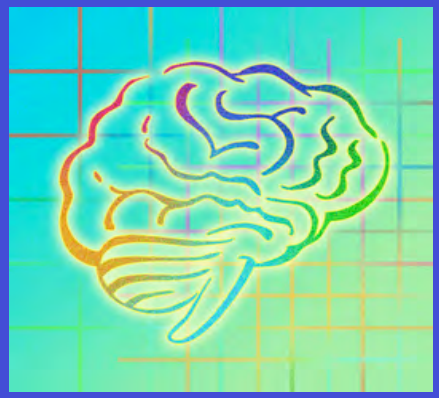
Imaging the Normal and Impaired Development of Reading.

Bruce McCandliss, PhD

Sackler Institute for Developmental Psychobiology

Weill-Cornell Medical College



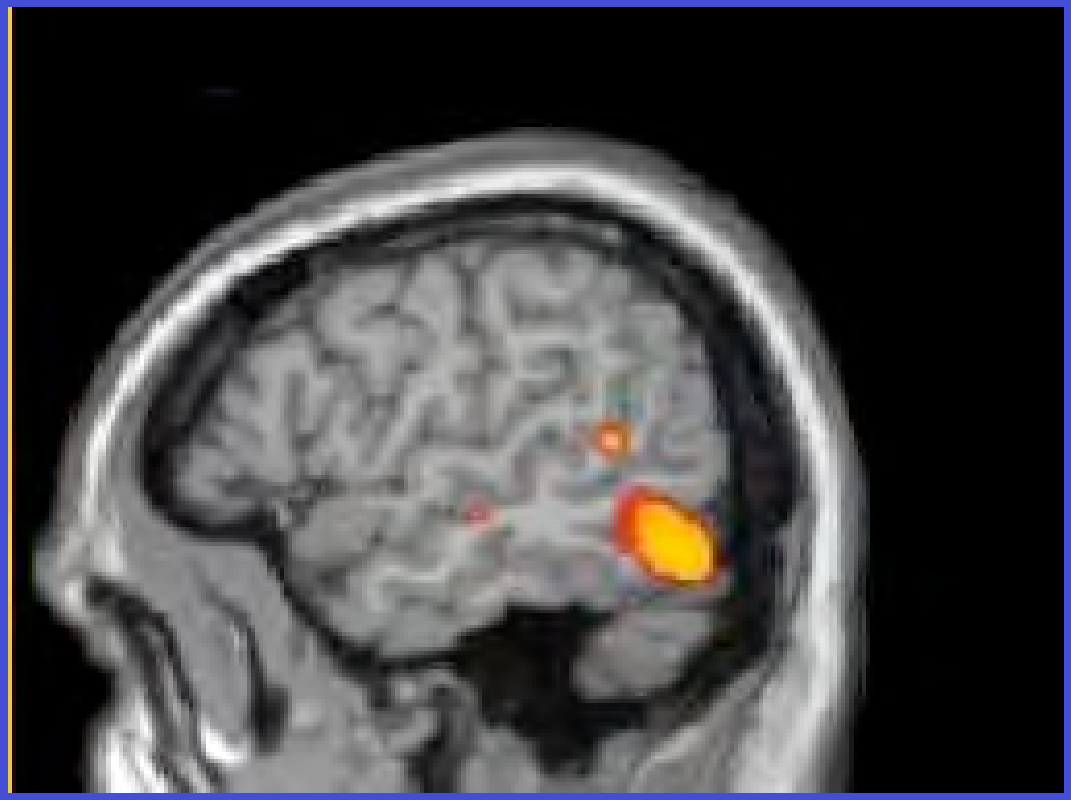
"We cannot understand how the mature system works until we understand how it is constructed in development, and we cannot fully understand that process of normal construction without understanding how development can go awry."

– Johnson & Pennington (1999)

Cognitive Neuroscience of Reading Ability/Disability

- Functional organization in experts
- Organization of function during development
- Physiological and anatomical correlates of individual differences
- Functional plasticity related to reorganization during intervention

Quantitative Meta-analysis of studies contrasting dyslexics and controls



7 studies involving orthographic contrasts

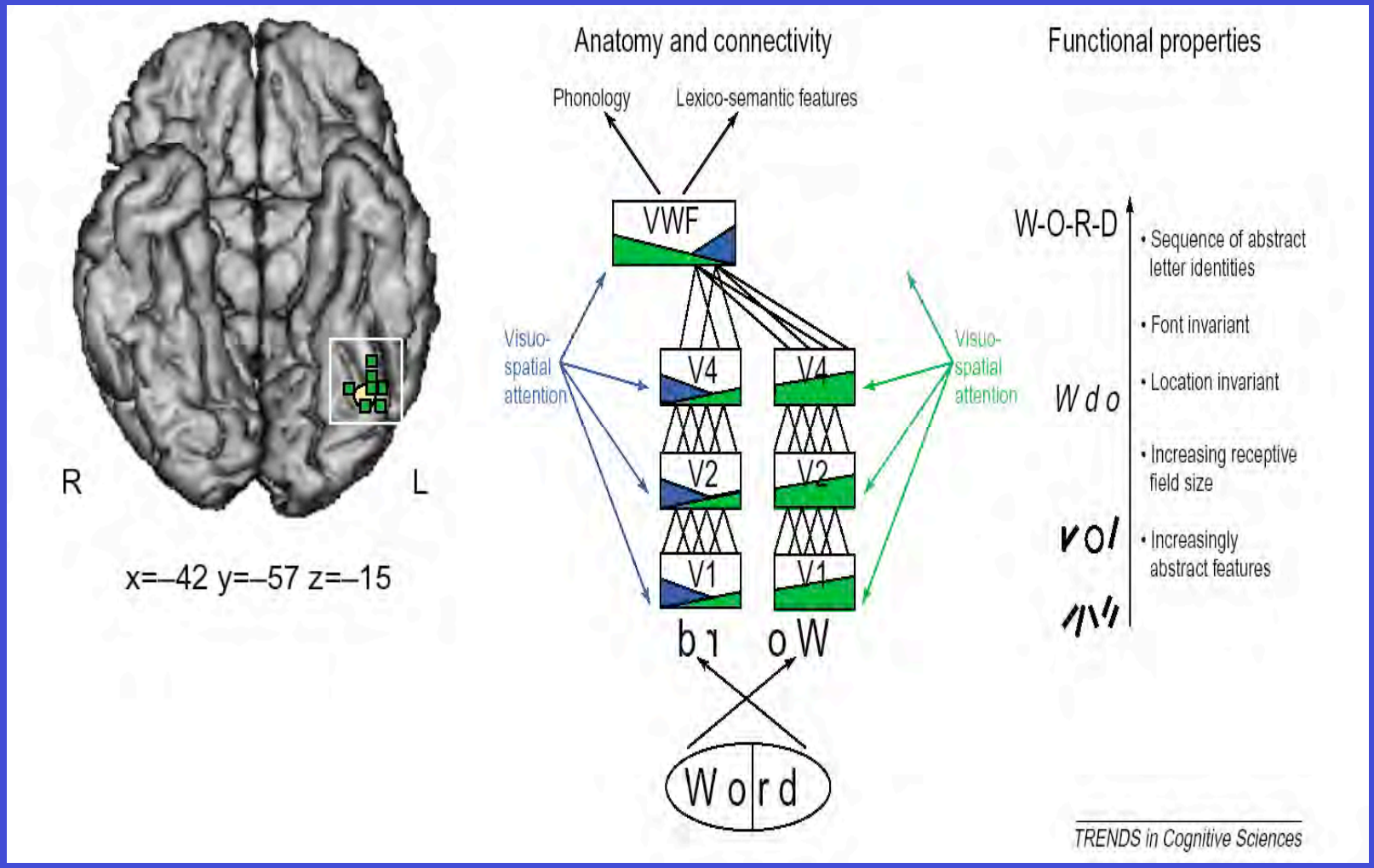
Monte-Carlo simulation based alpha of

$p < .0001$)

The expert reader

- Eye-mind lag less than 200 msec.
  (on-line lexical influence on eye-movements)
- Automatic activation of word information
  (automatic priming/interference effects)
- Letters automatically “chunked” into words
  (word superiority effects in tachistoscopic presentation)

Perceptual Expertise for Visual Word Forms



McCandliss, Cohen, Dehaene (2003)

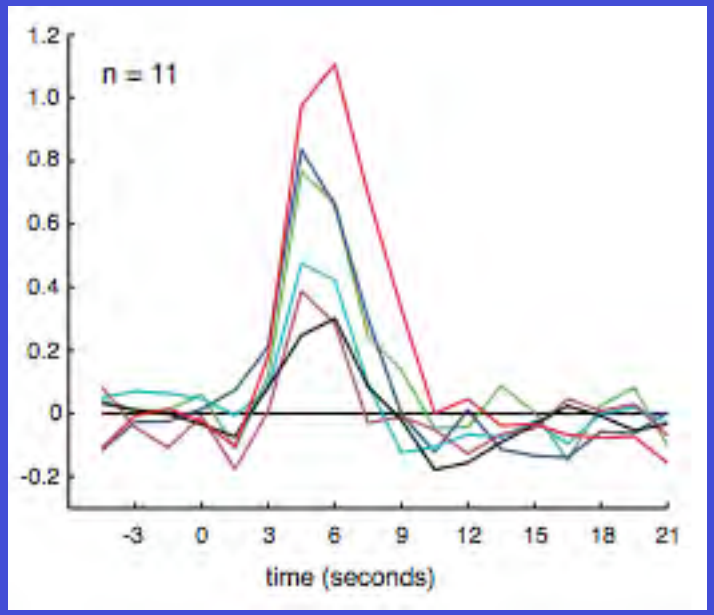
Visual word processing and experiential origins of functional selectivity in human extrastriate cortex

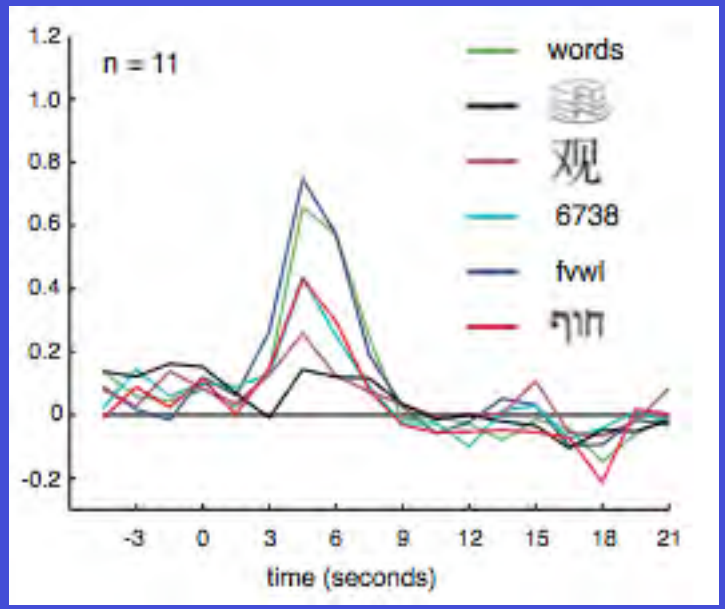
Chris I. Baker*†, Jia Liu‡, Lawrence L. Wald§, Kenneth K. Kwong§, Thomas Benner§, and Nancy Kanwisher†§¶

*Laboratory of Brain and Cognition, National Institute of Mental Health, National Institutes of Health, 10 Center Drive, Building 10, Room 4C104, Bethesda, MD 20892; ‡State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing 100875, China; §Massachusetts General Hospital/Massachusetts Institute of Technology/Harvard Medical School Athinoula A. Martinos Center for Biomedical Imaging, Massachusetts General Hospital, 13th Street, Charlestown, MA 02129; and ¶McGovern Institute for Brain Research and Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

