Developmental Dyslexia: Early Identification, Brain-correlates and Remediation Strategies

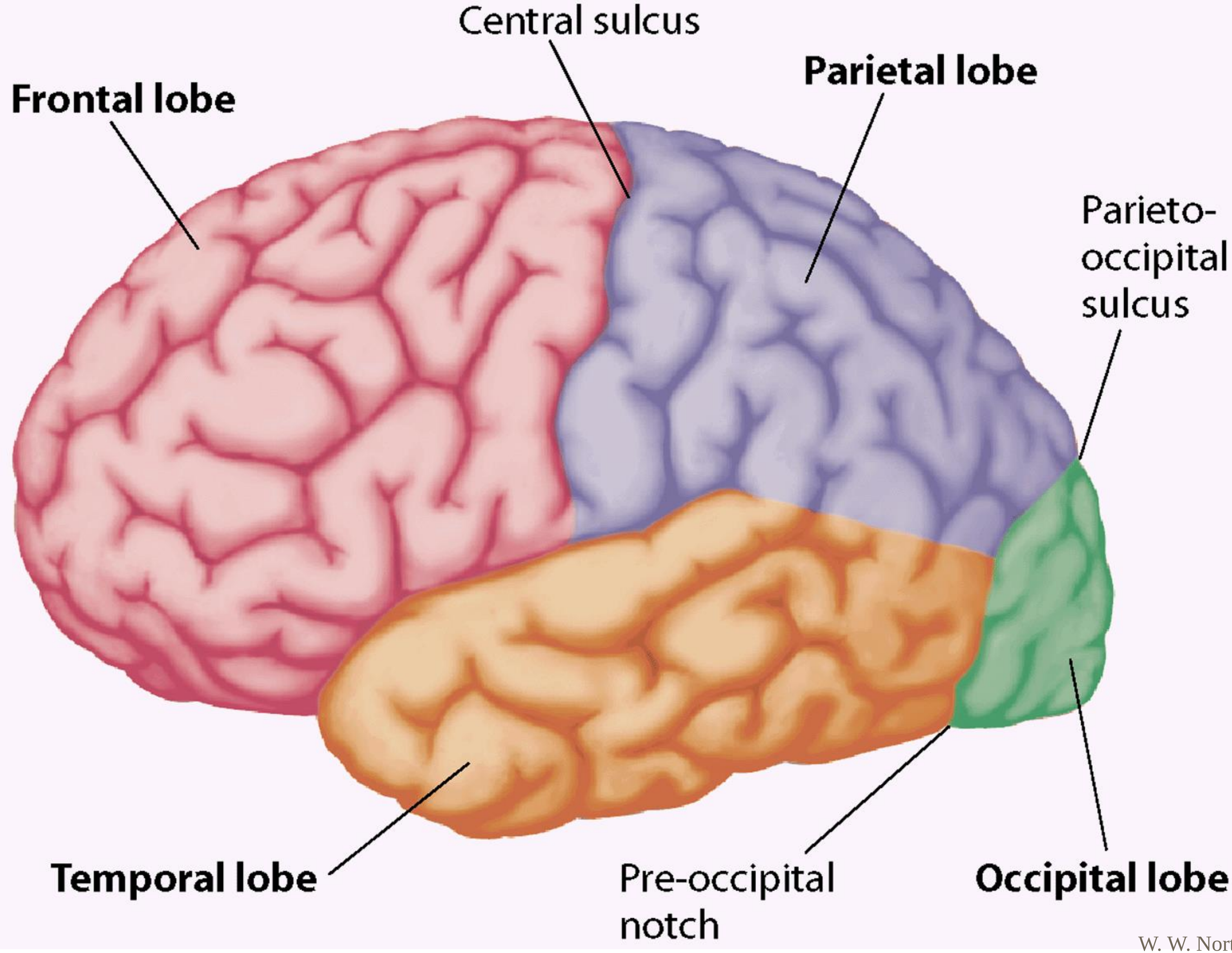
Nadine Gaab, PhD
Associate Professor of Pediatrics
Harvard Medical School
Children's Hospital Boston
Developmental Medicine Center
Laboratories of Cognitive Neuroscience

Children's Hospital Boston
Harvard Medical School
HARVARD GRADUATE SCHOOL OF EDUCATION

www.childrenshospital.org/research-and-innovation/research-labs/gaab-laboratory
www.babymri.org

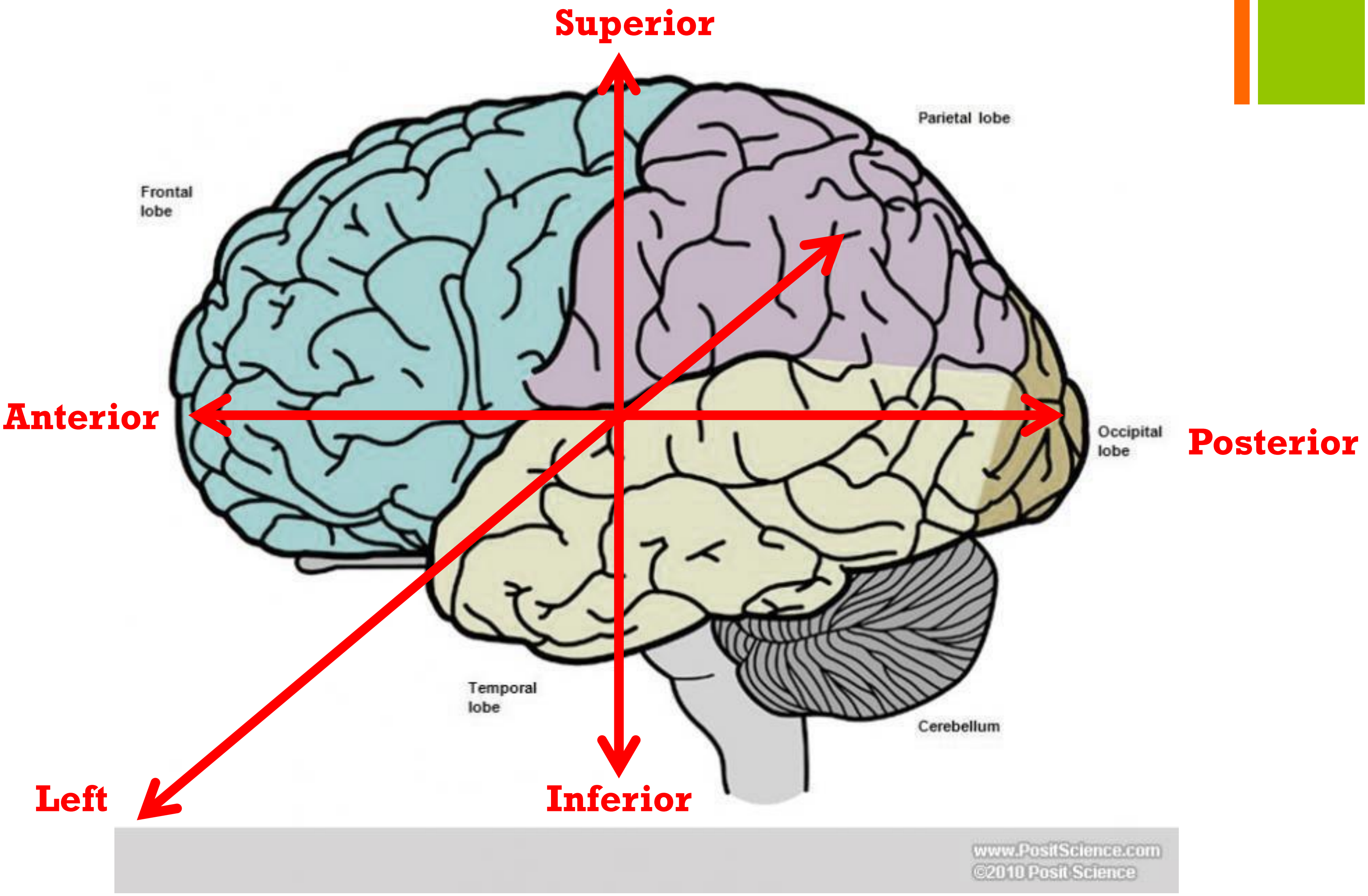
Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

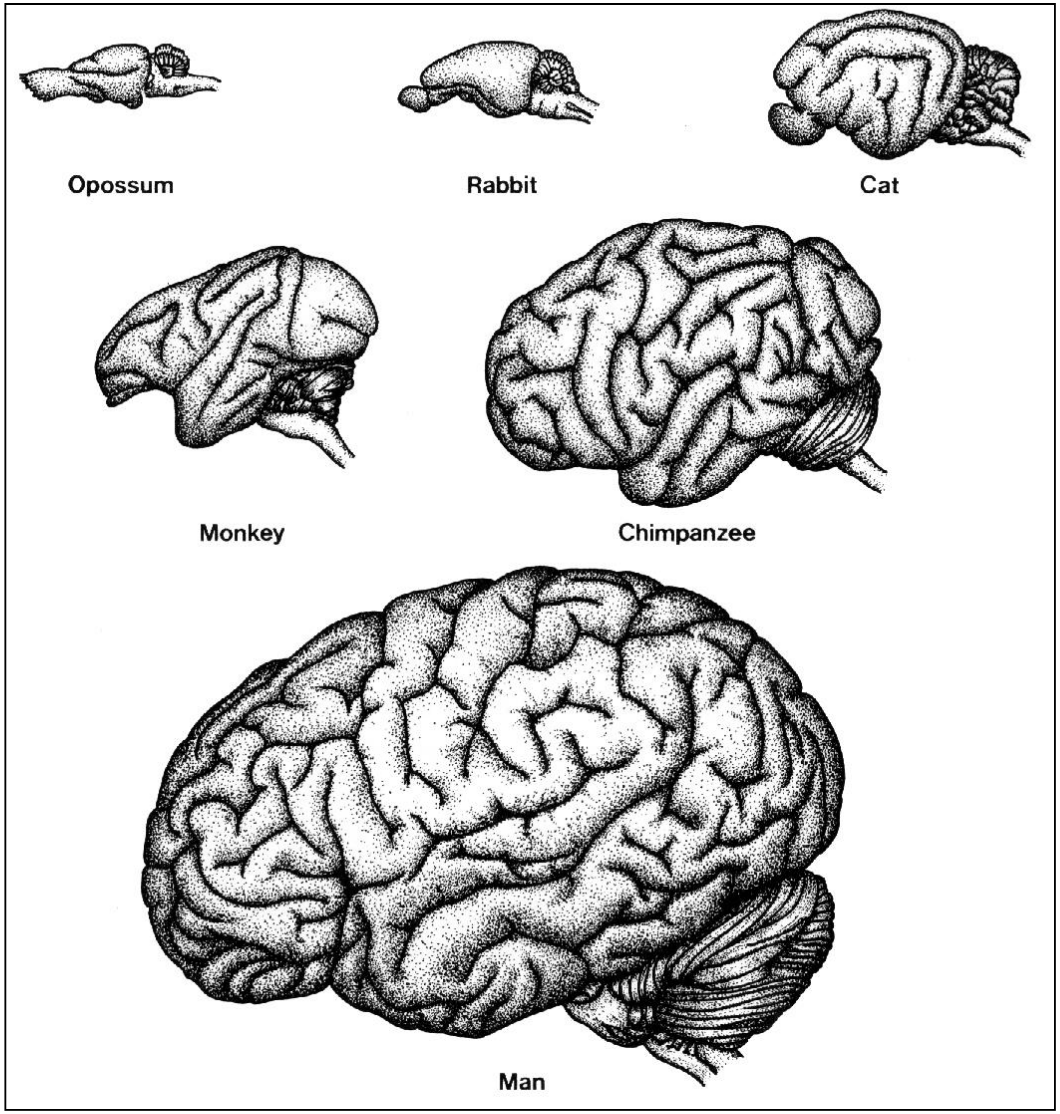

Central sulcus
Frontal lobe
Parietal lobe
Parieto-occipital sulcus
Temporal lobe
Pre-occipital notch
Occipital lobe

W. W. Norton

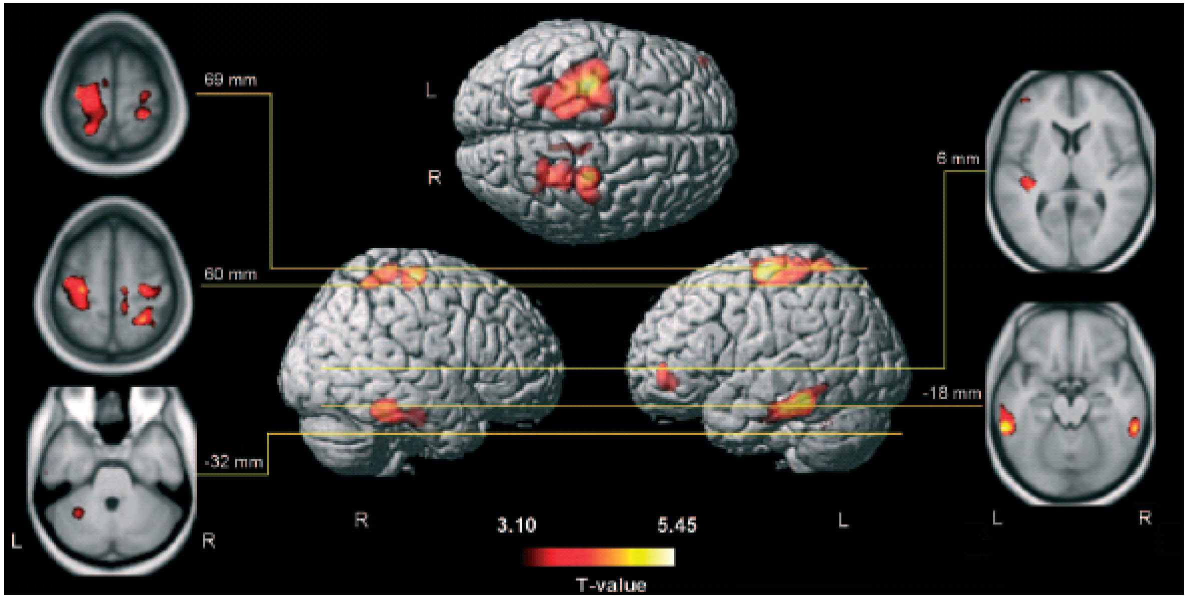
Lobes & Directions



Brain Size: Is bigger better?



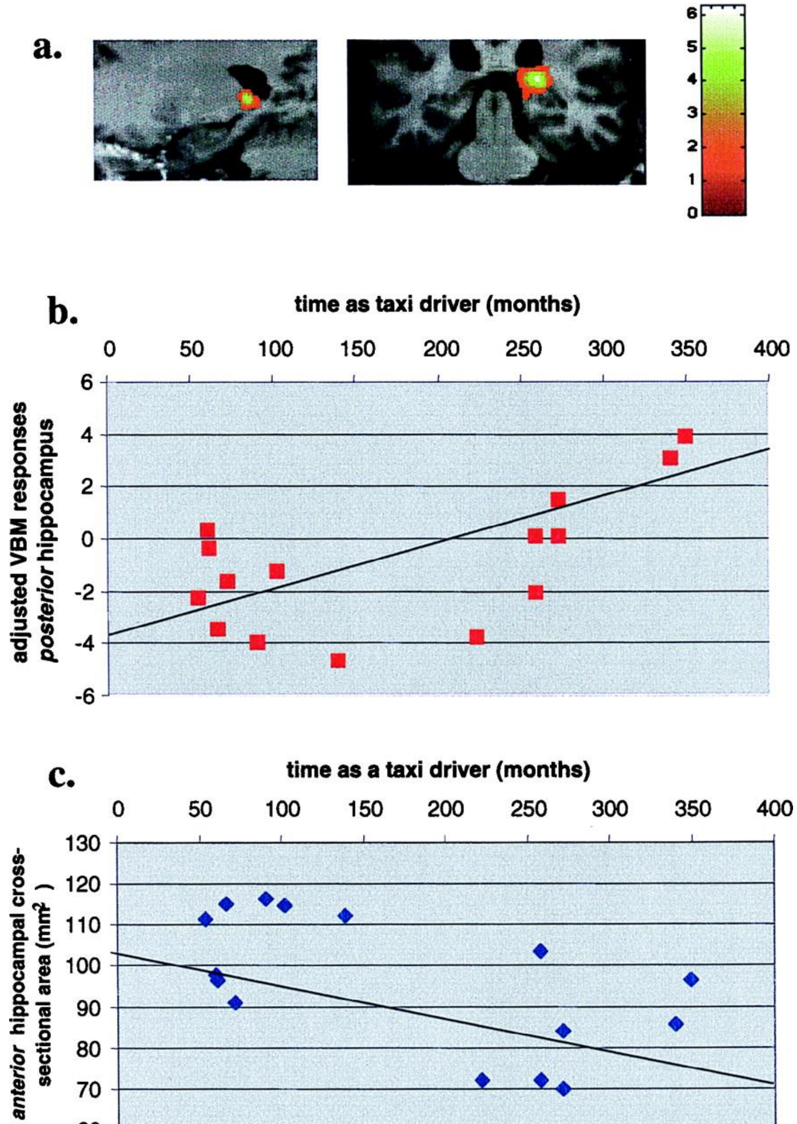
Anatomical differences between musicians and non-musicians



Brain regions with gray matter differences between professional musicians, amateur musicians and nonmusicians.

Gaser, Schlaug; 2003. The Journal of Neuroscience

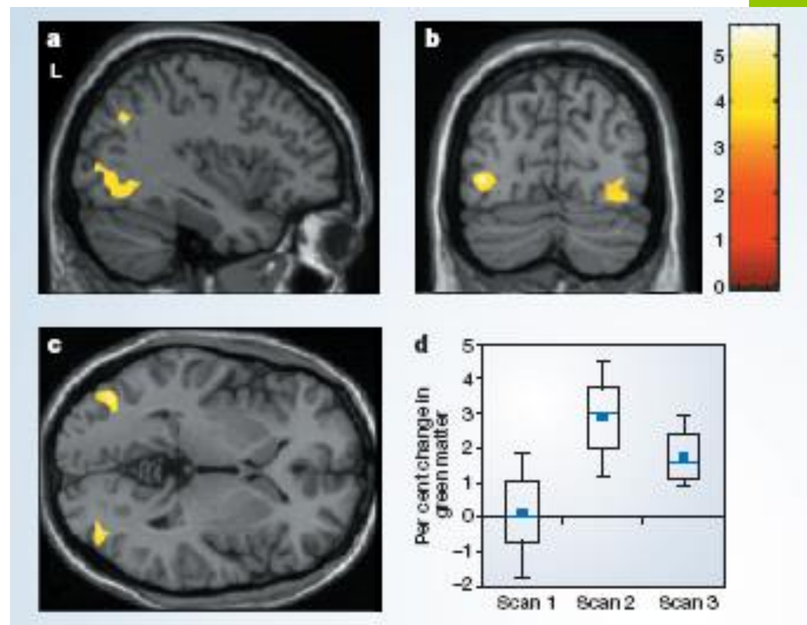
Plasticity in taxi drivers



Maguire et al., (2000)

Morphological changes induced by a short intervention

Draganski et al., 2004. Nature.



3 months training in juggling

Increased density of the grey matter in the jugglers compared to the non-juggler controls.

Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

GHOTI

- "FISH"

- gh as in *TOUGH*
- o as in *WOMEN*
- ti as in *NATION*

George Bernard Shaw

Why learning to read is so difficult:

- Learning to read **in English** is particularly difficult. Some language systems are based on a system where each syllable represented a symbol (learn the symbols and you have mastered the system) or where the number of phonemes and graphemes are similar (e.g. Italian).

