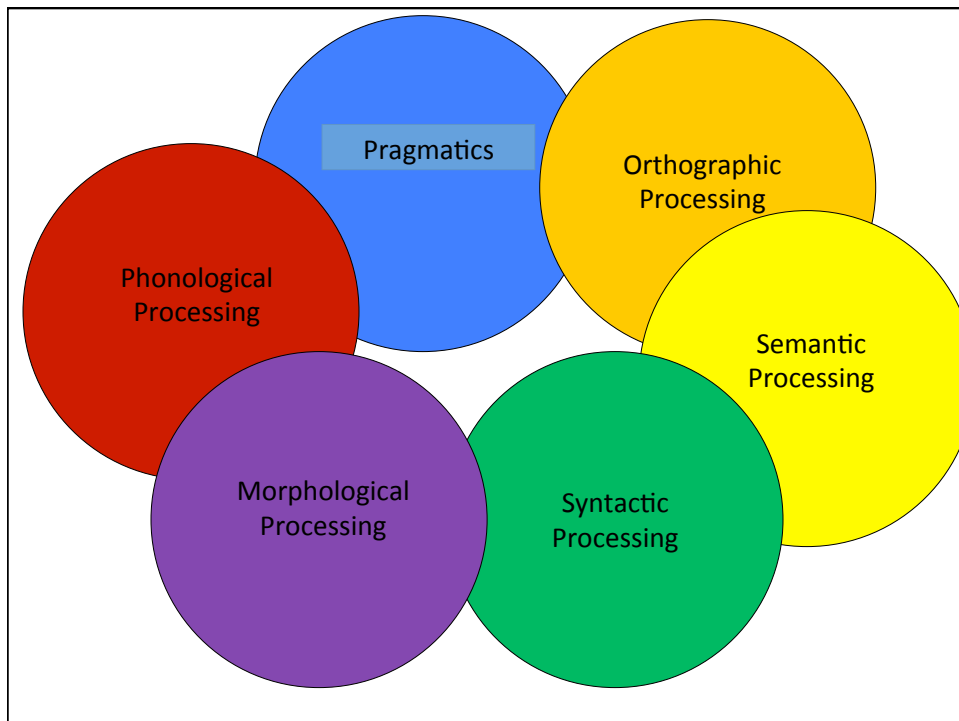
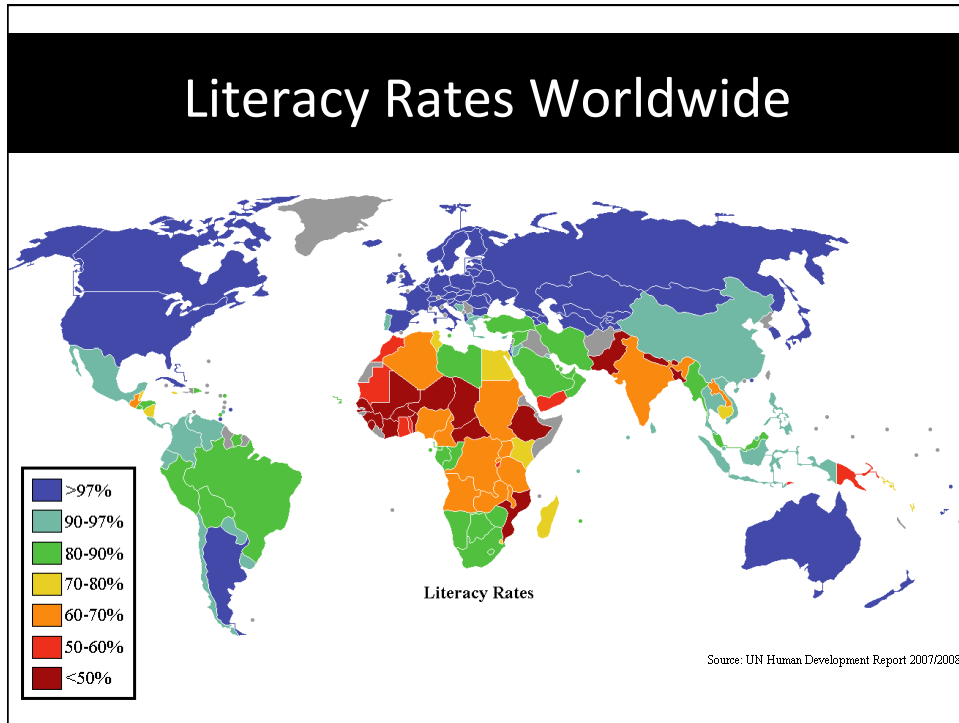
Regardless of IQ, poor readers have similar kinds of reading difficulties in relation to phonological processing

(Tanaka et al., 2011)