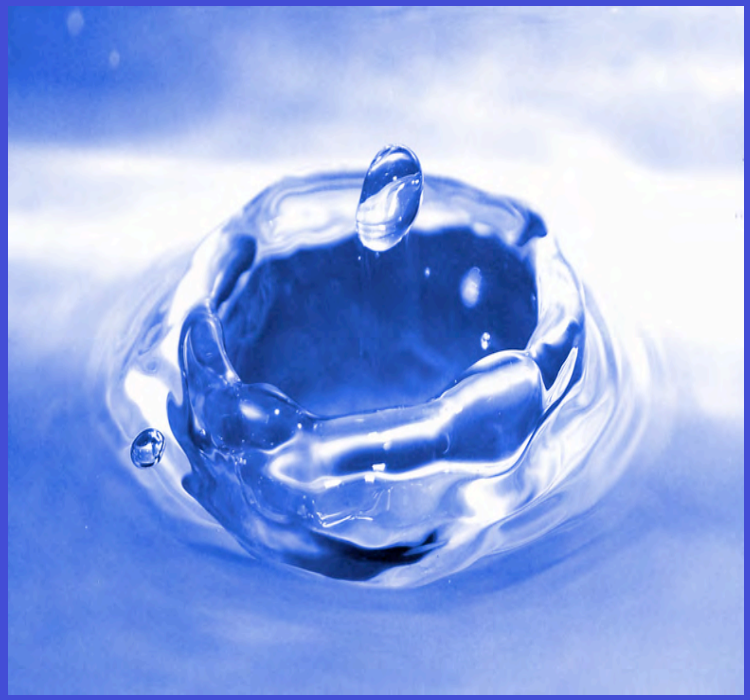
Contributed by Nancy Kanwisher, April 11, 2007 (sent for review March 13, 2007)

www.pnas.org/cgi/doi/10.1073/pnas.0703300104 PNAS | May 22, 2007 | vol. 104 | no. 21 | 9087–9092

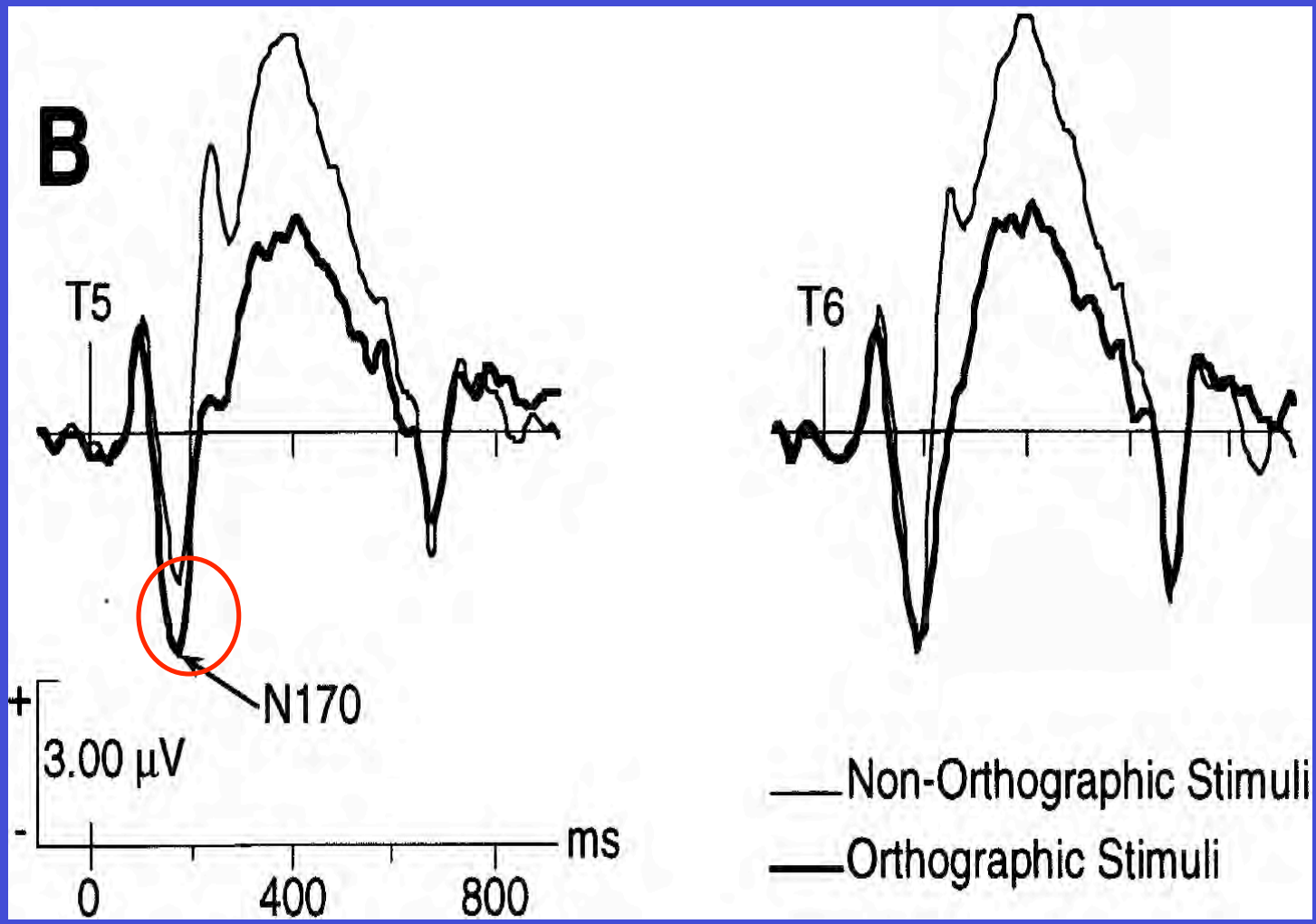




Electrophysiology



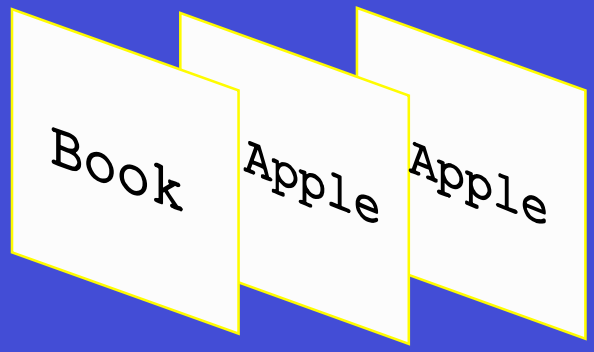
ERP: Reading and Perceptual Expertise



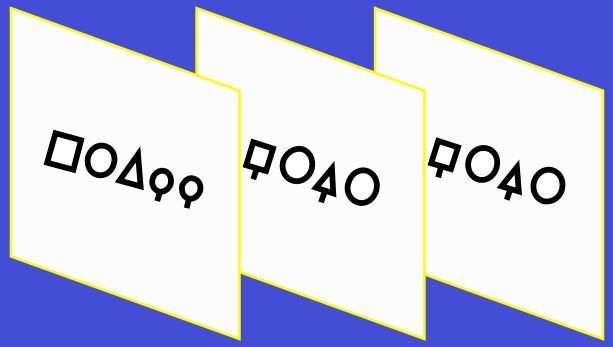
Bentin et al. (1999)

One-Back Activation ERP Task

Words

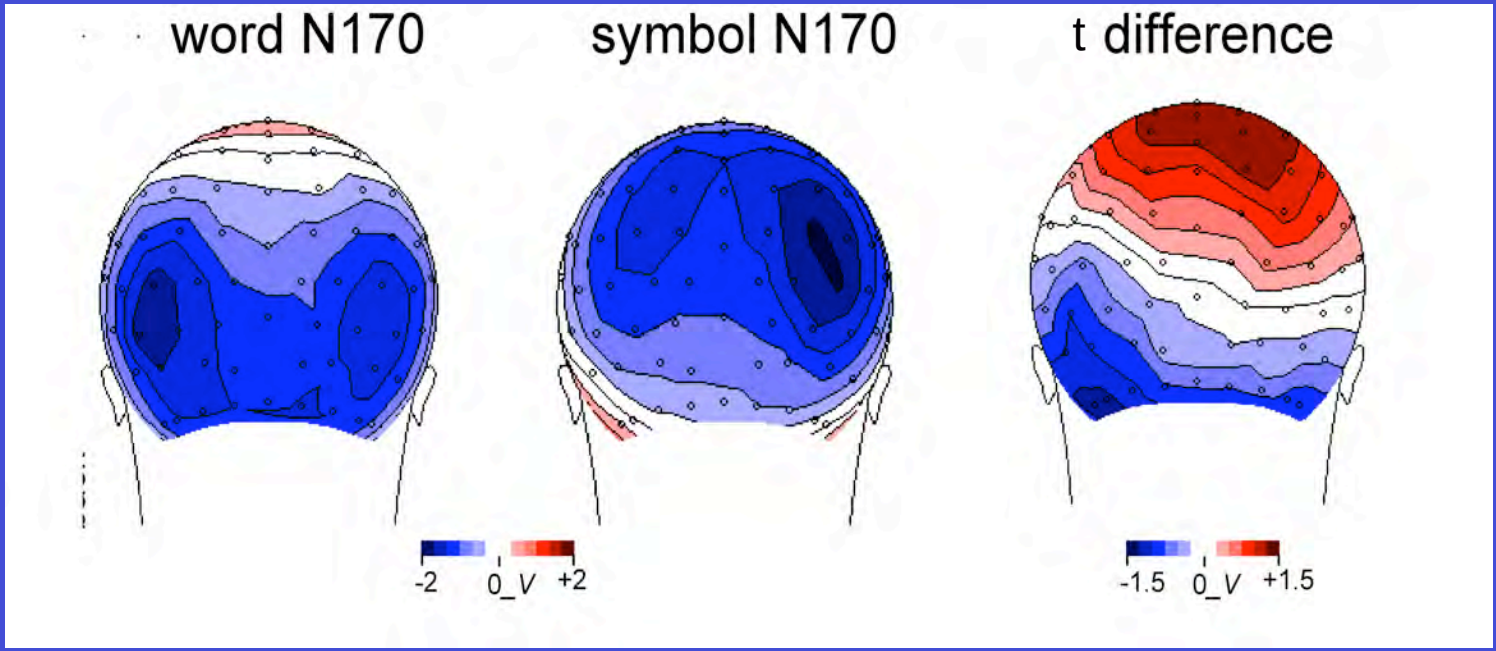


Symbol String Control



Maurer, Brandeis & McCandliss (2005)