Examples:

- College
- Collegial
- Colleague
- **Gh**ost versus nei**gh**borhood

Timeline of Reading development

Sound and Language Processing

Phonological Processing/ Letter recognition

Grapheme-morpheme Mapping Single word/ Connected text reading

Connected text/ Lexical Access/ Comprehension

Stages of Reading development

Exhibit 3. Stages of Reading Development

Stage	Name	The Learner
Stage 0: **Birth to Grade 1**	Emergent Literacy	Gains control of oral language; relies heavily on pictures in text; pretends to read; recognizes rhyme
Stage 1: **Beginning Grade 1**	Decoding	Grows aware of sound/symbol relationships; focuses on printed symbols; attempts to break code of print; uses decoding to figure out words
Stage 2: **End of Grade 1 to End of Grade 3**	Confirmation and Fluency	Develops fluency in reading; recognizes patterns in words; checks for meaning and sense; knows a stock of sight words
Stage 3: **Grade 4 to Grade 8**	Learning the New (Single Viewpoint)	Uses reading as a tool for learning; applies reading strategies; expands reading vocabulary; comprehends from a singular point of view
Stage 4: **Secondary and Early Higher Education**	Multiple Viewpoints	Analyzes what is read; reacts critically to texts; deals with layers of facts and concepts; comprehends from multiple points of view
Stage 5: **Late Higher Education and Graduate School**	A Worldview	Develops a well-rounded view of the world through reading

Source: Roskos et al., 2009.

Key predictors of reading ability before reading instruction starts:

- Phonological processing/Phonological awareness
- Speech perception
- Syntax production and comprehension
- Object naming
- Receptive/expressive vocabulary
- Rapid automatized naming abilities
- Letter name knowledge
- Verbal short-term memory

(e.g., Schatschneider et al., 2004; Georgiou et al., 2008; de Jong & van der Leij, 1999; Scarborough, 1998).

Home Literacy Environment (HLE)

Aspects of HLE that are most predictive of future language and literacy skills include (e.g., Hamilton, 2013; Payne, Whitehurst, & Angell, 1994; Bus et al., 1995):

- Age of onset of shared reading
- Frequency and quality of book reading
- Library visits
- Parent's knowledge of storybook titles
- Maternal mediating style during shared reading
- Child's perceived interest in reading

What is Developmental Dyslexia?

- Affects 5-17% of children.
- Specific learning disability characterized by
  - difficulties with speed and accuracy of word/text decoding
  - poor spelling and poor comprehension performance.
- Cognitive difficulties may further include speech perception, the accurate representation and manipulation of speech sounds, problems with language memory, rapid automatized naming or letter sound knowledge.
- Cannot be explained by poor vision or hearing, lack of motivation or educational opportunities.
- Familial occurrences as well as twin studies strongly support a genetic basis for DD.
- Currently up to seven theories that try to explain DD.
- No medications available.
- Strong psychological and clinical implications which start long before reading failure.

Psychological and Clinical Implications of DD

- Children with DD are often perceived by others as being ‘lazy’ or as those who ‘do not try enough.

- Teachers, parents and peers often misinterpret the ‘dyslexic’ child’s struggle to learn as negative attitude or poor behavior and decreased self-esteem is often a result [Saracoglu *et al.,* 1989; Riddick *et al.,* 1999].

- These negative experiences leave children with DD vulnerable to feelings of shame failure, inadequacy, helplessness, depression and loneliness [e.g.; Valas *et al*., 1999].

- Possible anti-social behavior with long-standing consequences [Baker *et al.,* 2007].

- Less likely that these children will complete high school [Marder *et al.,* 1992] or join programs of higher education [Quinn *et al*., 2001], and increased probability that they will enter the juvenile justice system [Wagner *et al.,* 1993].

Genetics

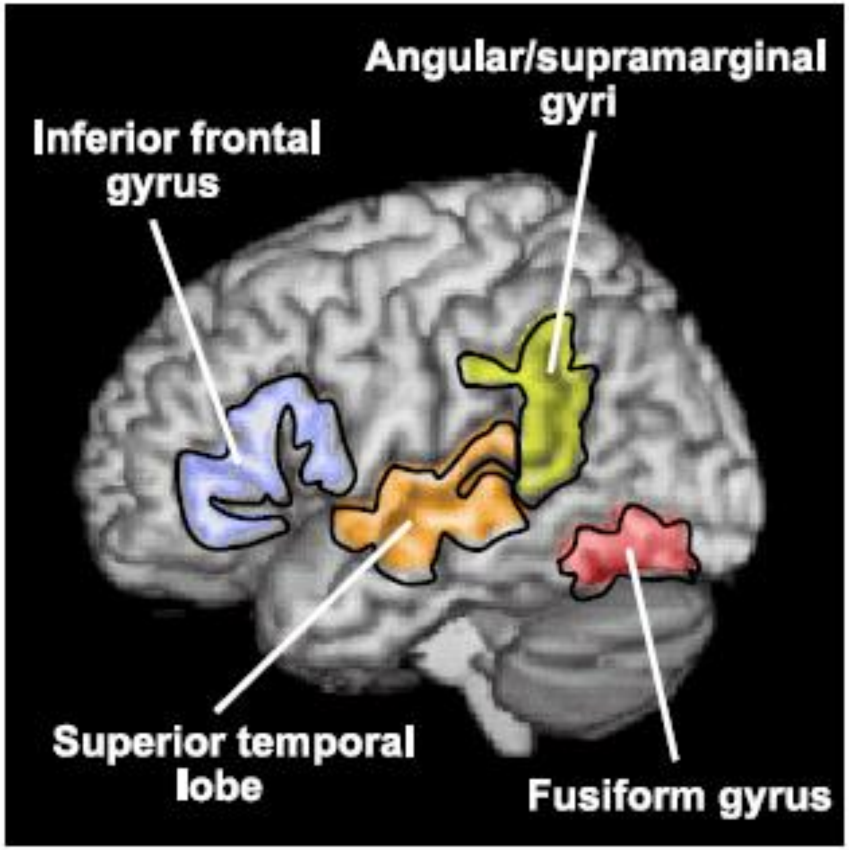
- Studies of families with DD suggest that DD is strongly heritable, occurring in up to 68% of identical twins and up to 50% of individuals who have a first degree relative with DD [Finucci *et al.,* 1984; Volger *et al.,* 1985).

- The genetic foundation of developmental disorders may be formed not by isolated genes, but rather by a combination of genes and the pathways that these genes regulate [Grigorenko, 2009].

- Several genes (e.g.; ROBO1, DCDC2, DYX1C1, KIAA0319) have been reported to be candidates for dyslexia susceptibility and it has been suggested that the majority of these genes plays a role in brain development. [e.g.; Galaburda *et al*., 2006; Hannula-Jouppi *et al*., 2005; Meng *et al.,* 2005; Paracchini *et al*., 2006; Skiba *et al*., 2011].

- It has been hypothesized that DD may be the result of abnormal migration and maturation of neurons during early development [e.g.; Galaburda *et al.,* 2006].

The typical reading network with its key components



- A tentative pathway between a genetic effect, developmental brain changes and perceptual/cognitive deficits in DD has been proposed based on studies in animal and humans (Galaburda et al., 2006).

Variant function in any number of genes involved in cortical development

↓

Subtle cortical malformation involving neuronal migration and axon growth

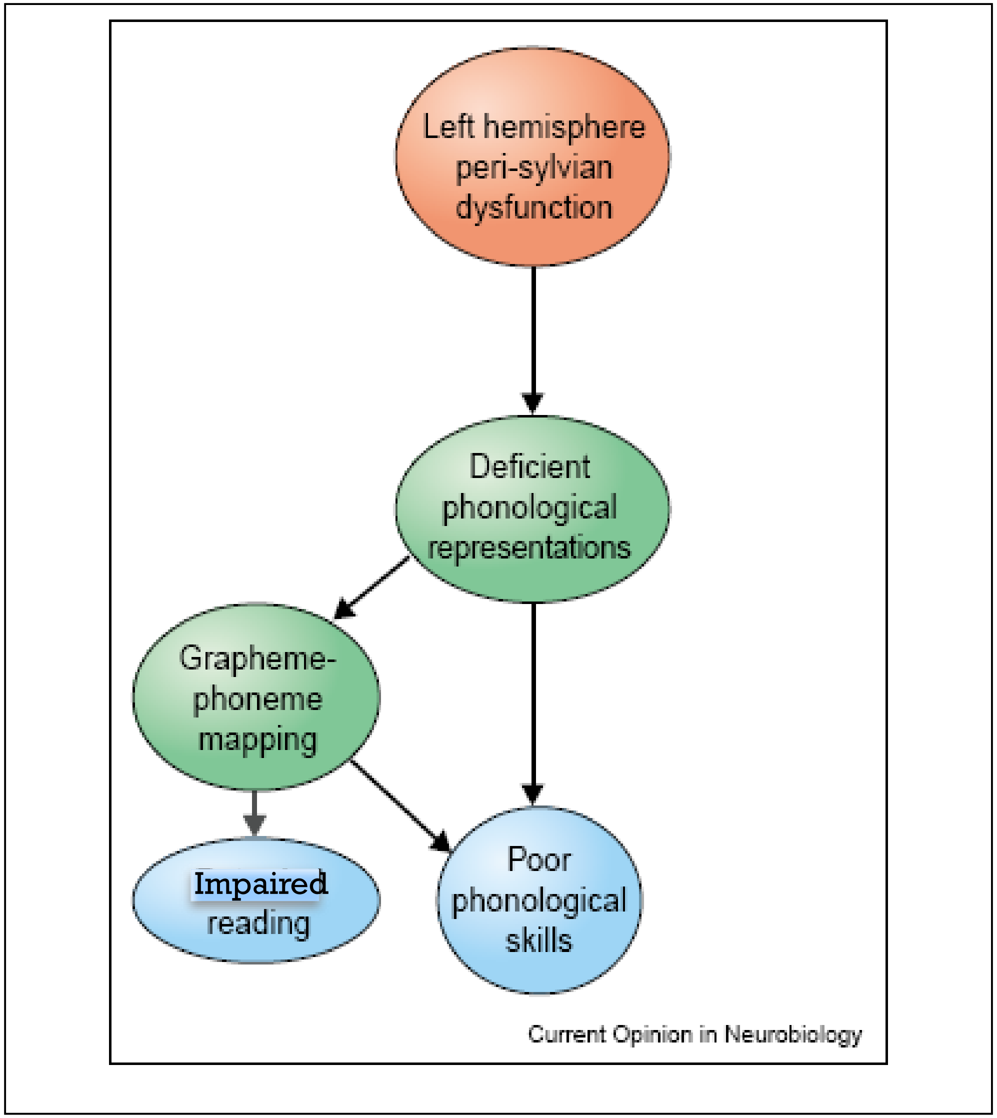
↓

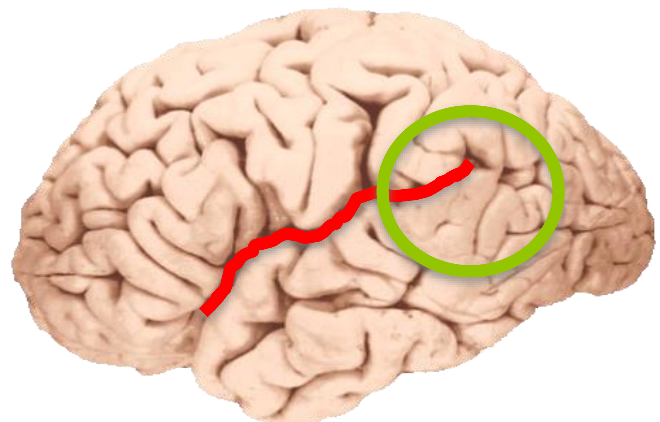
Atypical cortico-cortical and cortico-thalamic circuits

↓

Atypical sensorimotor, perceptual and cognitive processes critical for learning (to read)

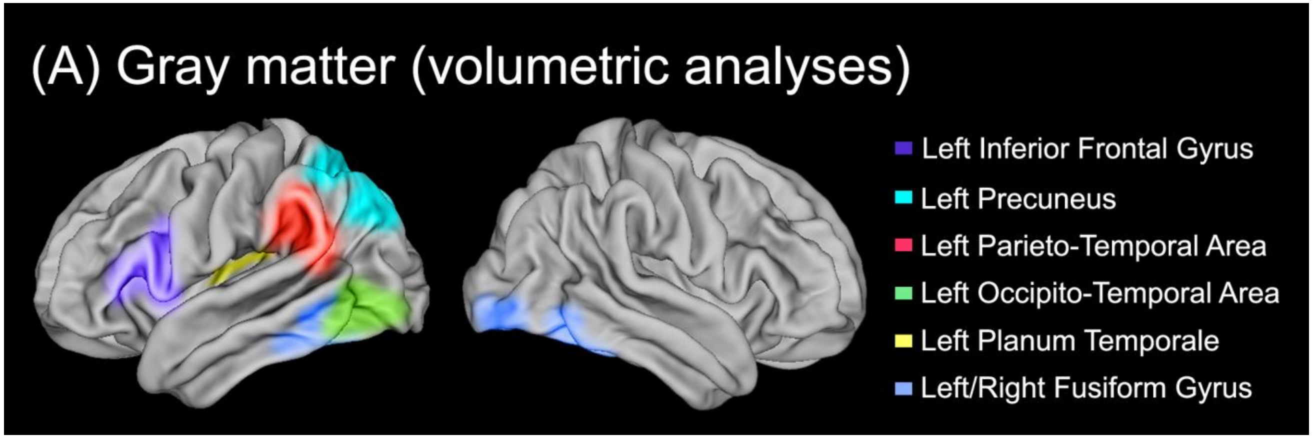
Several theories try to explain dyslexia:





[after Ramus, 2003]

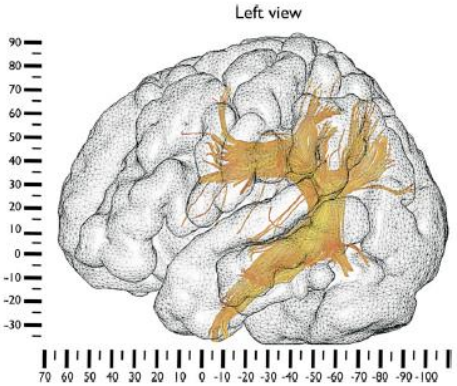
Structural and functional brain alterations in DD



[e.g. see Meta-analyses: Richlan et al., 2013; Linkerdoerfer et al., 2012, Martin et al., 20015]

[e.g. see Meta-analyses: Richlan et al., 2011; Temple et al., 2002]

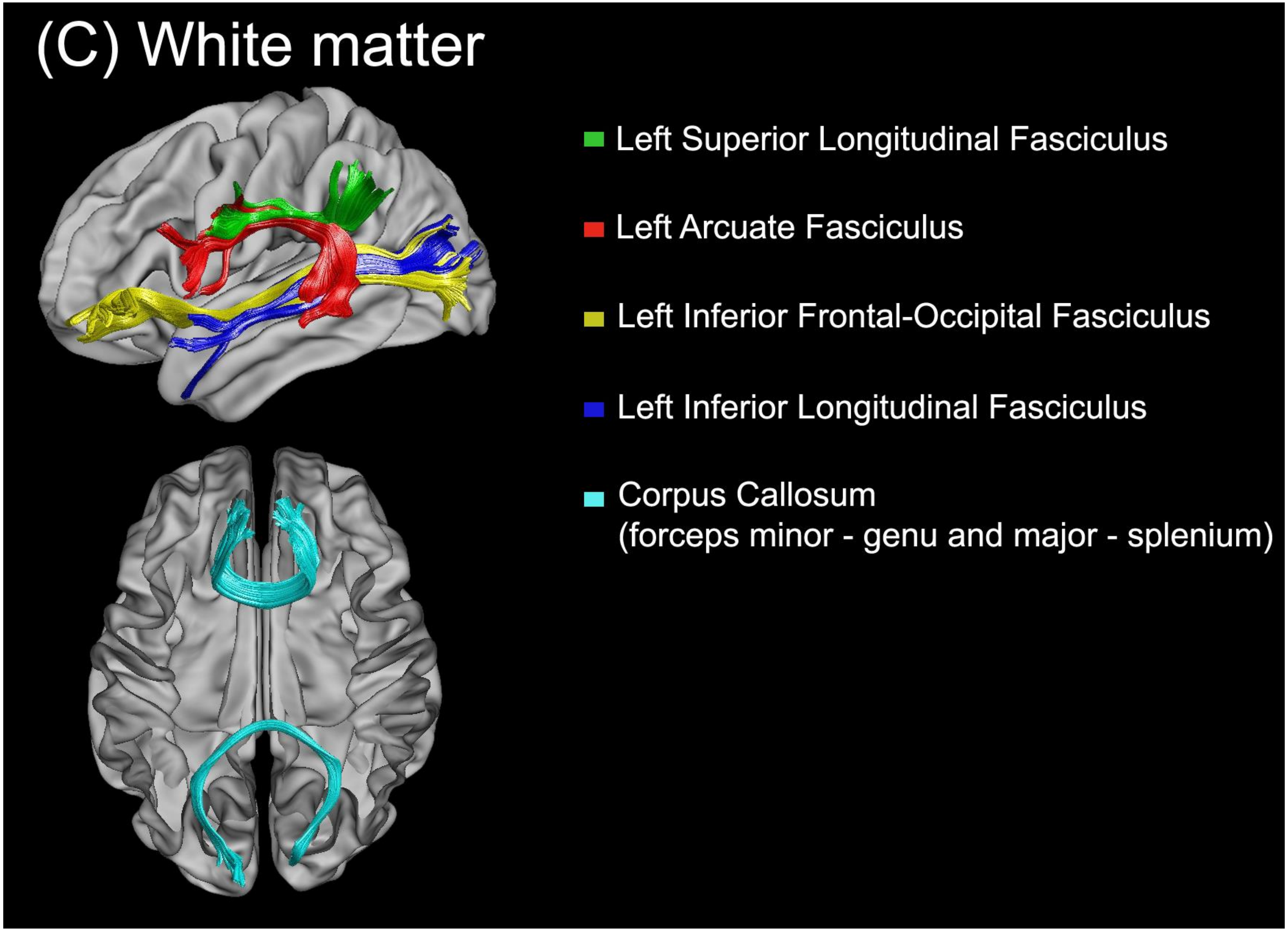
Structural brain differences (white matter): Typical and atypical readers

