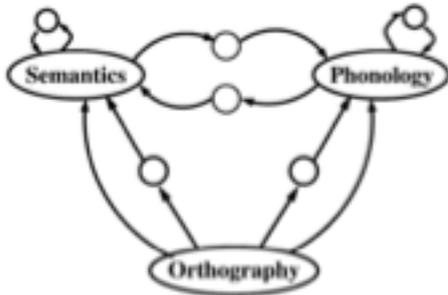


Haskins Labs neurocognitive research on language, reading and reading remediation: Some history and current research studies

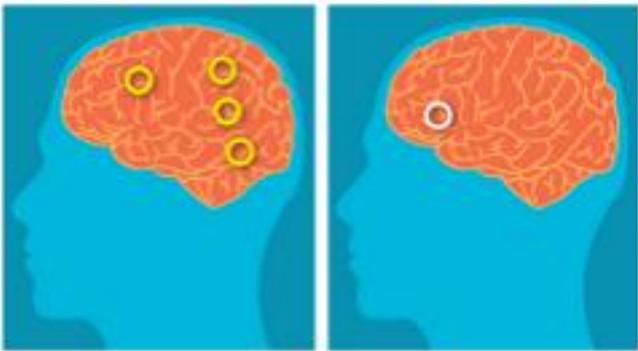
The Motor Theory of Speech
Perception (e.g. Liberman et al. 1967)



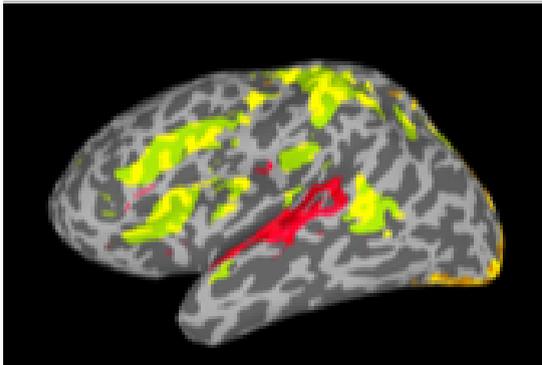
The Orthographic Depth
Hypothesis (e.g. Frost et al. 1987)



Phonological Deficit as
Central to Dyslexia (e.g. Liberman et al. 1974)



Brain bases of Speech & Reading
Related Disorders (e.g. Pugh et al. 2000; 2014)



Speech, Language, Reading, and the Brain

- Speech is a **biological specialization** but written language is largely a cultural invention.
-
- Speech is mastered naturally in almost all people, without direct instruction.
- But reading is difficult and reading failure occurs in large numbers of children across all written languages. **Explicit instruction is essential.**
- No brain specialization for reading. Reading is, in some sense, an exercise in neuronal recycling (Dehaene, 2010).



Exploring neurodiversity

Some “value added” from neuroscience in studying typical and atypical language and reading

Neuroimaging measures (e.g., neuroanatomy, neurochemistry, or functional organization) yield **mediating levels of analysis** between gene and behavioral phenotype.

Exquisite sensitivity to **individual differences**.

Development of **brain-informed approaches** to instruction and treatment of reading difficulties

Cognitive Neuroscience: Neuroplasticity and the cognitive challenge of learning to read

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

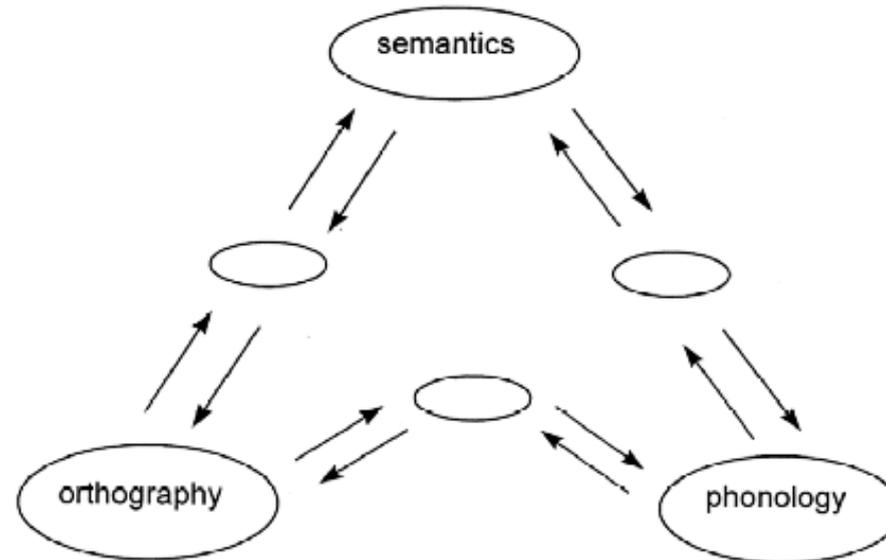
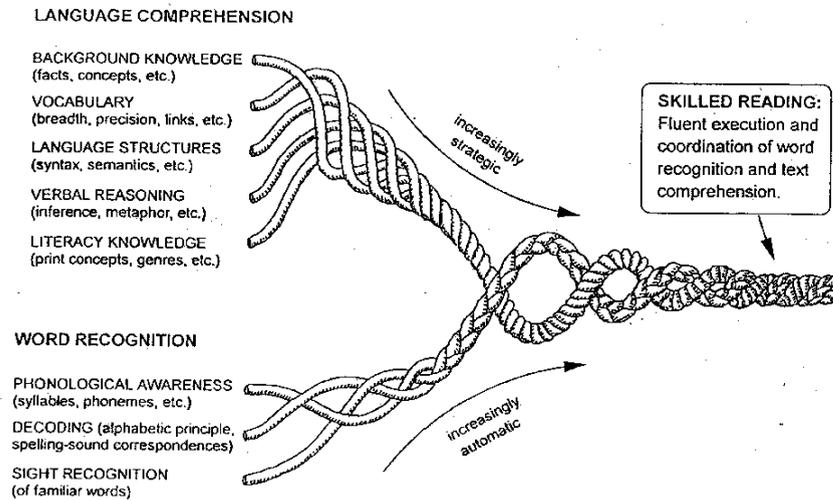
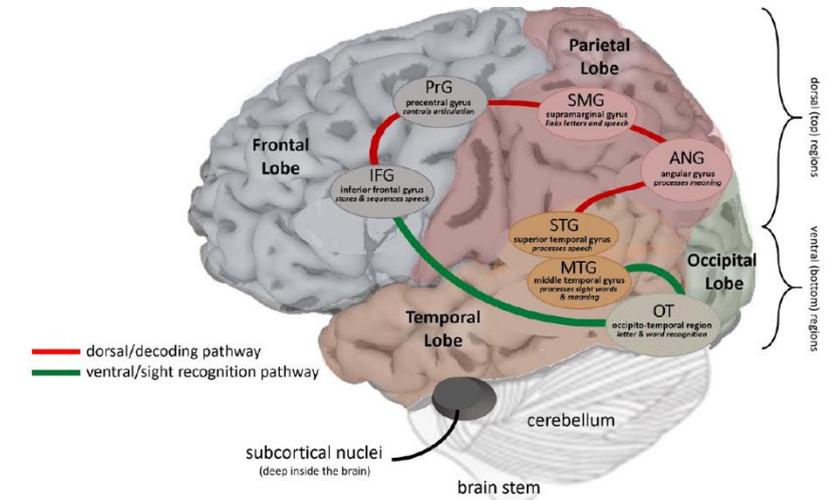
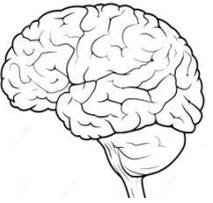
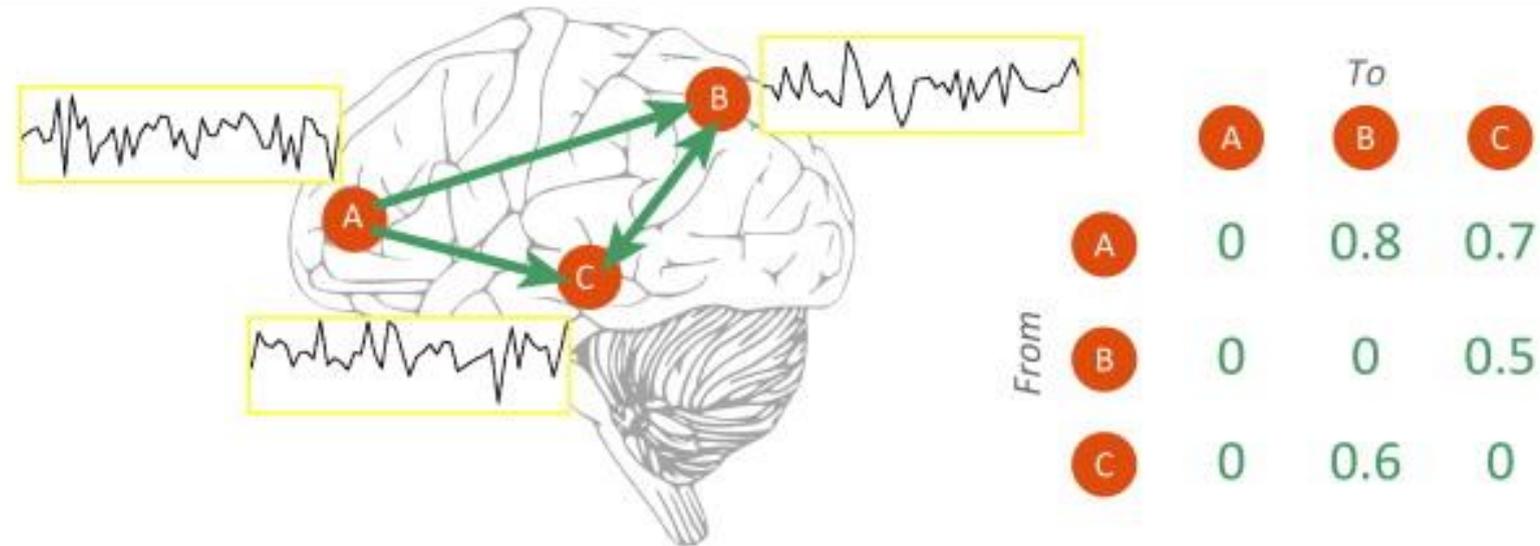
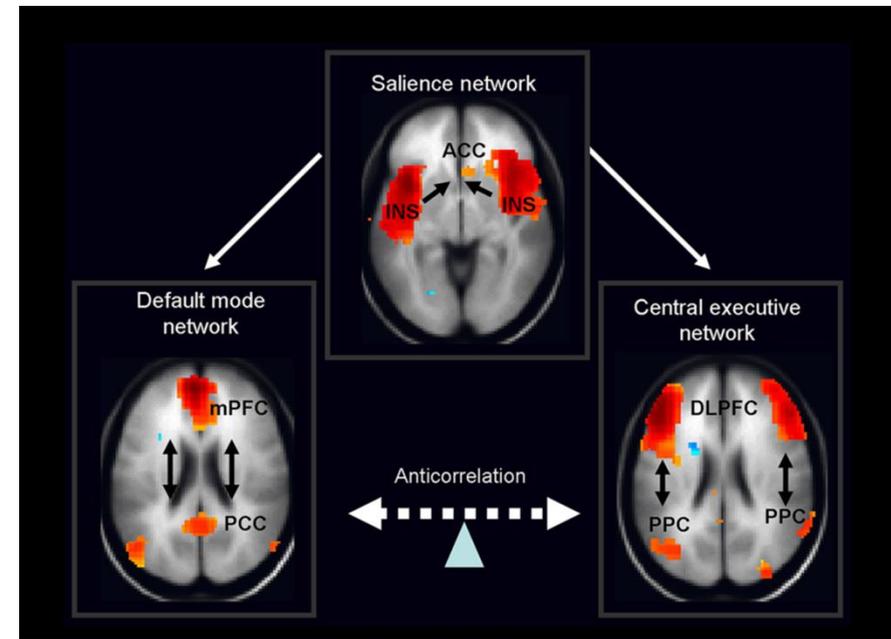