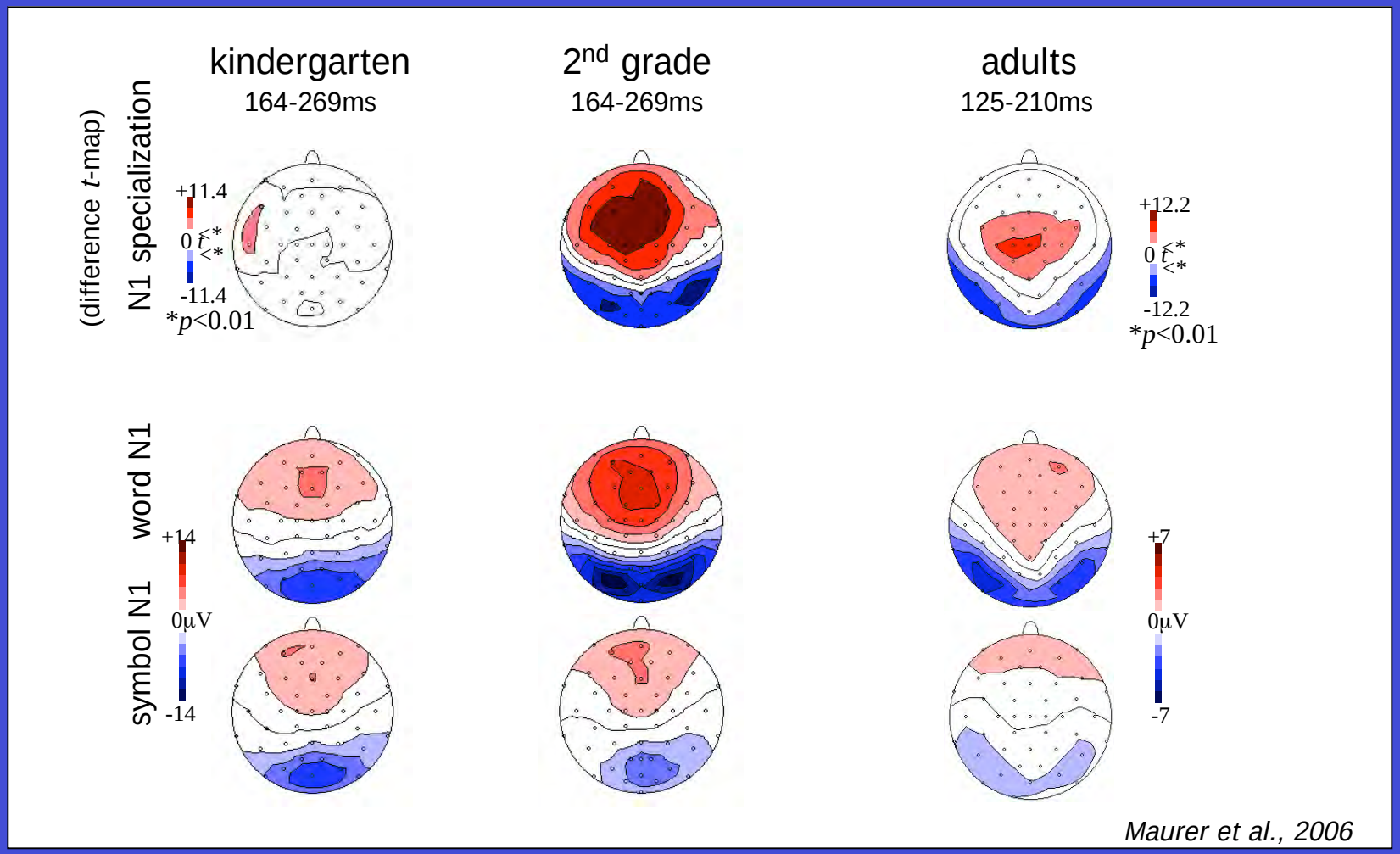
N170 Expertise Effect for Visual Words



Maurer, Brandeis & McCandliss (2005)

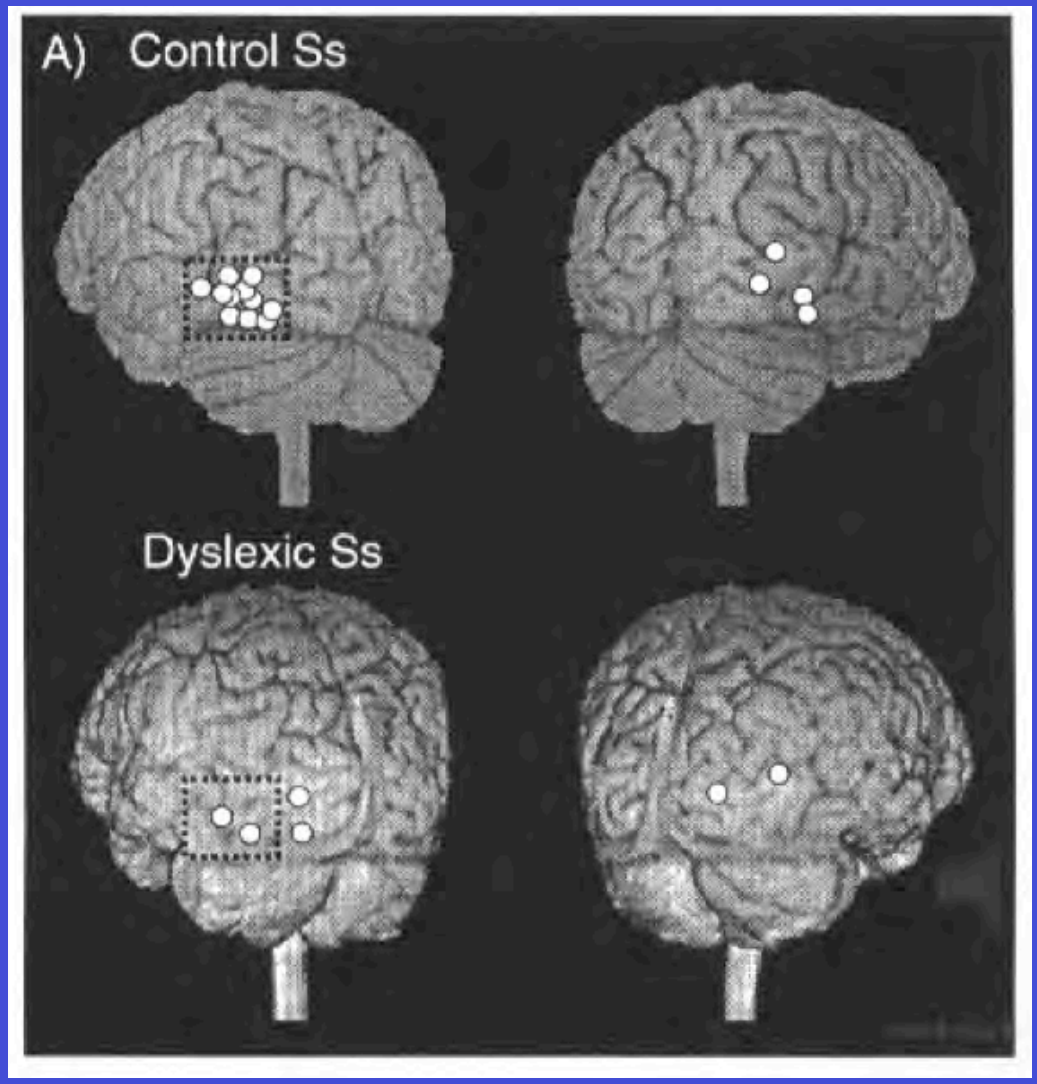
Development of ERP responses to visual words

Development of N2 Expertise Effect in Reading



Maurer et al., 2006

Dyslexic Adults versus Controls

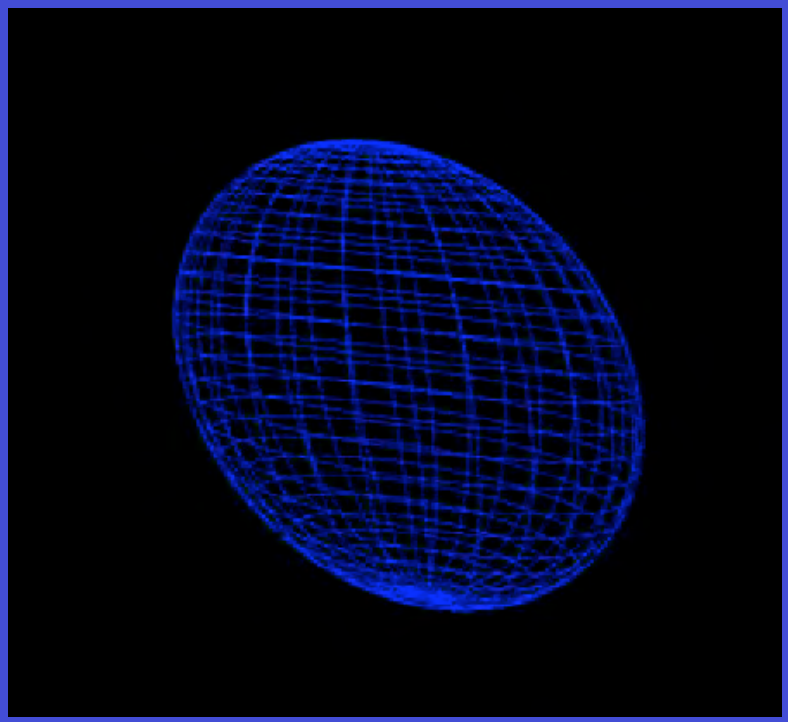


Magnetic Source localization:
Words > Symbols
~150 msec

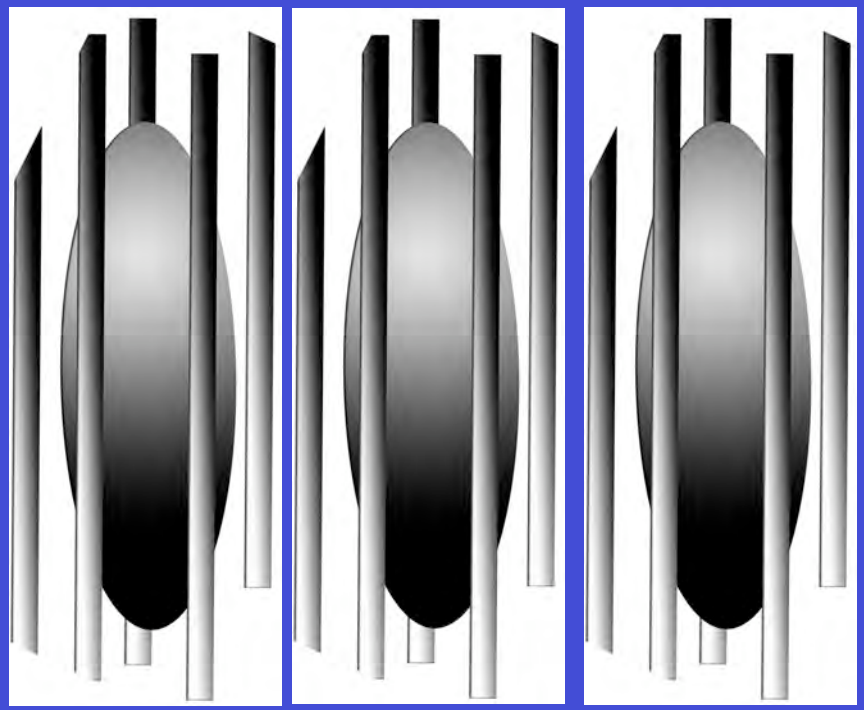
Helenius, et. al (1998)

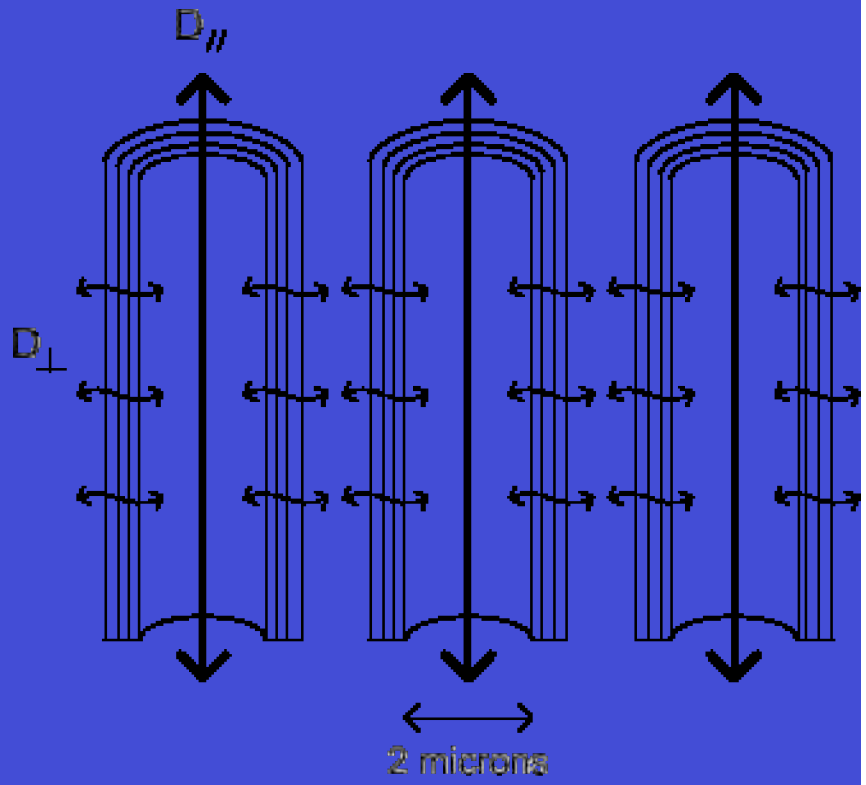
Linking anatomical measures to individual differences in reading development.