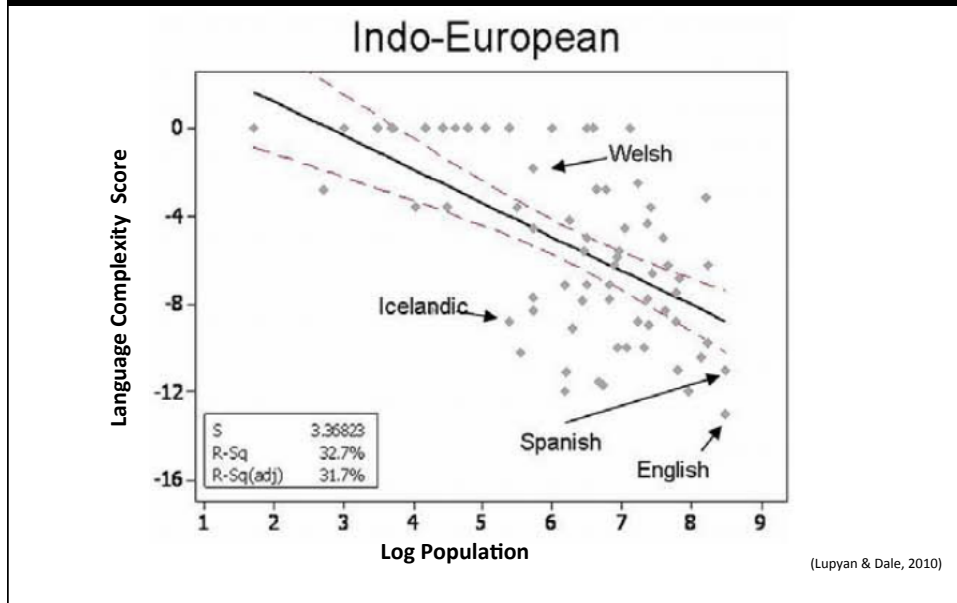


Region	Sample	Nondiscrepant Poor Readers	Discrepant Poor Readers	Typical Readers
LtiPL	CMU	-0.1	-0.1	0.1
	Stanford	-0.1	-0.1	0.1
LtFG	CMU	0.2	0.2	0.45
	Stanford	0.2	0.2	0.45
LIPL	CMU	-0.2	-0.2	0.05
	Stanford	-0.2	-0.2	0.05
LtFG	CMU	0.1	0.1	0.35
	Stanford	0.1	0.1	0.35