Figure 2. Regions of the reading brain



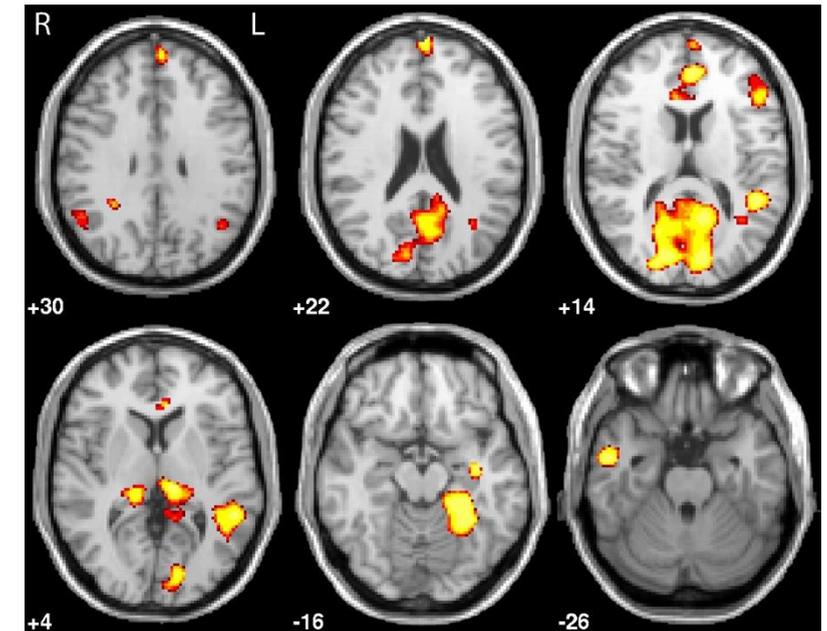
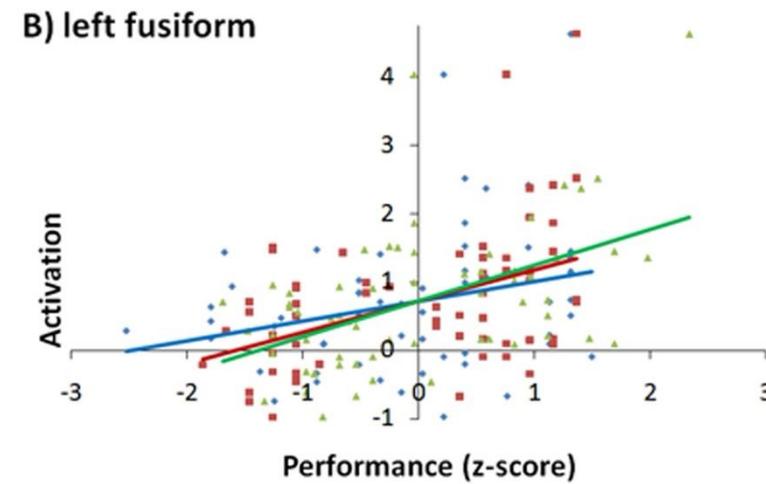
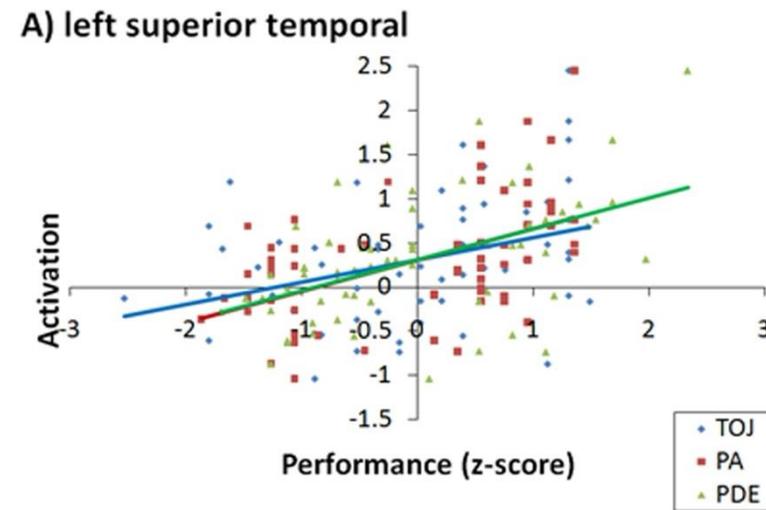
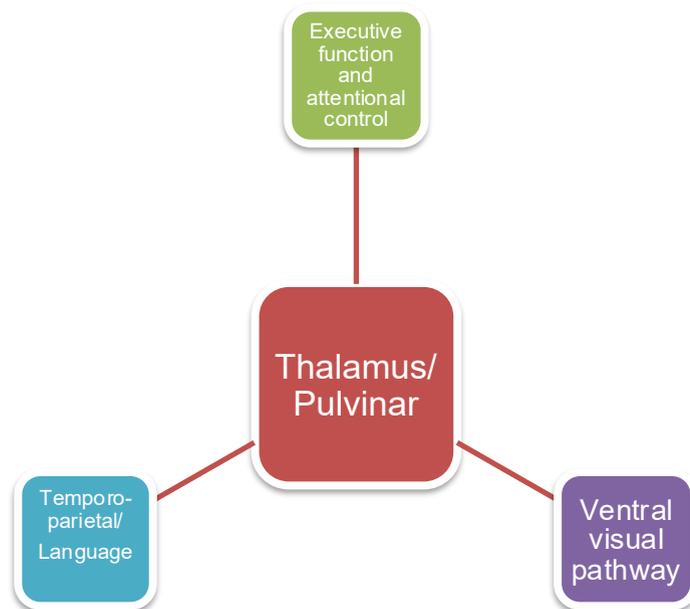


Functional Connectivity



- Define network *nodes* (spatial coordinates or regions of interest)
- Identify a timeseries associated with each node
- Estimate the *edge strengths*, or connections between the nodes
 - For example, correlate each timeseries with every other timeseries
 - If the data (and method for estimating edges) permits the estimation of causality, the edges may be uni-directional, resulting in an asymmetric network matrix

The Learning Circuitry (Pugh et al., 2013)



Print-Speech Convergence Predicts Future Reading Outcomes in Early Readers

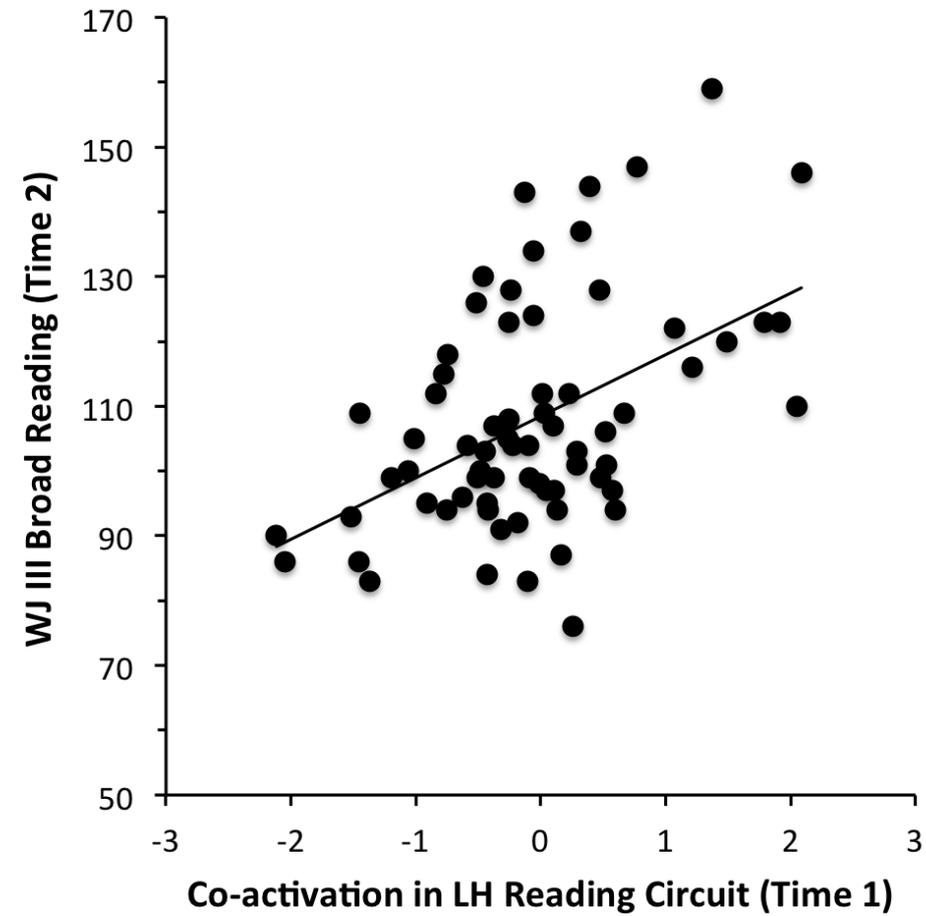
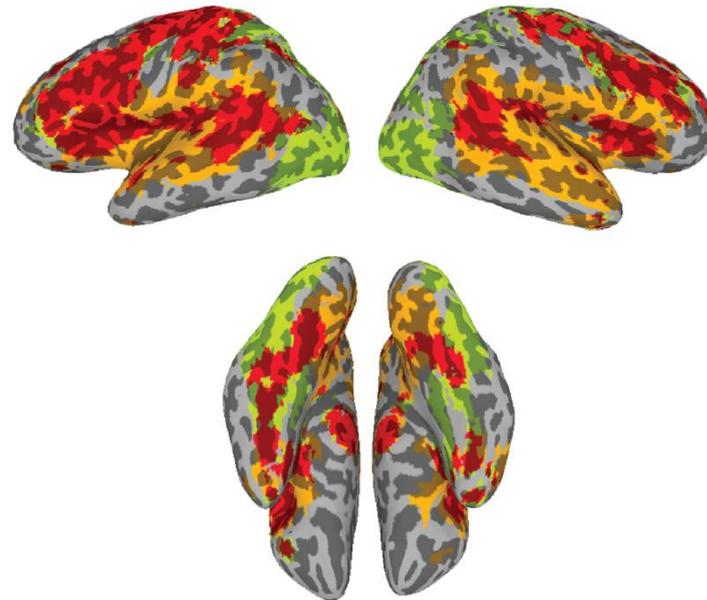
Jonathan L. Preston^{1,2}, Peter J. Molfese^{2,3}, Stephen J. Frost²,
W. Einar Mencl², Robert K. Fulbright⁴, Fumiko Hoeft^{2,5},
Nicole Landi^{2,3}, Donald Shankweiler^{2,3}, and
Kenneth R. Pugh^{2,3}

¹Department of Communication Sciences & Disorders, Syracuse University; ²Haskins Laboratories, Yale University; ³Department of Psychology, University of Connecticut; ⁴Diagnostic Radiology, Yale University School of Medicine; and ⁵Department of Psychiatry, University of California, San Francisco

Psychological Science
1–10
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Abstract

Becoming a skilled reader requires building a functional neurocircuitry for printed-language processing that integrates with spoken-language-processing networks. In this longitudinal study, functional MRI (fMRI) was used to examine convergent activation for printed and spoken language (print-speech coactivation) in selected regions implicated in printed-language processing (the reading network). We found that print-speech coactivation across the left-hemisphere reading network in beginning readers predicted reading achievement 2 years later beyond the effects of brain activity for either modality alone; moreover, coactivation effects accounted for variance in later reading after controlling for initial reading performance. Within the reading network, effects of coactivation were significant in bilateral inferior frontal gyrus (IFG) and left inferior parietal cortex and fusiform gyrus. The contribution of left and right IFG differed





Universal brain signature of proficient reading: Evidence from four contrasting languages

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Roeland Hancock^f, Denise H. Wu^g, William Einar Mencl^a, Jon Andoni Duñabeitia^c, Jun-Ren Lee^h, Myriam Oliver^c,
Jason D. Zevin^{a,i,j}, Fumiko Hoeft^{a,f}, Manuel Carreiras^{c,k}, Ovid J. L. Tzeng^{l,m,n}, Kenneth R. Pugh^{a,b,o}, and Ram Frost^{a,c,e}

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Edited by Michael I. Posner, University of Oregon, Eugene, OR, and approved November 2, 2015 (received for review May 12, 2015)

We propose and test a theoretical perspective in which a universal hallmark of successful literacy acquisition is the convergence of the speech and orthographic processing systems onto a common network of neural structures, regardless of how spoken words are represented orthographically in a writing system. During functional MRI, skilled adult readers of four distinct and highly contrasting languages, Spanish, English, Hebrew, and Chinese, performed an identical semantic categorization task to spoken and written words. Results from three complementary analytic approaches demonstrate limited language variation, with speech–print convergence emerging as a common brain signature of reading proficiency across the wide spectrum of selected languages, whether their writing system is alphabetic or logographic, whether it is opaque or transparent, and regardless of the phonological and morphological structure it represents.

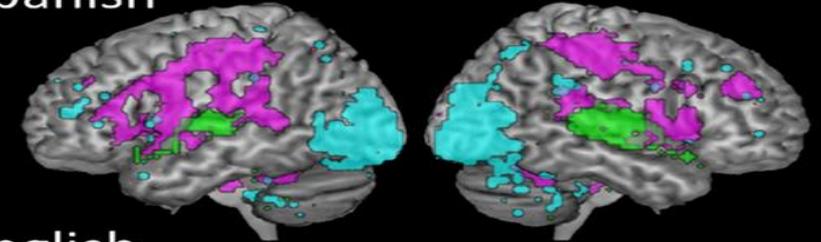
cross-language invariance | word recognition | functional MRI

reading would not only recruit the neural circuits best suited for processing its orthographic symbols (which could show some front-end variation due to visuospatial differences) but would fundamentally depend on access to existing neurocircuits implicated in processing meaningful spoken words (16). By this view, a universal hallmark of successful literacy acquisition would be the emergence of a reading network that is strongly constrained by the brain network underlying the processing of spoken words (a network itself likely to be largely universal across languages), regardless of how these words are represented orthographically (17, 18).