Unrestricted Flow, Isotropic Diffusion

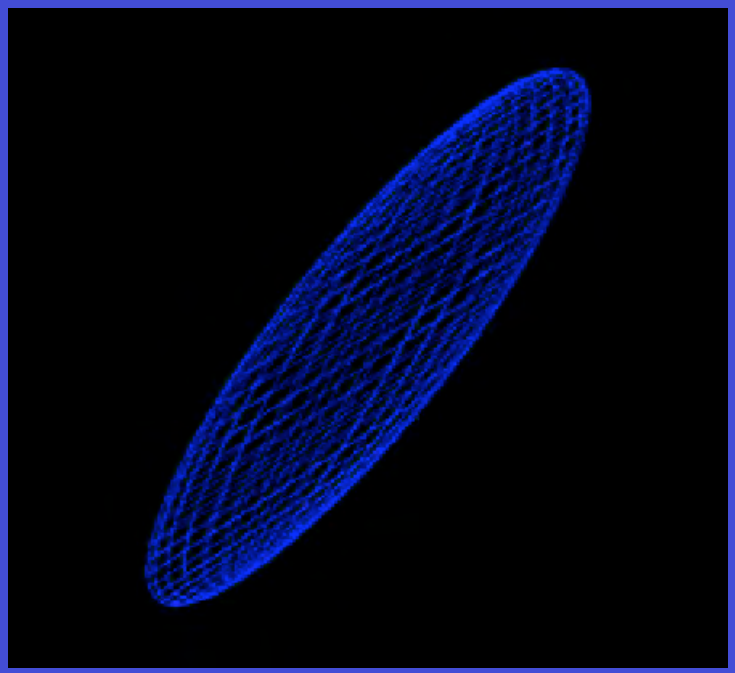


Restricted Flow

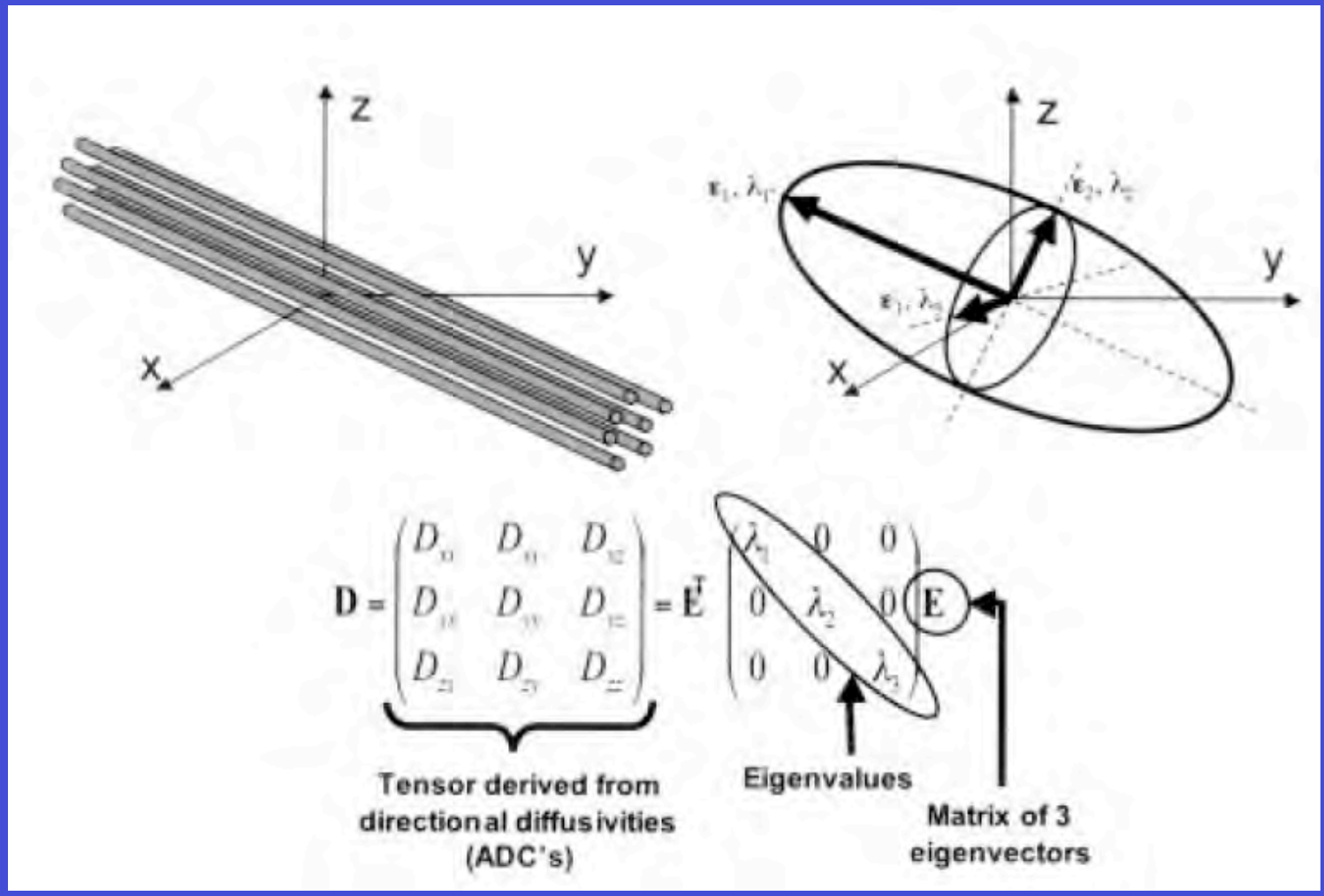




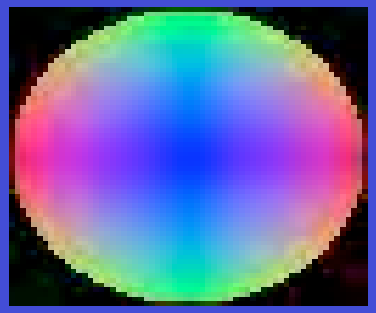
Anisotropic Diffusion



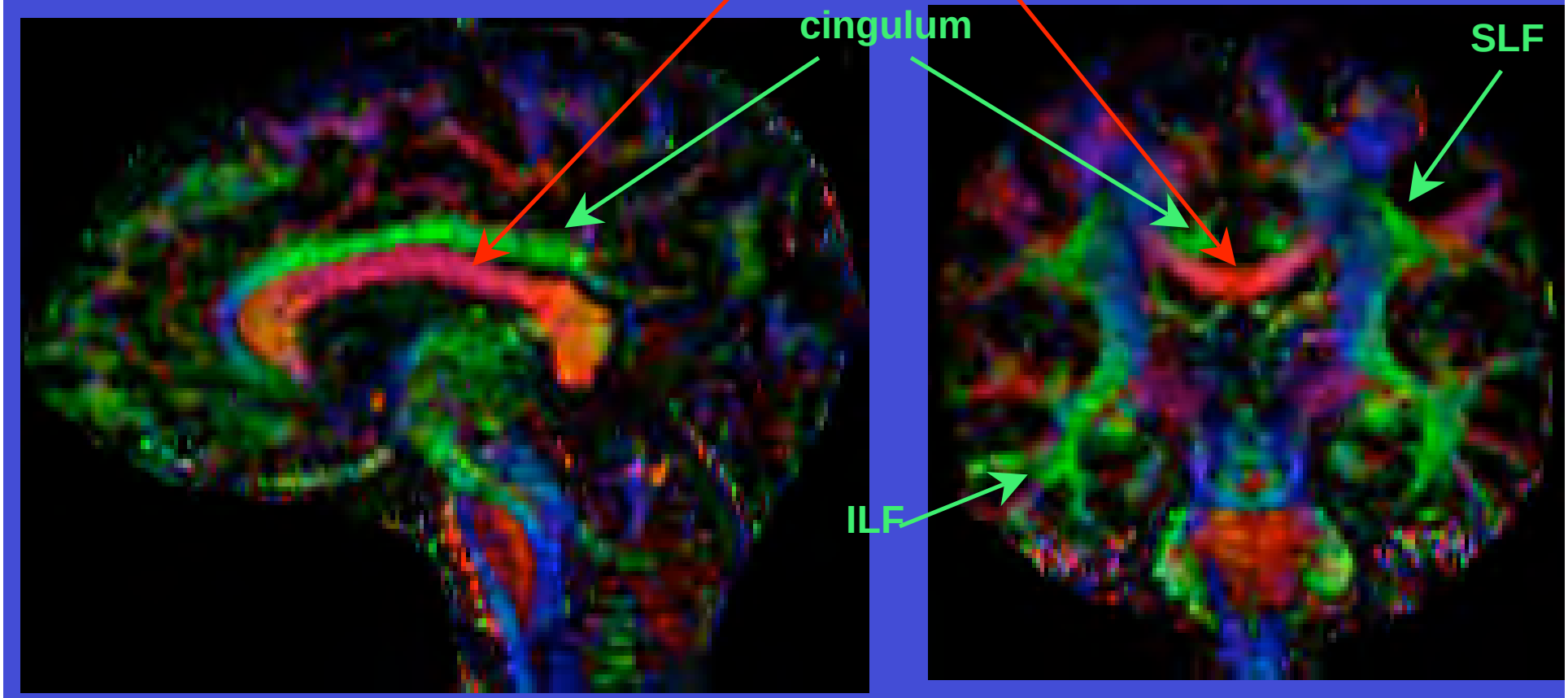
The Diffusion Tensor



Jellison 2004



Direction of Diffusion



ELSEVIER

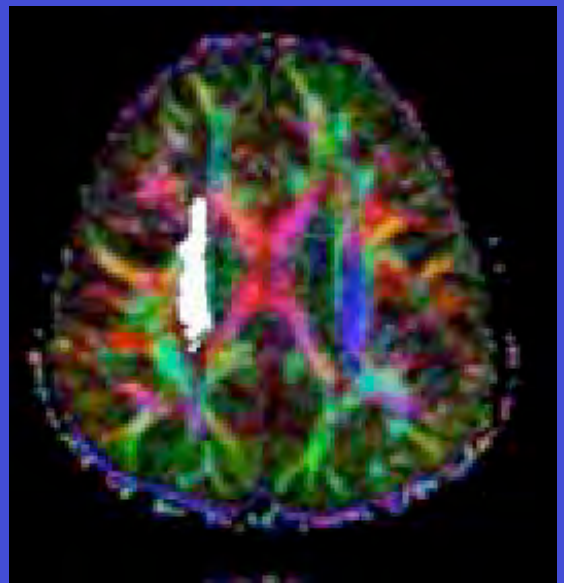
NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage xx (2006) xxx–xxx