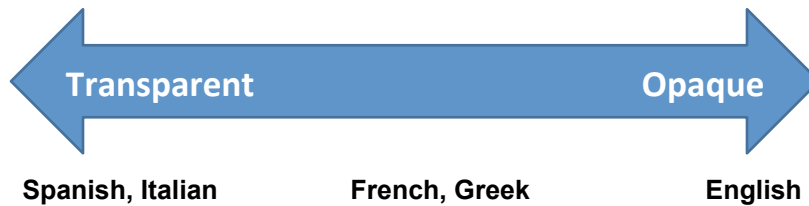


Less language complexity is associated with more language users

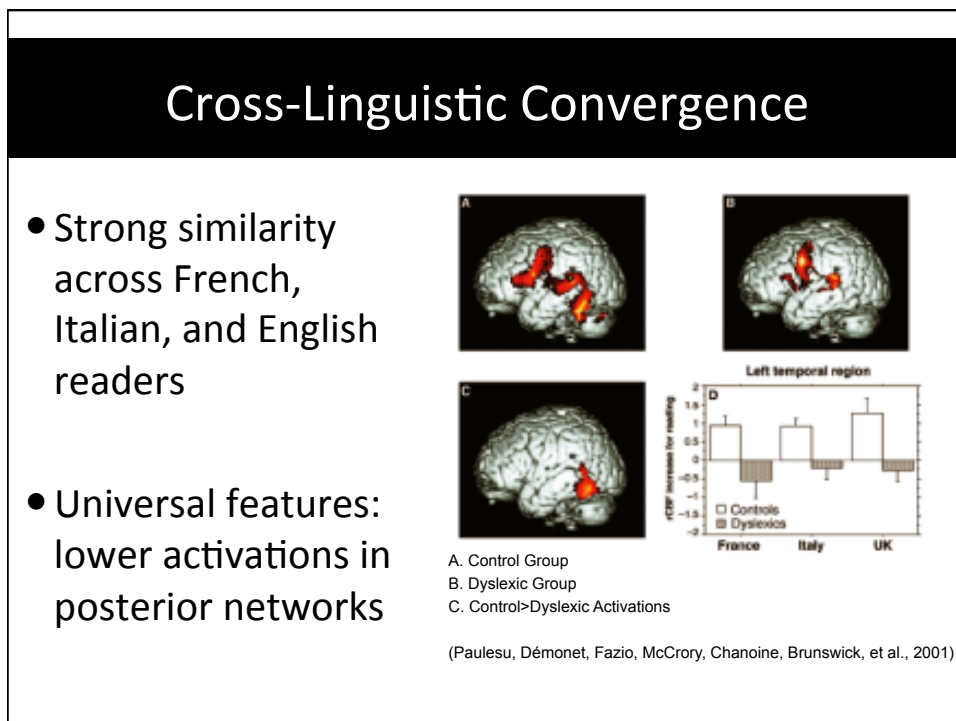
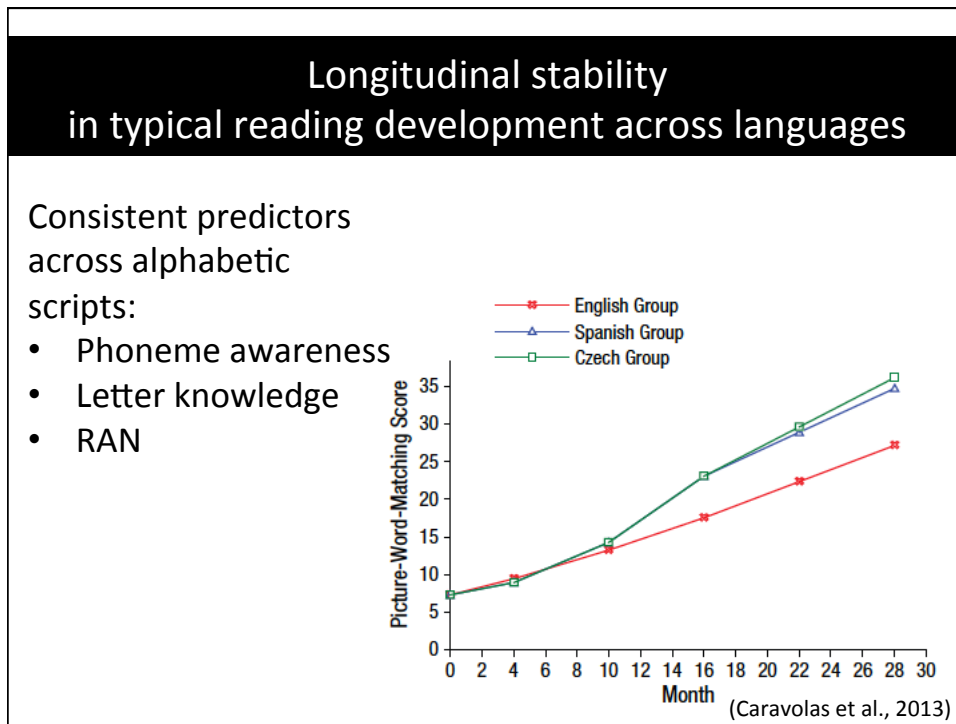


Orthographic Transparency

Spectrum of orthographic structures in alphabetic scripts

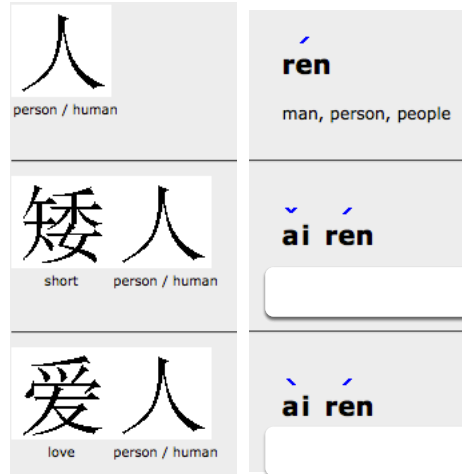


Language structure matters for reading demands



Chinese Characters

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



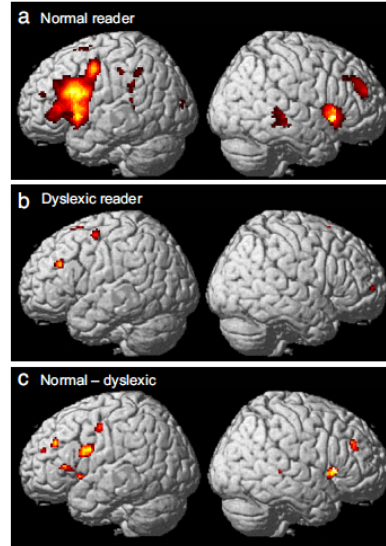
Language Specific Features: Chinese & Dyslexia

- 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

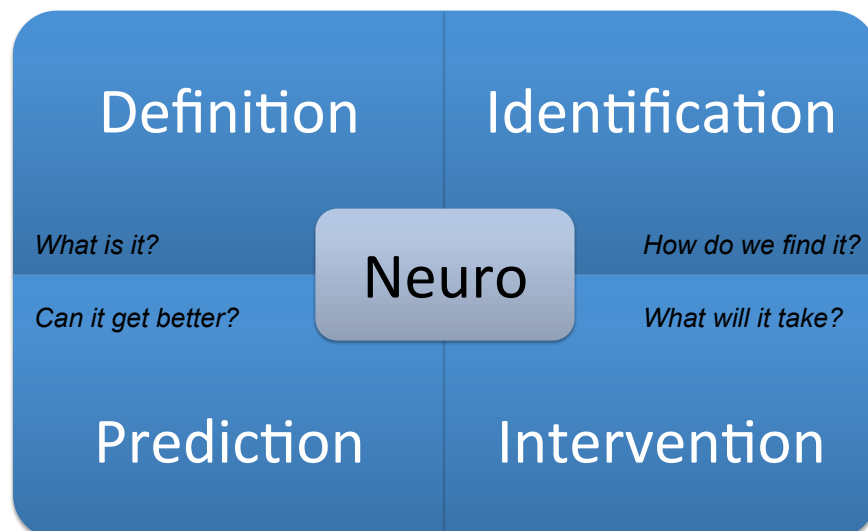
(Siok et al., 2004)

