

## Reading Development in Atypical Readers: Neuroscience, Intervention, & Compensation Perspectives

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## Research Context

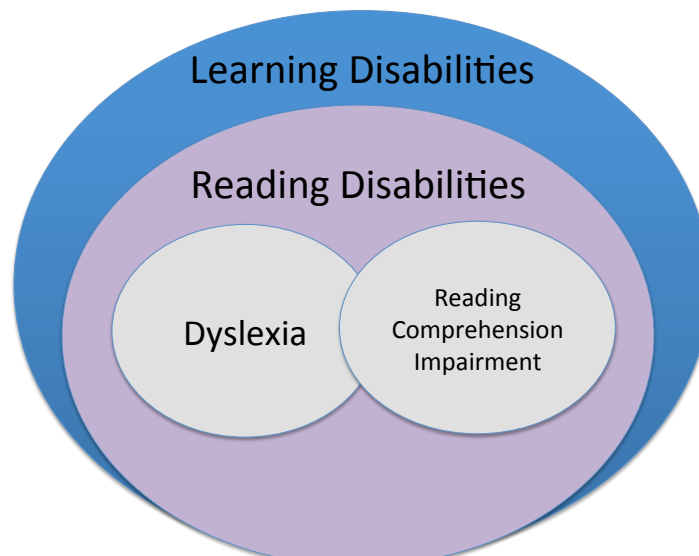


- **Reading disabilities** are the most commonly identified learning challenge in school-age populations
- Remediation efforts are a significant focus for **educators and clinicians**
- **Effective interventions** can help a struggling reader, whose efforts are consumed by attempts to *access* the text, to use written language as a tool for *understanding* the content
- Impact of **early** intervention is well established

## Reading Disability (RD)

- DSM-V criteria for specific learning disorder (SLD) in reading:
  - Word reading accuracy
  - Reading rate or fluency
  - Reading comprehension
- Reading ability serves as the “chief foundational academic skill underlying all school-based learning” (Lyon, 1998)
  - Impacts kids across all academic content areas and throughout school & beyond

## Contextualizing Reading Difficulties



## IDEA definition

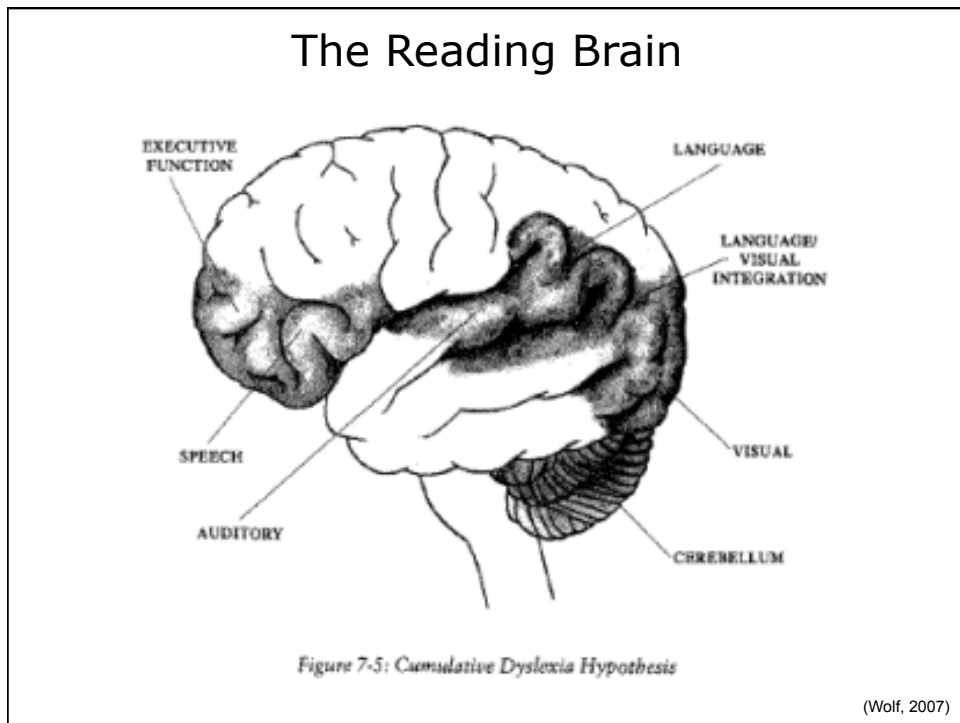
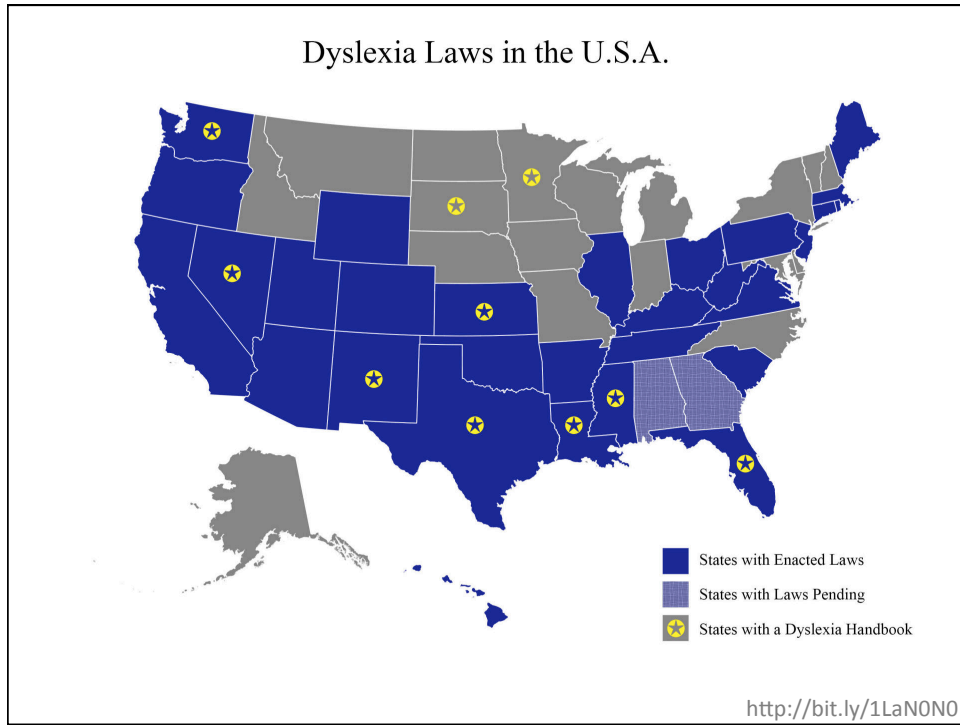
Specific learning disability: Definition