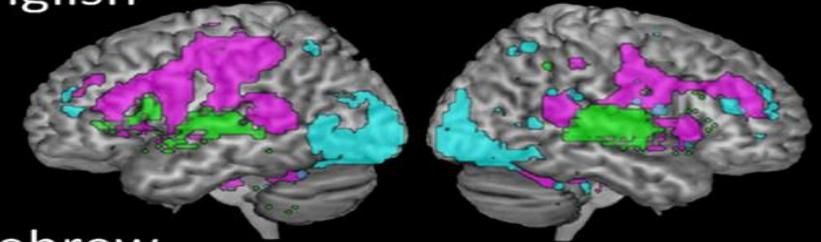
We examined the extent of convergence of neural networks involved in spoken and written word recognition in 84 right-handed, healthy, and skilled adult readers in Spanish, English, Hebrew, and Chinese ($n = 21$ per language; see Table S1 for details on group matching). These languages were selected because they provide contrasts of transparent vs. opaque orthographies with alphabetic vs. logographic writing systems, which map into monomorphemic and monosyllabic words vs. morphologically

PSYCHOLOGICAL AND
COGNITIVE SCIENCES

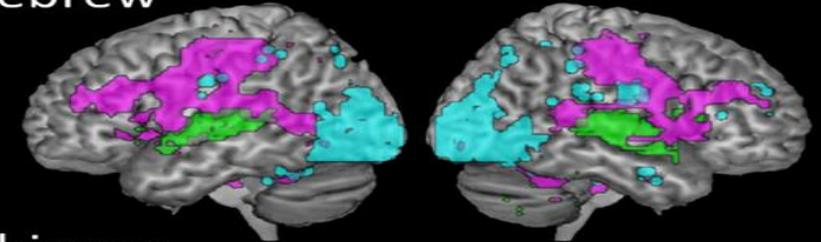
A. Spanish



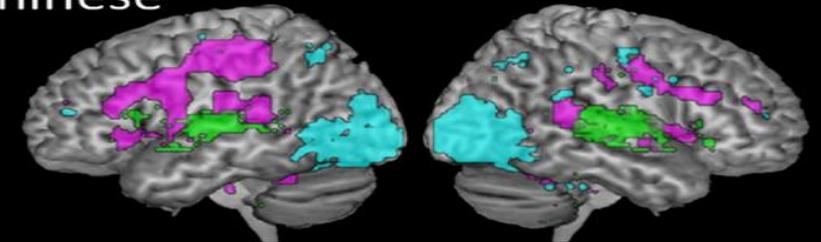
B. English



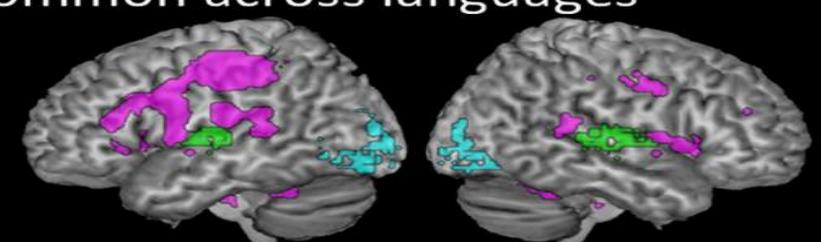
C. Hebrew



D. Chinese



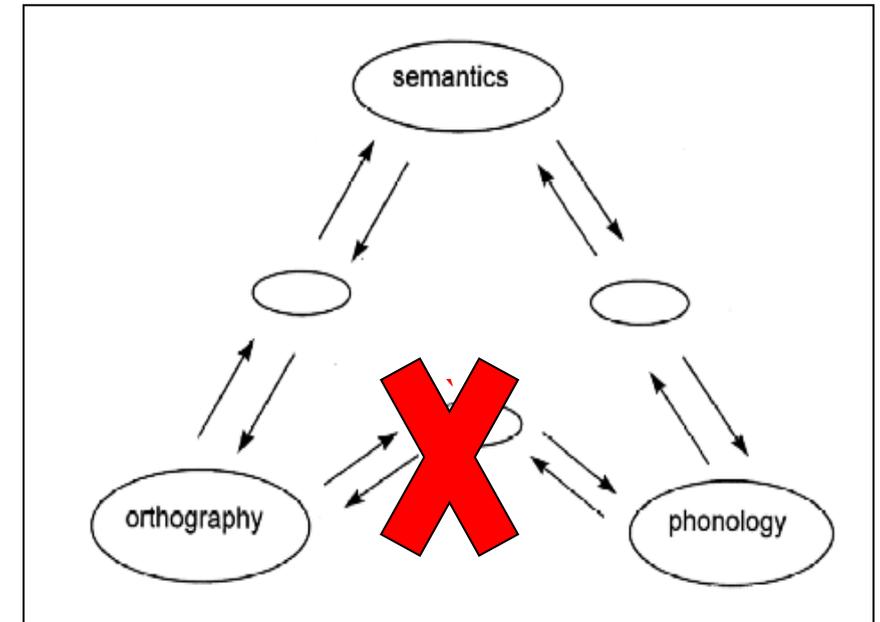
E. Common across languages



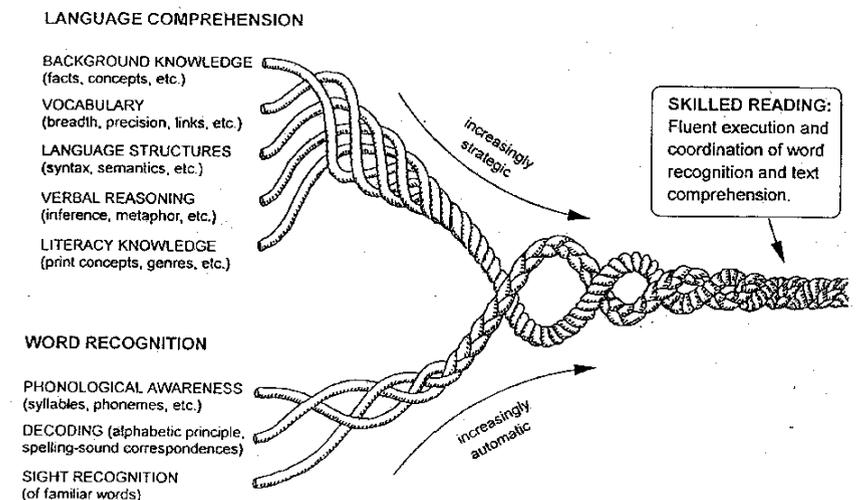
● Visual ● Auditory ● Overlap

Reading Disabilities

- **Dyslexia** is a neurodevelopmental disorder characterized by a deficit in the accurate or fluent decoding of single printed words that is not accounted for by a specific sensory deficit or more general intellectual impairment. (IDA, 2002)
 - Approximately 9% of school age children (Pennington & Bishop, 2009)
- **[Specific] Reading Comprehension Disability** refers to difficulties with reading comprehension that are unexpected based on decoding and other competencies.
 - “...between 10 and 15% of children experience poor comprehension despite ... normal levels of reading accuracy and fluency” (Stothard and Hulme, 1995)

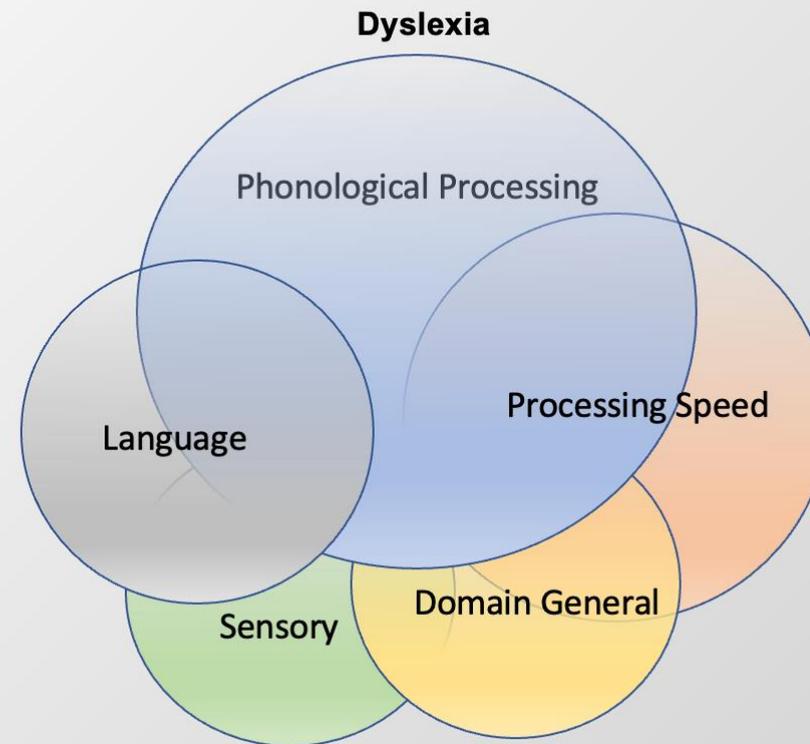


The Many Strands that are Woven into Skilled Reading
(Scarborough, 2001)



Models and Heterogeneity

Multifactorial Model of Reading Disability

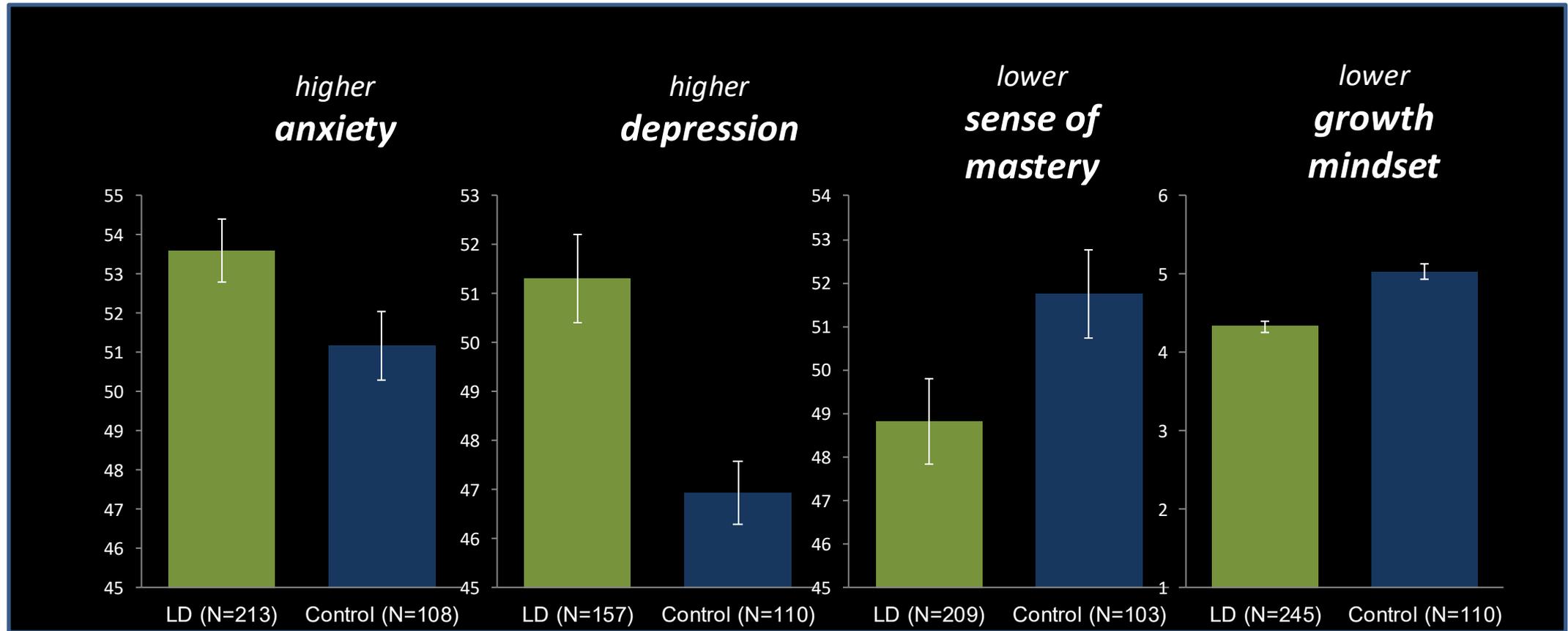


Pennington (2006); Ramus et al. (2003); Menghini et al. (2010); Ziegler et al. (2008); O'Brien & Yeatman (2020)

Reading falls on a continuum, performance has a multifactorial basis, and dyslexia/RD is low tail of the distribution