Language Specific Features: Chinese & Dyslexia

- Orthography-to-phonology mapping task
 - Judge whether 2 synchronously exposed Chinese characters had an identical pronunciation vs form
- Frontal regions serve as a unique neuroanatomical marker of Chinese reading difficulty

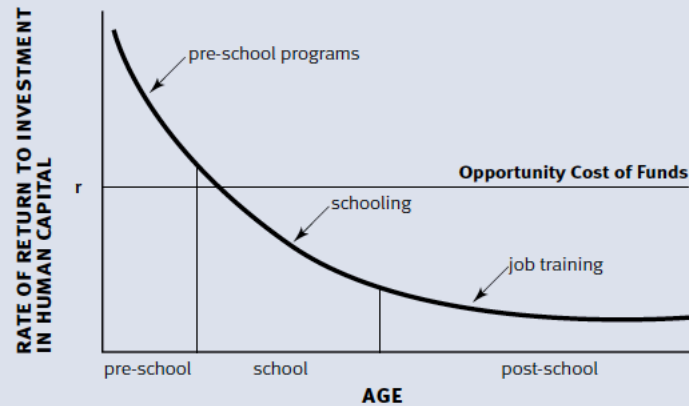


Potential Contributions of Neuroscience



Earliest remediation yields greatest impact

Return on Investment Over Time



Rates of return to investment in human capital as function of age when the investment was initiated. The data were derived from a life cycle model of dynamic human capital accumulation with multiple periods and credit constraints. Investments were initially set to be equal across all ages. 'r' represents the cost of the funds. Data are from Cunha et al (2005).
Source: Knudsen, et al.⁹

Cunha et al., 2005; James Heckman

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

- Next steps
 - Compensation vs remediation
 - Differentiate by intervention type
 - Determine dosage needed per case

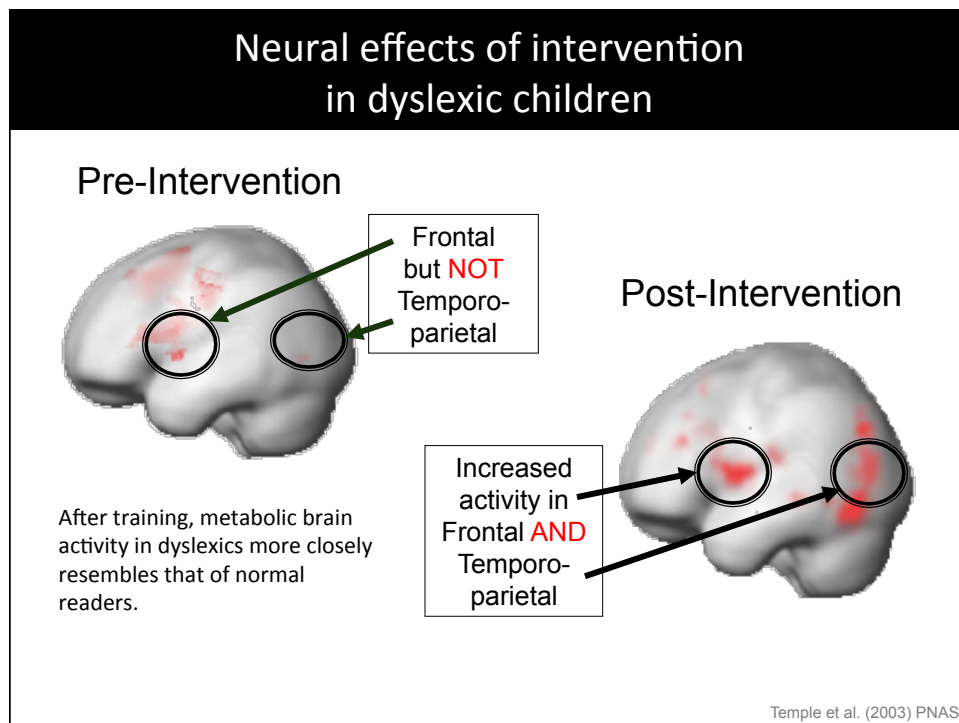
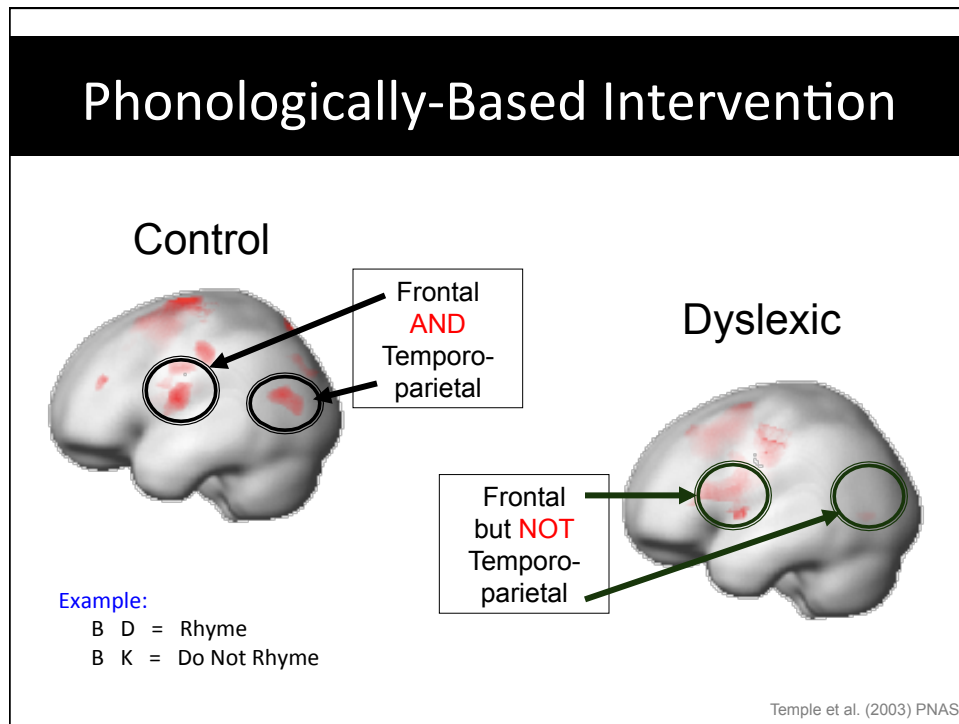
Intervention Meta-Analysis