*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.*

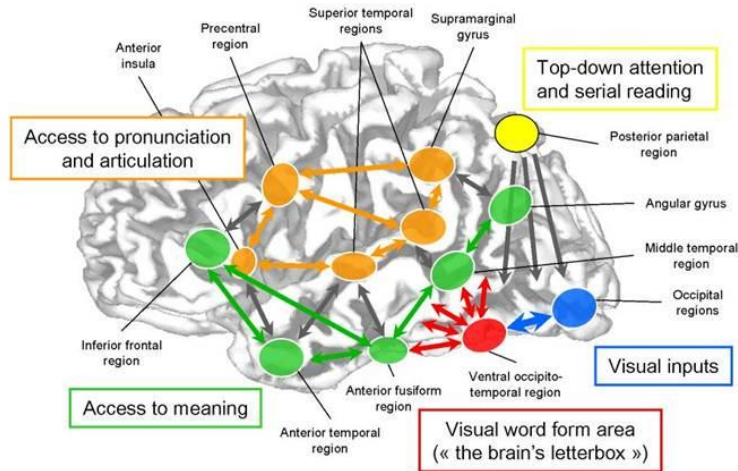
(20 U.S.C. § 1401 (30))

## 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

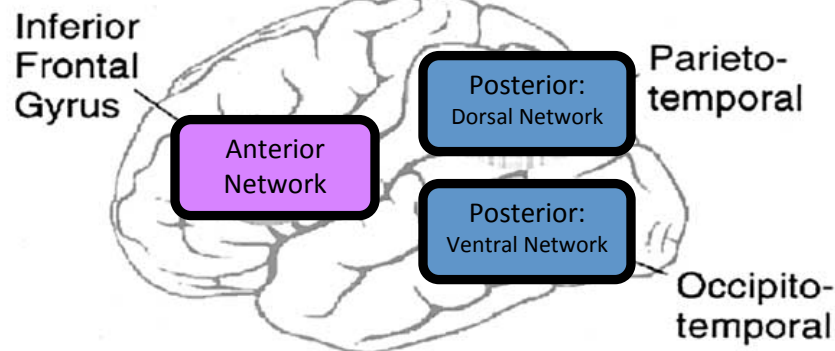


## Cortical Networks for Reading

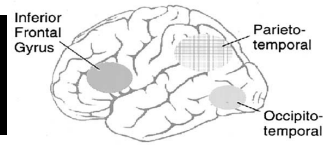


(Dehaene, 2009)

## Core Reading Brain Networks



## Reading Brain Networks



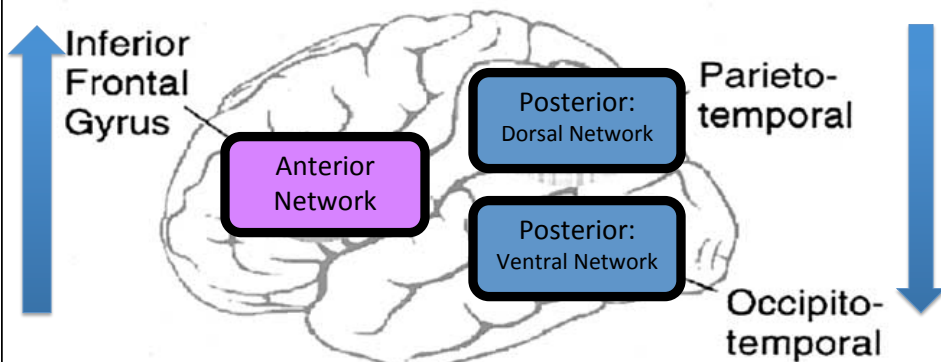
- **Anterior**
  - Motor production
  - Processing of low-frequency exception words and nonwords
- **Posterior – Dorsal**
  - Efficient word reading & phonological processing
- **Posterior – Ventral**
  - *Automatic* recognition of printed words

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

## Characteristics of Developmental Dyslexia

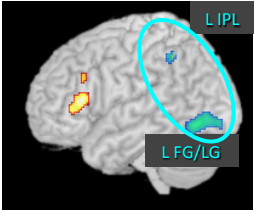
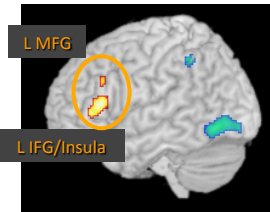
- **Anterior *hyper*activation**
- **Posterior *hypo*activations**
- Recruitment of **right hemisphere** homologous regions

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



## 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)

## Dyslexia and IQ

Similar recruitment patterns for reading:

- Garden-variety poor readers
- IQ-reading discrepant readers
- *Unexplored: High IQ-average reading*

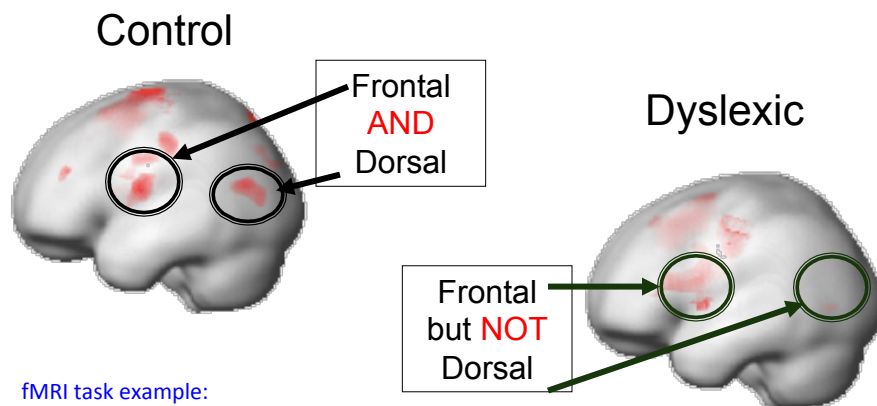
(Tanaka et al., 2011)

Sample	Region	Nondiscrepant Poor Readers	Discrepant Poor Readers	Typical Readers
CMU Sample	LtIPL	-0.1	-0.1	0.1
	LtFG	0.2	0.2	0.45
Stanford Sample	LtIPL	-0.2	-0.3	0.05
	LtFG	0.1	0.1	0.35

## Intervention: Brain & Behavior Changes

- In general, the best instruction for children with dyslexia is:
  - Multisensory
  - Explicit
  - Structured and sequential
  - Provides extensive opportunities for review and practice
- 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