Key: RD students also experience socio-emotional challenges

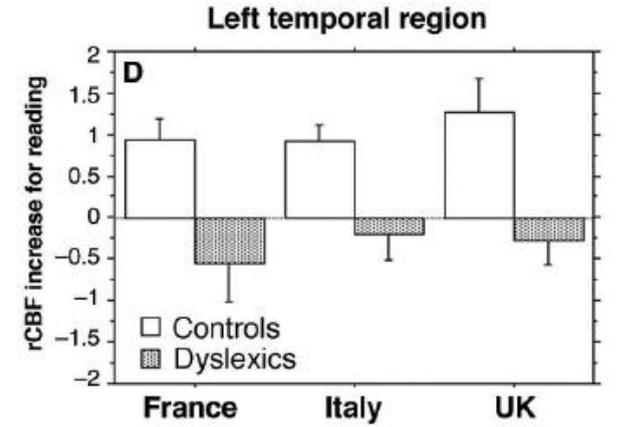
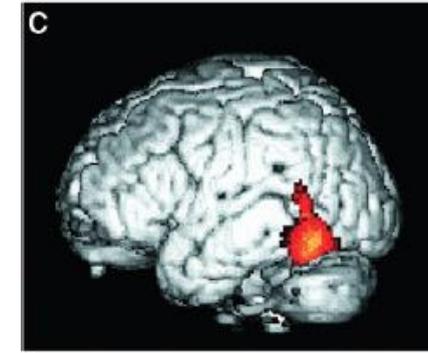
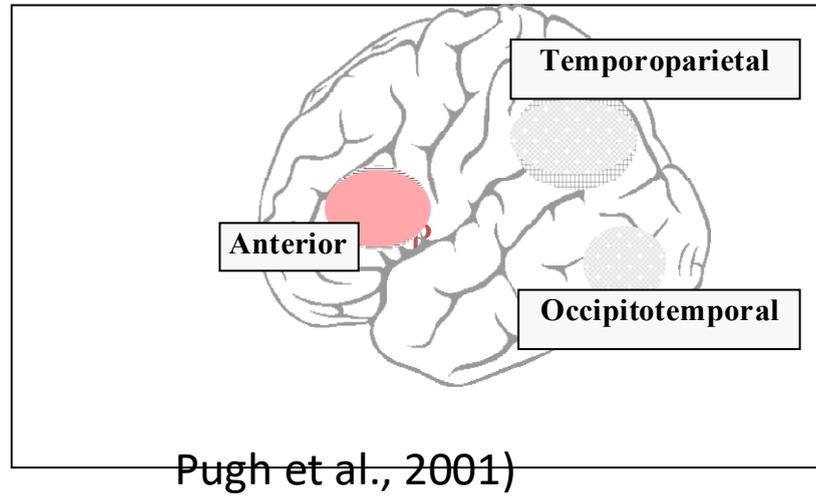
Students with learning DIFFERENCES experience significantly:



...compared to same-aged peers.

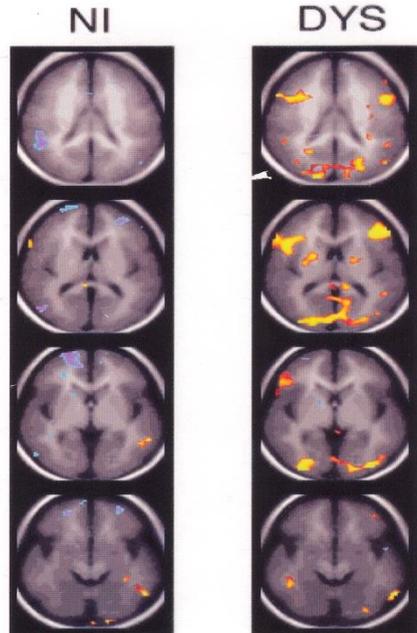
Haft ... Hoeft. JACP '18; Haft ... Hoeft. CAMH '19

LH Brain circuits and reading difficulties

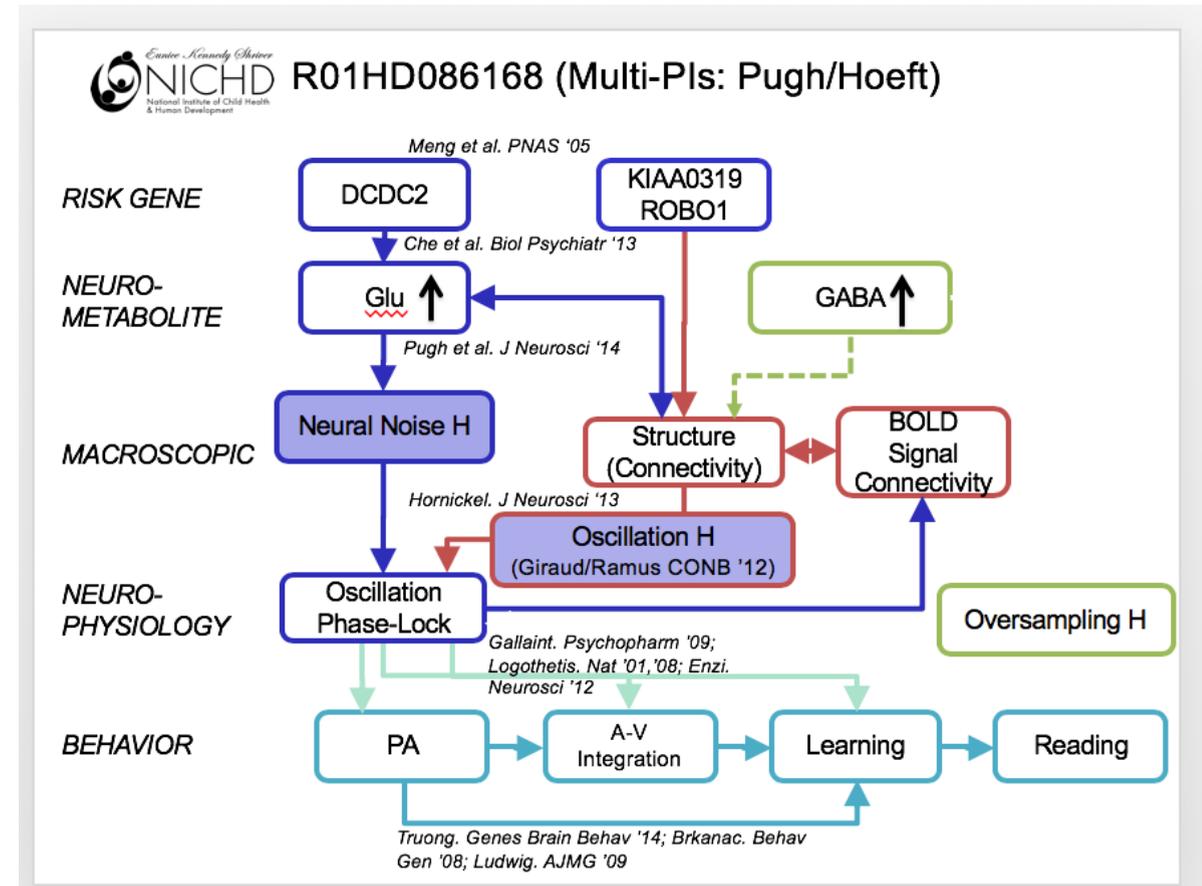
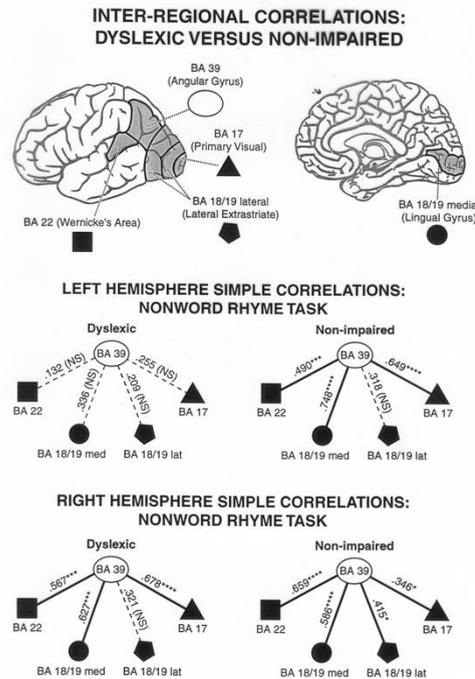


Developmental trajectory in dyslexia (Shaywitz, Pugh et al. 2002)

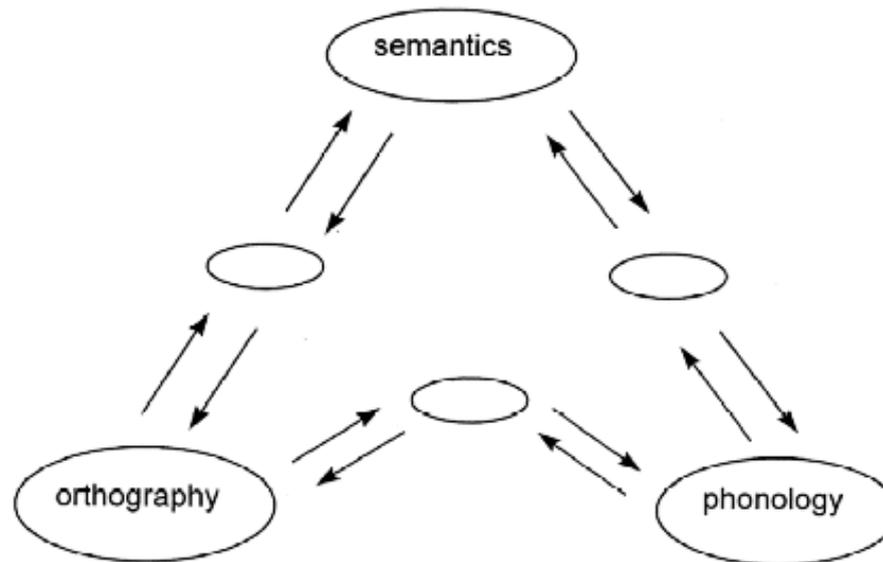
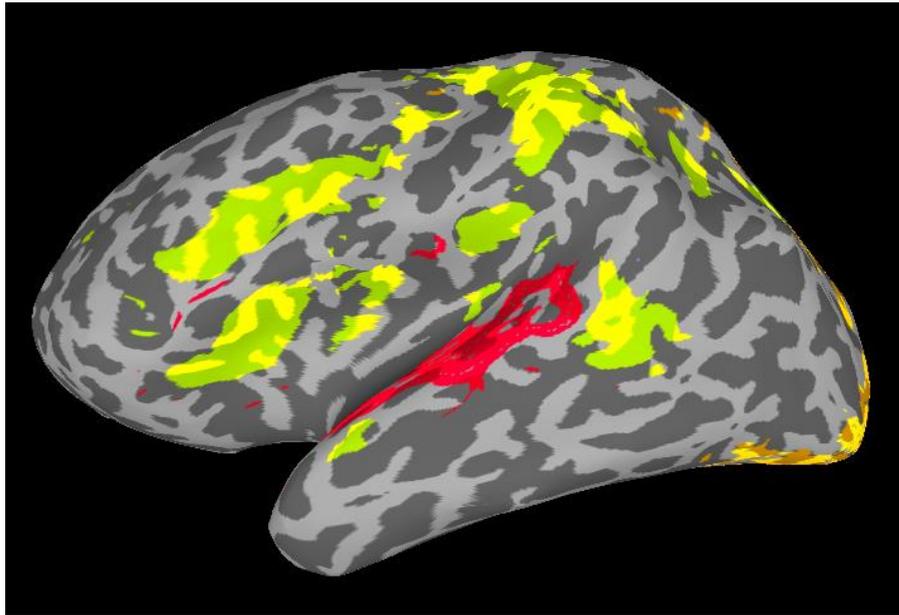
Age Correlations: NWR



Functional Connectivity in in dyslexia (Pugh et al. 2000)



Treatment studies: Strengthening print/speech connections



In class treatment: Empower program

Strategies reflect the use of different grain-sizes in word reading

Sounding out: Individual letter-sounds

Rhyming: Body-rime units rhyming

Peeling off: Use of morphological units

Vowel alert: Meta-cognitive flexing of ambiguous pronunciations

Four colorful cards from the Empower program, each illustrating a different reading strategy with a small illustration and a mnemonic:

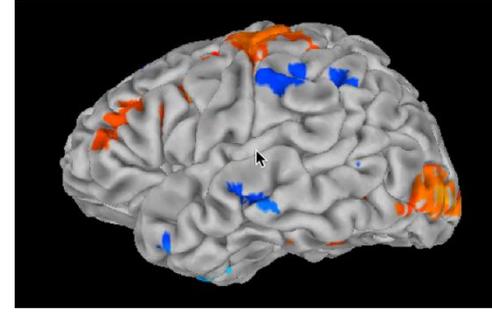
- Sounding Out Strategy** (red card, cat illustration): First, I know the sounds. Next, I blend the sounds (say without stopping). Last, I read the word.
- Rhyming Strategy** (blue card, key illustration): I'll checkmark the vowel and underline the spelling path. The spelling pattern is... The keyword is... If I know... then I know...
- Peeling Off Strategy** (green card, tree illustration): I'll Peel Off... of the beginning/end of the word. The root is... The word is...
- Vowel Alert Strategy** (orange card, traffic light illustration): I'll stop. Try both sounds. First, I'll try... Then, I'll try... Then, go.