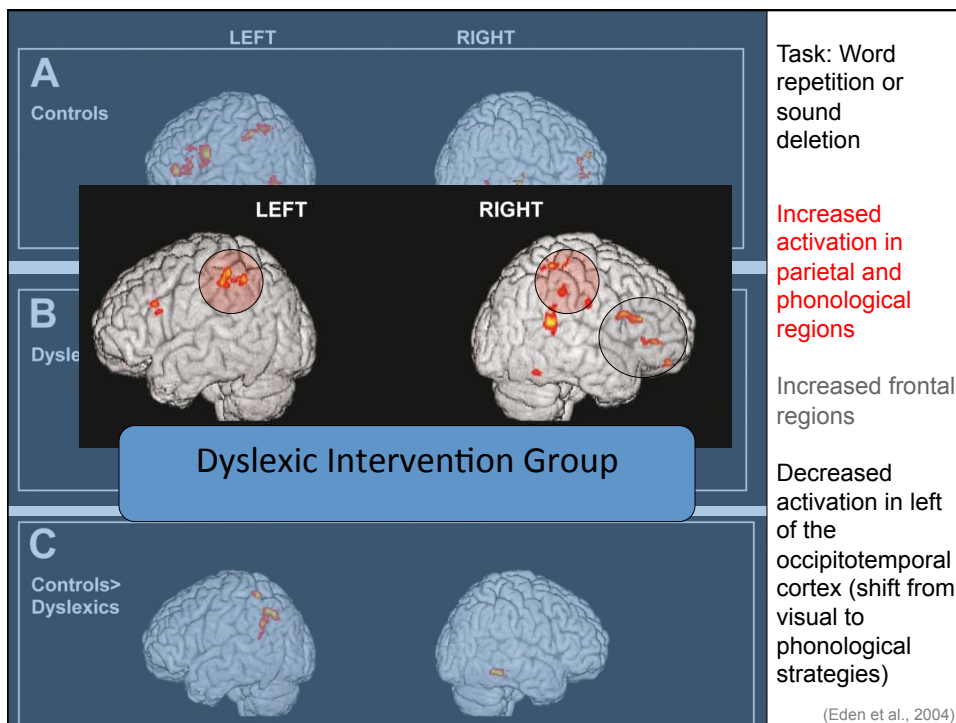
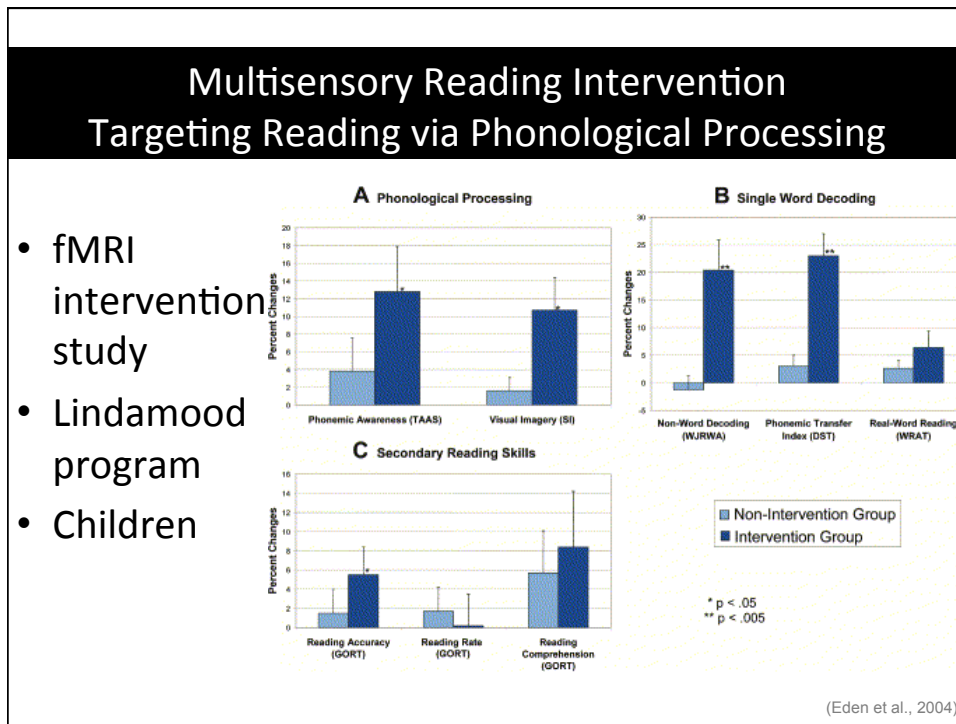
Table 3. Contrasts Used in fMRI Analyses of Studies Included in ALE.