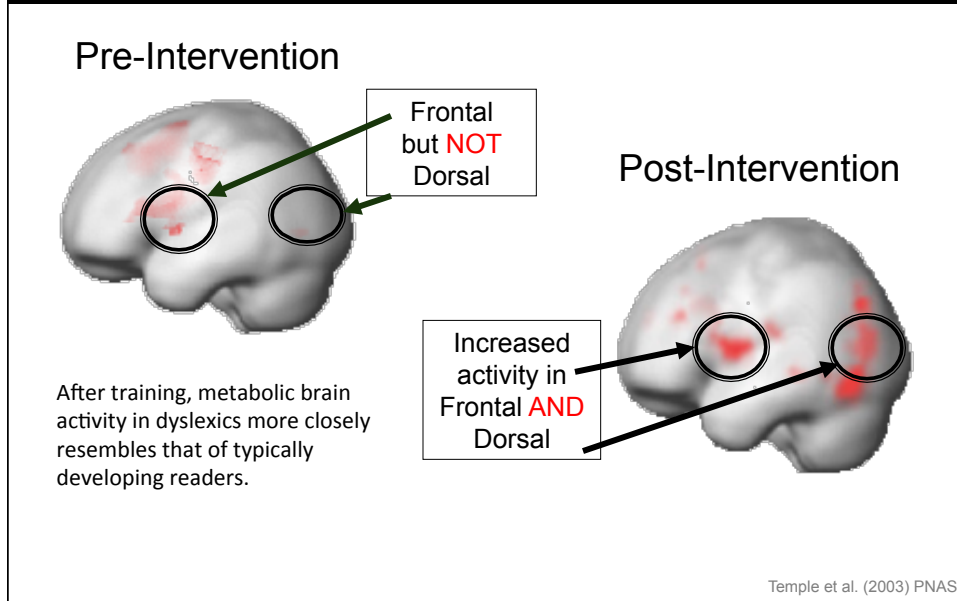
fMRI task example:

B D = Rhyme

B K = Do Not Rhyme

Temple et al. (2003) PNAS

## Neural effects of intervention in children with dyslexia



## 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

**Summer**

**SETBACK SLUMP SLIDE REGRESSION**

## Why do we have summer vacation?

- Common misconception:
  - Summer vacation originally was required so that children could support farming responsibilities in agricultural society.

## Why do we have summer vacation?

- Clarification (Gold, 2002):
  - Schooling held during the summer months was relatively common in the early to mid 1800s.
  - Summer vacation was implemented to make rural and urban school schedules consistent

Rural/Farming  
communities in school:  
5-6 months

Urban  
communities in school:  
11-12 months

## What is summer slump?

- Comparing growth on repeated assessments during two time periods, fall to spring (i.e., the school year) and spring to fall (i.e., the summer)
- Comparing readers by ability level during the summer on reading growth

## 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

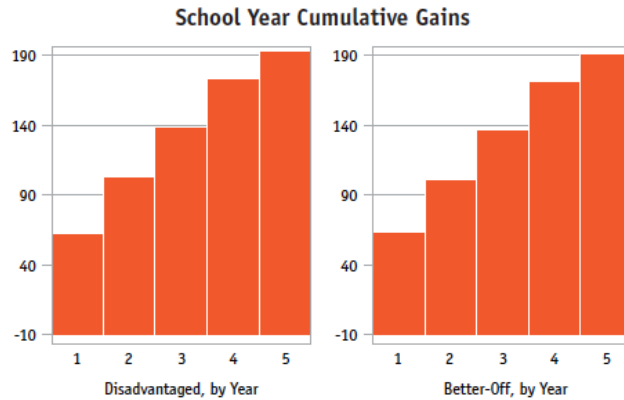
- **General student population**
  - Indirect investigations of the summer lag have shown higher gains from fall to spring (academic year) than during spring to spring (full year) time periods (Borman & D'Agostino, 1996)
- **Children receiving general special education services**
  - Lose ground and their typically developing peers continue to build reading skills, albeit at a slower rate than during the school year (Heyns, 1987; Mraz & Rasinski, 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, & Olson, 2007a; Alexander, Entwisle, & Olson, 2007b; 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 (Hayes & Grether, 1983)
  - Dropout rate & attendance of 4-year college differences (Alexander, Entwisle, & Olson, 2007)

## Summer Slump: Evidence

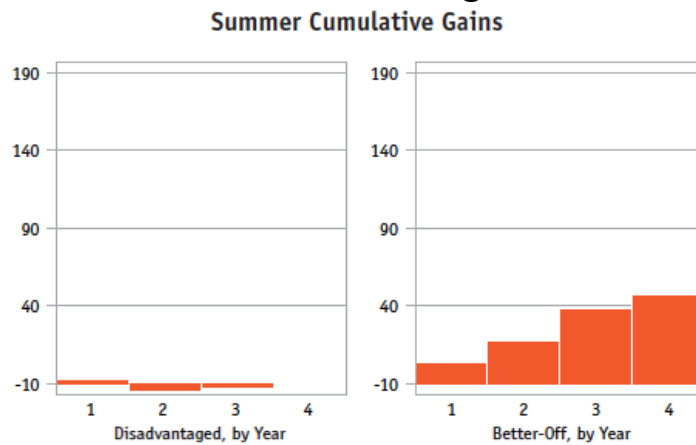
- Comparable gains **during the school year** for students of diverse SES backgrounds