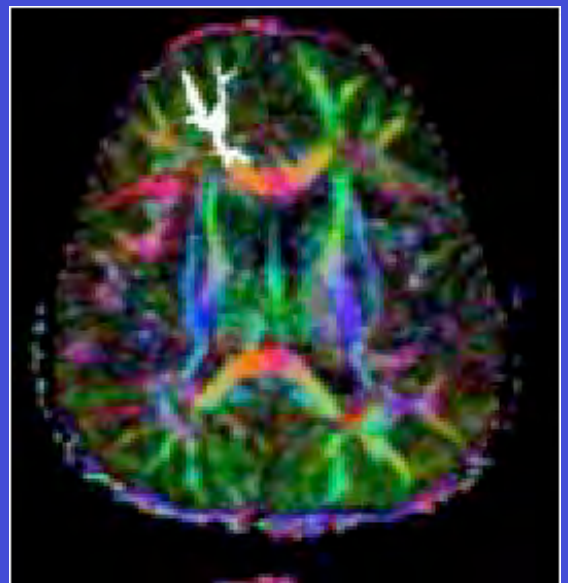
Diffusion tensor imaging segmentation of white matter structures using a Reproducible Objective Quantification Scheme (ROQS)

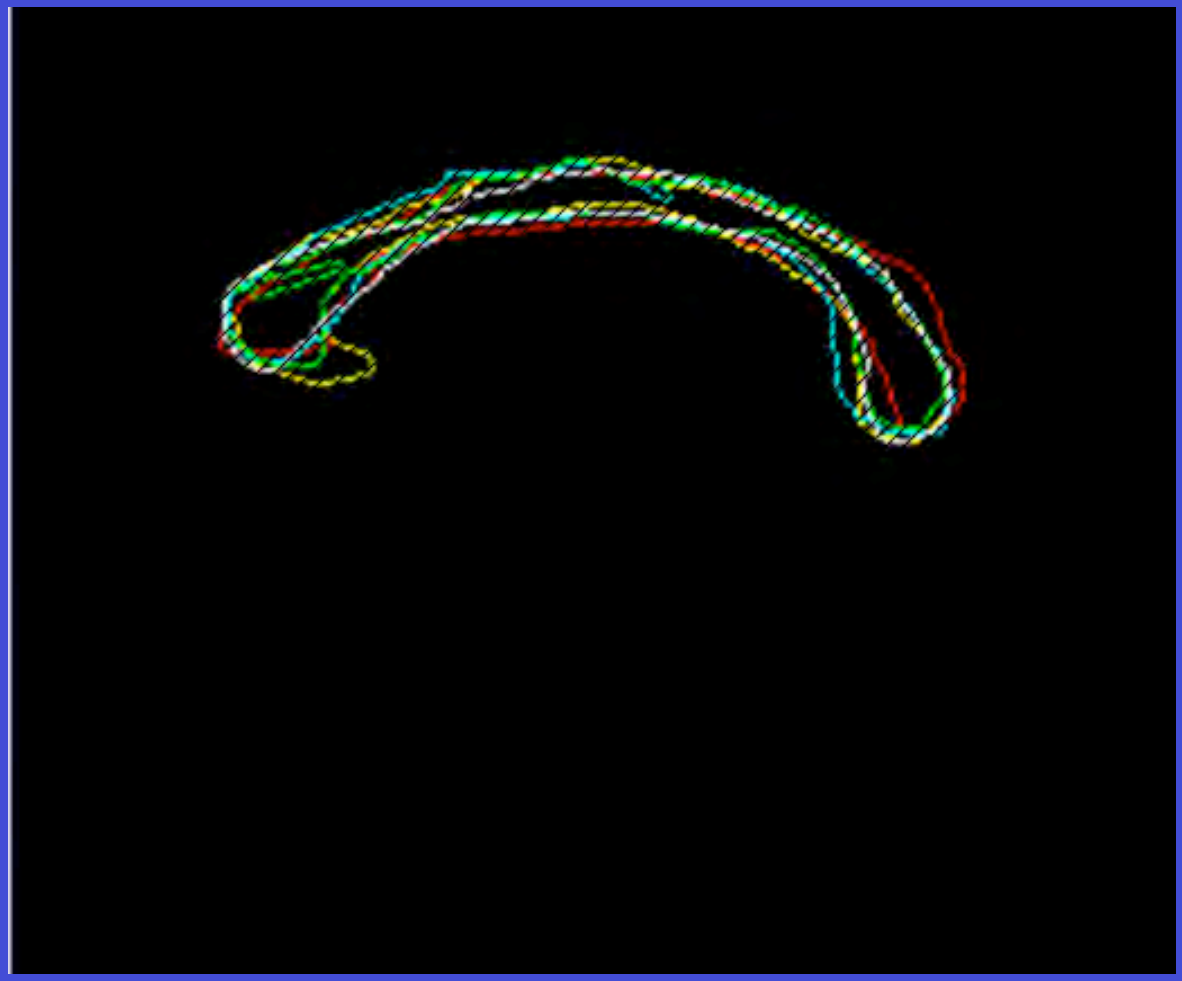
Sumit N. Niogi,[a,b] Pratik Mukherjee,[c] and Bruce D. McCandliss[a,*]