Study	<i>n</i>	# foci	Group or Session Contrast	Task Contrast
Temple, 2003	32	14	Post > Pre for RD > CT (masked out CT clusters)	Rhyme Letters > Match Letters
Eden, 2004	38	14	Post > Pre for Intervention > No Intervention	Sound Deletion > Word Repetition
Shaywitz, 2004	25	6	Follow-up > Pre in RD	Letter/Sound Match > Tone/Symbol
Richards, 2006	8	5	Post > Pre in Orthographic group	Real Words > Letter Strings
Odegard, 2008	18	1	Post, Responder > Nonresponder & Control	Phoneme/Grapheme > Tone/Symbol
Meyler, 2008	35	3	Post, RD > CT	Sentences > Baseline Fixation
Yamada, 2011	7	40	Post > Pre in RD	Letter > False Font
Gebauer, 2012	10	7	Post > Pre in Training Group	Pseudoword > Baseline Fixation
Total	173	90		

doi:10.1371/journal.pone.0083668.t003

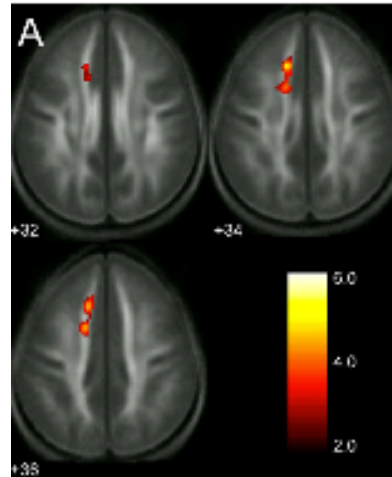
(Barquero, Davis, Cutting, 2014)





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)

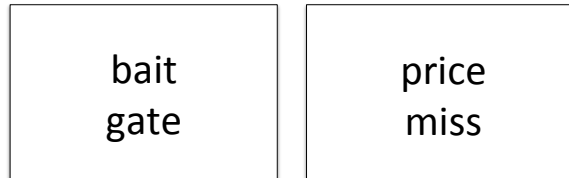


Can neuroprediction be informative?

- Life-Style
 - Predict positive affect with reactivity to reward and recent life stress (Nikolova et al., 2012)
 - Predict weight loss program outcomes with fMRI reactivity to food images (Murdaugh et al., 2012)
- Aging
 - Predict cognitive functioning in older adults based on white matter structure (Meier et al. 2012)
- Treatments
 - Predict treatment response for depression and anxiety (Hernández-Ribas, 2012; Doehrmann et al., 2013)
 - Predict outcomes following head trauma (Bernick et al, 2012)

Predicting Reading Outcomes with Neuroimaging

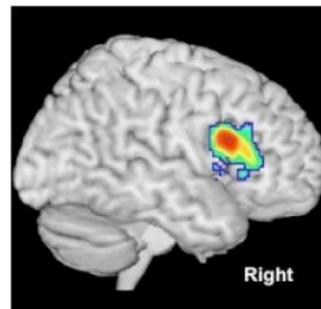
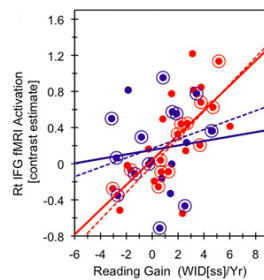
- 25 children with dyslexia
- 20 typical readers
- Predict reading over time: age 14 → 16.5
- fMRI Rhyme task