A consistent story on treatment effects “on average” is emerging...

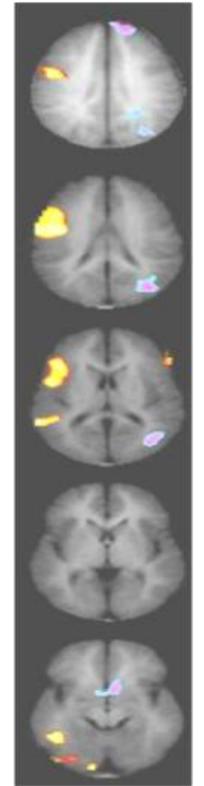
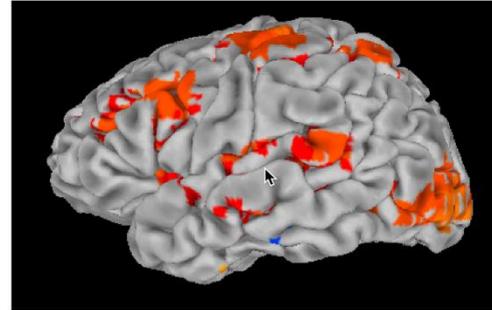
- A growing number of treatment studies have shown modulation of LH reading circuits with effective treatment (see Richlan 2021 for review)
- **However, we must better understand why some children do not respond to conventional treatment and what to do for this kids!**

The neurobiological bases of treatment effects “on average”

Pre Intervention



Post Intervention

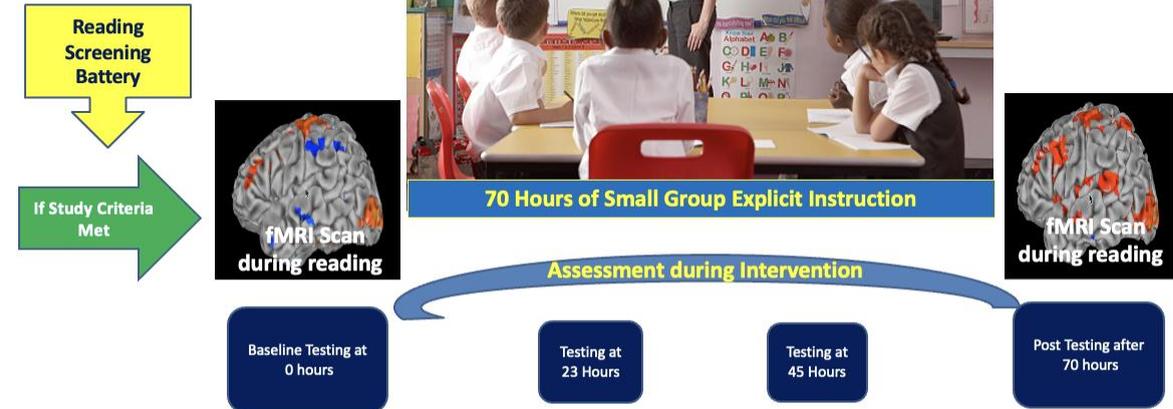
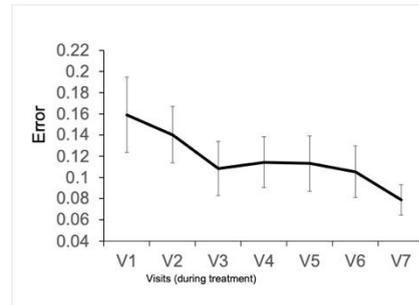


Treatment can modify trajectory
(Shaywitz Pugh et al. BP 2004)

Up to 30% of participants will be treatment resisters in a conventional intervention program!

Can we use cognitive neuroscience tools to “tailor treatment to the individual”?

NIH R37 MERIT Award (Pugh): Here we used frequent multimodal brain imaging sessions during treatment to gain insight into HOW treatment works.



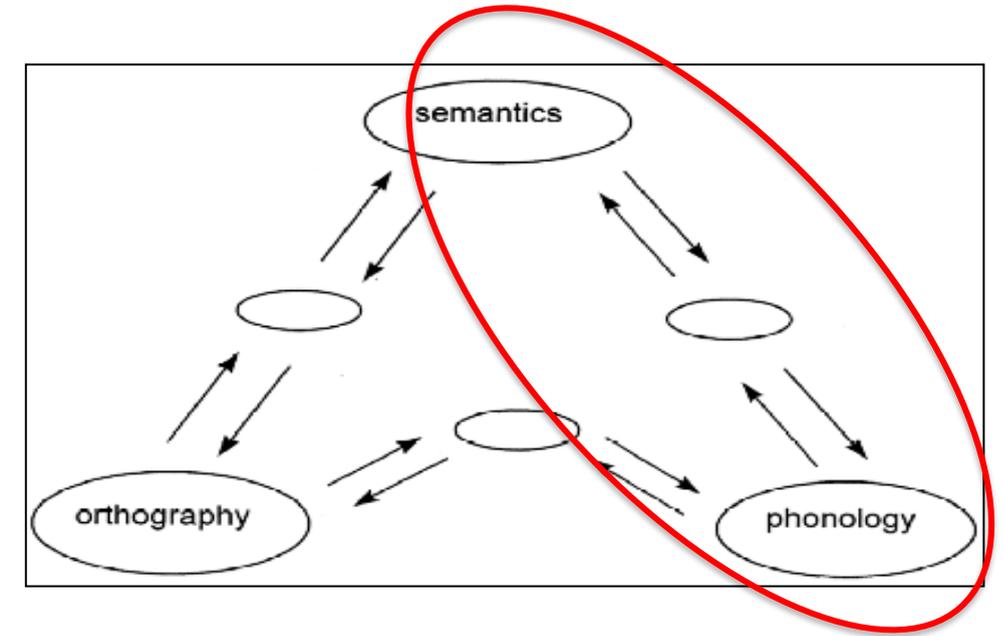
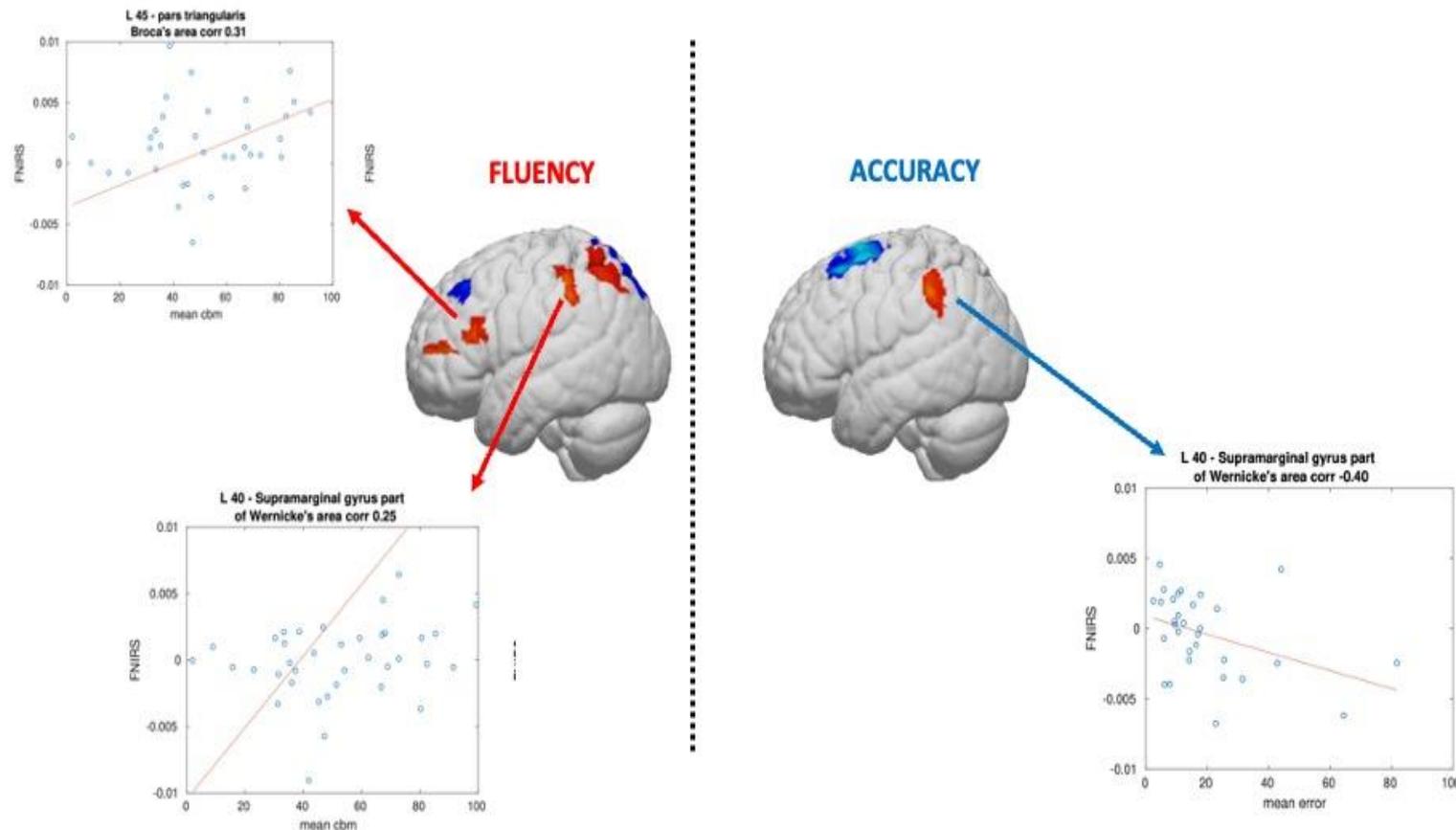
Neurocognitive bases of treatment resistance in developmental dyslexia



Note: Our ongoing “in-school neuroscience” project at **AIM** (N. Landi PI) focuses on individual differences in the classroom to get at treatment response in a more naturalistic context!

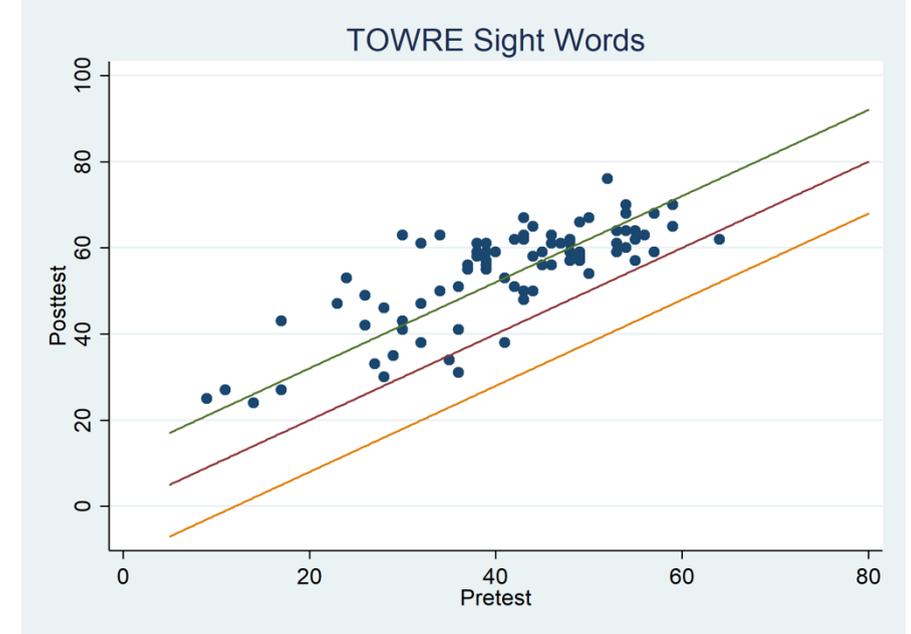
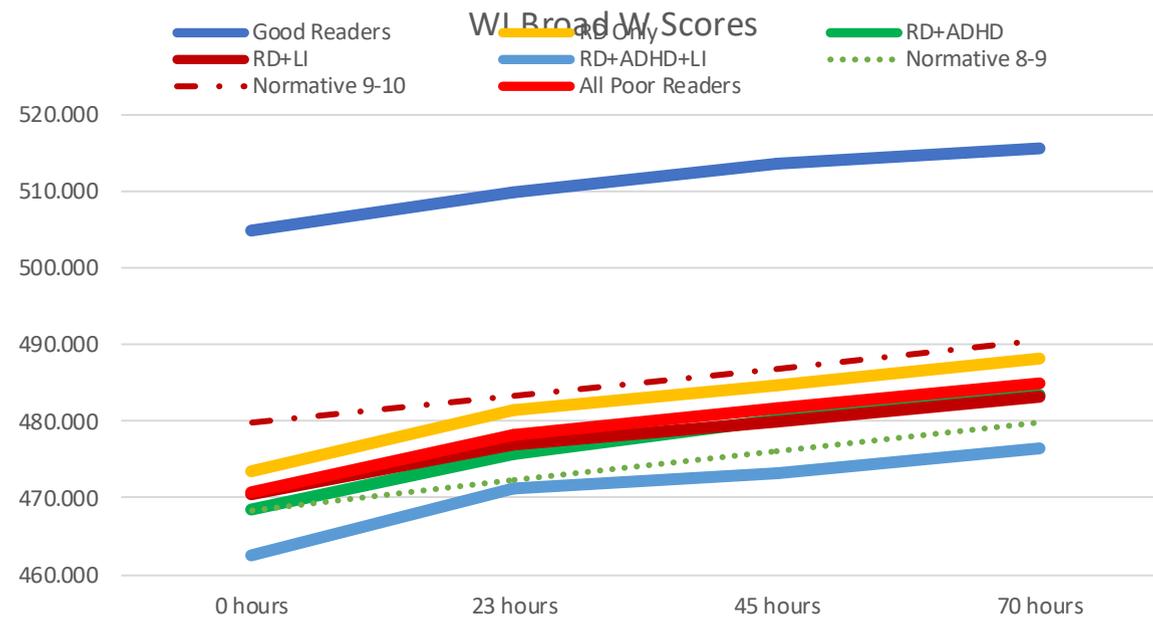
Neurocognitive measures predicting variation in treatment response: brain/behavior relations for gains in word reading fluency and accuracy

Brain-behavior relationship for improvements in reading fluency and word reading accuracy.