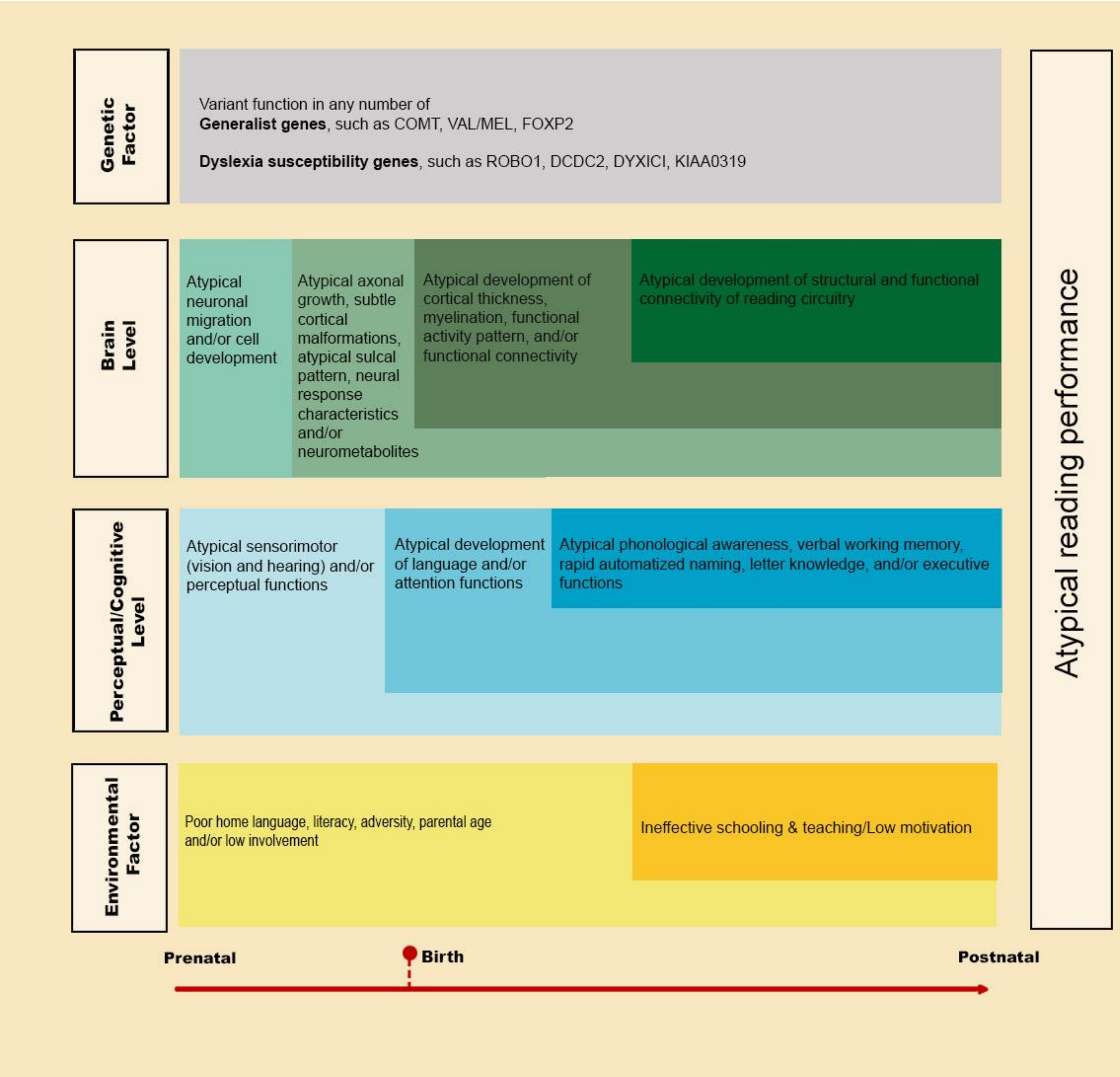


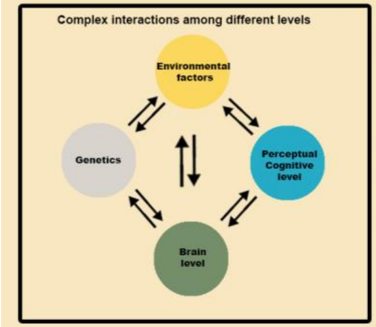
[Catani, 2008]

- DD has been associated with structural differences in left-hemispheric white matter organization as measured by Diffusion tensor imaging tractography [e.g., Klingberg *et al*., 2000; Rimrodt *et al*., 2010; Steinbrink *et al.,* 2008].
- Most studies report alterations of the Arcuate Fasciculus, a neural pathway connecting the posterior part of the temporoparietal junction with the frontal cortex.
- Differences may reflect weakened white-matter connectivity among left-hemispheric areas that support reading. Measures (e.g.; fractional anisotropy) in left temporoparietal regions corelate positively with reading skills [e.g.,Deutsch *et al.,* 2005].

White matter alterations in DD





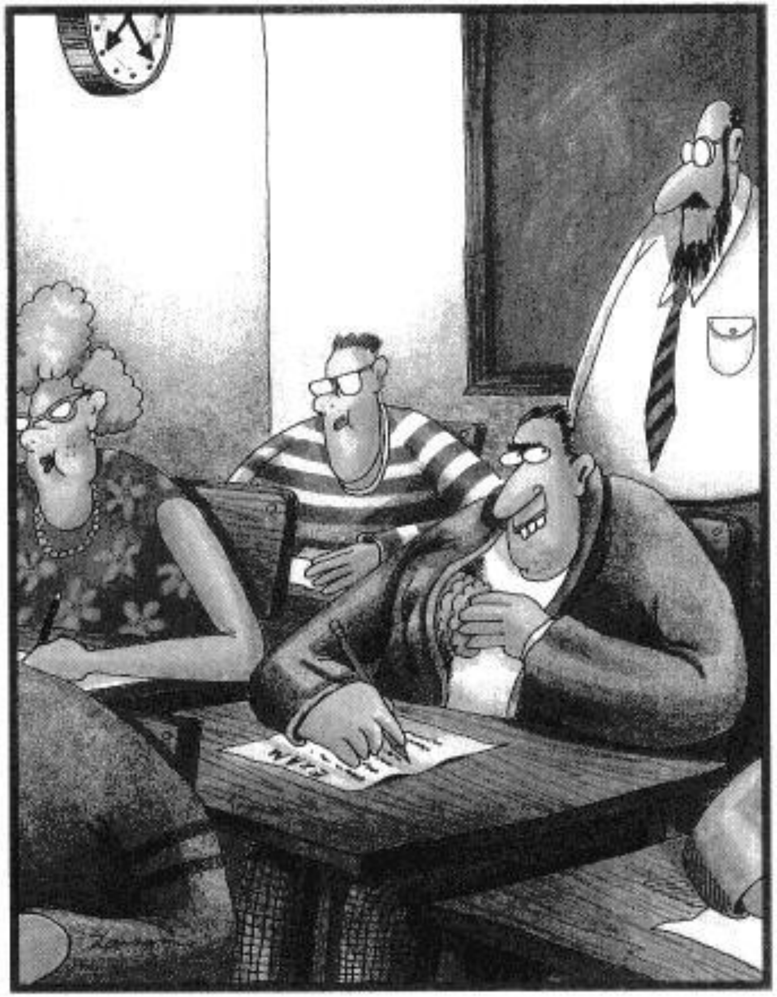


Ozernov-Palchik et al.,

Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

Brain Changes After Remediation



Midway through the exam, Allen pulls out a bigger brain.

Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI

Elise Temple[†‡], Gayle K. Deutsch[§], Russell A. Poldrack[¶], Steven L. Miller[‖], Paula Tallal[‖††], Michael M. Merzenich[‖‡‡], and John D. E. Gabrieli[†§]

n= 45
Intervention:
Fast ForWord (8 weeks)

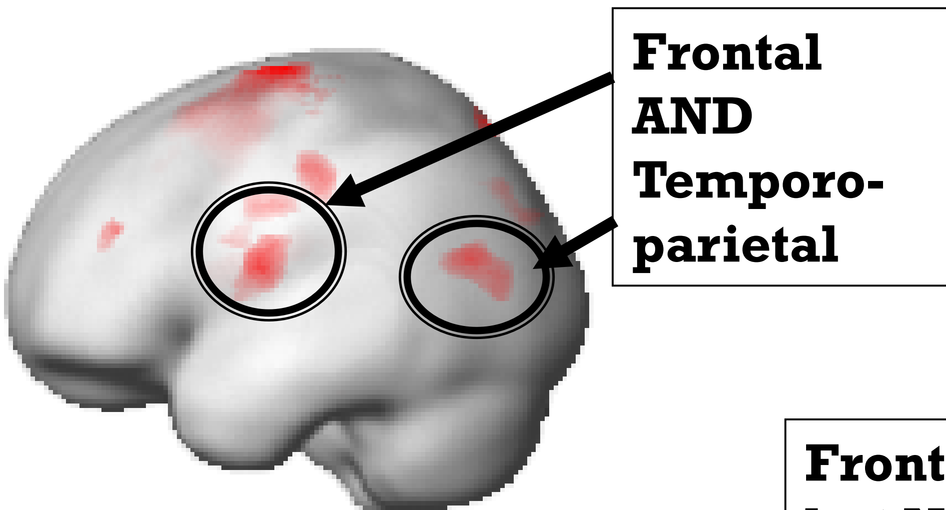
	Dyslexic-reading children				Normal-reading children			
	Pretraining	Posttraining	T-stat	*P*	1st scan	2nd scan	T-stat	*P*
Reading: WJ-RMT								
Word ID	78.2 (56–95)	86.0 (72–99)	3.9	0.0005	109.0 (95–120)	108.3 (97–126)	0.6	0.6
Word Attack	85.5 (72–102)	93.7 (82–109)	6.8	0.0001	112.3 (99–132)	109.4 (99–125)	1.1	0.3
Passage Comp	83.3 (51–103)	88.9 (77–107)	2.9	0.005	112.8 (104–120)	110.3 (100–122)	1.8	0.03
Language: CELF-3								
Receptive	92.5 (69–120)	101.3 (75–122)	3.6	0.001	118.6 (108–135)	121.8 (108–139)	1.5	0.2
Expressive	95.0 (61–125)	102.2 (80–150)	2.8	0.006	112.3 (102–125)	113.8 (92–139)	0.5	0.6
Rapid Naming	79.1 (35–97)	86.5 (67–103)	2.8	0.006	106.8 (94–121)	104.3 (82–124)	0.9	0.4

Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI

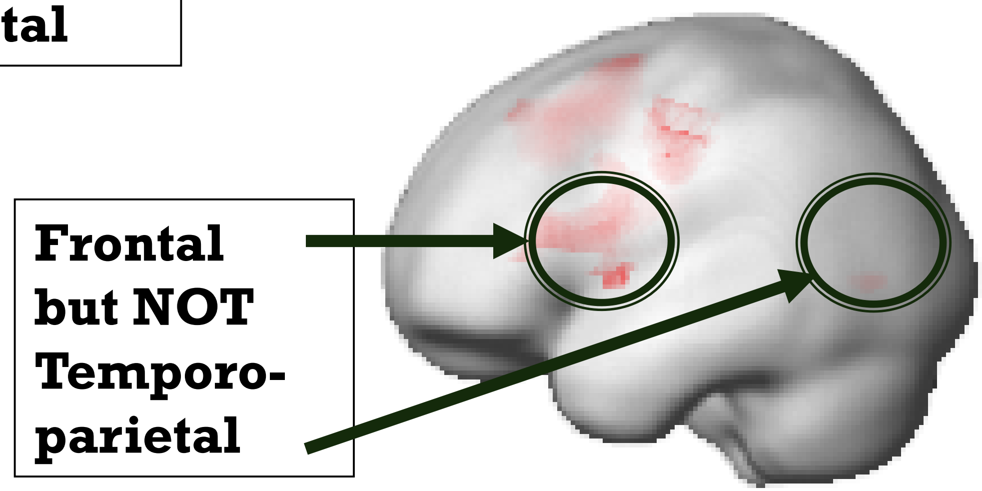
Elise Temple[†‡], Gayle K. Deutsch[§], Russell A. Poldrack[¶], Steven L. Miller[‖], Paula Tallal[**], Michael M. Merzenich[‡‡], and John D. E. Gabrieli[†§]

n= 45
8 weeks intervention

Control



Dyslexia



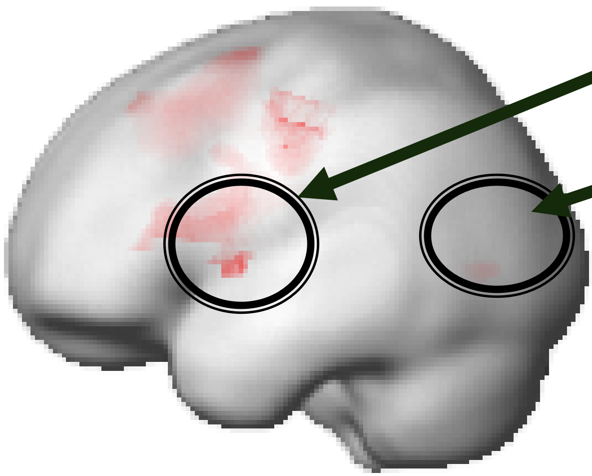
Example:

B D = Rhyme
B K = Do Not Rhyme

[Temple et al. (2003) PNAS, 100]

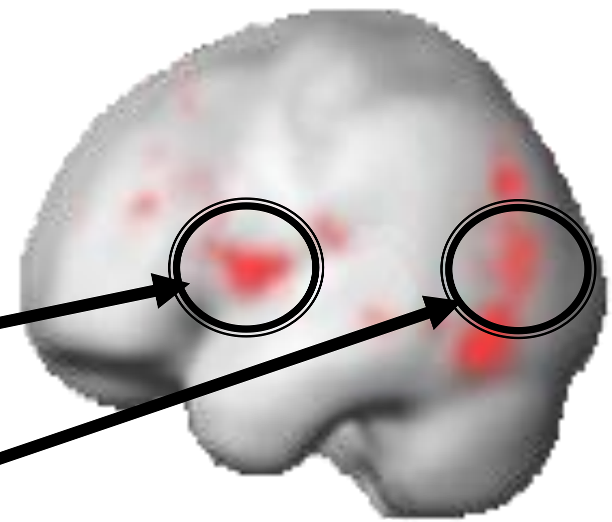
Neural effect of intervention

Pre-Intervention



Frontal but NOT Temporo-parietal

Post-Intervention



Increased activity in Frontal AND Temporo-parietal

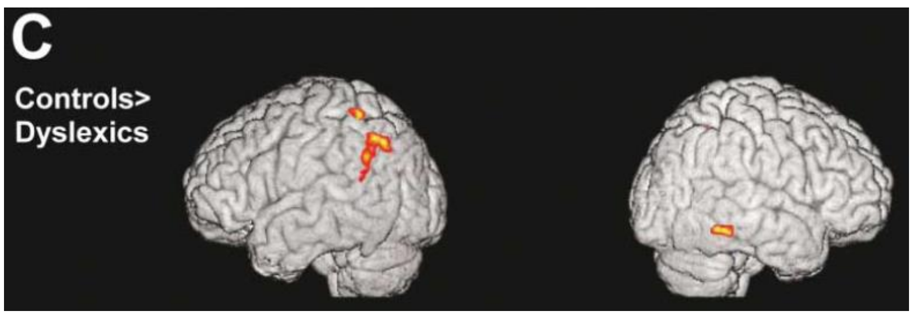
After training, metabolic brain activity in dyslexics more closely resembles that of typical readers.

[Temple et al. (2003) PNAS, 100]

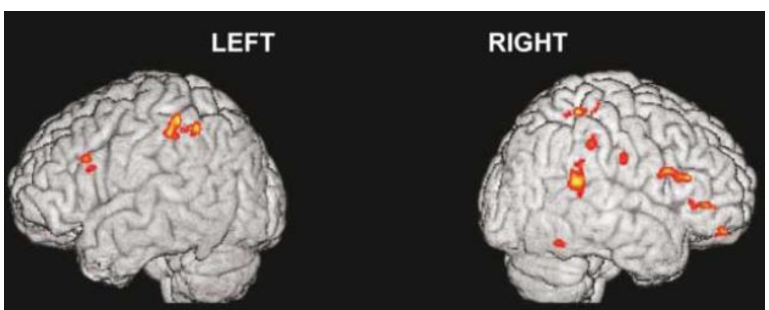
Neural Changes following Remediation in Adult Developmental Dyslexia

Guinevere F. Eden,[1,*] Karen M. Jones,[1] Katherine Cappell,[1] Lynn Gareau,[1] Frank B. Wood,[2] Thomas A. Zeffiro,[1] Nicole A.E. Dietz,[1] John A. Agnew,[1] and D. Lynn Flowers[1,2]

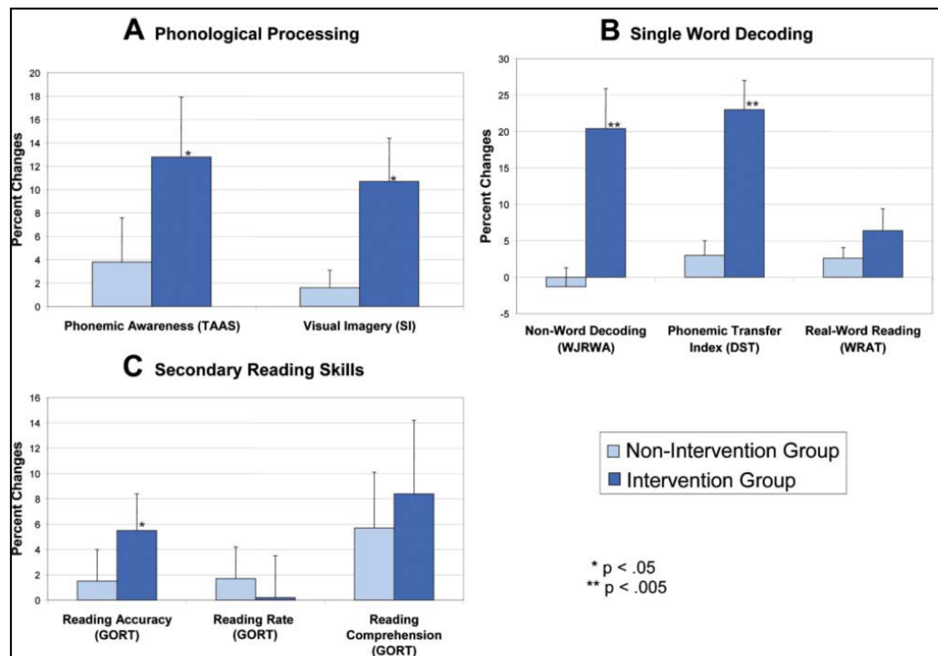
n= 38
Intervention: Lindamood-Bell (8 weeks)



Sound deletion > word repetition



Post remediation > Pre-remediation

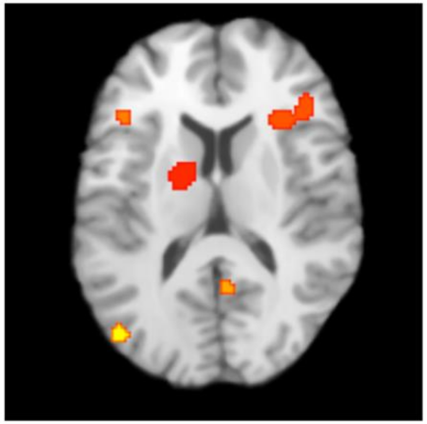


Neuroimaging of Reading Intervention: A Systematic Review and Activation Likelihood Estimate Meta-Analysis

Laura A. Barquero[1]*, Nicole Davis[1,2,3,4], Laurie E. Cutting[1,2,3,4,5]

Table 1. Participant groups and interventions.