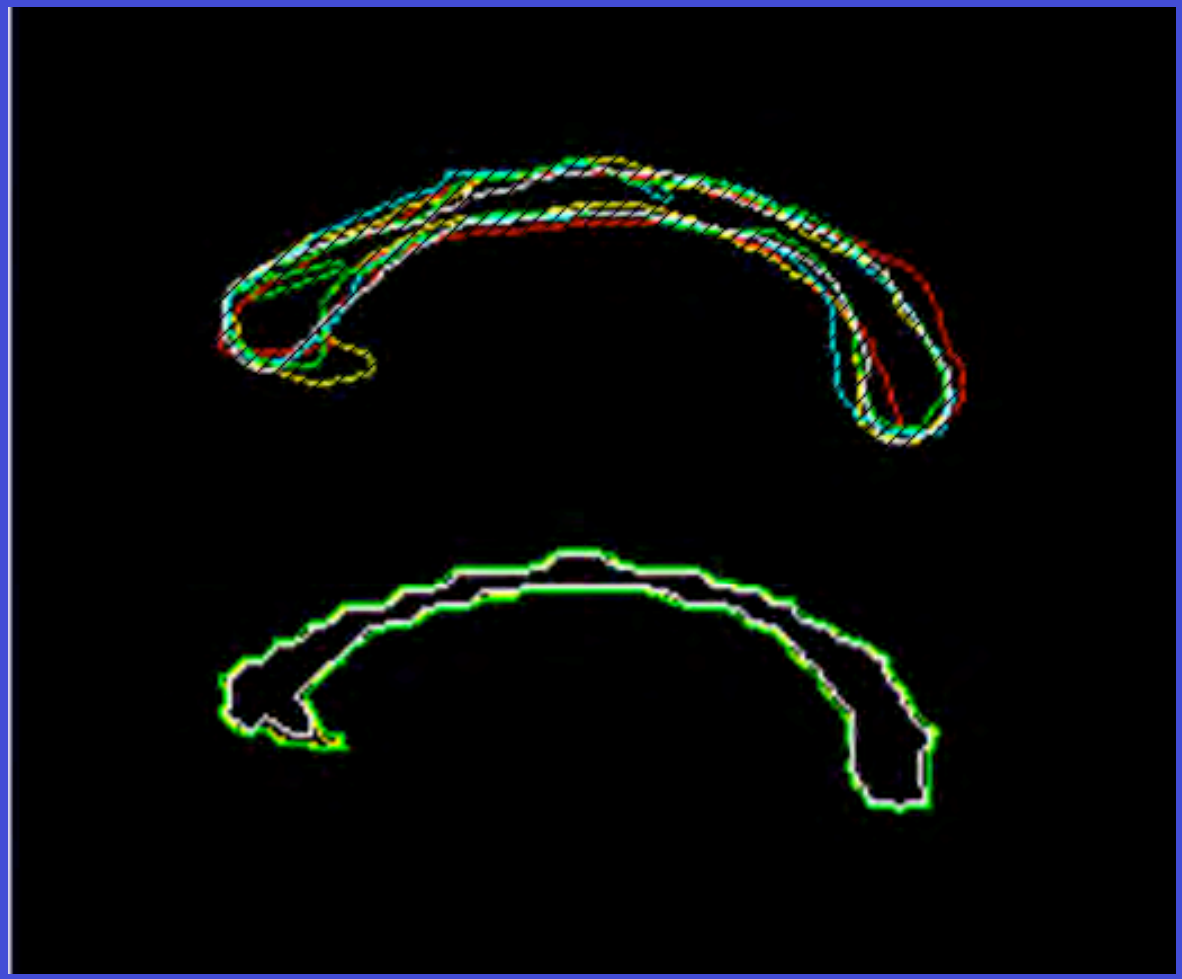
Superior Corona Radiata



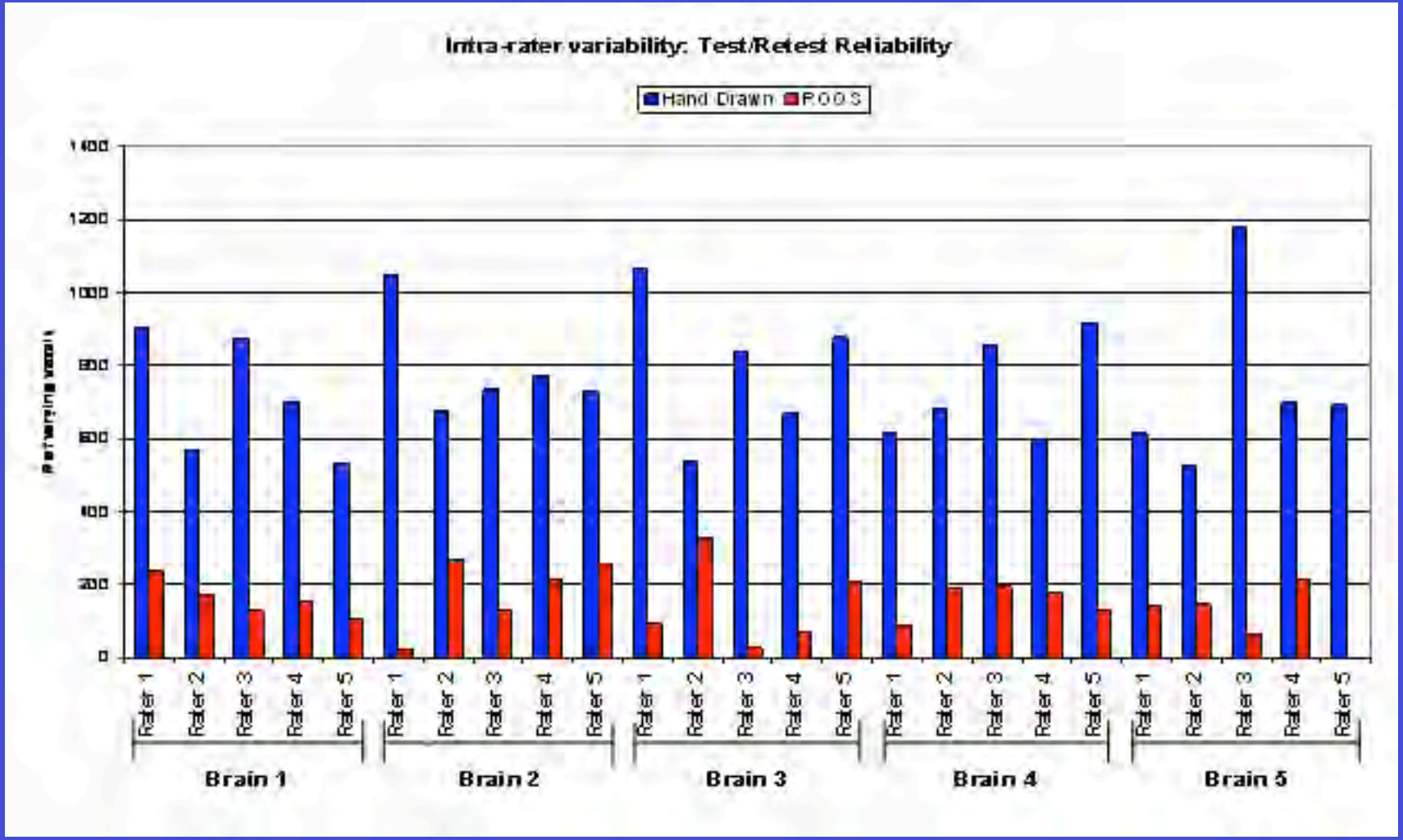
Anterior Corona Radiata







Intra-rater reliability

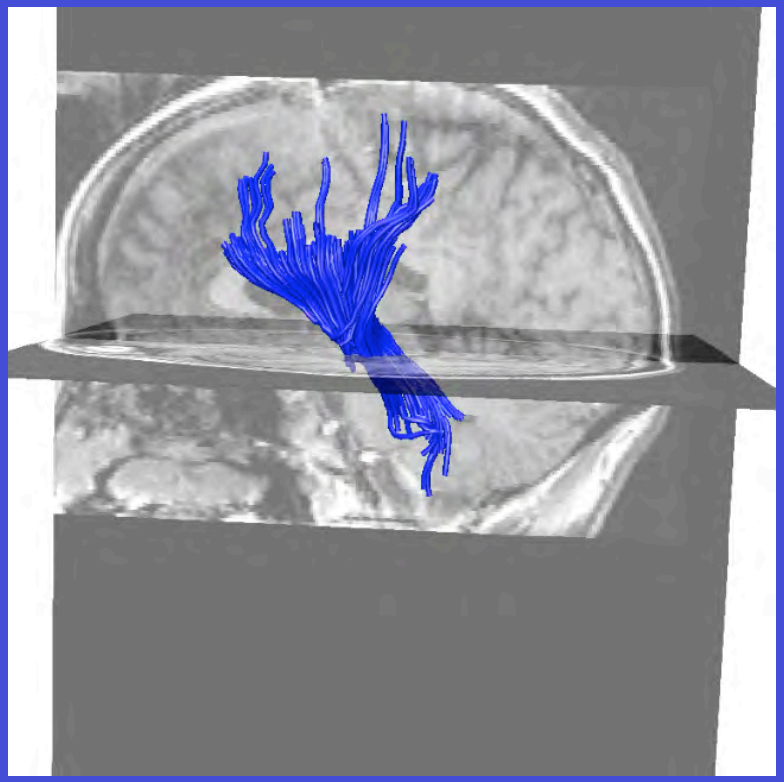


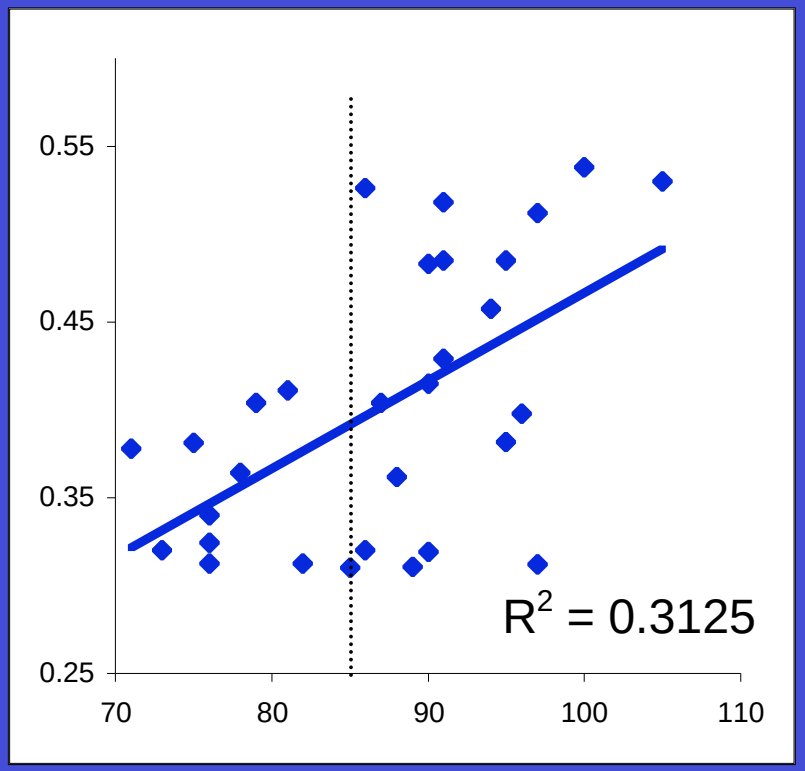
Neuroimaging during reading development

DTI study of Reading Disability

- N=31
- Age 6.5 - 10.3
- Reading scores ranging from average to severe reading impairments
- 1.5 T GE Signa Scanner
- Individual ROI's selected from FA maps

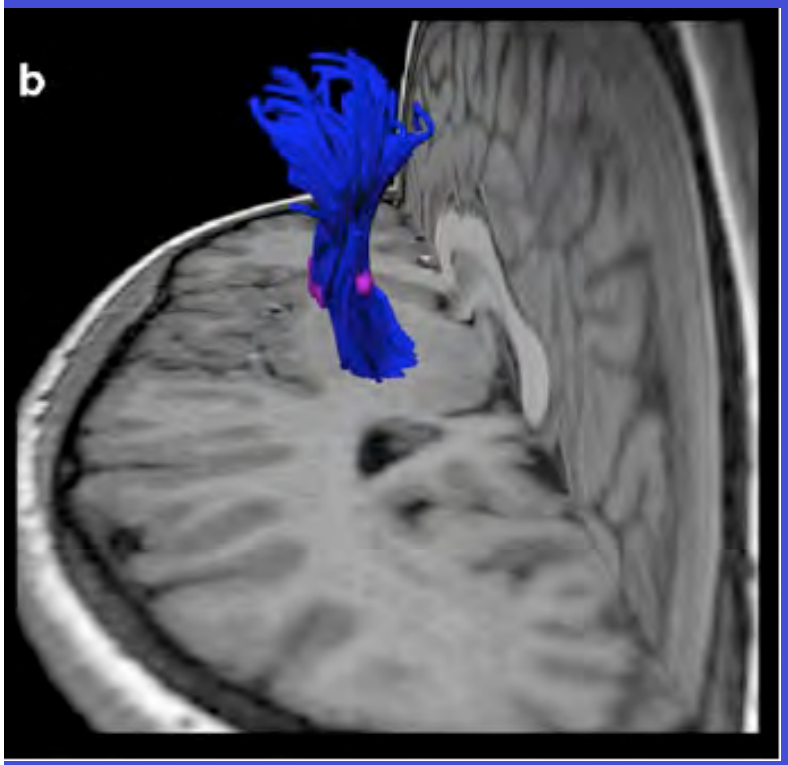
Fractional Anisotropy in left SCR in Childhood: Average to Impaired Readers

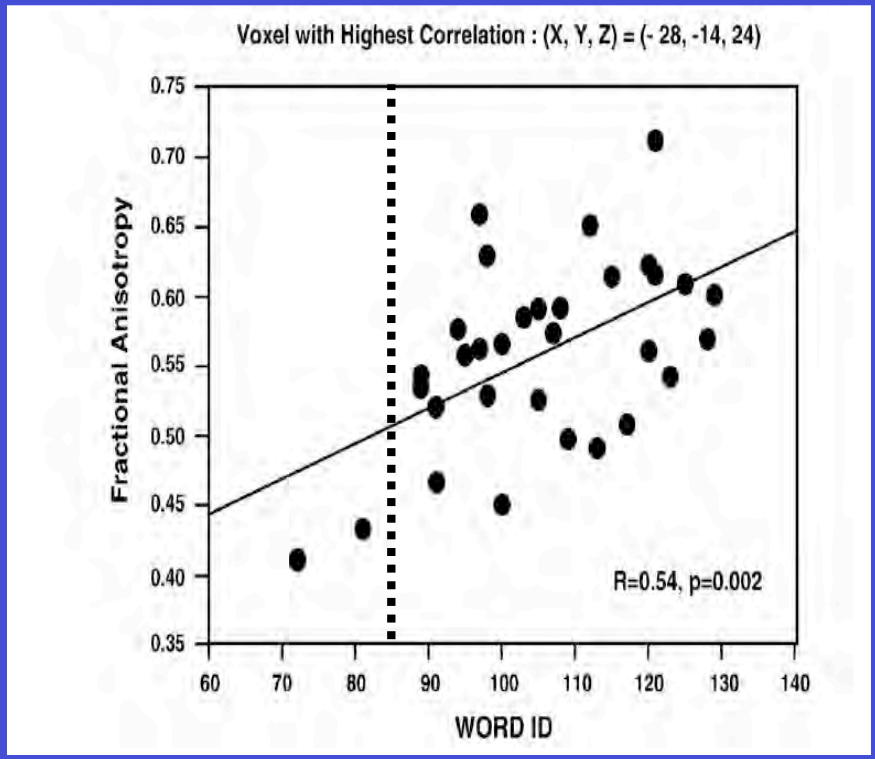




Niogi & McCandliss (2006)

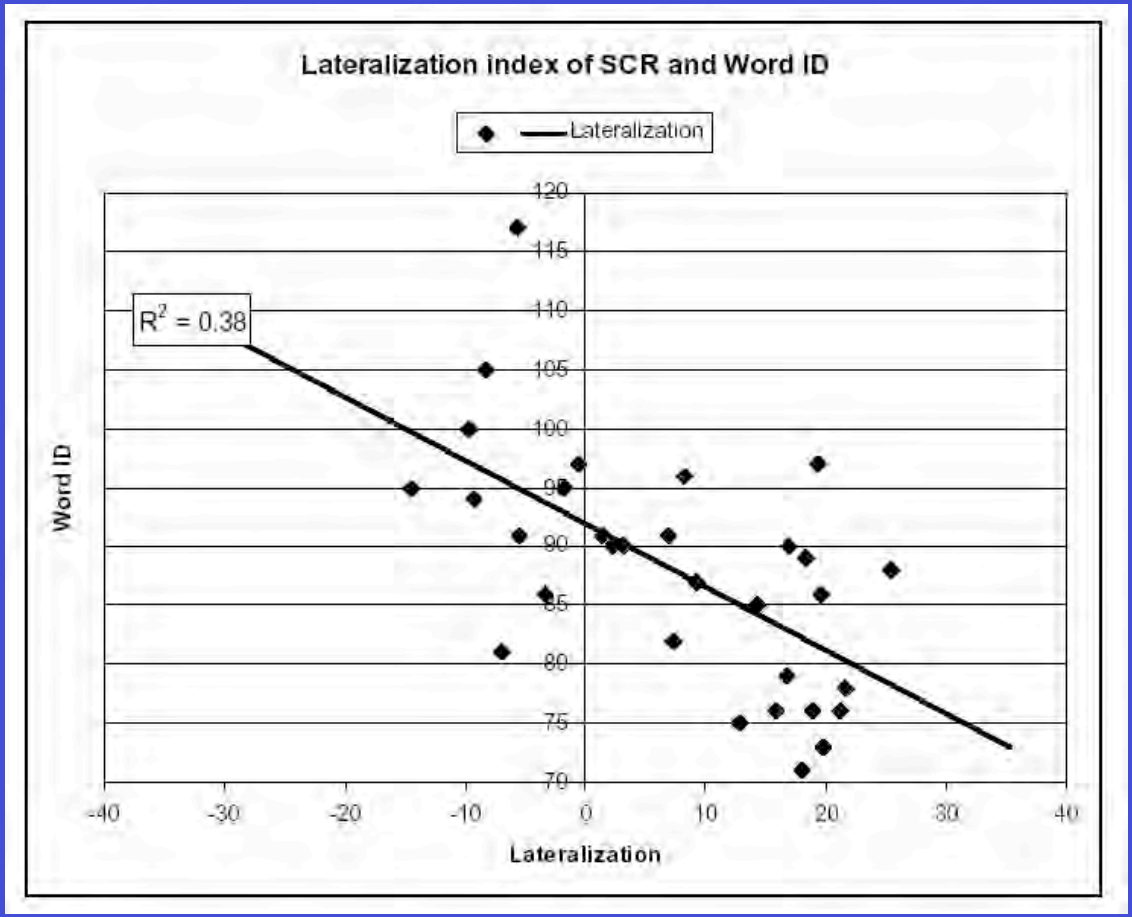
Fractional Anisotropy in left SCR in Childhood: Average to Exceptional Readers