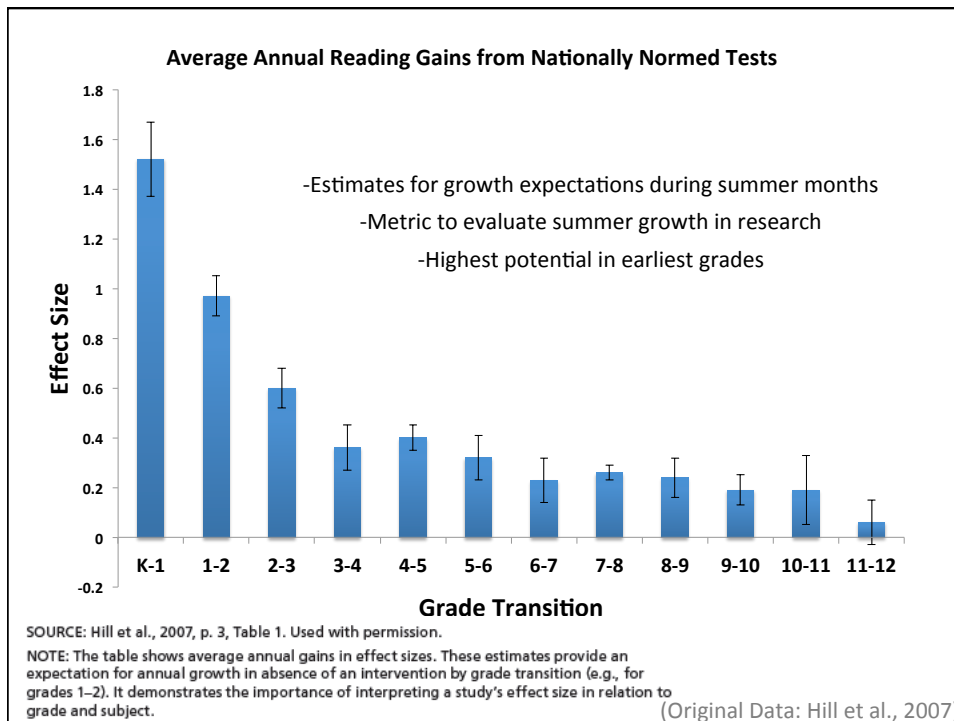
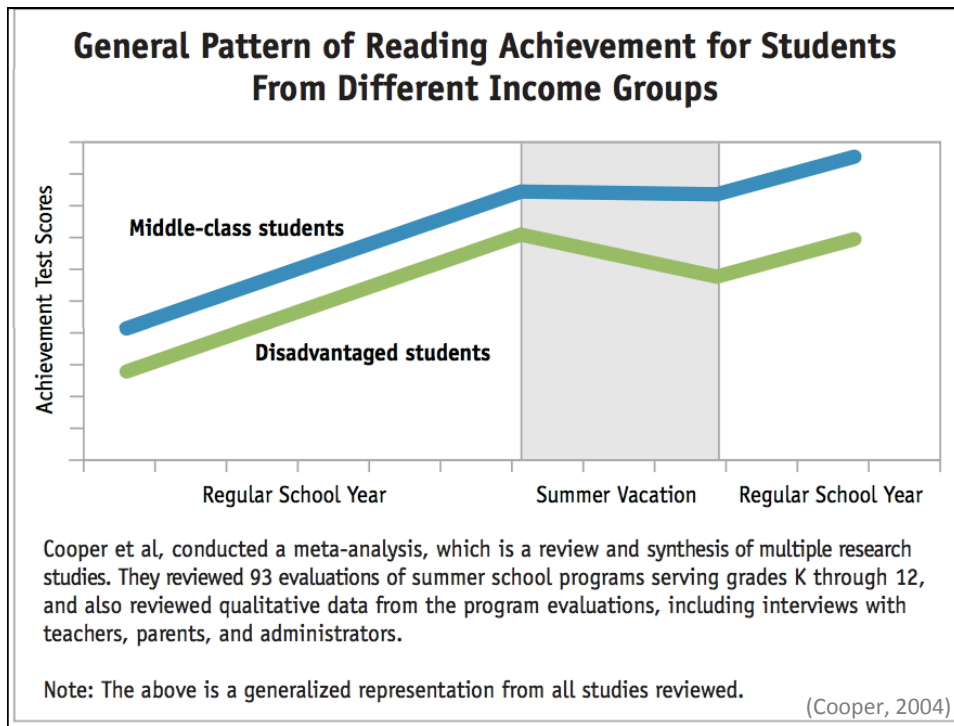
(Entwisle, Alexander, & Olson, 1997)

## Summer Slump: Evidence

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



(Entwisle, Alexander, & Olson, 1997)

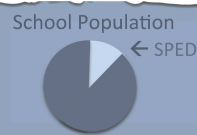


## Summer Slump: Evidence for Reading

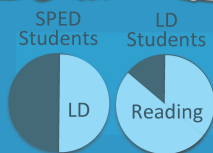
Students who are struggling readers



## How widespread is dyslexia?



About **13-14%** of the school population nationwide are identified as having a handicapping condition that qualifies for Special Education (SPED) services.



One **half** of all students who are identified for special education are classified as having a learning disability (LD). About **85%** of those students have a primary learning disability in reading and language processing.



Up to **15-20%** of the population as a whole may have symptoms of dyslexia, including slow or inaccurate reading, weak spelling, and poor writing. Not all will qualify for Special Education, but most benefit from systematic, explicit instruction in reading, writing, and language (AKA, [Structured Literacy Instruction](#)).



Find solutions at the International Dyslexia Association (IDA) • [ida.org](http://ida.org)  
Source: IDA Fact Sheet, "[Dyslexia Basics](#)" • Moats & Dakin (© 2016 Cowen For IDA)

## New Research: Summer Reading & Struggling Readers

- What is the impact of intervention for young struggling readers during the summer?



Collaborators: John Gabrieli; Jack Murtagh; Kelly Halverson;  
Abigail Cyr; Pamela Hook; Patricia Chang

## 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



(Christodoulou et al., 2016)

## 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



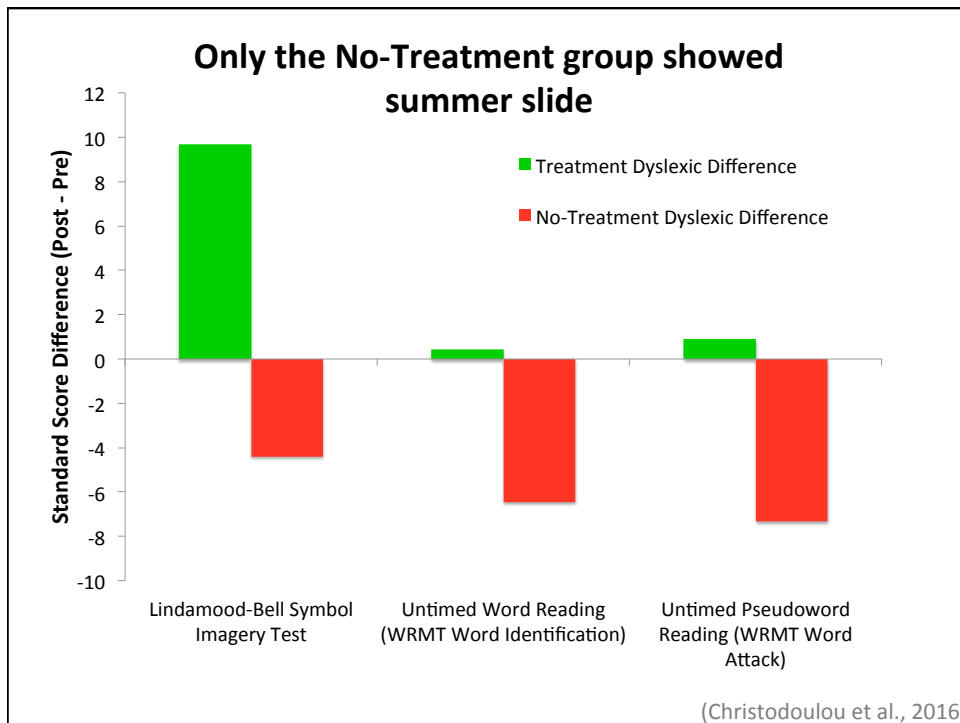
(Christodoulou et al., 2016)