Study	RD N	CT N	Age	Intervention	Dosage
Simos et al., 2002	8; 6 received Phono-Graphix, 2 received Lindamood Phonemic Sequencing	8	7–17 yrs	Phono-Graphix (Read America, Orlando FL) Lindamood Phonemic Sequencing (Lindamood-Bell, San Luis Obispo, CA)	80 hrs: 1-2 hr/day over 8 wk
Aylward et al., 2003	10	11	139.1 (9.8) months, 137.5 (7.9) months	Instruction in linguistic awareness, alphabetic principle, fluency, and reading comprehension	28 hrs: 2hr/day over 14 session days (3 wk)
Temple et al., 2003	20	12	8–12 yrs	Fast ForWord Language (Scientific Learning Corporation, Oakland, CA)	100 min/day, 5 days/wk, average 27.9 days
Eden et al., 2004	19 total; 9 received intervention	19	adults, RD 44.0 (9.4), CT 41.1 (9.7)	Multisensory instruction including sound awareness, letter-sound association, articulatory feedback administered by Lindamood-Bell Learning Corporation staff	3 hr/day, 8 wks, avg 112.5 hr total
Shaywitz et al., 2004	49 total; 37 received experimental intervention, 12 received community intervention	28	6.1 – 9.4 yrs; RD experimental 7.9 (0.5), RD community 8.1 (0.6), CT 8.0 (0.5)	Experimental intervention [127] included sound-symbol associations, blending, timed reading for fluency, oral reading, dictation	50 min/day for 8 months
Simos, et al., 2005	16; 13 responders, 3 non-responders	17	5.6–7.2 yrs at baseline (Low risk group 5.6–6.5, High risk group 6.0–7.2) 6.4–8.1 yrs at posttest (Low risk 6.4 – 7.5, High risk group 7.0 – 8.1)	Proactive Reading and Responsive Reading [128]	40 min/day, 5 day/wk for 8 months
Richards et al., 2006	18; 8 orthographic treatment, 10 morphological treatment	21	RD 130.8 months, CT 132.6 months	Instruction in alphabetic principle, composition, and either orthographic spelling treatment or morphological spelling treatment	28 hr total: 2 hr/day for 14 sessions over 3 wk
Hoeft et al., 2007	64 struggling readers (identified by teachers, many had scores in average range)	-	10.0 (1.09) yrs	Power4Kids Reading Initiative. Many participants received 1 of 4 interventions, but there was no significant effect of intervention on decoding scores.	about 6 months during school year
Richards et al., 2007	20; 11 phonological treatment, 9 nonphonological treatment	10 nonphonological treatment	RD phonological 137.7 (10.00) months, RD nonphonological 134.60 (11.10) months, CT 128.60 (8.00) months	Phonological treatment included explicit written language instruction using phonological working memory, phoneme-grapheme correspondences in spelling, and science report writing [129]. Nonphonological treatment included nonverbal virtual reality supported science problem solving [130]	24 hrs total—8 sessions over 2 wks with 3 hr/session
Simos, Fletcher, Sarkari, Billingsley-Marshall, et al., 2007	15	-	7–9 years	Phono-Graphix [131] and Read Naturally [132]	16 weeks total: 2 hr/day for 8 wks Phono-Graphix, 1 hr/day for 8 wks Read Naturally
Simos, Fletcher, Sarkari, Billingsley, et al., 2007	15; 8 responders, 7 nonresponders (same as Simos, et al., 2007 above)	10	7–9 years	Phono-Graphix [131] and Read Naturally [132]	16 weeks total: 2 hr/day for 8 wks Phono-Graphix, 1 hr/day for 8 wks Read Naturally
Meyler et al., 2008	23 (possible overlap with Hoeft, et al., 2007)	12	5th grade	Power4Kids project used four programs: Corrective Reading, Wilson Reading, Spell Read Phonological Auditory Training (PAT), Failure Free Reading	100 hrs total over 6 months
Odegard et al., 2008	12 total: 6 responders, 6 nonresponders	6	10 – 14 yrs	Take flight: A comprehensive intervention for students with dyslexia [133]	90 min/day, 4 days/wk for 2 school years
Richards & Berninger, 2008	18 (same as Richards et al., 2006)	21	RD 130.8 months, CT 132.6 months	Instruction in alphabetic principle, composition, and either orthographic spelling treatment or morphological spelling treatment	28 hrs total—14 sessions over 3 wks with 2hr/session;
Davis et al., 2011	10 total: 5 responders, 5 nonresponders	4	7.5 (0.43) yrs	Intervention consisted of sight word reading, letter sound practice, decoding practice, and reading for fluency.	45 min, 3 days/wk, 17 weeks
Farris et al., 2011	10 total: 5 responders, 5 nonresponders (same as Odegard et al., 2008)	5	10 – 14 yrs	Take flight: A comprehensive intervention for students with dyslexia [133]	90 min/day, 4 days/wk for 2 years
Hoeft et al., 2011	25	20	RD 14.0 (1.96) CT 11.0 (2.57)	*This study did not provide an intervention.* 11 participants received some form of intervention, but no differences were observed for intervention.	-
Rezaie et al., 2011a	20 total: 10 Adequate Responders (AR), 10 Inadequate Responders (IR)	20	Adequate Responders 158±7 months, Inadequate Responders 153±11 months, CT 151±11 months	Instruction included word study, fluency, vocabulary, comprehension [134]	45–50 min/day over 1 schoolyear
Rezaie et al., 2011b	27 total: 16 AR, 11 IR (possible overlap with Rezaie, et al., 2011a)	23	Adequate Responders 159±9 months, Inadequate Responders 156±16 months, CT 153±12 months	Instruction included word study, fluency, vocabulary, comprehension [134]	45–50 min/day over 1 schoolyear
Yamada et al., 2011	7 (at-risk)	7 (on-track)	At-risk 5.6 (0.2) yrs, On-track 5.7 (0.3) yrs	Early Reading Intervention [135]	30 min/day, 3 months
Gebauer Fink, Kargl et al., 2012	20 total (poor reading and spelling): 10 Treatment (TG), 10 Waiting Group (WG)	10	10–15 yrs, ($M = 11.80$; $SD = 1.58$)	Morpheus: a computer-aided morpheme-based spelling training in German [136]	Daily handwritten and computer homework, 1/wk instructor-guided courses for 2 hr, over 5 wks.
Bach et al., in press	6 poor readers (group classification made at follow-up)	11	Poor Readers 6.33±0.19 yr, Normal Readers 6.35±0.29 yr	Graphogame: a computerized training game teaching grapheme-phoneme correspondences in German [137–139]	321.5±124.3 min over 8 wk



Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

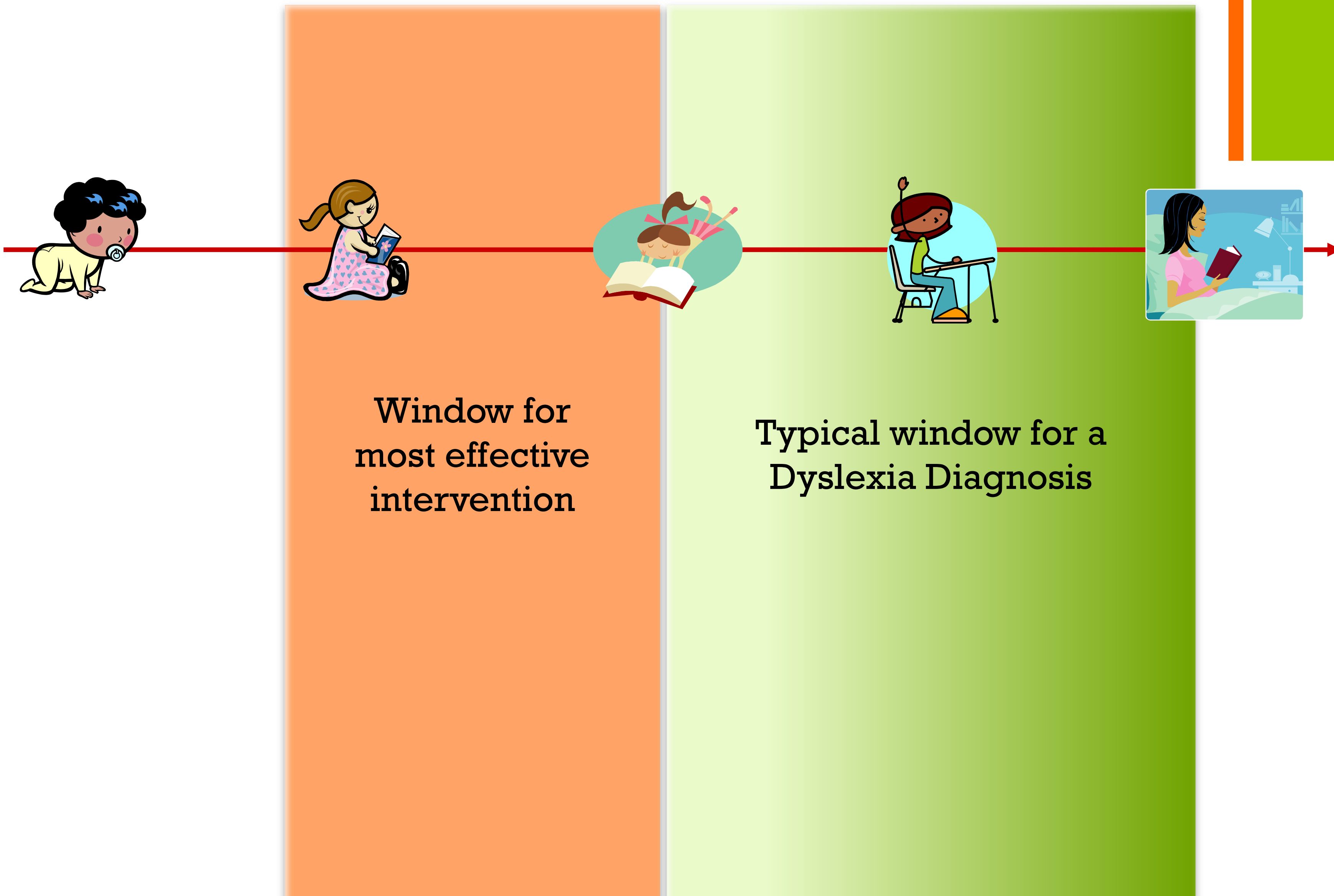
The 'Dyslexia Paradox'

- Typically, dyslexia is not diagnosed until a child has failed to learn to read as expected, usually in third grade or later. As a result, children with dyslexia must often make up a large gap in reading ability and experience to reach the level of their typically reading peers (e.g., Hiebert & Taylor, 2000)

- A meta-analysis comparing intervention studies offering at least 100 sessions, reported larger effect sizes for intervention studies conducted with kindergarten and first graders than with children in 2nd and 3rd grades (Wanzek & Vaughn, 2007) .

- When "at risk" beginning readers receive intensive instruction, 56% to 92% of at-risk children across six studies reached the range of average reading ability [Torgesen, 2004].

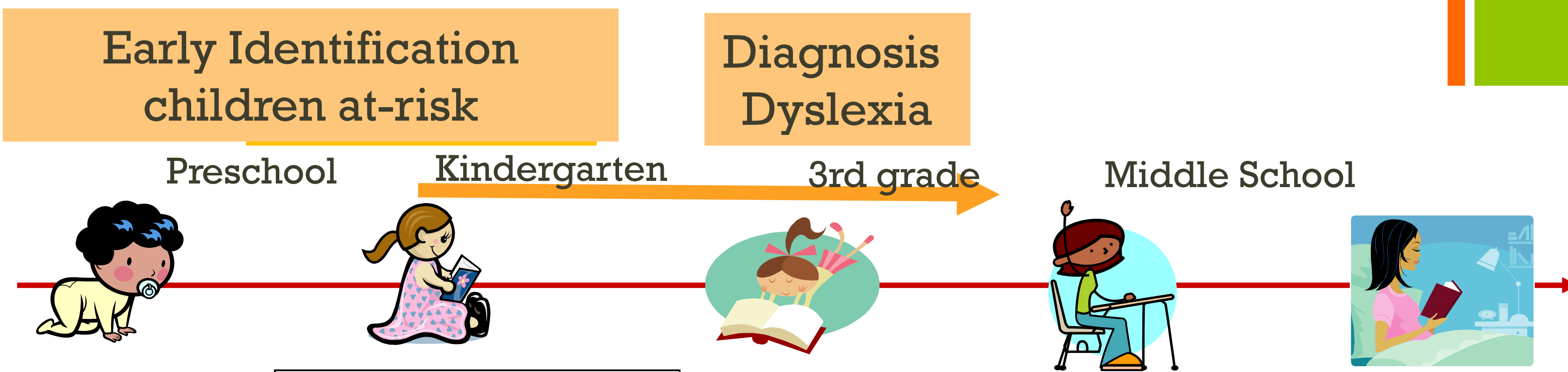
The dyslexia paradox



Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

The Boston Longitudinal Dyslexia Study (BOLD)



- Functional MRI
- Structural MRI
-Behavioral tests
-Psychophysics
-Questionaires
-DNA

Follow up:
-prior to first grade
-prior to second grade
-prior to third grade

- To date 114 children enrolled longitudinally (64 FHD+/50 FHD-).
- Pre-readers (Word ID <5), reading instruction within next year.

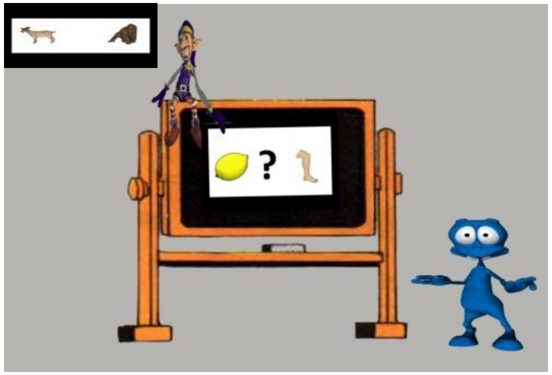
Psychometric Measures:
- Clinical Evaluation Language Fundamentals –Preschool 2
- Comprehensive Test Of Phonological Processing
- Grammar And Phonology Screening Test
- York Assessment for Reading for Comprehension
- Rapid Automatized Naming and Rapid Alternating Stimulus Test
- Kaufman Brief Intelligence Test 2
- Year 2: Word reading (timed/untimed), passage comprehension, fluency, spelling, letter knowledge

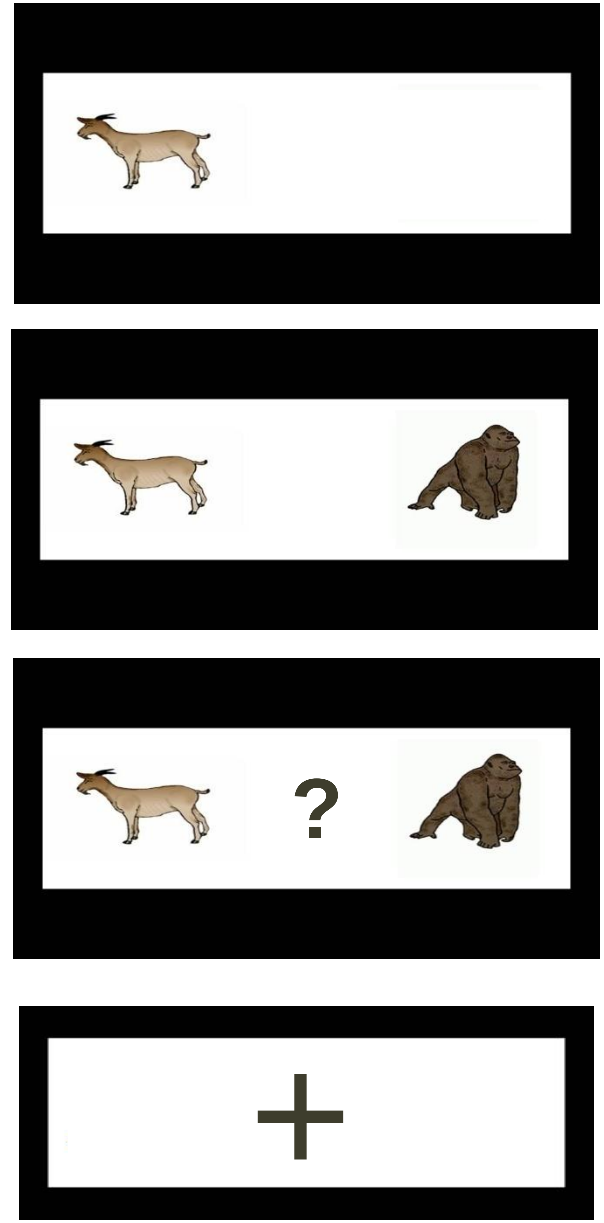
Psychophysics Measures:
- RAP (tones and environmental sounds)
- Rise Time perception

Questionaires :
- Development
- Home literacy
- SES

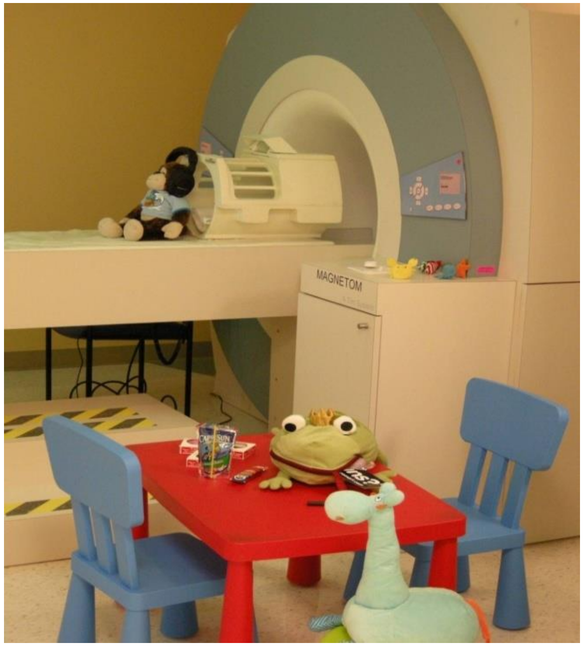
Tasks within MRI scanner :
- Phonological Processing
- Rapid auditory processing
- Executive functioning
- Reading Fluency

Structural brain differences (gray matter, DTI)



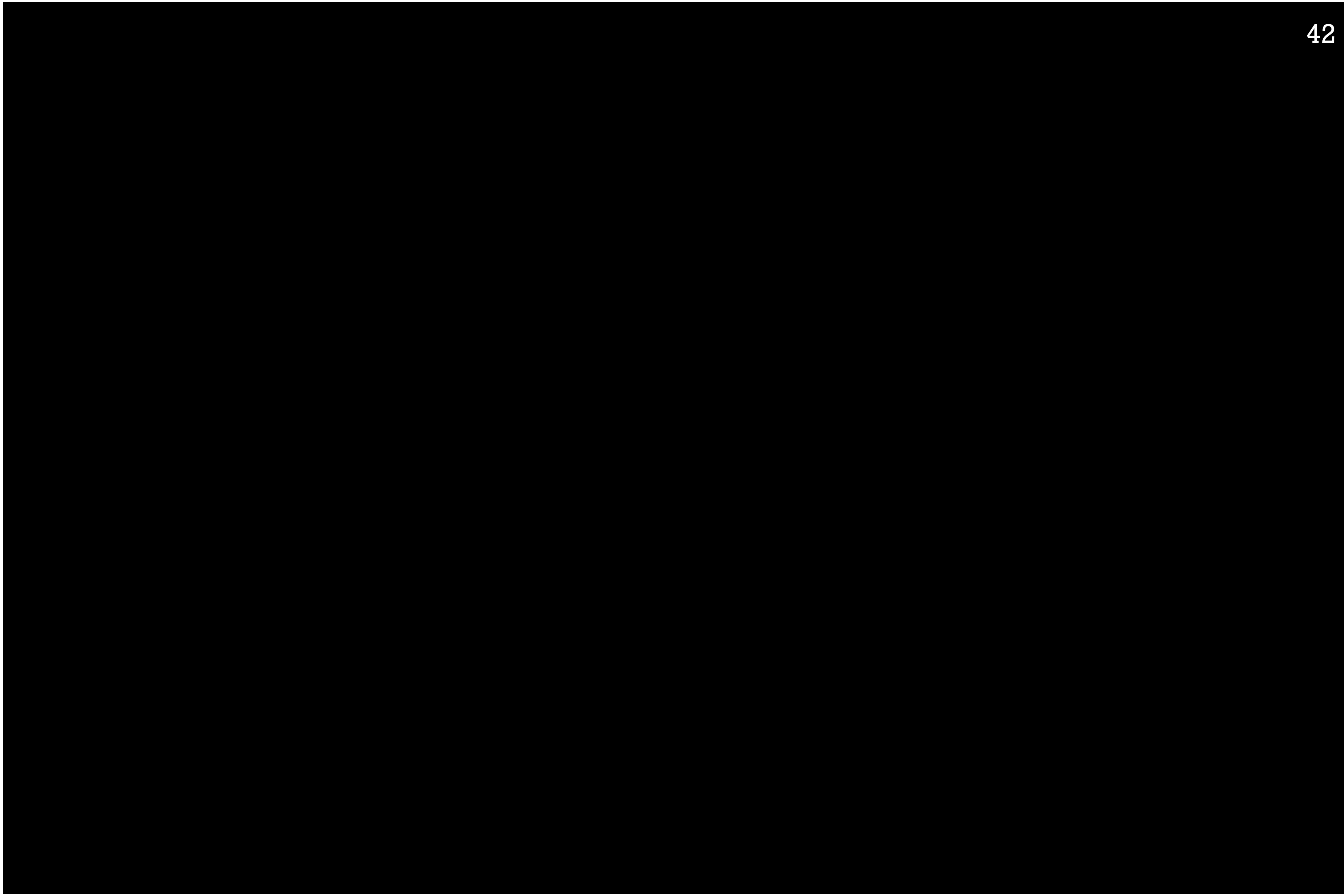


Control task:
Voice matching



[Raschle *et al.*, 2009; Raschle *et al*., 2012]