Beaulieu, et al., (2005) NeuroImage

Lateralization Index

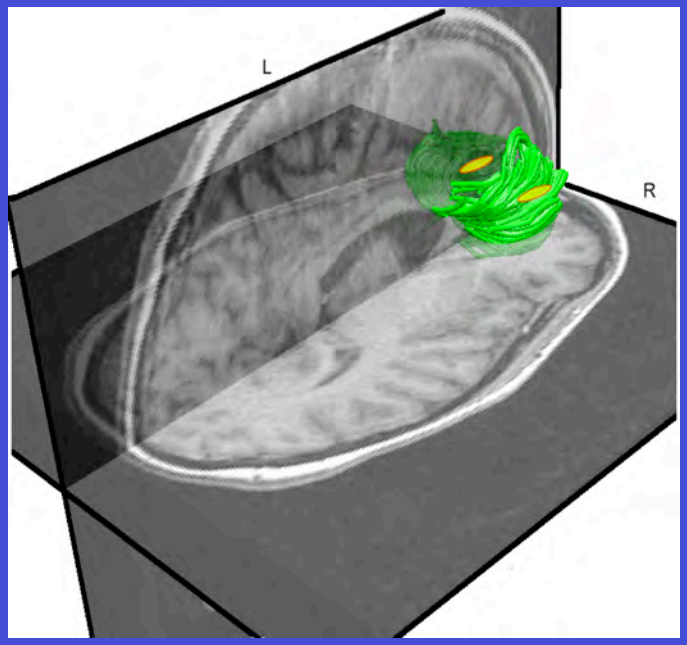


Replication Across Studies

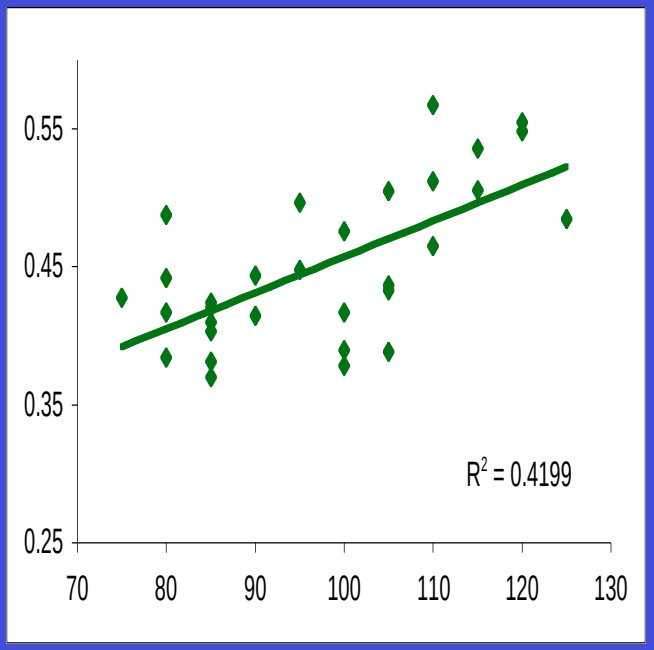
Correlation between Left SCR FA and Word ID in children

- Beaulieu, et al., (2005) NeuroImage
- Deutsch, et al., (2005) Journal of Cognitive Neuroscience
- Niogi and McCandliss (2006) Neuropsychologia
- Nagy et al., (2004) Journal of Cognitive Neuroscience

Bilateral Anterior Corona Radiata



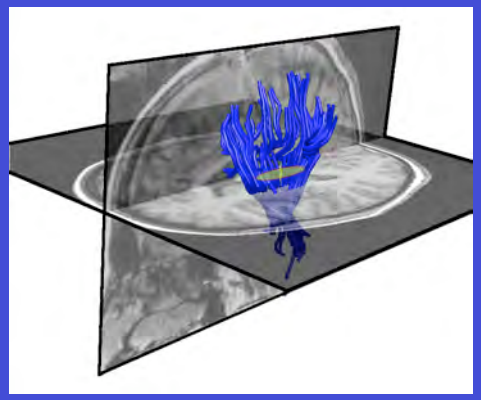
CTOPP Standardized Digit Recall (Short Term Memory)

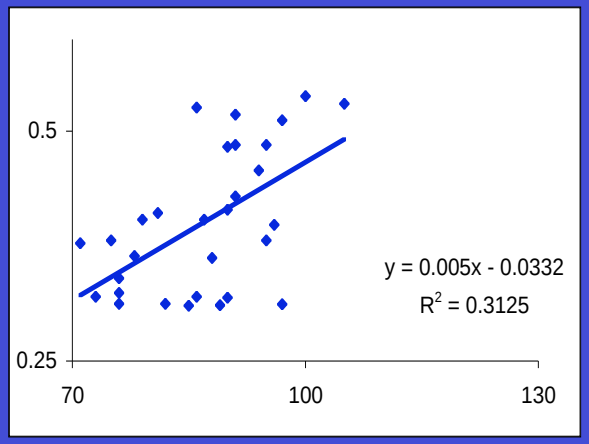


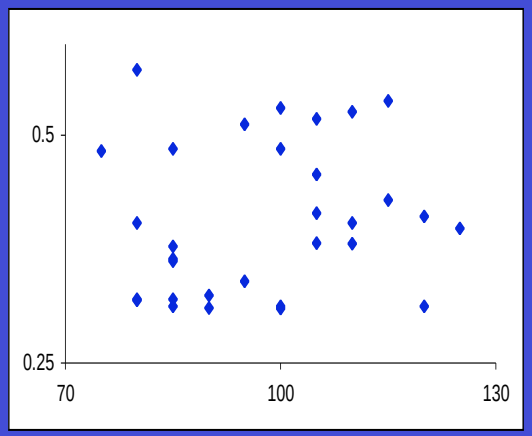
“Double Dissociation” in Correlation Patterns

Standardized Word ID

Standardized Digit Recall



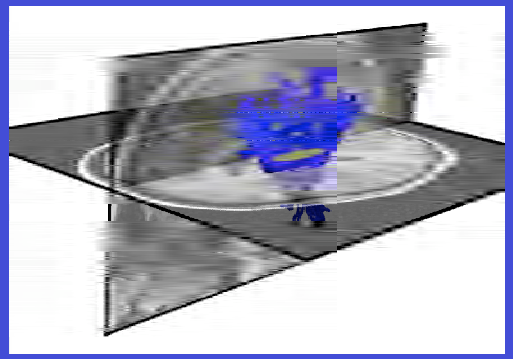


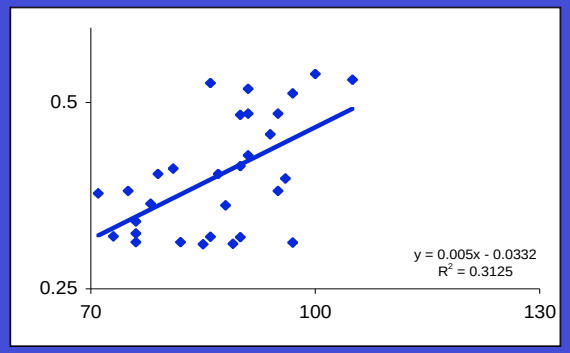


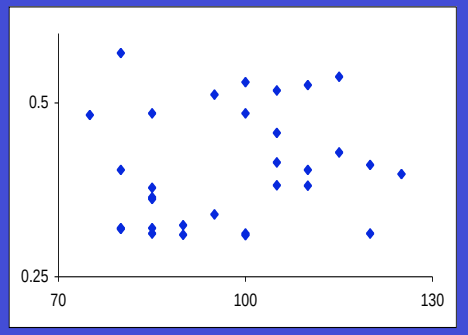
“Double Dissociation” in Correlation Patterns

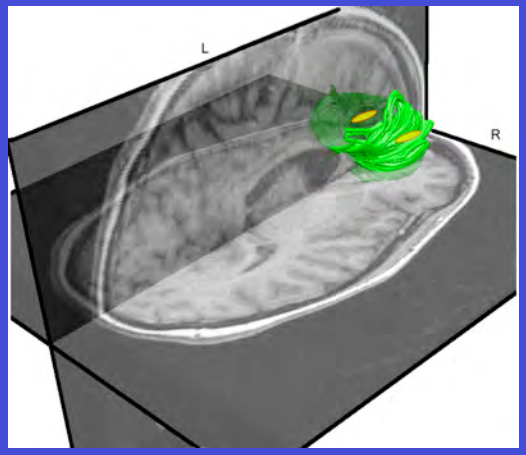
Standardized Word ID

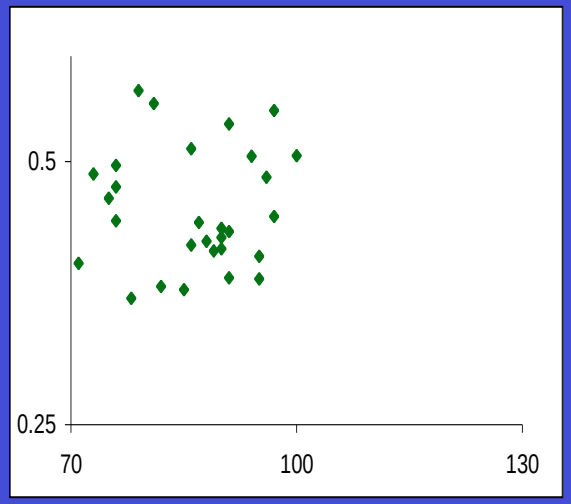
Standardized Digit Recall

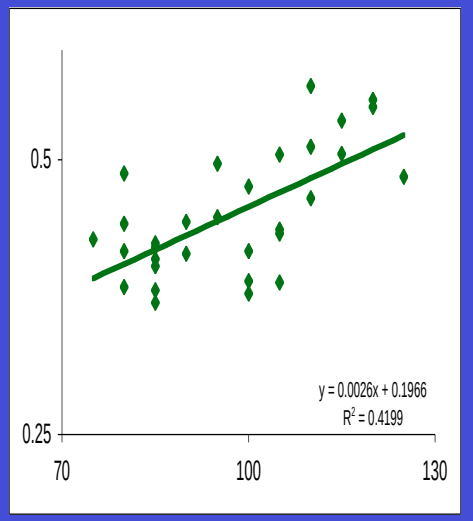












Multiple Regression Analyses of Domain Specificity

FA in Left Superior Corona Radiata	Change R-square	
Model 1: Non-verbal IQ, age	.10	
Model 2: Non-verbal IQ, age, *Digit Recall*	. 00	
Model 3: Non-verbal IQ, age, *Digit Recall*, **Word ID**	. 40	*** (p<.0001)

Multiple Regression Analyses of Domain Specificity and Tract Specificity

FA in Left Superior Corona Radiata

	Change R-square	
Model 1: Non-verbal IQ, age	.10	
Model 2: Non-verbal IQ, age, *Digit Recall*	. 00	
Model 3: Non-verbal IQ, age, *Digit Recall*, **Word ID**	. 40	*** (p<.0001)

FA in Bilateral ACR

	Change R-square	
Model 1: Non-verbal IQ, age	.005	
Model 2: Non-verbal IQ, age, *Word ID*	.001	
Model 3: Non-verbal IQ, age, *Word ID*, **Digit Recall**	.419	*** (p<.0001)

–(see also Nagy et al., 2004 JCN)