More pre-intervention sensitivity to consistency (greater reliance on O-P) and less pre-intervention sensitivity to imageability (less initial reliance on O-S) predict better response to treatment across reading sub-tests.

Siegelman et.al., 2021 - 2022

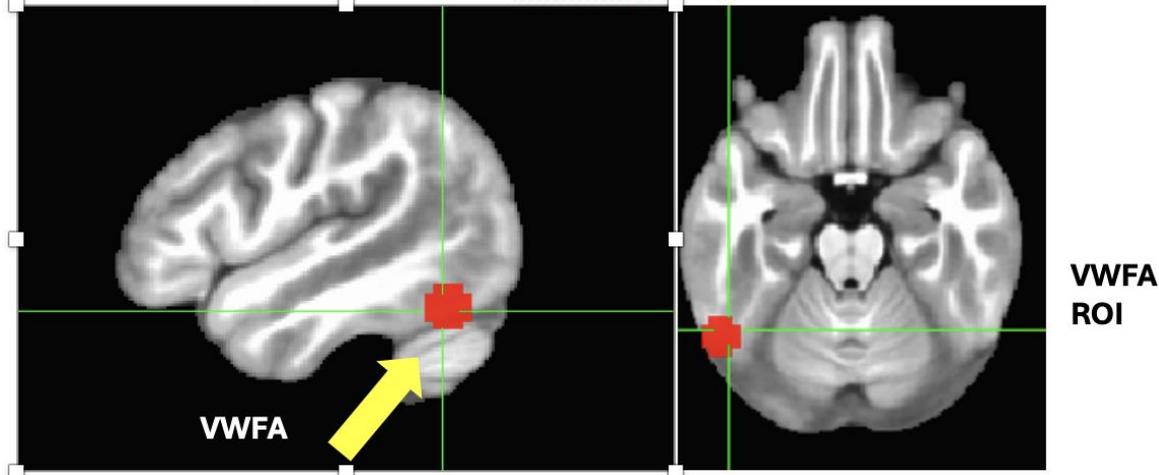


We use multiple outcome measures for assessing treatment response (e.g. reading accuracy vs. reading fluency)

WJ Attack	WJ Ident.	WJ Fluency	WJ PassCom	SRI Acc.	SRI Comp.	Test of Tr.
0	0	1	0	0	1	0
0	0	1	1	0	1	0
0	1	1	0	0	0	0
0	1	0	0	1	1	1
1	1	1	0	0	1	0
1	1	1	0	0	1	1
0	1	1	1	0	1	1
1	1	1	1	0	0	0
0	1	1	1	0	0	1

Fast Loc fMRI task: Region of Interest Analyses: Visual Word Form Area

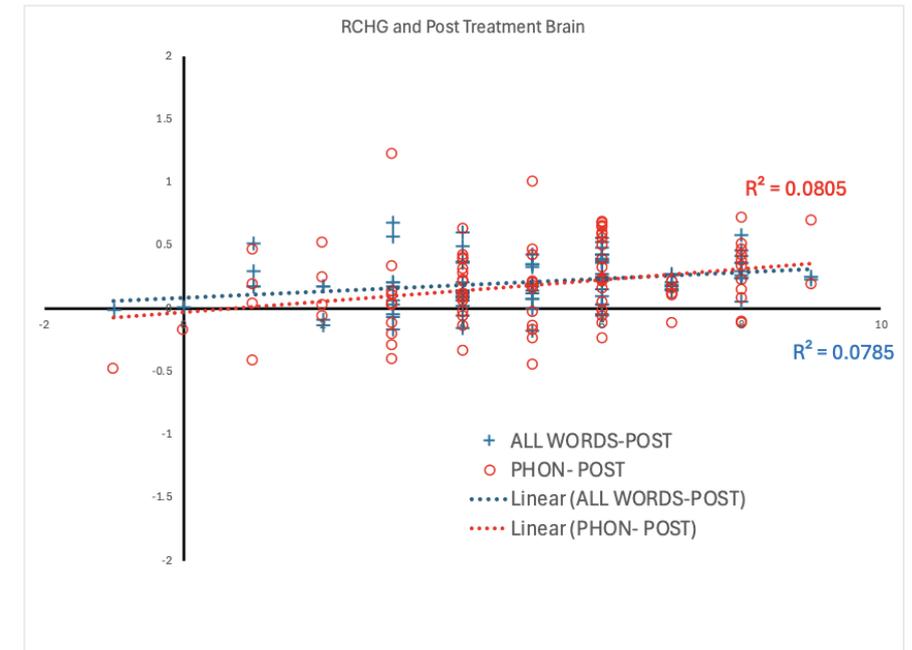
Well-known marker of reading proficiency (McCandliss et al. (2003); Cohen and Dehaene (2004) and so on



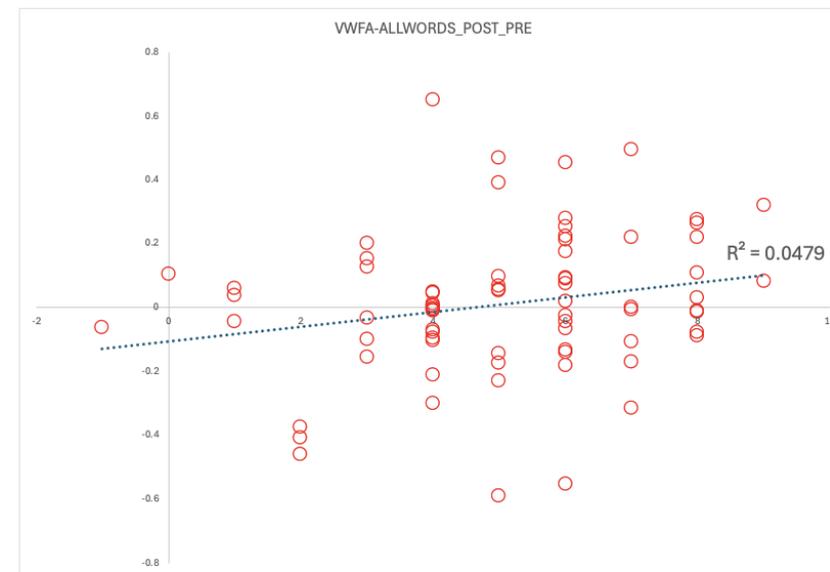
Key finding: The more participants developed strong involvement of the important **LH VWFA** the greater the gains on both accuracy **AND** fluency subtests.

Stay tuned for more on this data

POST-TREATMENT:
RCHG_ALL
Also correlated with brain activation for
PHON-MINUS
ALLWORDS



POST > PRE for VWFA beta correlated with RCHNGE All (score 0-9)

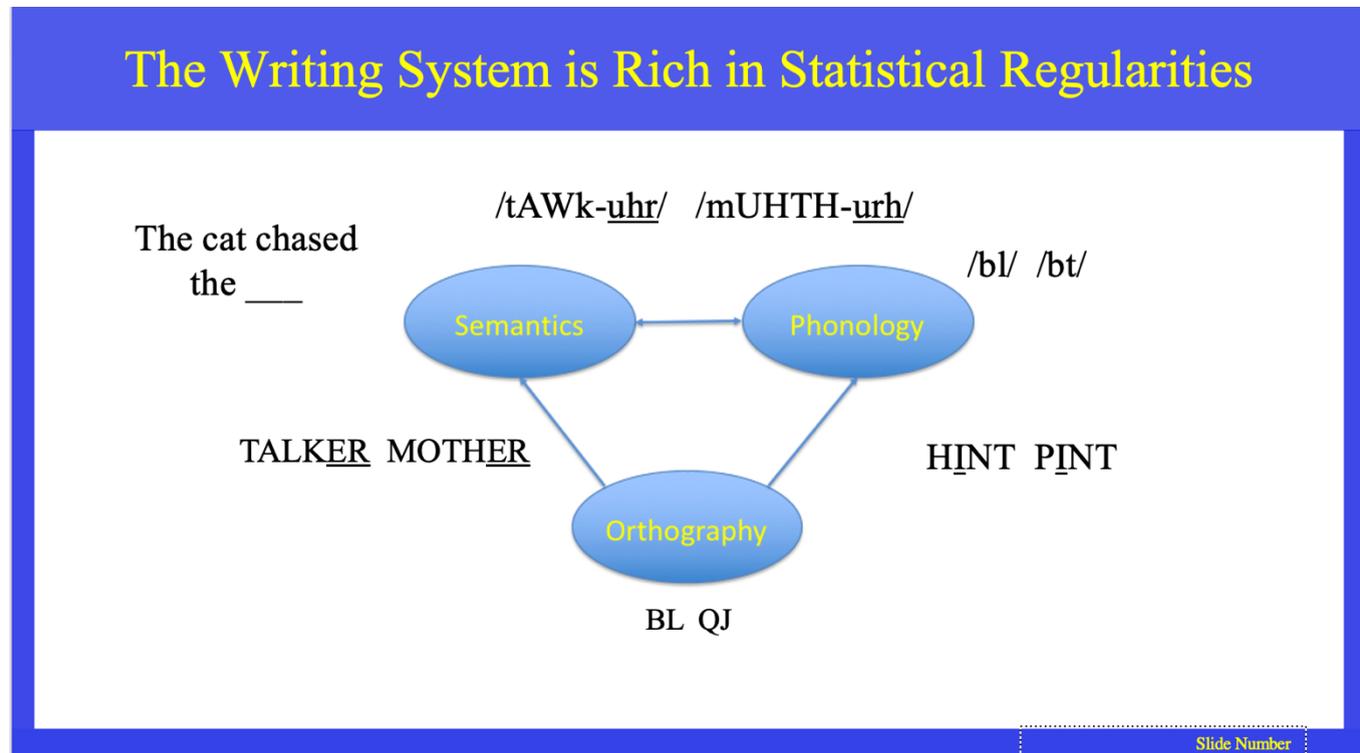


A focus on cognitive predictors (Siegelman et al., 2020; 2021):