1
2
3
Can you help them?



http://www.jove.com/Details.stp?ID=1309

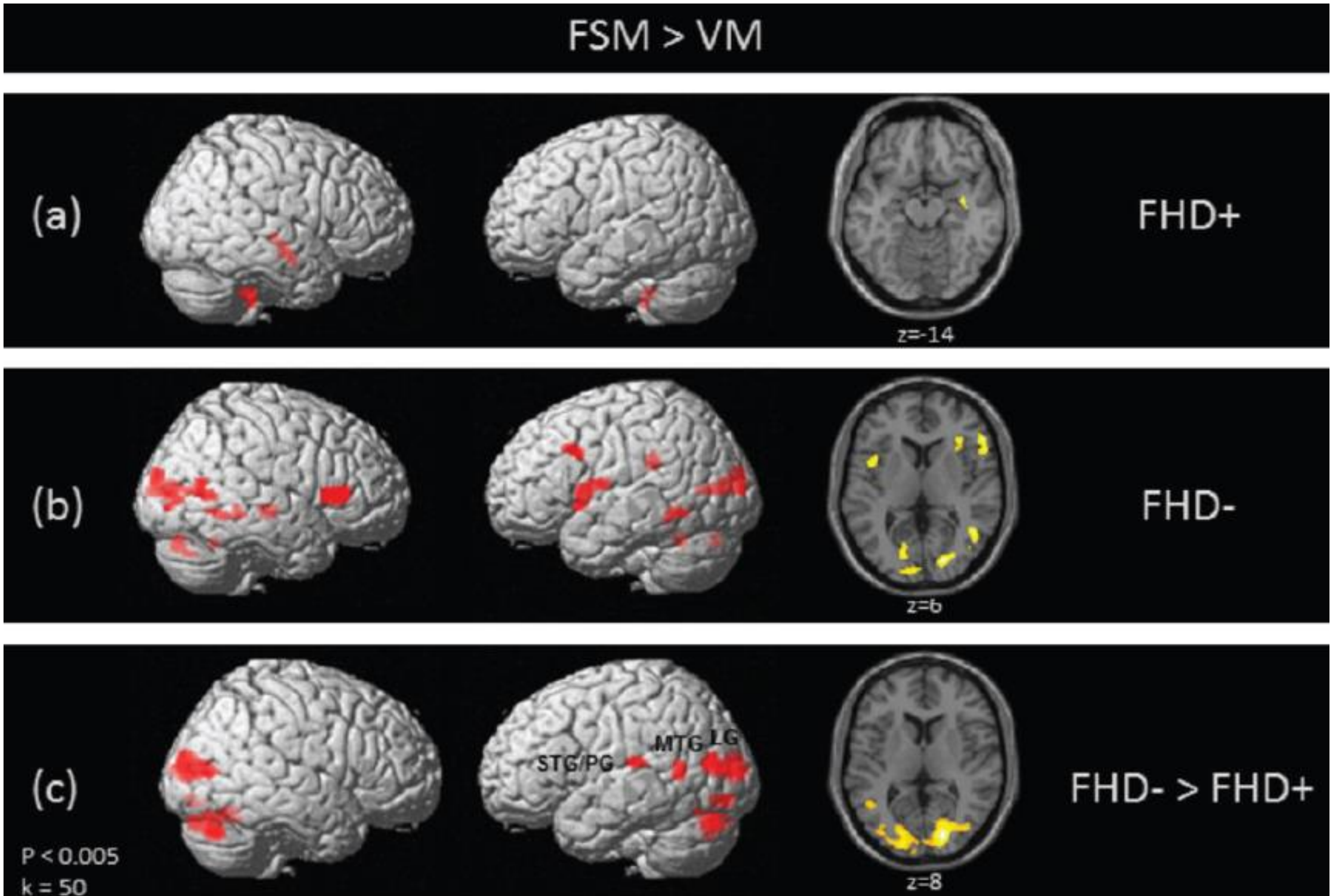
[Raschle *et al.* 2009]

YEAR 1 (prereading status)	**YEAR 2 (beginning readers)**	**YEAR 3/4 (readers)**
Significant differences in:	*Significant differences in:*	*Significant differences in:*
Expressive and receptive language/content	Expressive language/ Language content	Core and receptive Language
Phonological processing	Phonological processing	
Rapid automatized naming	Rapid automatized naming	Rapid automatized naming
Rapid auditory Processing	Letter knowledge	
	Single word reading (timed/untimed)	Single word reading (timed/untimed)
	Passage comprehension	Passage comprehension
	Spelling	Spelling
		Reading Fluency
all $p<0.05$	*all $p<0.05$*	*all $p<0.05$*

No differences in
IQ, age, Home Literacy, SES

Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset

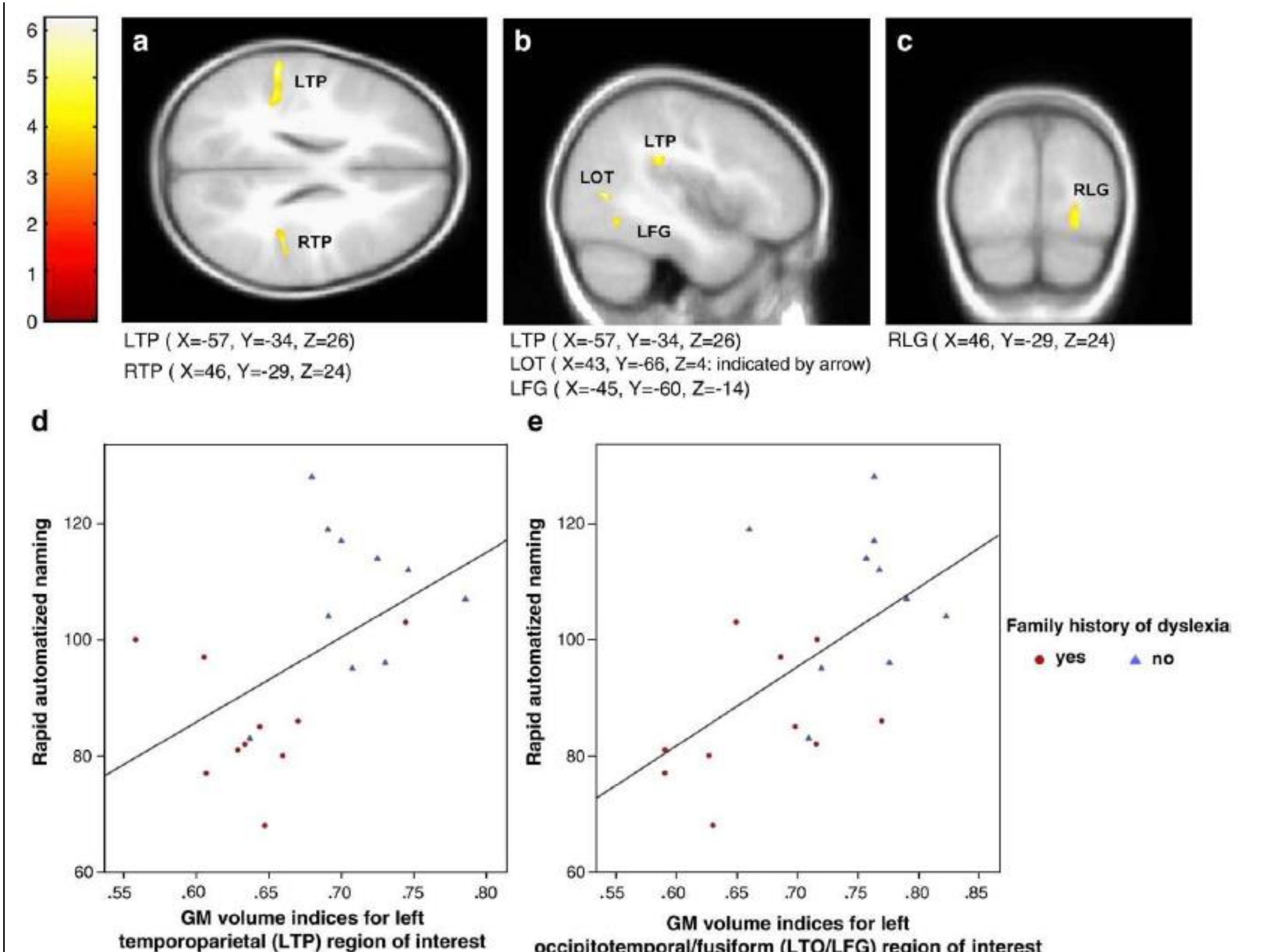
Nora Maria Raschle[a,b], Jennifer Zuk[a], and Nadine Gaab[a,b,c,1]



[Raschle *et al.*, PNAS 2012]

Structural brain alterations associated with dyslexia predate reading onset

Nora Maria Raschle, Maria Chang, Nadine Gaab *



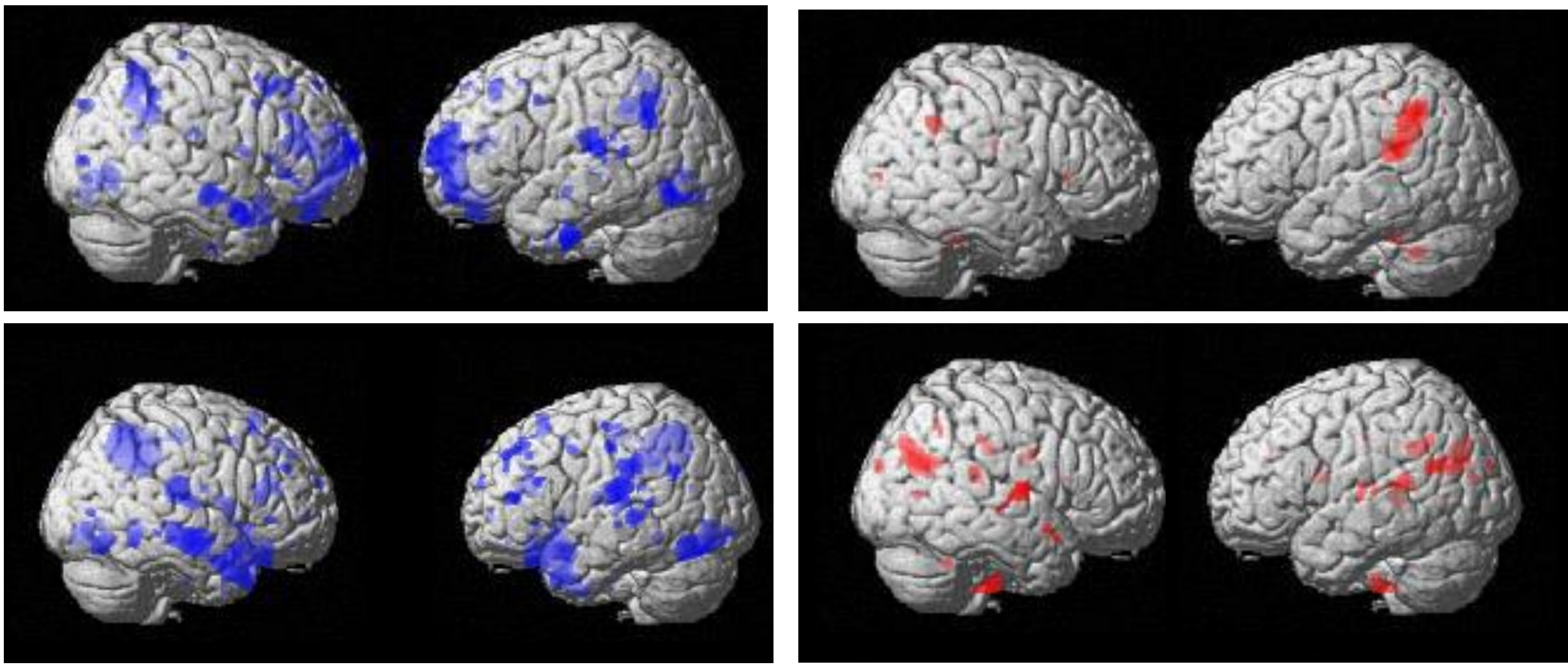
[Raschle *et al.*, Neuroimage 2010]

Longitudinal data (before and after reading onset) in subsequent good and poor readers

[Raschle *et al.*, in prep]

Preschool

Kinder-
garten



Subsequent Good >
Subsequent Poor Reader

Subsequent Good >
Subsequent Poor Reader

$p < 0.001$ &
$p < 0.005$

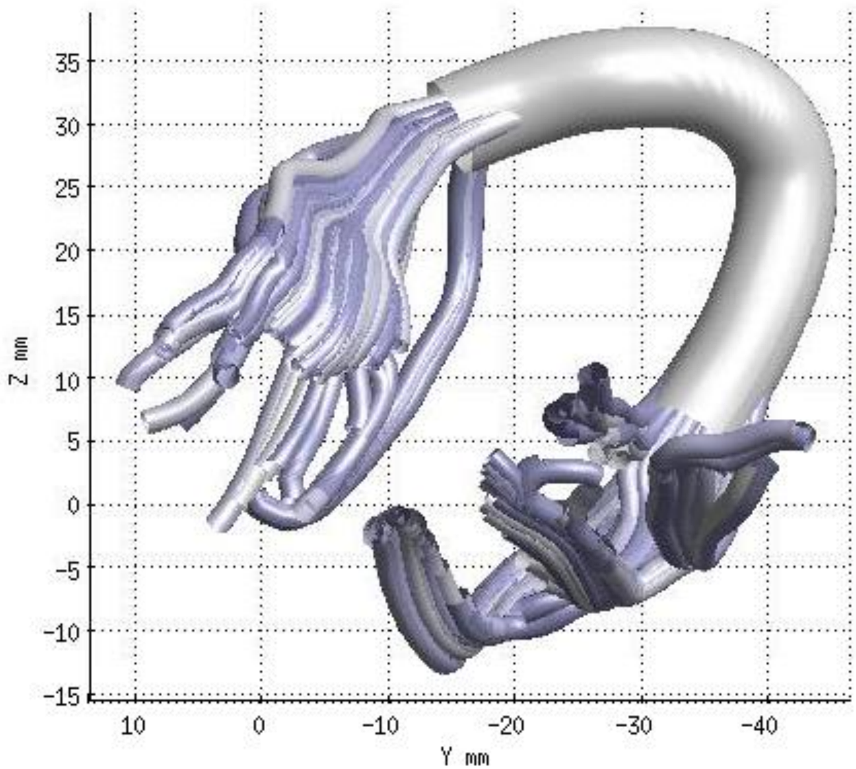
OPEN ACCESS Freely available online

PLOS ONE

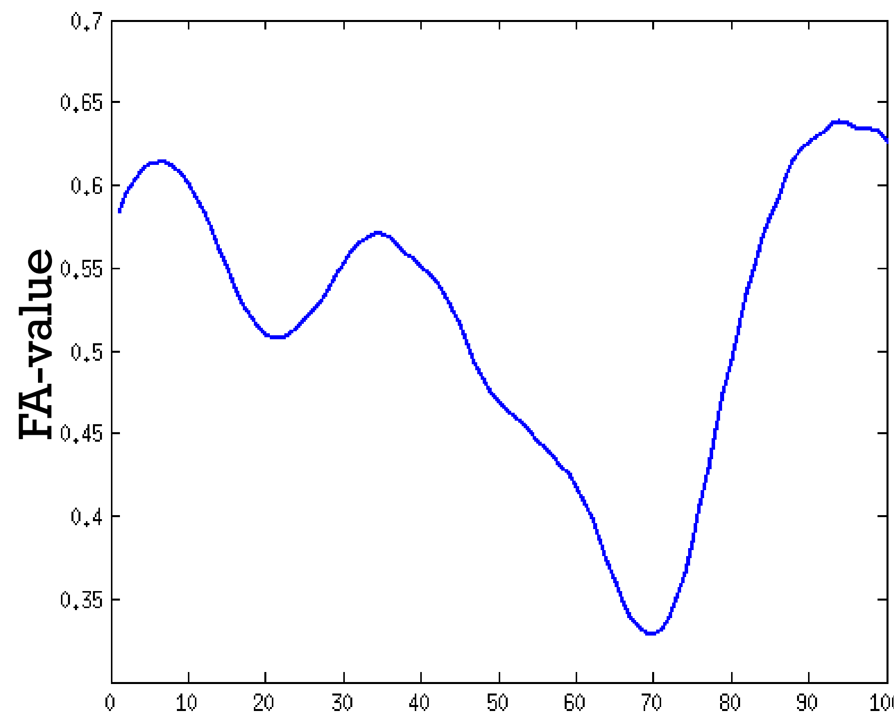
Tract Profiles of White Matter Properties: Automating Fiber-Tract Quantification

Jason D. Yeatman[1,2]*, Robert F. Dougherty[2], Nathaniel J. Myall[3], Brian A. Wandell[1,2], Heidi M. Feldman[3,4]

1 Department of Psychology, Stanford University, Stanford, California, United States of America, 2 Stanford Center for Cognitive and Neurobiological Imaging, Stanford University, Stanford, California, United States of America, 3 Stanford University School of Medicine, Stanford, California, United States of America, 4 Division of Neonatal and Developmental Medicine, Department of Pediatrics, Stanford University School of Medicine, Stanford, California, United States of America

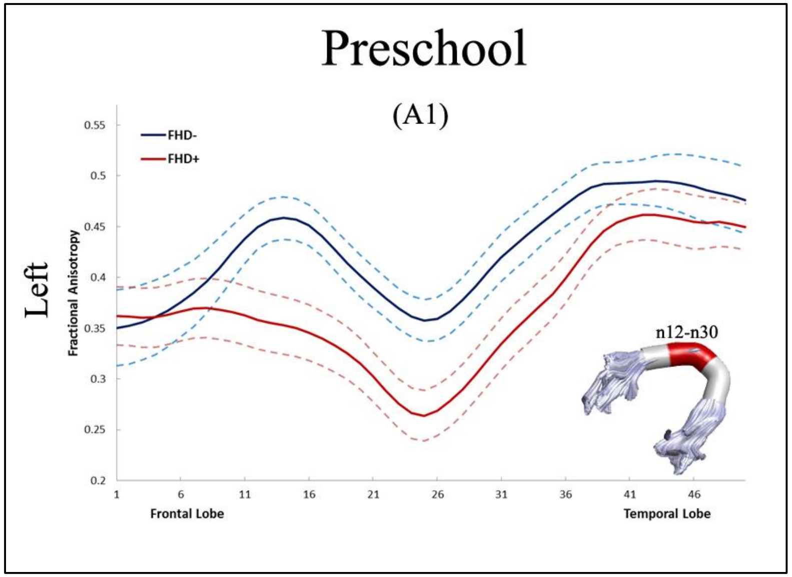


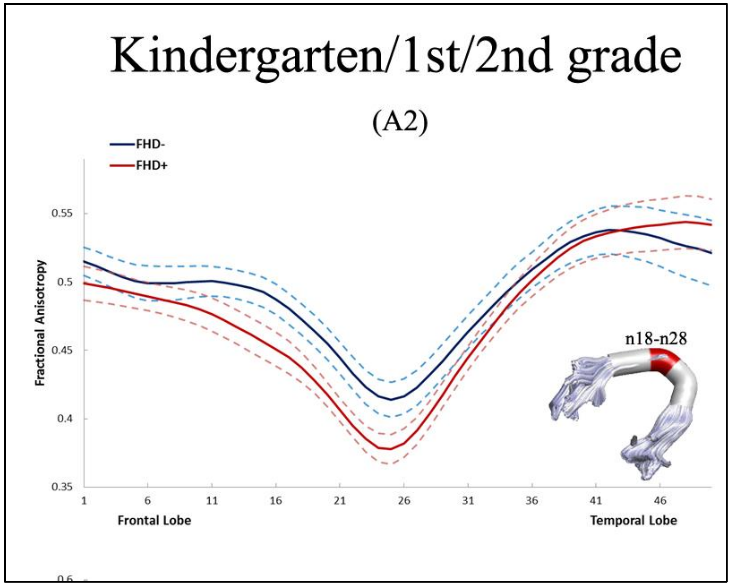
Tract Diffusion Profile

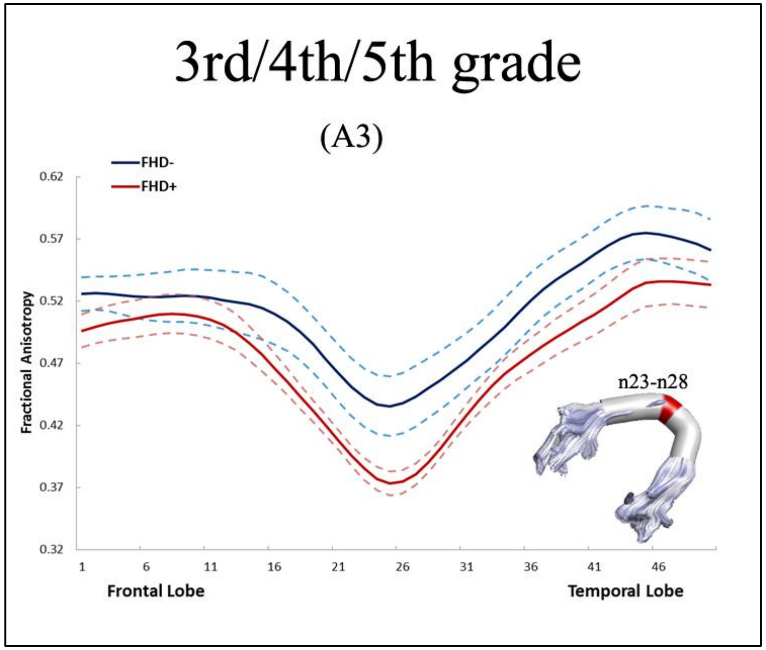


location on the tract

Development of the AF (Cross-sectional)