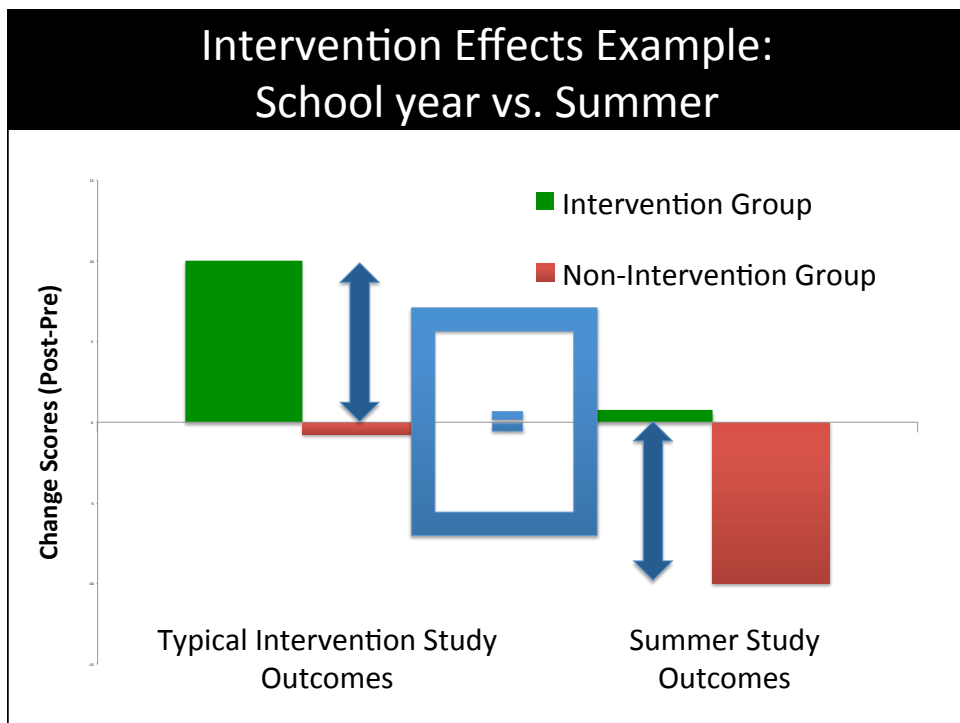
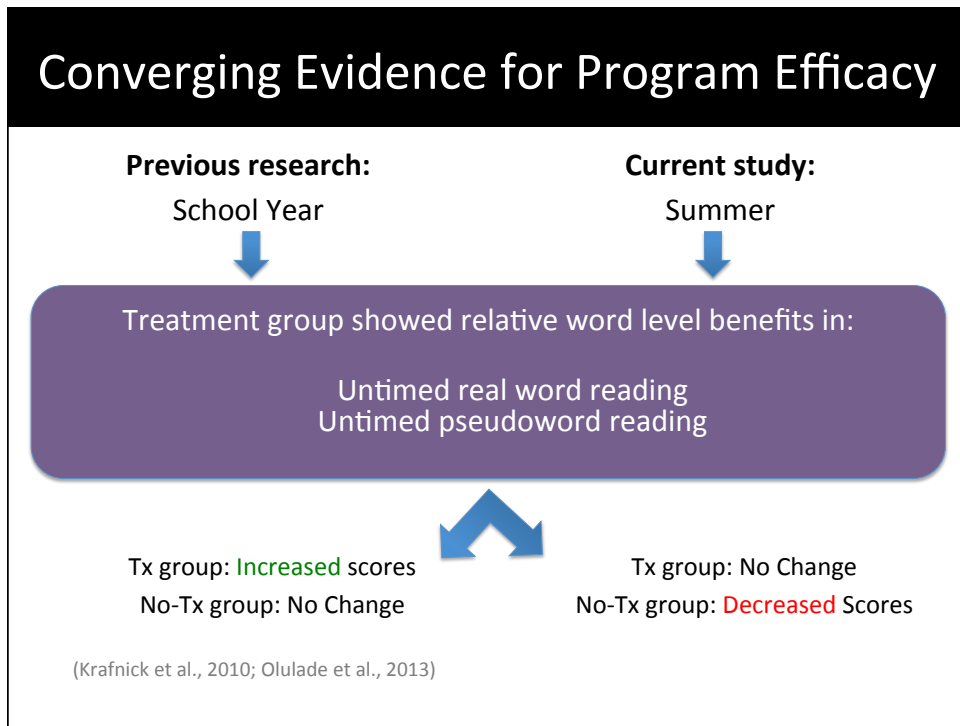
## Seeing Stars: Symbol Imagery for Fluency, Orthography, Sight Words, and Spelling