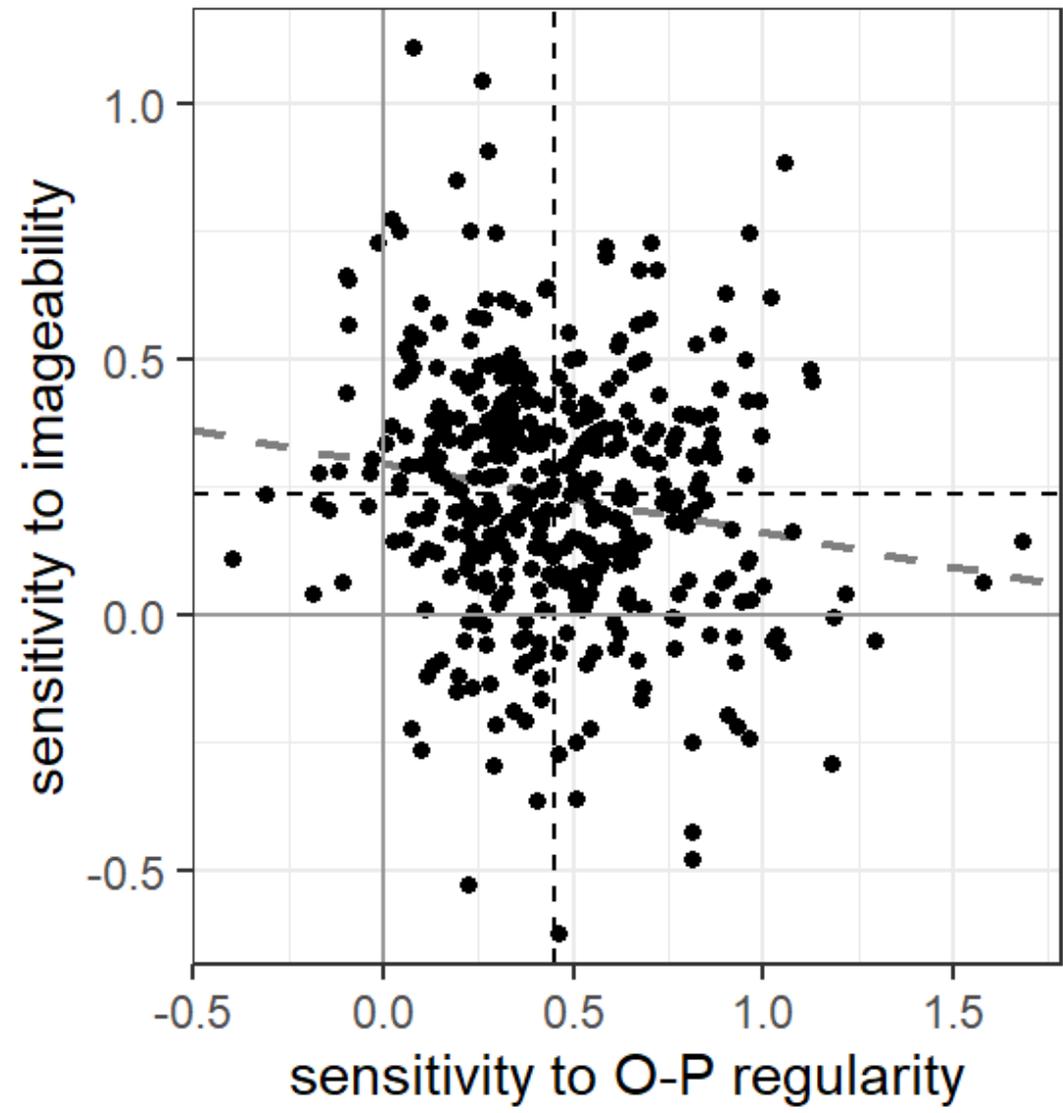
Q) Can variation in the kinds of statistical information (from the Division of Labor (DOL) for reading) used by the early reader predict:

1) current reading skills

2) response to intervention

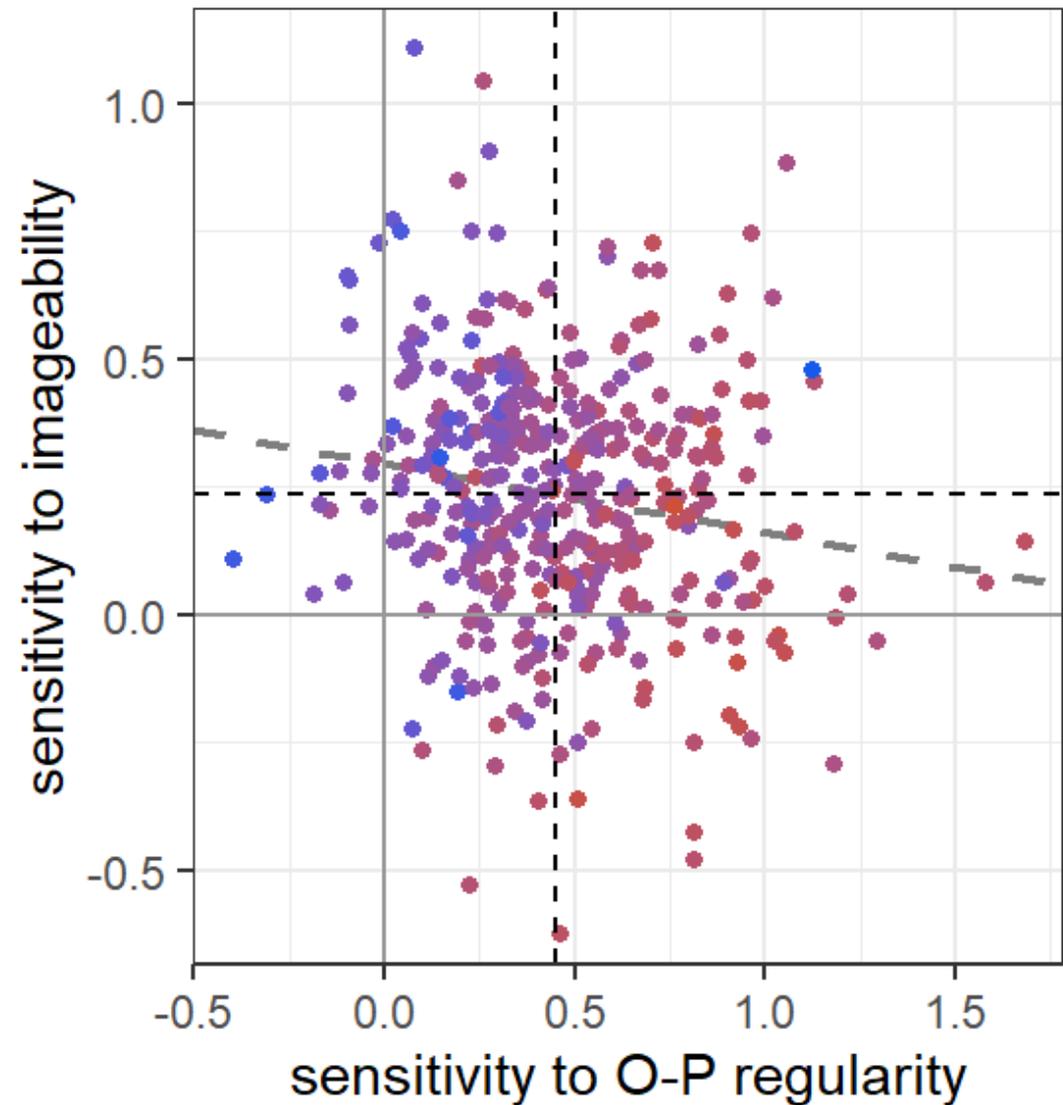


Individual differences in reliance on O-P and O-S associations



Substantial variability in reliance on O-P and imageability.

Individual differences in reliance on O-P and O-S associations



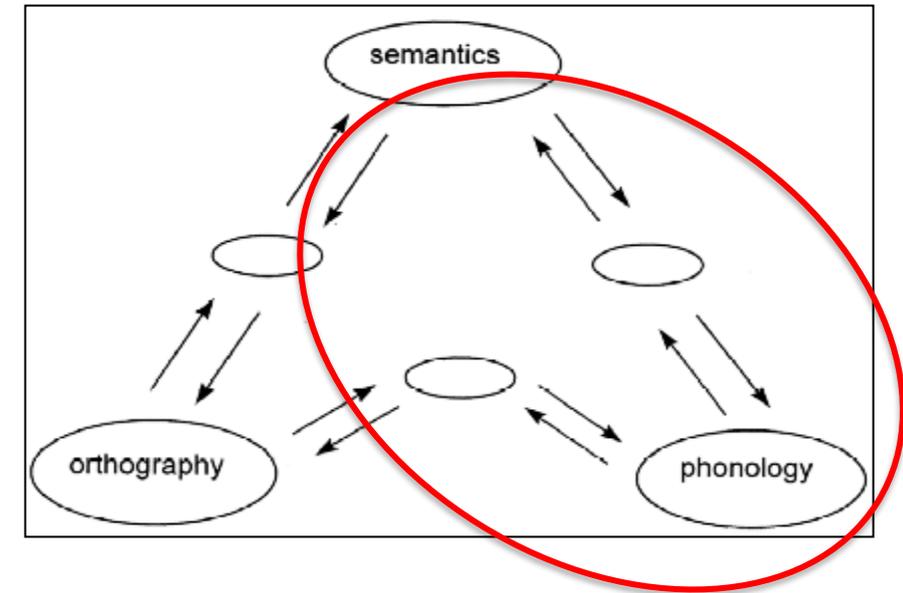
Substantial variability in reliance on O-P and imageability.

These two factors are strong predictors of (concurrent) reading skill ($R^2=32-45\%$):

- ☐ **Higher** reliance on **O-P** → better reading skill
- ☐ **Less** reliance on **imageability** → better reading skill

Summary of key findings

- **At pre-test**, individual-differences in reliance on O-P consistency and O-S imageability are strongly predictive of reading skills.
- Both are very strong predictors of treatment outcomes but in opposite direction:
- **More pre-intervention sensitivity to consistency** (greater reliance on O-P) and **less pre-intervention sensitivity to imageability** (less initial reliance on O-S) predict **better response to treatment** across reading sub-tests.
- A critical finding is that this difference in O-P and Imageability sensitivity is strongly associated with **oral language skills**



CURRENT STUDIES: Questions being addressed in the Year 6-10 continuation of the Pugh R37 MERIT study (toward a brain-guided learning approach)

What causes these individual differences in relative reliance on O-P or Imageability in reading?

Can we **move** at-risk kids "stuck in this suboptimal state-space" to a more efficient code emphasis?

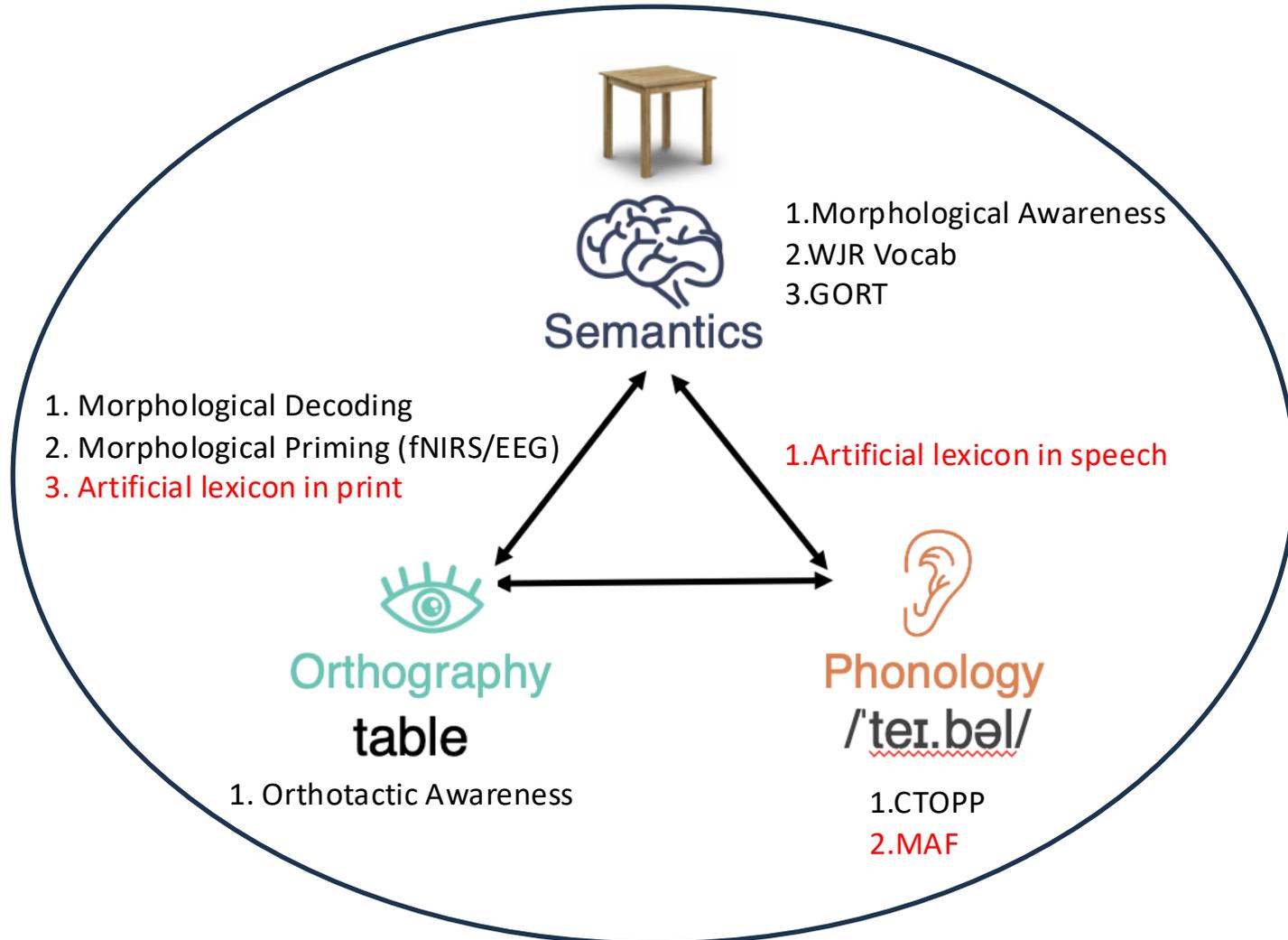
Should we use more intense programs of the same type or ones with a greater emphasis on additional intervention components?