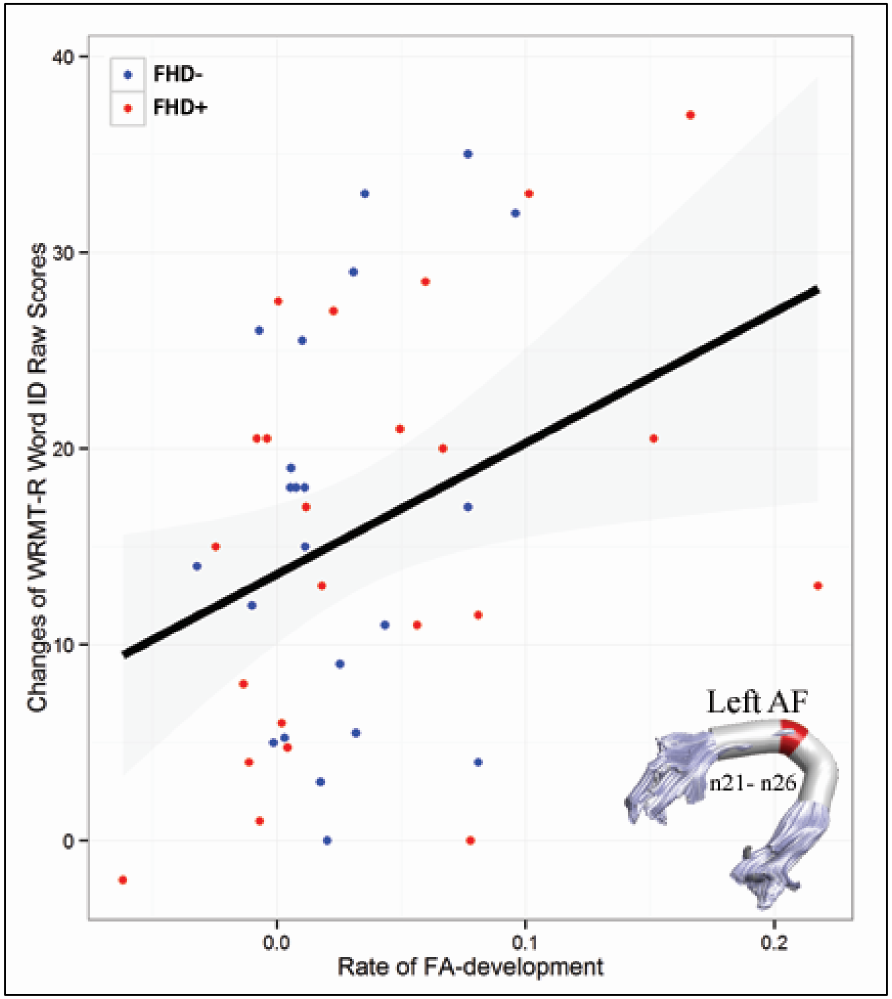




n = 78
112 scans included

Wang *et al.*, in revision

Linking FA development and reading development



Wang *et al*., in revision

ORIGINAL ARTICLE

Atypical Sulcal Pattern in Children with Developmental Dyslexia and At-Risk Kindergarteners

Kiho Im[1,4], Nora Maria Raschle[2,4,6], Sara Ashley Smith[2], P. Ellen Grant[1,3,4], and Nadine Gaab[2,4,5]

- Sulcal pattern (global pattern of arrangement, number and size of sulcal segments)has been hypothesized to relate to optimal organization of cortical function and white matter connectivity (Van Essen, 1997; Klyachko and Stevens, 2003; O'Leary et al., 2007; Fischl et al., 2008).
- Individuals with DD may undergo atypical sulcal development. Moreover, global sulcal pattern is determined during prenatal development and may therefore better reflect genetic brain development (Rakic, 2004; Kostovic and Vasung, 2009).

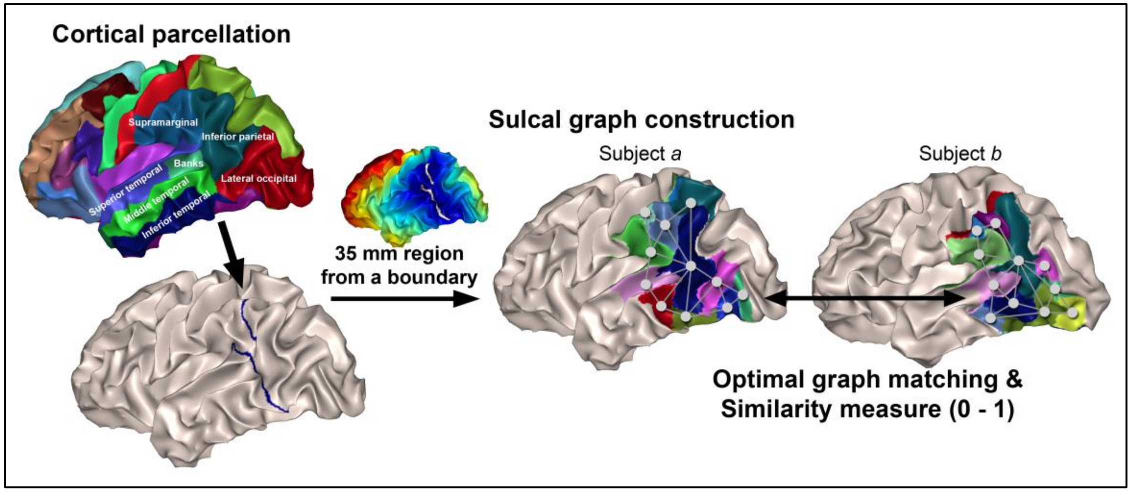
[Im *et al.*, Cerebral Cortex 2015]

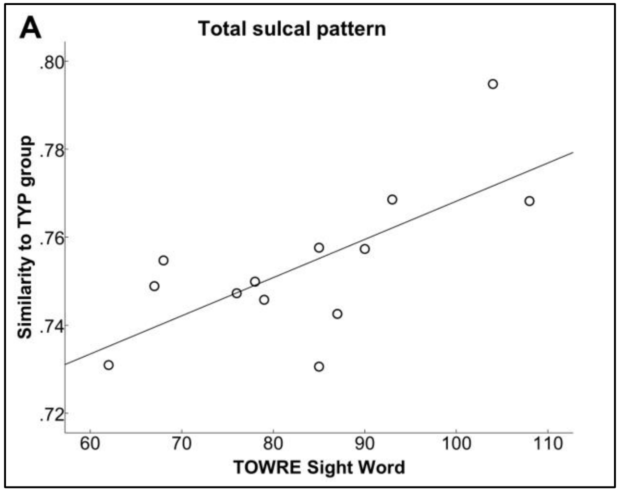
Four groups:
1. Beginning readers FHD-
2. Beginning readers FHD+

3. Developmental Dyslexia
4. Typical developing children

- The pattern of sulcal basin area in the left parieto-temporal and occipito-temporal regions was significantly atypical in children with DD compared to controls.

- Significantly atypical sulcal area pattern was also confirmed in kindergarteners with a familial risk of DD compared to controls.





Im *et al.*, in 2015

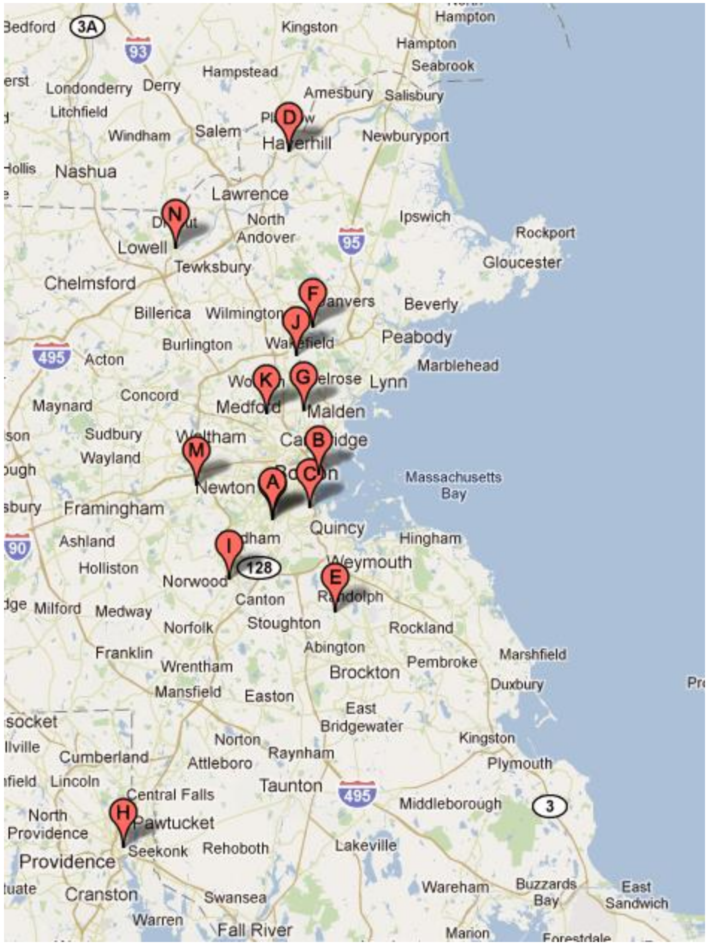
Massachusetts Institute of Technology

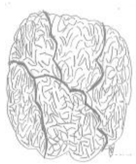
The READ Study
(Researching Early Attributes of Dyslexia)

- Screening of 1,433 children in 21 ‘partner’ schools in New England in 2011, 2012 and 2013. Highly diverse sample in terms of SES, race/ethnicity, and school type.
- Invited children with and without risk for dyslexia to participate in a follow-up study including brain imaging with MRI and EEG (n =180 for EEG and n=160 for MRI).
- Following these children to see which measures from kindergarten best predict reading ability at the end of 1st and 2nd grade.

READ at a Glance

- 21 schools: inner-city charter schools, private, suburban district-run schools, and Archdiocese schools
- Free/reduced lunch eligibility from 0% to 80%
- Ethnically diverse student population (49% minority)
- Teacher professional developments and parent presentations conducted in all schools
- Brain awareness days conducted in various schools





"We very much enjoyed everything you and your staff provided. You are warm and professional and certainly put your subjects at ease…It's exciting to see such cutting-edge research from the inside out!" (Parent, Wheeler School)

"Your whole team was terrific in making the afternoons lots of fun and educational" (Parent, Hosmer Elementary)

"…They were excellent presenters. The students had a wonderful time and were very engaged in the activities." (Teacher, Lowell Elementary)

Key Assessments

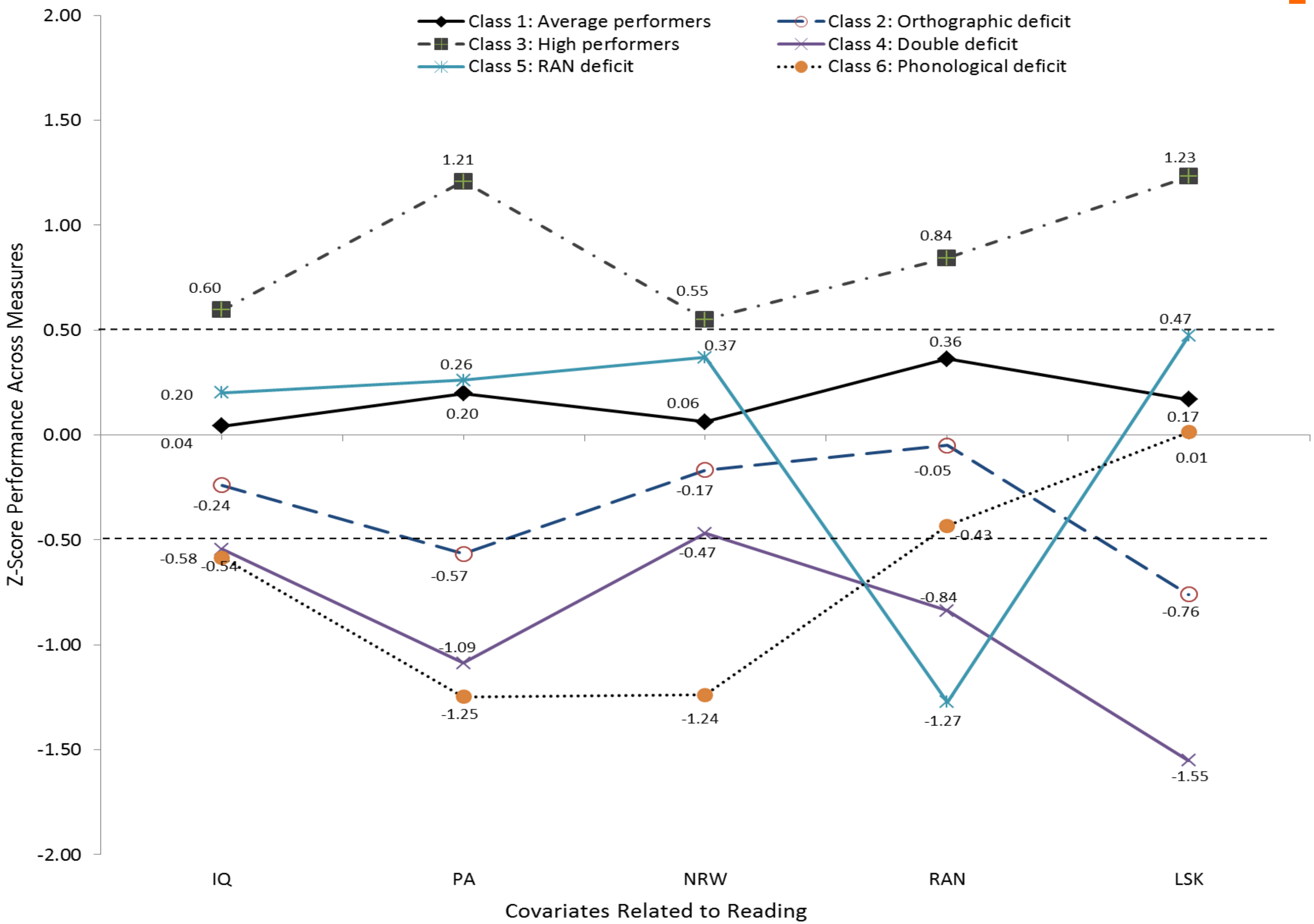
Kindergarten

Phonological Awareness (CTOPP)	Rapid Automatized Naming (RAN/RAS Tests)	Letter and Word ID (WRMT-3)
- Elision - Blending	- Objects - Colors - Letters	- Letter ID - Word ID - Letter sound (YARC)

1st Grade

Reading (GORT-5)

Six Distinct Cognitive Profiles of Early Reading



Ozernov-Palchik et al., in prep

Project READ

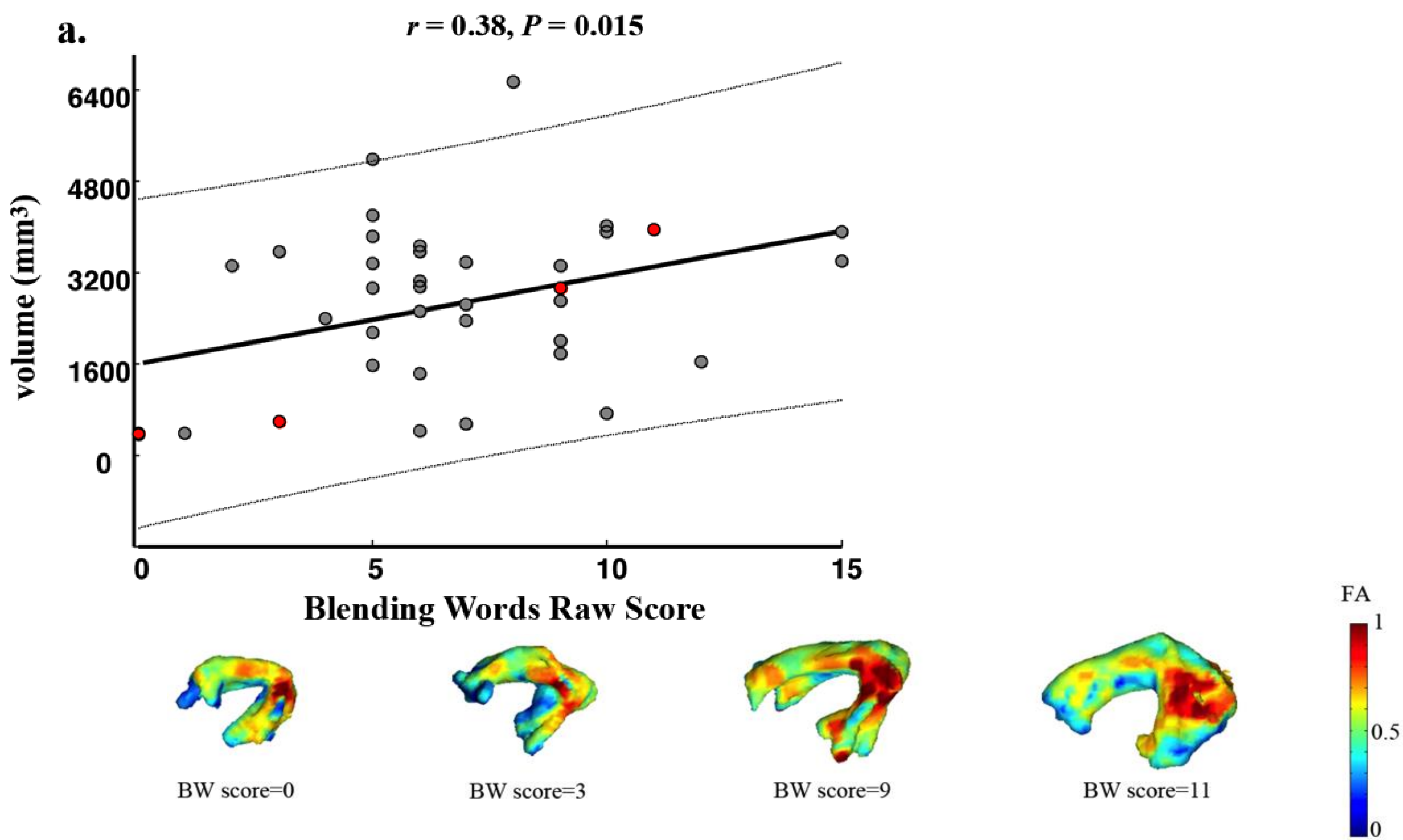
Brain Imaging and Longitudinal Follow-up