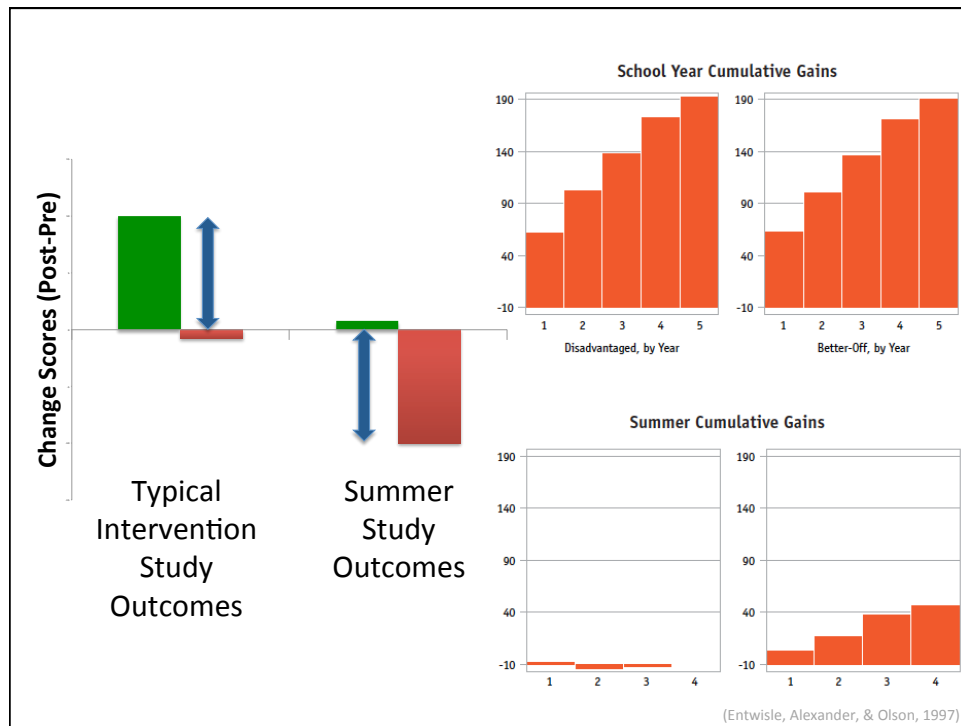
- Orthographic and visual processing training, and consequently phonological training
- Visualize:
  - Letters
  - Syllables
  - Words
  - Connected text  
(Semantic information)
- *Just as the stars are parts of the sky, letters are parts of words*

	Treatment - Struggling (n=24)	No-Treatment Struggling (n=25)	
Age in years (SD)	7.73 (.59)	7.74 (.69)	matched
Gender	15 M, 9 F	17 M, 8 F	balanced
Non-Verbal Cognitive Abilities (SD)	105.5 (12.10)	103.9 (14.50)	matched

**Matched: Socioeconomic Status** (Christodoulou et al., 2016)







## 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., 2016)

## Effects of Reading Intervention

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



## New Research: Summer Reading & SES

- How does socioeconomic status relate to literacy skills & response to summer reading intervention?



Collaborators: Rachel Romeo (supported by NIH 5T32DC000038); John Gabrieli; Kelly Halverson; Abigail Cyr; Jack Murtagh; Patricia Chang; Pamela Hook

## 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)

(Romeo, Christodoulou, et al., in prep.)

## SES & Reading Disability

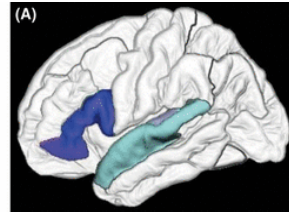
- Low-income students have a disproportionately higher rate of RD diagnosis (Shifrer *et al.*, 2010; Fluss *et al.*, 2009)
- Studies of SES & cognition are typically conducted on “typically developing” children with scores in the average range.
- Studies of RD are typically conducted on mid-to-high-SES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

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

(Romeo, Christodoulou, et al., in prep.)

## Socioeconomic Status & Language

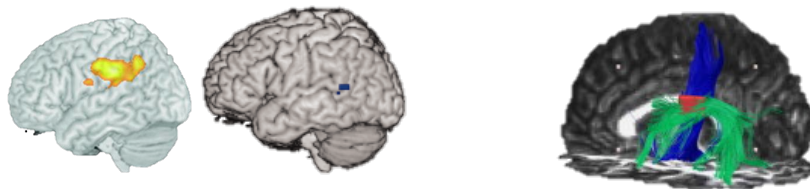
- Strong predictor of brain structure, with a disproportionate effect on the canonical “**language areas**”  
(Raizada *et al.*, 2008; Noble *et al.*, 2012)
  - SES differences in size increase with age
  - To date, these studies have largely been done in “**typically**” developing readers



(Noble *et al.*, 2012)

## Reading Disability

- Structural brain differences include:
  - Reduced grey matter in left temporo-parietal cortical regions (Hoeft *et al.*, 2007; Richlan *et al.*, 2012)
  - Reduced cerebral white matter in the “reading pathway” (left arcuate fasciculus) (Vandermosten *et al.*, 2012)



## Study Goals

1. How is SES related to language and literacy performance in children with RD?
2. Does the brain structure of students with RD vary by SES? If so, how?
3. Are there SES-related differences in children's response to reading intervention, at the level of behavior and/or brain?

## Participants

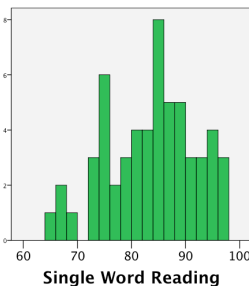
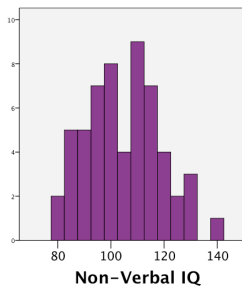
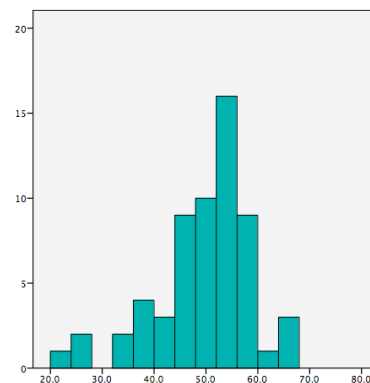
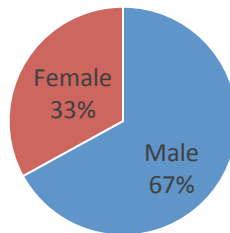
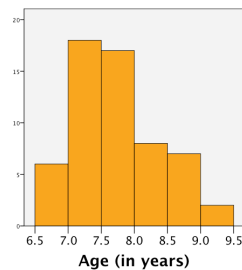
- 64 children with reading disability
- Completing grade 1 or 2
- Recruited from the community and from a high-quality inner-city charter school (=good reading instruction)
- Criteria for inclusion:
  - Nonverbal IQ standard score of >80  
and, either
  - <90 on at least 2 (of 4) single word reading subtests (TOWRE-2: SWE & PDE, WRMT-III: WI & WA)  
or
  - >15 point difference between Nonverbal IQ & Reading standard scores

## Measures

Nonverbal Cognition, Oral Language, Sub-reading skills,  
& Literacy skills (accuracy, fluency, comprehension)