(Hoeft et al., 2010, PNAS)

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



(Hoeft et al., 2010, PNAS)

Summer Time Adventures in Reading & Teaching (START Study)

- Major Goal
 - Can we use neuroimaging tools to improve our ability to **predict which children will benefit from which intervention?**
- Current Approach
 - Choose 1 program
 - Evaluate brain-behavior links for individuals



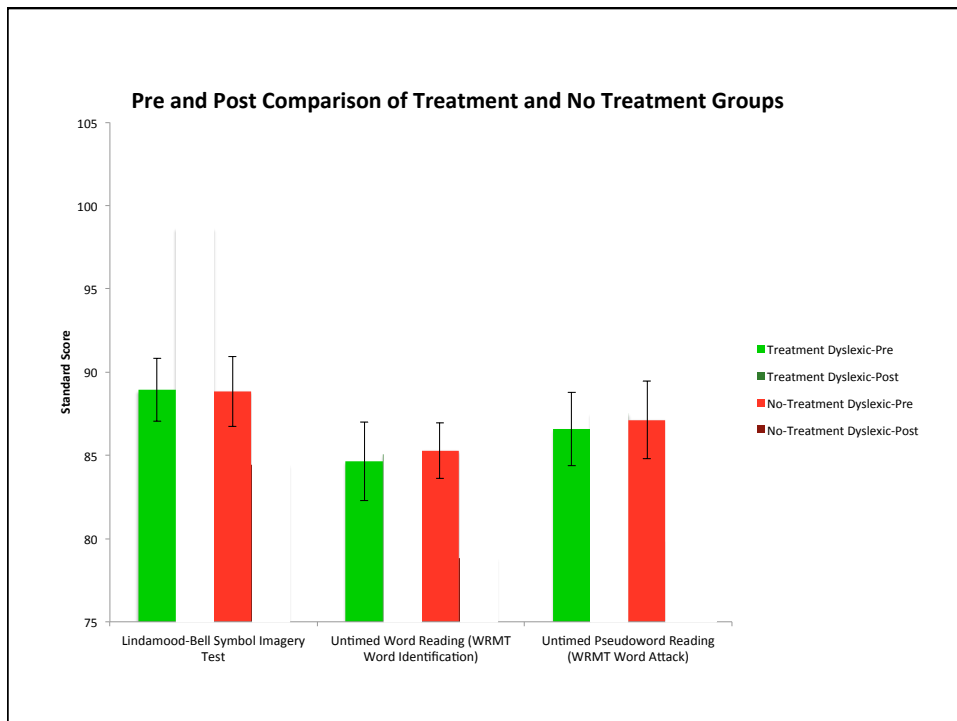
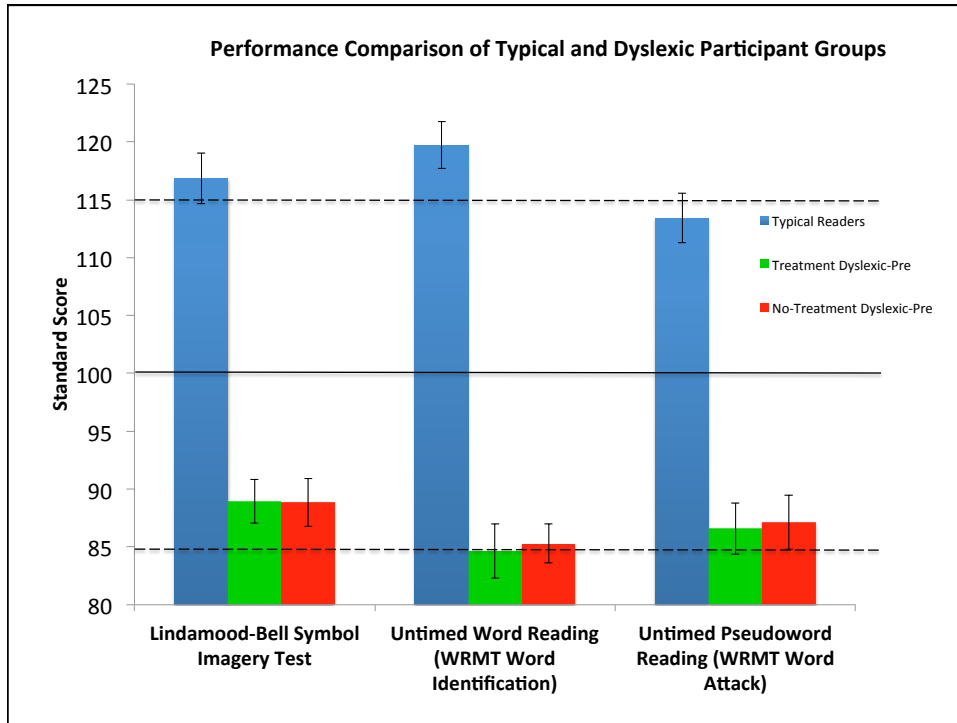
(Christodoulou et al., 2016)