- 186 children total, 115 with risk for dyslexia
  - 31% low phonological awareness
  - 28% low letter knowledge
  - 38% low RAN scores
  - 15% with family history of dyslexia

Tracking the Roots of Reading Ability: White Matter Volume and Integrity Correlate with Phonological Awareness in Prereading and Early-Reading Kindergarten Children

Zeynep M. Saygin,[1*] Elizabeth S. Norton,[1*] David E. Osher,[1] Sara D. Beach,[1] Abigail B. Cyr,[1] Ola Ozernov-Palchik,[3] Anastasia Yendiki,[4] Bruce Fischl,[2,4] Nadine Gaab,[3] and John D.E. Gabrieli[1]

The Journal of Neuroscience, August 14, 2013 • 33(33):13251–13258 • **13251**



Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

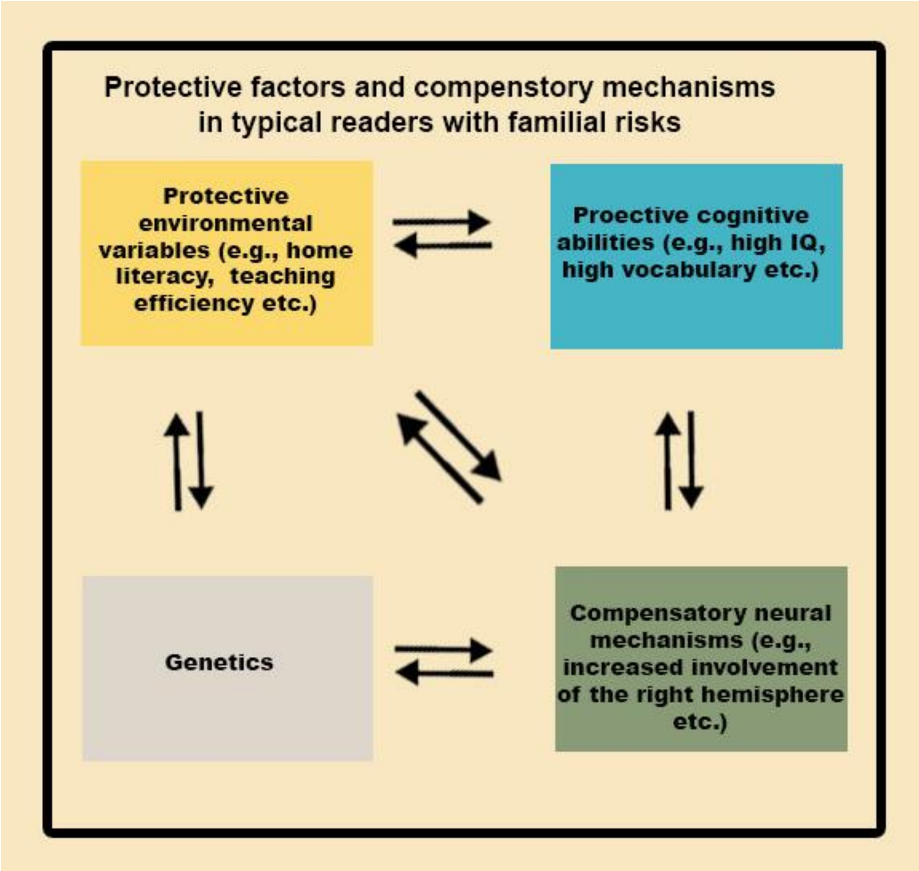
Why do some kids improve and others don't?

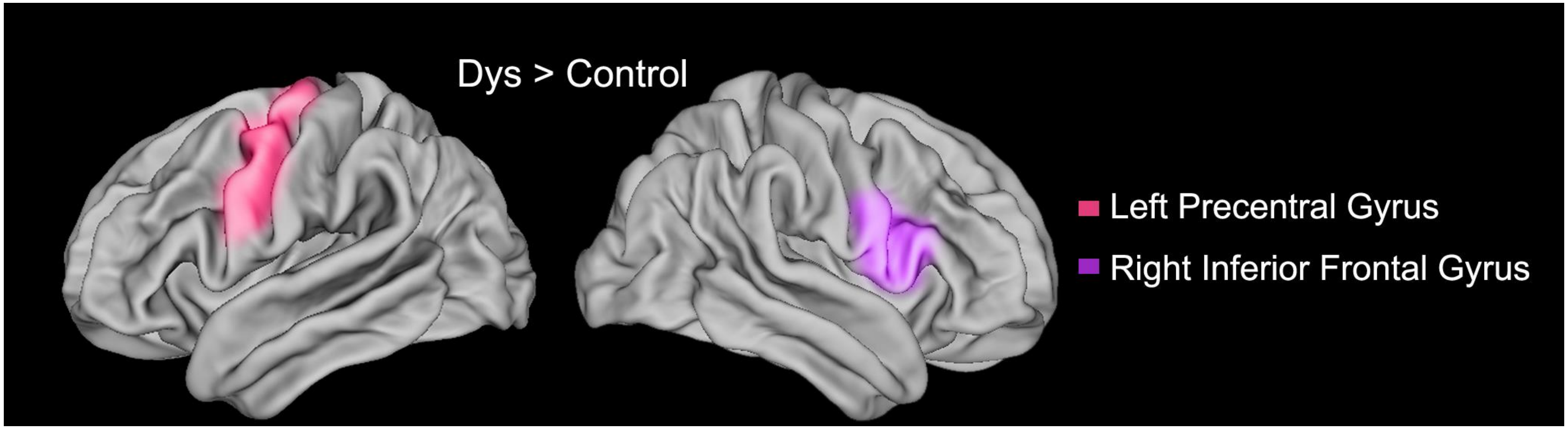
- Some children do compensate and some don't
- What is the brain basis of compensation?

→ more like typical development?

→ Alternative pathway(s)?

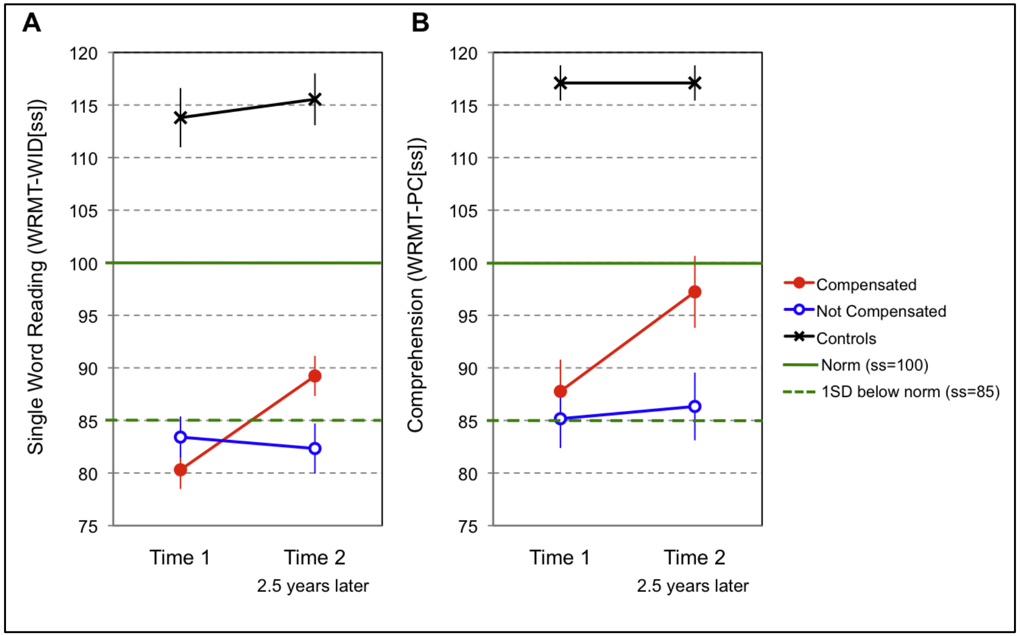
Who does compensate?

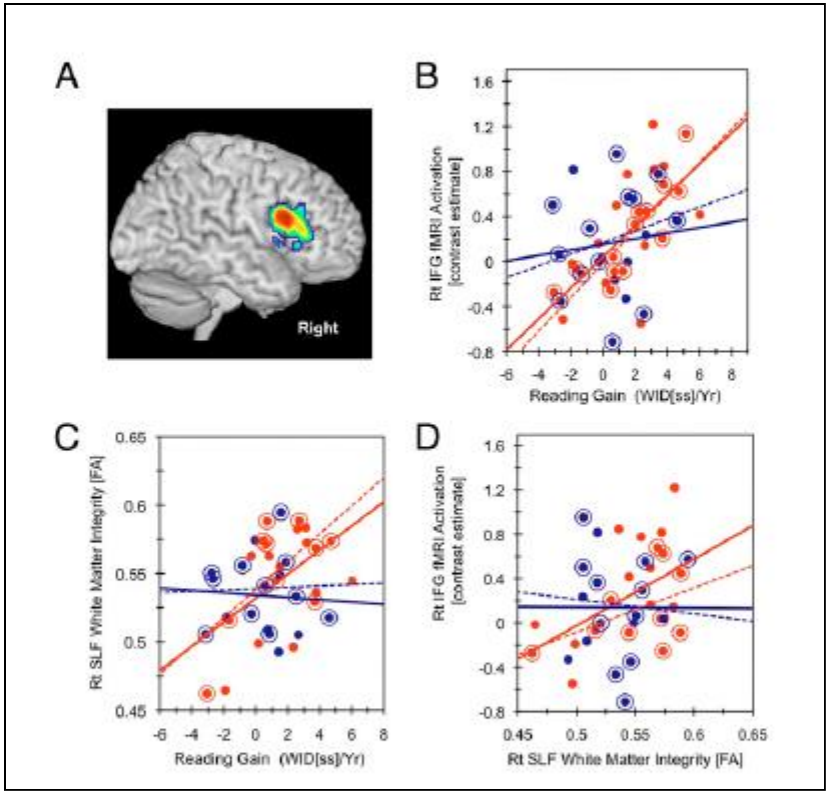

Protective factors and compenstory mechanisms in typical readers with familial risks
Protective environmental variables (e.g., home literacy, teaching efficiency etc.)
Proective cognitive abilities (e.g., high IQ, high vocabulary etc.)
Genetics
Compensatory neural mechanisms (e.g., increased involvement of the right hemisphere etc.)


Dys > Control
Left Precentral Gyrus
Right Inferior Frontal Gyrus

Neural systems predicting long-term outcome in dyslexia

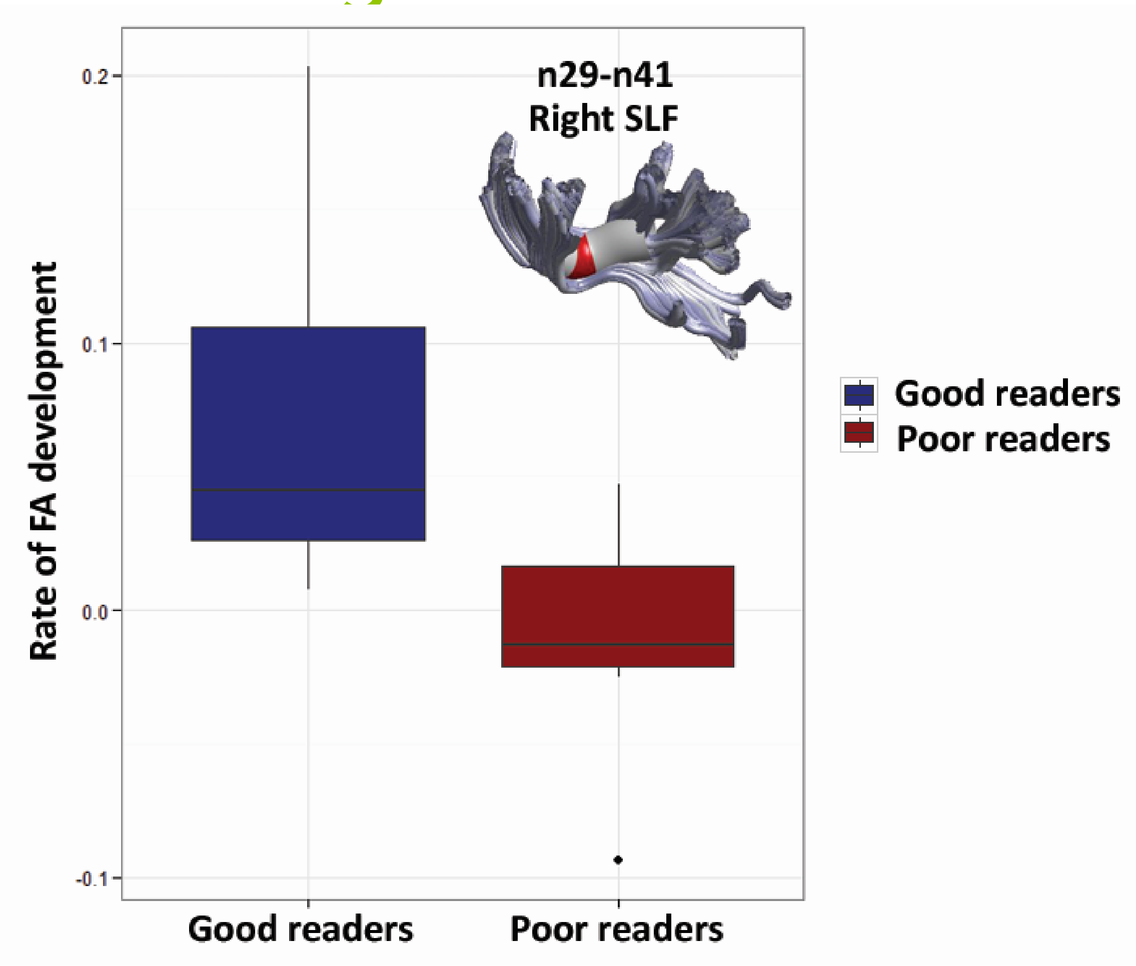
Fumiko Hoeft[a,b,1], Bruce D. McCandliss[c], Jessica M. Black[a,d], Alexander Gantman[a], Nahal Zakerani[a], Charles Hulme[e], Heikki Lyytinen[f], Susan Whitfield-Gabrieli[g], Gary H. Glover[h], Allan L. Reiss[a,b,h], and John D. E. Gabrieli[h]

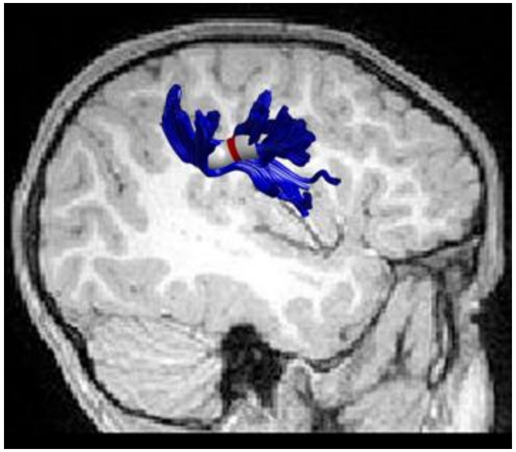




- Brain measures predicted with 92% accuracy which individual children improved and which individual children did not improve 2.5 years later.

Compensatory effects prior to reading onset?





Of 21 FHD+ children, 11 developed into good readers, while 10 developed into poor readers. The subsequent good readers show higher FA development rates in right SLF

Wang *et al*., in revision

Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

Demographics

	FHD-	FHD+	T-test 2-tailed
N	18	14	
Age (days)	297.78 ± 99.13	332.64 ± 117.91	$p > .100$
Expressive Mullen T-score	48.67 ± 4.77	47.90 ± 10.87	$p > .100$

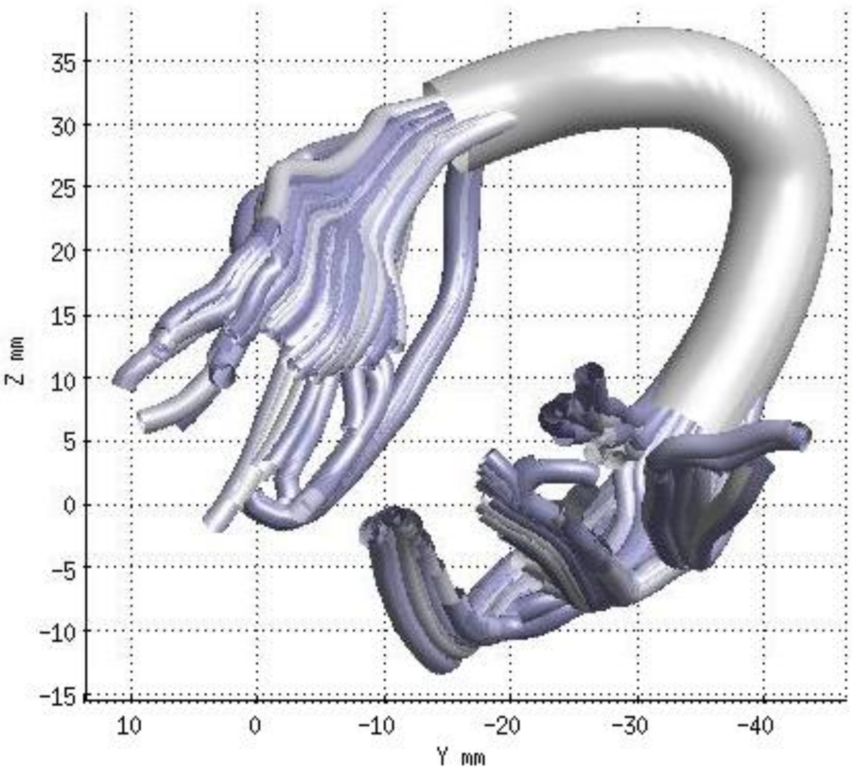
Langer *et al.*, in press

OPEN ACCESS Freely available online PLOS ONE

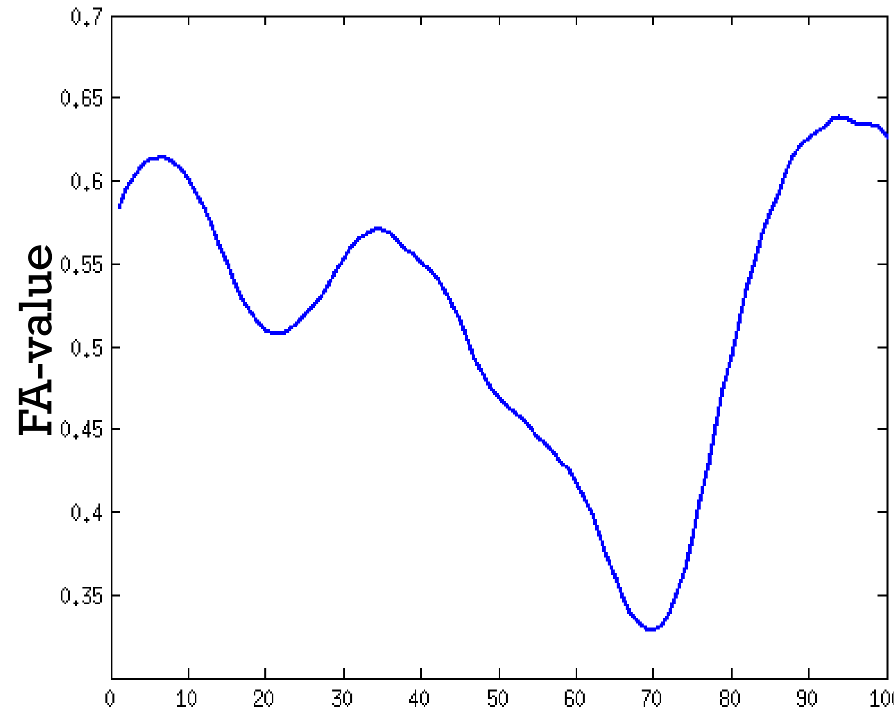
Tract Profiles of White Matter Properties: Automating Fiber-Tract Quantification