Test & Subtest	Domain	Test & Subtest	Domain
KBIT2 - Matrices	Non-Verbal Cognitive Ability	WRMT3 - Word Identification	Word Accuracy
WISC4 - Coding	Processing Speed	WRMT3 - Word Attack	NonWord Accuracy
WISC4 - Symbol Search	Processing Speed	TOWRE2 - Sight Word Efficiency	Word Accuracy/Fluency
PPVT4	Receptive Vocabulary	TOWRE2 - Phonemic Decoding	NonWord Accuracy/Fluency
OWLS2 - Listening Comp.	Listening Comprehension	WRAML - Sentence Memory	Grammatical Processing
RAN - Objects	Rapid Naming (automaticity)	PIAT-R NU - Spelling	Spelling - receptive
RAN - Letters	Rapid Naming (automaticity)	TWS4	Spelling - expressive
RAN - 2 Set	Rapid Naming (automaticity)	WJ-III Ach - Reading Fluency	Text Reading Fluency
CTOPP - Elision	Phonological Awareness	WRMT3 - Passage Comp.	Text Comprehension
CTOPP - Blending Words	Phonological Awareness	SIT	Symbol Imagery
CTOPP - Nonword Repetition	Phonological Memory	JLRRT3	Left-Right symbol reversal
CTOPP - Memory for Digits	Phonological Memory	DOLCH words	common sight words

## Participant Summary

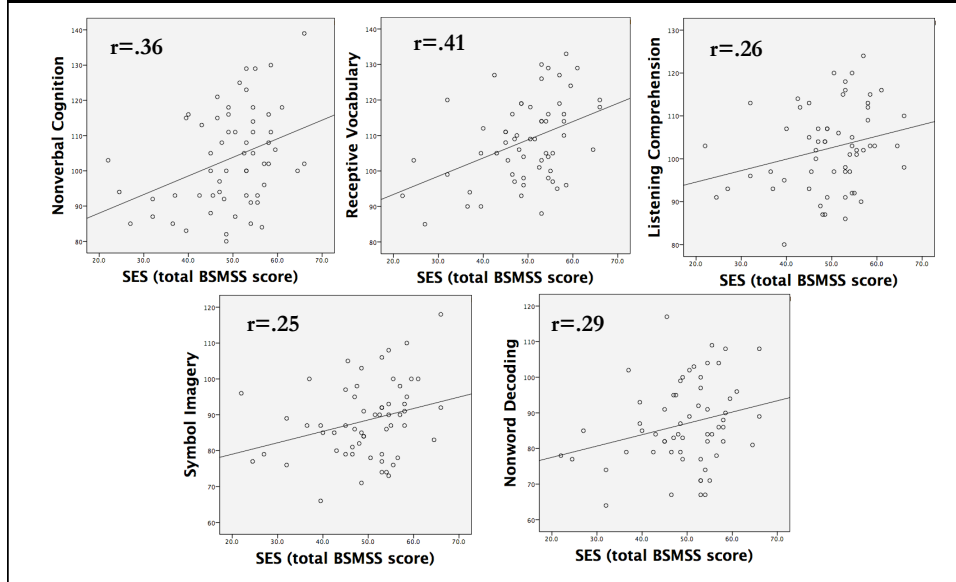


**SES (total BSMSS score)**

BSMSS = education +  
occupational prestige

(Barratt, 2006)

## SES correlates with cognition, language, and literacy skills



## Summary of Results

How is SES related to language and literacy performance in children with RD?

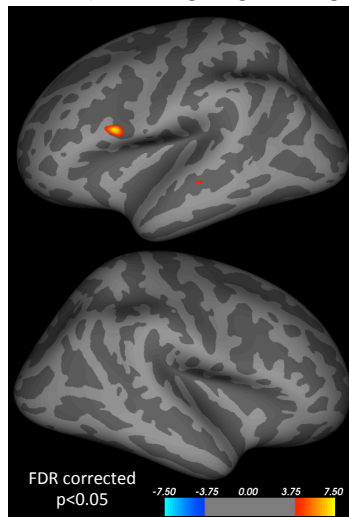
**SES was positively correlated with pre-intervention scores on tests of nonverbal cognition, oral language, nonword decoding, and orthographic imagery.**

## Study Goals

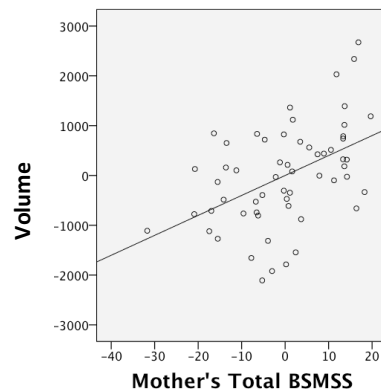
1. How is SES related to language and literacy performance in children with RD?
2. **Does the brain structure of students with RD vary by SES? If so, how?**
  - Which is a stronger predictor of anatomy: SES or reading ability?
3. Are there SES-related differences in children's response to reading intervention, at the level of behavior and/or brain?

## SES predicts size of Broca's area in children with reading disability

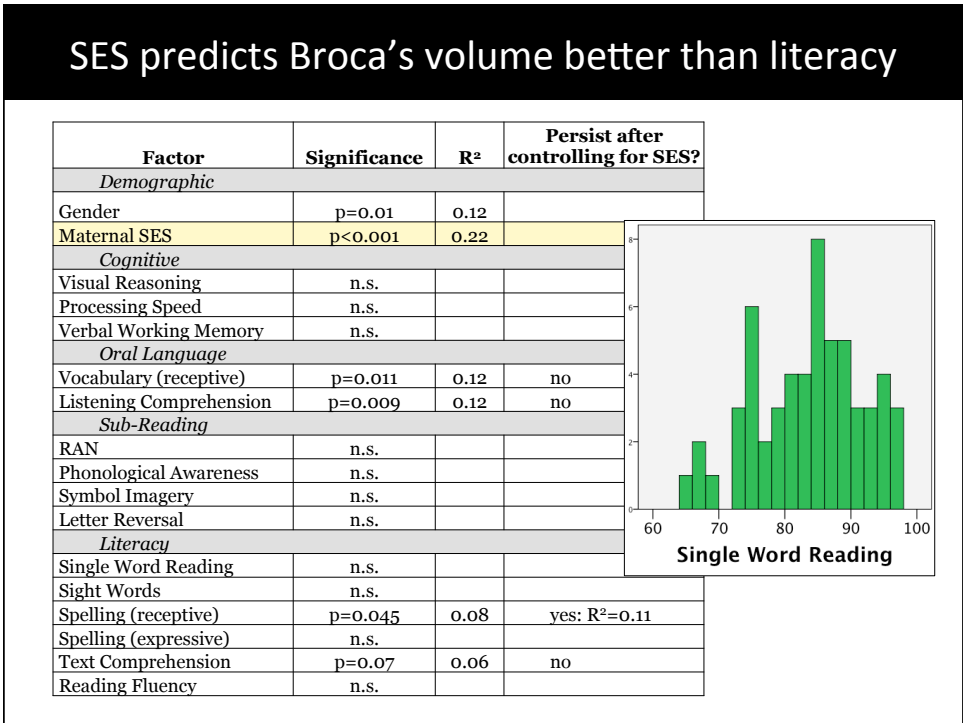
Correlation between **cortical thickness** and SES (controlling for gender, age):