Can we tailor the content to the brain (brain-guided learning) using BCI and neurofeedback?

Do we need additional focus on EF problems, anxiety mitigation, and the like in low responders?

How might any of this vary across different languages??

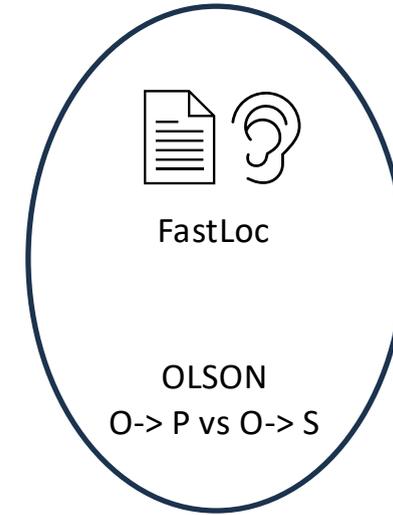
Large N



1. Strain (Individual differences in O->P and O->S)
2. Repetition Naming with fNIRS/EEG (Individual differences in O->P and O->S learning)
3. Cross modal repetition learning (Words/Pseudowords/Letter strings)

- Aim 2A from R37 (static)
- Aim 2B from R37 (has learning component)
- Aim 2C (TBD – learning with technology)

Localizers (Imaging)



EdTech

Small N

- Anxiety mitigation with meditation – impact on learning
- 1. ALT in print and speech
- 2. MAF
- 3. Repetition Naming with fNIRS/EEG/fMRI? (some version of the existing task)

Brain/behavior studies (Pugh R37):

Integrated fNIRS/EEG **during** learning experiments that vary code emphasis in order to examine the neurocognitive bases of individual differences in optimal word learning and to move toward **brain-informed treatments**

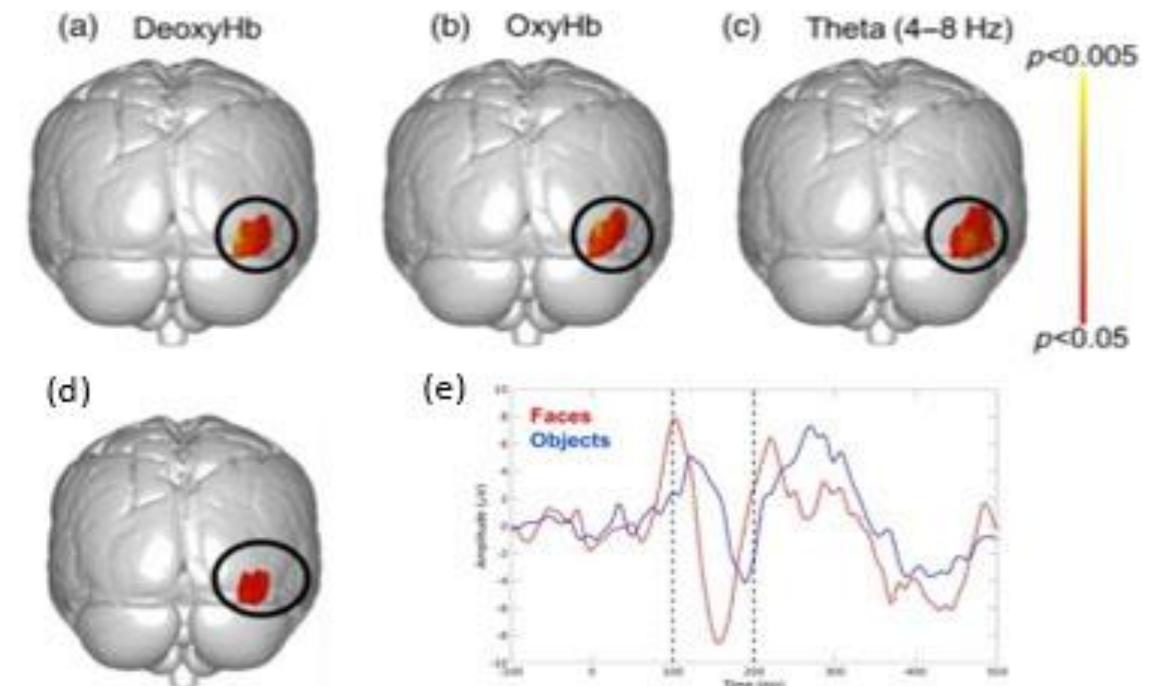
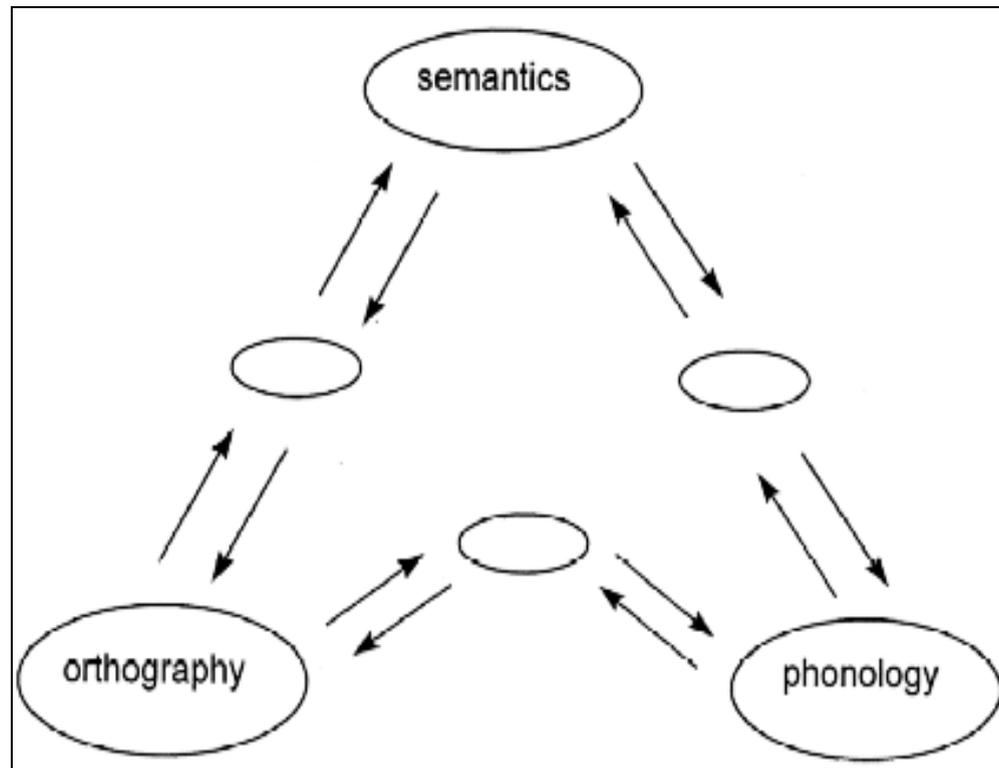


Figure 1. Comparison of fNIRS (A and B) and EEG responses (C, D, and E) for contrast face > object. These are responses to conventional static stimuli. Hemodynamic responses are shown in ventral occipital face area (indicated by black circle) for deOxyHb and OxyHb signals (A, B). Co-localization of EEG responses during face vs object task for theta power spectra (C). ERP comparison of n170 responses for face versus object responses (E). Source localized n170 response (D). (Dravida et al 2019).

Using fMRI and EEG Modality effects to predict reading abilities (Ren et al., under review)



The multimodal model significantly improved model fit in TOWRE performance ($fMRI R^2 = 0.347$, $Multimodal R^2 = 0.457$, $\Delta R^2 = 0.111$, $F(2, 49) = 4.99$, $p = 0.0106$)

Some additional next steps in the R37 project

Anxiety Mitigation



Buddhist monk Matthieu Ricard in preparation for conducting an electroencephalography (EEG) test at the EEG facility in the Waisman Center at the University of Wisconsin-Madison.

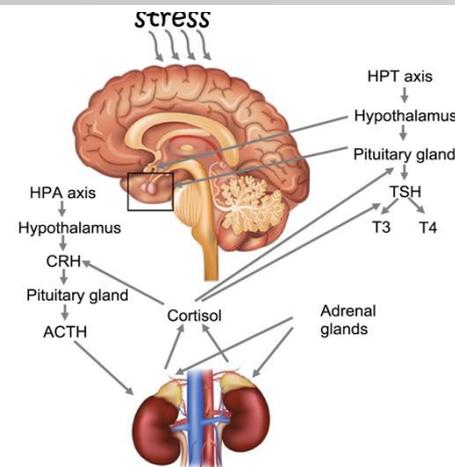
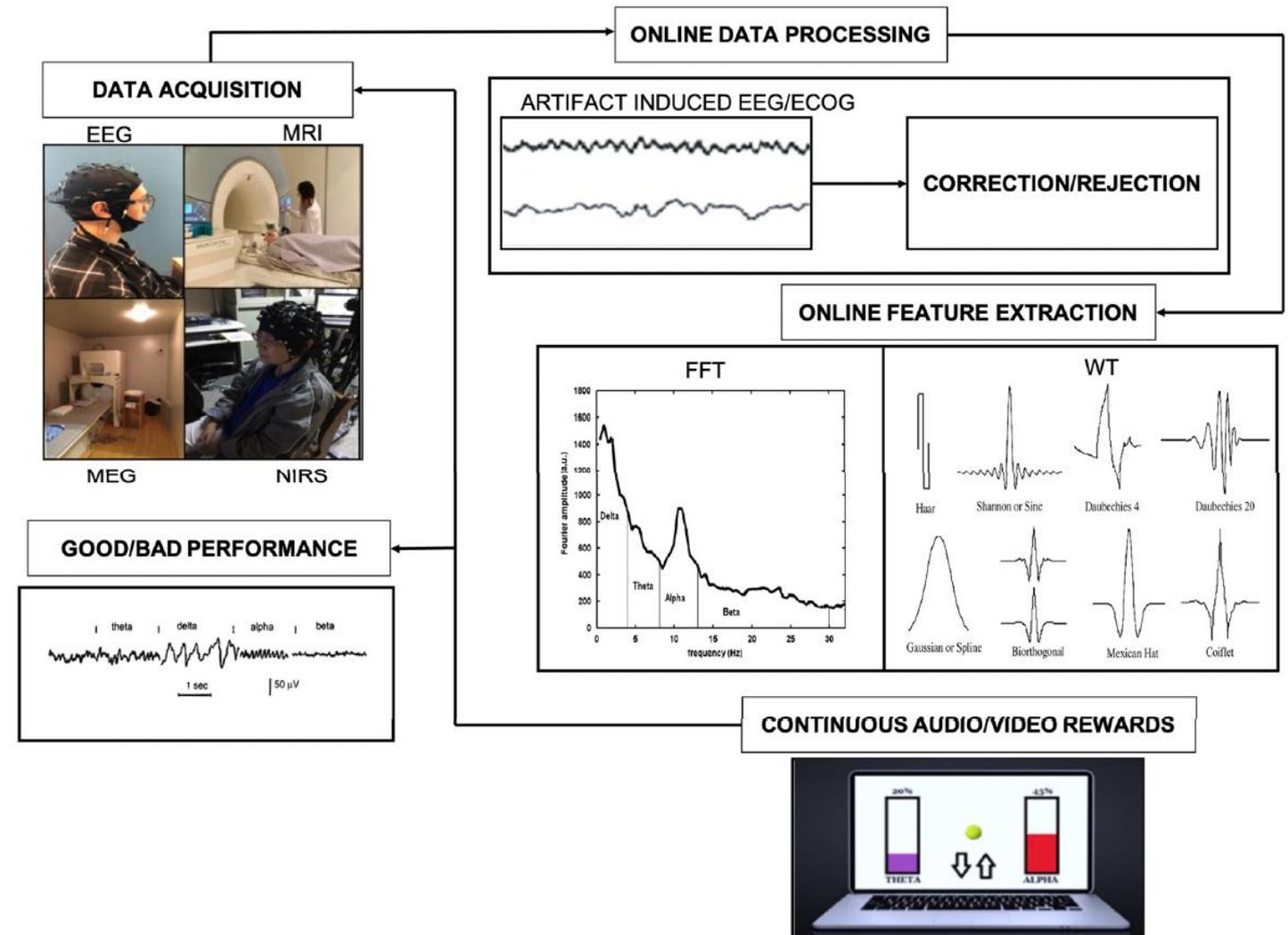


Figure 1. The Role of the Endocrine System in Mediating Stress. Abbreviations: ACTH, Adrenocorticotropic hormone; CRH, corticotropin-releasing hormone; HPA, hypothalamic-pituitary-adrenal; HPT, hypothalamic-pituitary-thyroid; T3, triiodothyronine; T4, thyroxine; TSH, thyroid-stimulating hormone.

BCI and Neurofeedback to modify learning content to individual differences in neurocognitive profiles



Thank you for your attention

The amazing human Brain

**Glass Brain
Flythrough
(Gazzaley-
lab UCSF)**