Jason D. Yeatman[1,2]*, Robert F. Dougherty[2], Nathaniel J. Myall[3], Brian A. Wandell[1,2], Heidi M. Feldman[3,4]

1 Department of Psychology, Stanford University, Stanford, California, United States of America, 2 Stanford Center for Cognitive and Neurobiological Imaging, Stanford University, Stanford, California, United States of America, 3 Stanford University School of Medicine, Stanford, California, United States of America, 4 Division of Neonatal and Developmental Medicine, Department of Pediatrics, Stanford University School of Medicine, Stanford, California, United States of America

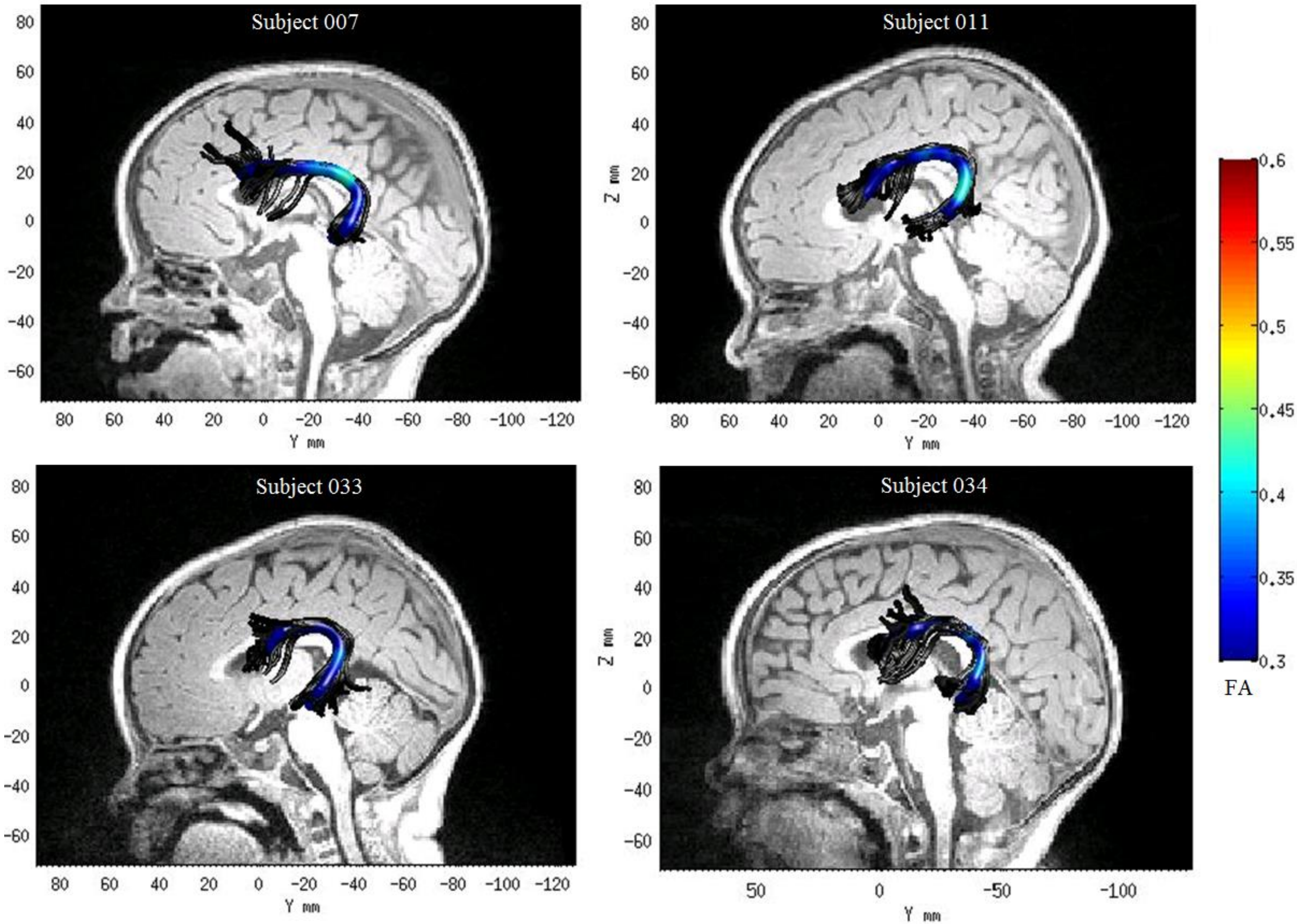


Tract Diffusion Profile



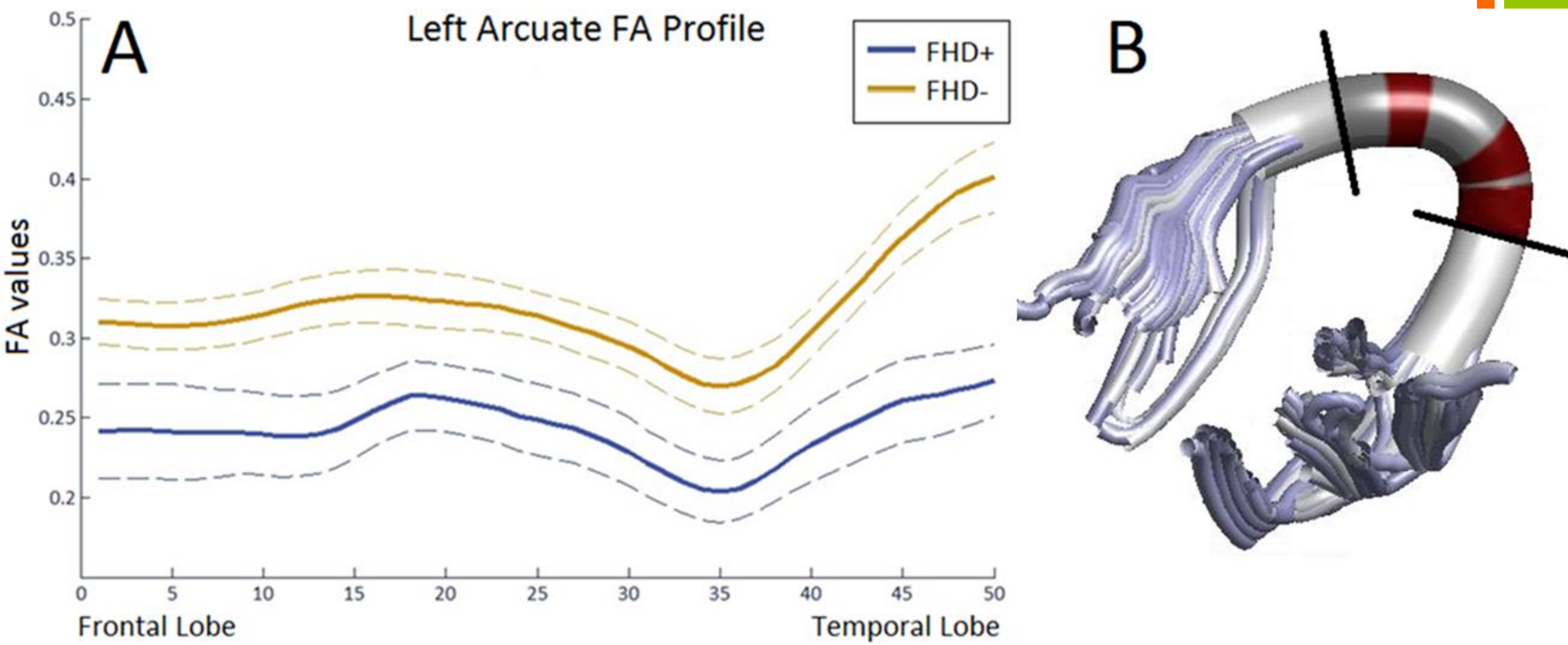
location on the tract

AFQ



Subject 007
Subject 011
Subject 033
Subject 034
Y mm
Z mm
FA
0.6
0.55
0.5
0.45
0.4
0.35
0.3

Automated Fiber Track Quantification in FHD+/FHD- infants



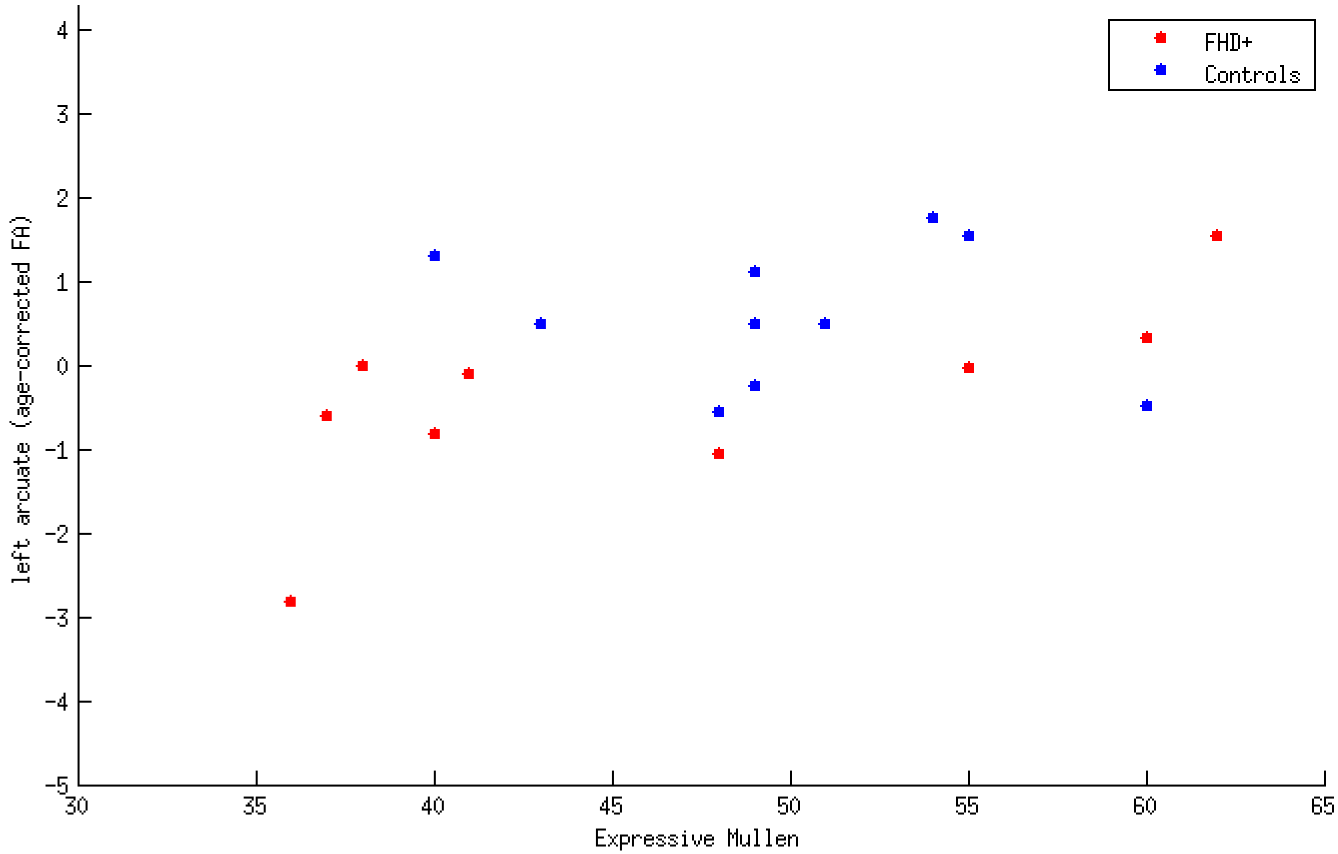
[A] FA values in FHD+ and FHD- infants at each of the 50 nodes.
[B] FHD+ infants exhibit significantly lower FA values compared to FHD- infants in red regions (all $p < 0.02$, controlled for multiple comparisons)

Multivariate pattern analysis (MVPA):
MVPA (using FA at each node of the left AF as input) was performed to determine whether FA can distinguish FHD+ and FHD- infants

- 82% prediction accuracy ($p = 0.001$)

Langer *et al.*, in press

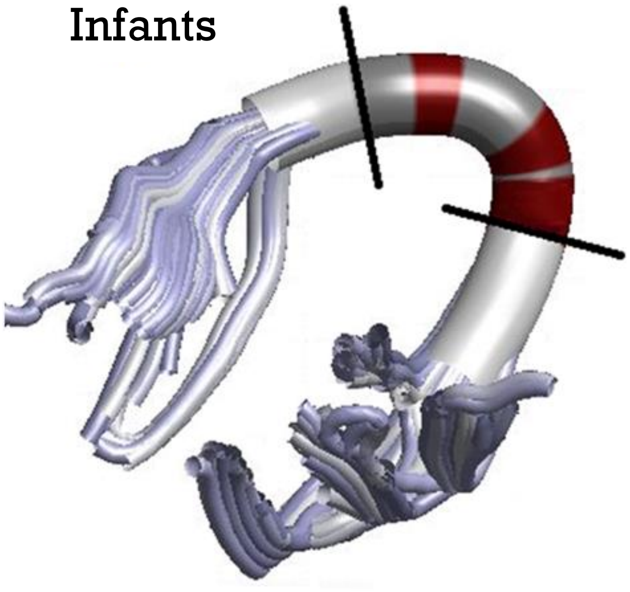
FA values correlate with Expressive Language Scores

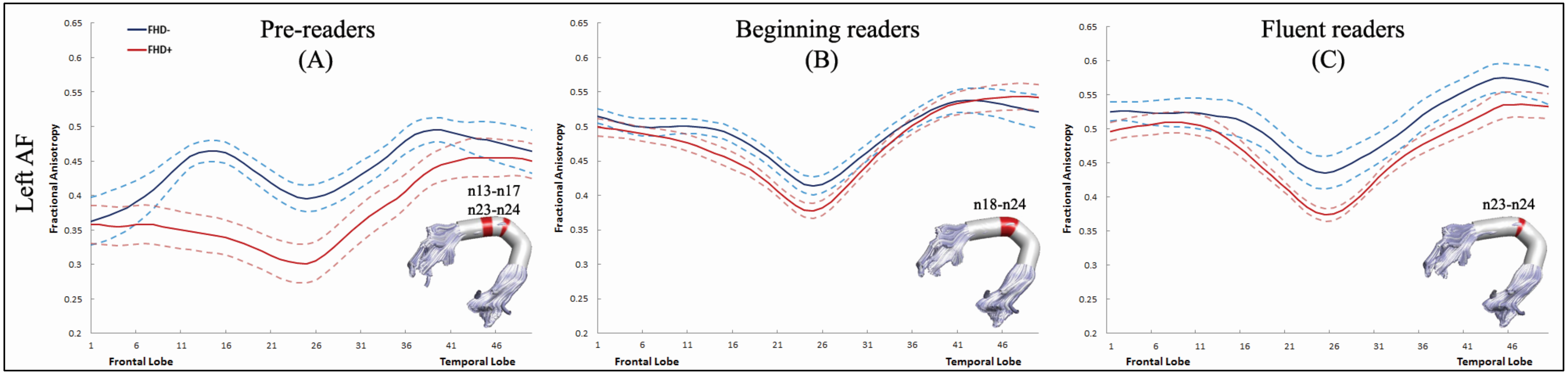


Langer *et al.*, in press

R = 0.481
p = 0.037

Atypical development of AF from infancy to late elementary school?





Overview

- Overview about the Brain
- The typical and atypical reading brain
- Remediating the reading brain
- The dyslexia paradox
- Early pre-markers of dyslexia before reading onset
- Compensatory mechanism and protective factors in DD
- Detecting children at risk for DD in infancy?
- Educational and Clinical Implications

Educational and Clinical Implications

- Early identification may reduce the clinical, psychological and social implications of DD.
- Development and implementation of early and customized remediation programs (who should get which intervention) → Subtyping and early customized remediation
- Informing (early) diagnostic guidelines
- Changes in educational policies (early IEPs; design and implementation of customized curriculums for children at-risk).
- Evaluation and improvement of existing remediation programs will likely prove cost-efficient as programs are made more effective.
- Which brain will benefit from which schooling/teaching style?
- Can we determine if someone is ready for schooling based on their brain?
- Improved psycho-social development (reduced child stress, parental stress, improved overall family dynamic).
- Maximizing use of 'intellectual potential'.
- Most importantly, maximizing the joy to learn to read.

11 Common Myths about Dyslexia

- Dyslexia is a visual problem.
- If you perform well in school, you cannot have dyslexia.
- Smart people can't be dyslexic, if you have dyslexia you cannot be very smart.
- People who have dyslexia are unable to read.
- There are no clues to dyslexia before a child enters school.
- Dyslexia mainly affects boys.
- Dyslexics are 'gifted'/'stupid'.
- Dyslexia disappears with age/can be outgrown.
- Dyslexia is rare.
- Dyslexics will not succeed in life.
- Dyslexia can be cured or helped by special balancing exercises, fish-oils, glasses with tinted lenses, vision exercises, NLP magical spelling, modeling clay letters, inner-ear-improving medications, training primitive reflexes, eye occlusion (patching), etc.

Collaborators:

John Gabrieli, MIT
Ellen Grant, CHB
Paula Tallal, Rutgers University
April Benasich, Rutgers University
Sandra/Joseph Jacobson, Wayne State
Gennaro Chierchia, Harvard University
Autism Excellence Center
Maryanne Wolf, Tufts University
Paulo Andrade, São Paulo
Georgio Sideridis, BCH

Current CHB/MIT Staff:

Nora Raschle (Postdoc)
Nicolas Langer (Postdoc)
Einat Shetreet (Postdoc)
Maria Dauvermann (Postdoc)
Elizabeth Norton (Post-doc READ)
Jennifer Zuk (Graduate student, HST)
Michael Figguccio (Graduate student, BU)
Ola Ozranov-Palchik (Graduate Student Tufts)
Bryce Becker (Project Coordinator BOLD)
Sara Smith (RA, BOLD + Infants)
Barbara Peysakhovic (RA, BOLD + Infants)
Danielle Sliva (RA, BOLD + Infants)
Michelle Lee (Psychometric Assessments)
Sarah Beach (RA, READ)
Abby Cyr (RA, READ)
Zeynep Saygin (READ)
MRI Team, Children's Hospital Boston & MIT

Funding:

- National Institutes of Health
  - BOLD: (1RO1HD065762-03)
  - READ: (1RO1HD067312-03)
  - ACE: (1R01MH100028-02)
- Harvard Catalyst (Infants)
- Harvard Mind/Brain/behavior Faculty Award (for Shetreet project)
- Charles H. Hood Foundation (BOLD)
- Grammy Foundation
- William Randolph Hearst Foundation (Infants)
- Children's Hospital Boston Pilot Award (BOLD)
- Developmental Medicine Center Young investigator Award
- Victory Foundation

www.childrenshospital.org/research-and-innovation/research-labs/gaab-laboratory
www.babymri.org

The Typical and Atypical Reading Brain

Nadine Gaab, PhD
Associate Professor of Pediatrics
Harvard Medical School
Children's Hospital Boston
Developmental Medicine Center
Laboratories of Cognitive Neuroscience

Children's Hospital Boston
Harvard Medical School
HARVARD GRADUATE SCHOOL OF EDUCATION

www.childrenshospital.org/research-and-innovation/research-labs/gaab-laboratory
www.babymri.org