Correlation between **volume** and SES (controlling for gender, age, ICV):



Linear regression:  $t=3.872$ ,  $p < 0.001$   
Partial correlation:  $R^2 = 0.22$ ,  $p < 0.001$



- ### Results
- Maternal SES predicts the size (both volume & thickness) of Broca's area in children with reading disabilities.
  - There is *no significant relationship* between the size of Broca's area and reading performance within this population.

## Study Goals

1. How is SES related to language and literacy performance in children with RD?
2. Does the brain structure of students with RD vary by SES? If so, how?
- 3. Are there SES-related differences in children's response to reading intervention, at the level of behavior and/or brain?**

## Intervention

- 36 participants from experiment 1
  - Groups balanced on age, gender, SES, nonverbal IQ, & reading scores
- Instruction: Lindamood-Bell Seeing Stars
  - 4 hours x 5 days x 6 weeks
  - Minimum of 100 hours
  - Academic summer months
  - Groups of 3-5 children
  - Taught by Lindamood-Bell teaching staff
- Part of a larger RCT study to predict individual outcomes (Christodoulou et al., 2016)

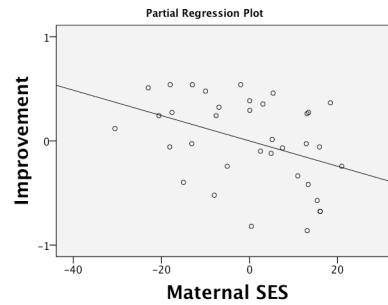


(Romeo, Christodoulou, et al., in prep.)

## Lower SES is associated with > improvement

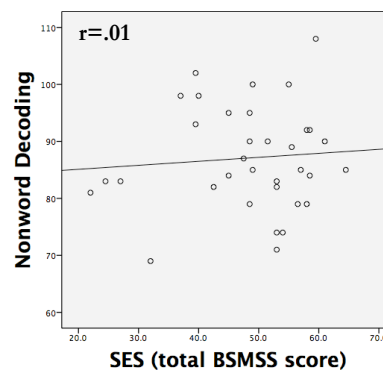
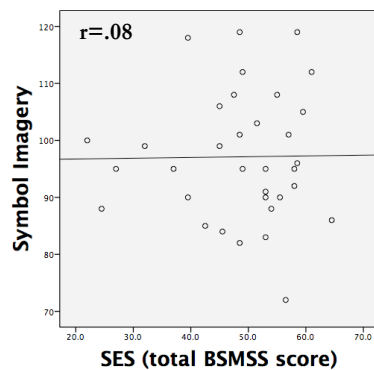
- “Improvement”= avg. post-intervention score > pre score
- Linear regression (model containing only significant predictors)  
Improvement = z-score of avg. initial score + gender + maternal SES

Factor	Beta	Significance	R <sup>2</sup>
Avg. Initial Score (z)	-0.252	p=0.001	0.297
Gender	.0422	p=0.006	0.212
Maternal SES	-0.012	p=0.018	0.162



(Romeo, Christodoulou, et al., in prep.)

## Intervention wiped out the SES – reading skills correlation



(Romeo, Christodoulou, et al., in prep.)

## Summary of Results

Are there SES-related differences in children's responses to a well-known reading intervention program?

- Yes, more lower-SES children exhibited improvement than higher-SES peers, even when controlling for initial scores.
- This suggests that intensive reading intervention might be even more effective for these dually at-risk children (especially in the summer).

## Studying Obligatory Compensation in Hemispherectomy

- **Prevalence:**
  - 16-20% of all epilepsy resections in the US
- **Plasticity:**
  - Ultimate opportunity to study re-organization of the remaining hemisphere for its \*maximum potential\*
- **Study:**
  - Given the compensatory role of the right hemisphere for reading, what potential does it offer in isolation for supporting reading and related skills?

(Christodoulou et al., under review)

## Language Lateralization

- The right hemisphere involvement is well-documented in developmental disorders of reading, where right hemisphere recruitment is associated with compensatory approaches.

(Temple et al., 2003; Shaywitz, 2008)

## Language and Literacy Profile in Hemispherectomy

### **Relative Strengths**

- Vocabulary
- Timed word reading

### **Relative Weaknesses**

- Untimed word reading
- Passage comprehension

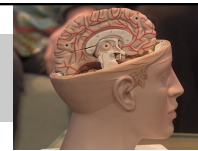
(Christodoulou et al., under review)

## Reading in the Right Hemisphere

- The isolated Right Hemisphere has potential to support reading
- Informs Compensation vs Remediation
- Two potential mechanisms to reading
  - Timed > Untimed
    - Acceleration phenomenon
    - Feedback/monitoring
  - Whole > Part
    - A word reading approach may favor whole over part oriented reading strategies



### Intervention and Compensation: Implications & Next Steps



- 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
- Effective and early treatment may relieve reliance on compensatory mechanisms for reading
- The right hemisphere can support reading, with potentially unique strategies
- Next steps:
  - Reading skills in clinical populations (e.g., CNS Disorders)
  - Consideration of psychosocial context
  - Dosage (frequency and duration) of treatment
  - For whom should we do what?

# Acknowledgements



The slide features a central graphic with several logos. At the top left is the MGH Institute of Health Professions logo, which includes a shield with a caduceus and the text 'MGH INSTITUTE OF HEALTH PROFESSIONS' and 'A graduate school founded by Massachusetts General Hospital'. To its right is the 'BEAM' logo, where the letters are large and teal, with a colorful sunburst above the 'A'. Further right is the Carroll School logo, a circular emblem with a compass rose and the text 'Carroll School'. Below these are the McGovern Institute logo (a blue square with a white cross) and the text 'MCGOVERN INSTITUTE FOR BRAIN RESEARCH AT MIT'. To the right of that is the MIT logo in red.

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