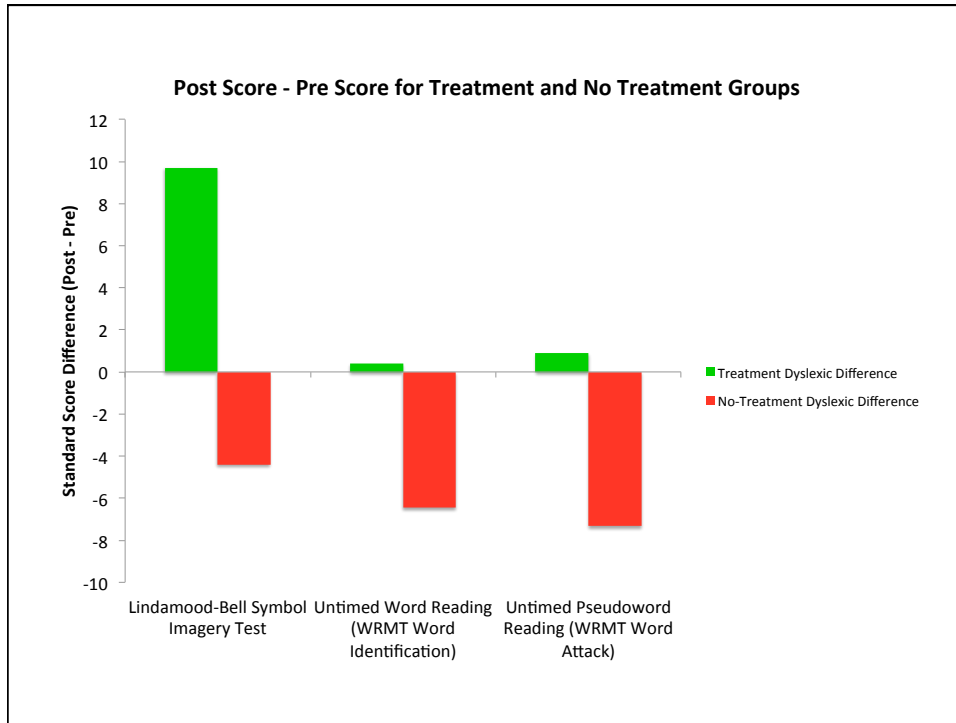
Summer Time Adventures in Reading & Teaching (START Study)

- 71 Students, ages 6-9
- 4 hours of instruction/ 5 days/ 6 weeks
 - Minimum of 100 hours
 - Academic summer months
 - Groups of 3-5 children
- Lindamood-Bell Curriculum: Seeing Stars Symbol Imagery for Phonemic Awareness, Sight Words and Spelling Program



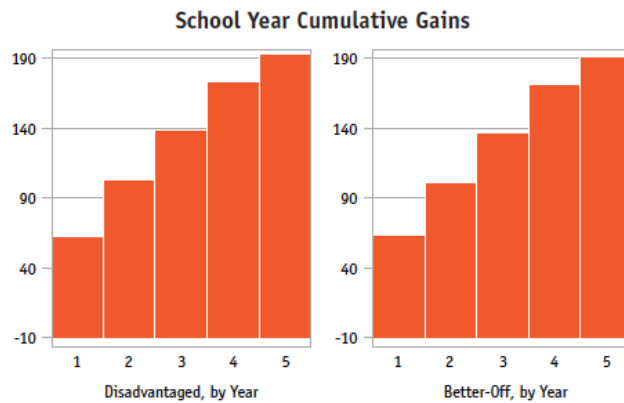
(Christodoulou et al., 2016)





Evaluating Intervention: Summer

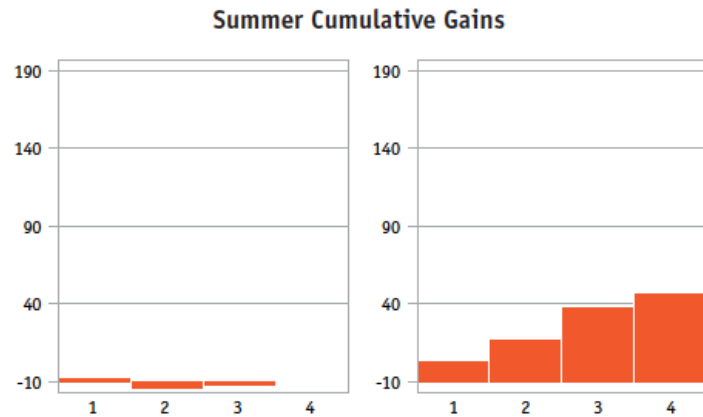
- Comparable gains during the school year for students of diverse SES backgrounds



Alexander, Entwisle, & Olson, 2007

Evaluating Intervention: Summer

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



Alexander, Entwisle, & Olson, 2007

Effects of Reading Intervention

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





- ## 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