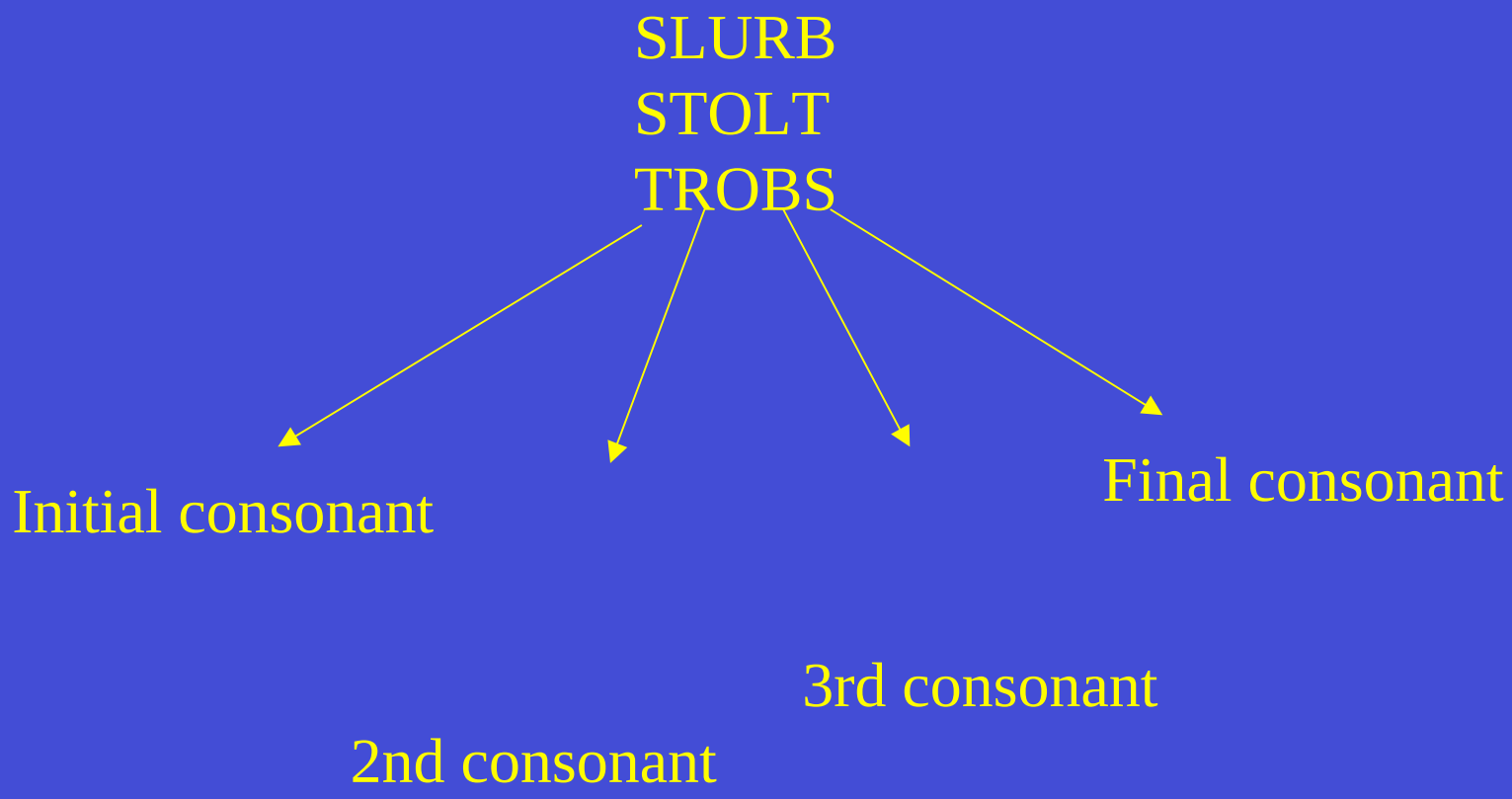
DTI Findings Summary: Left lateralized projection fibers

- Related to reading
  - replicates across 4 studies
- Related to phonological skill
  - specifically analysis and synthesis
- Unrelated to short term memory rehearsal or rapid automatized naming.
- Reflects localized rather than systemic white matter properties

Educationally Dependent Functional Reorganization?

Investigating the Impact of Instruction

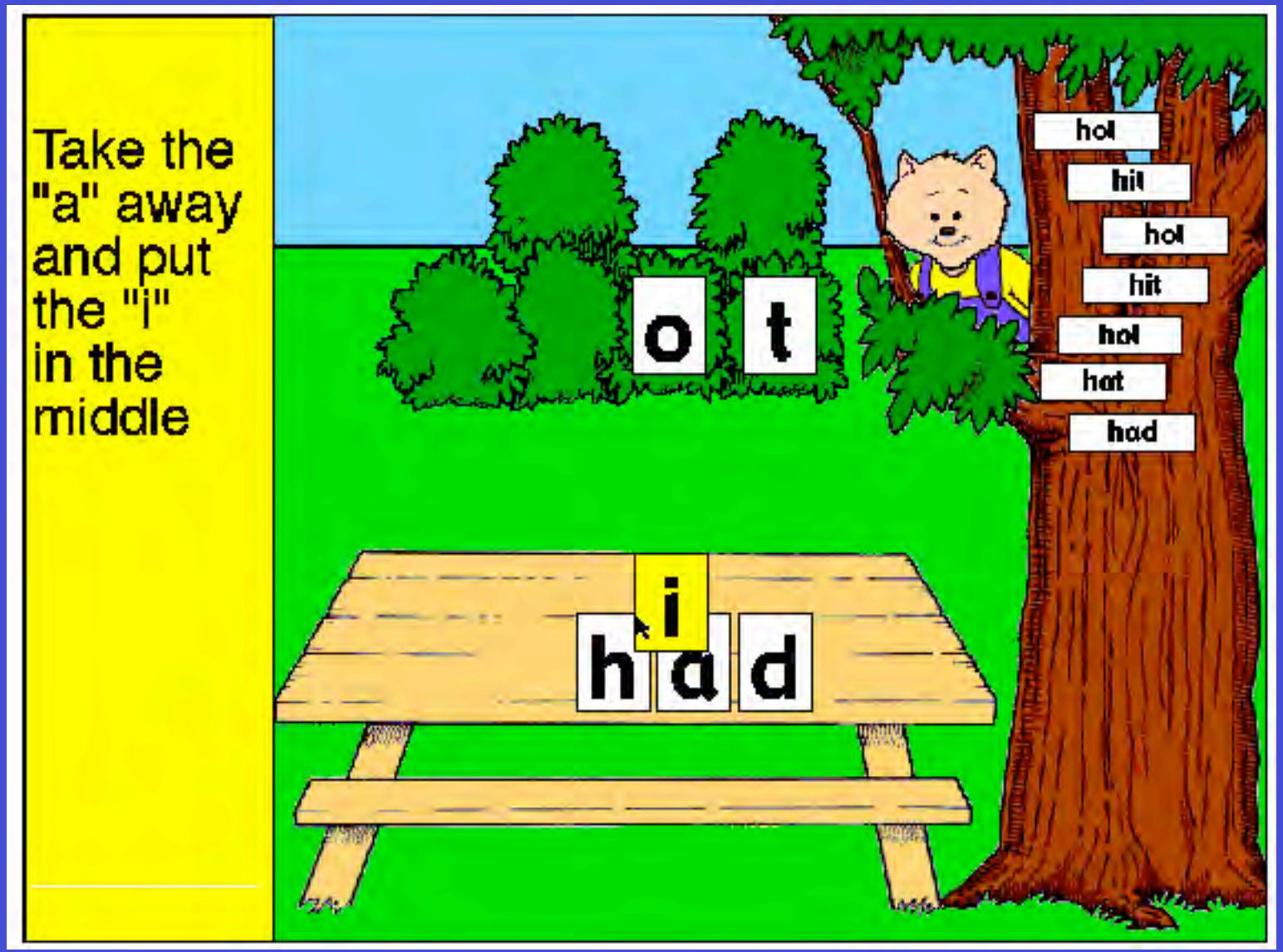
Reading Novel Words



Child Training Study:

Prototype: Word Building
(Beck & Hamilton, 1996)

Software Based Intervention



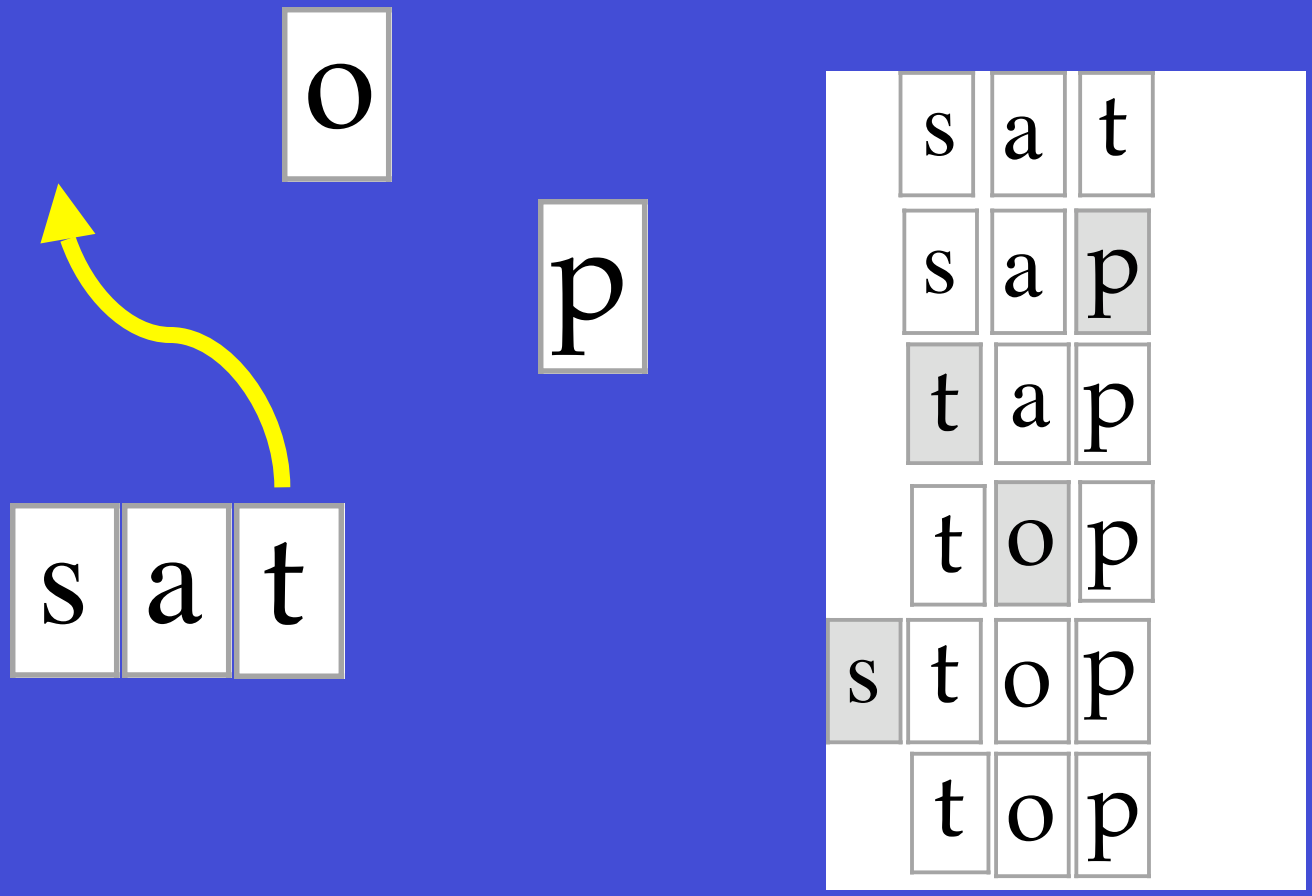
Impact of 20 Sessions

- Visual words are presented in contrastive pairs that focus attention on the impact of one letter
- Content difficulty adapted to each child to provide a balance between challenge and mastery

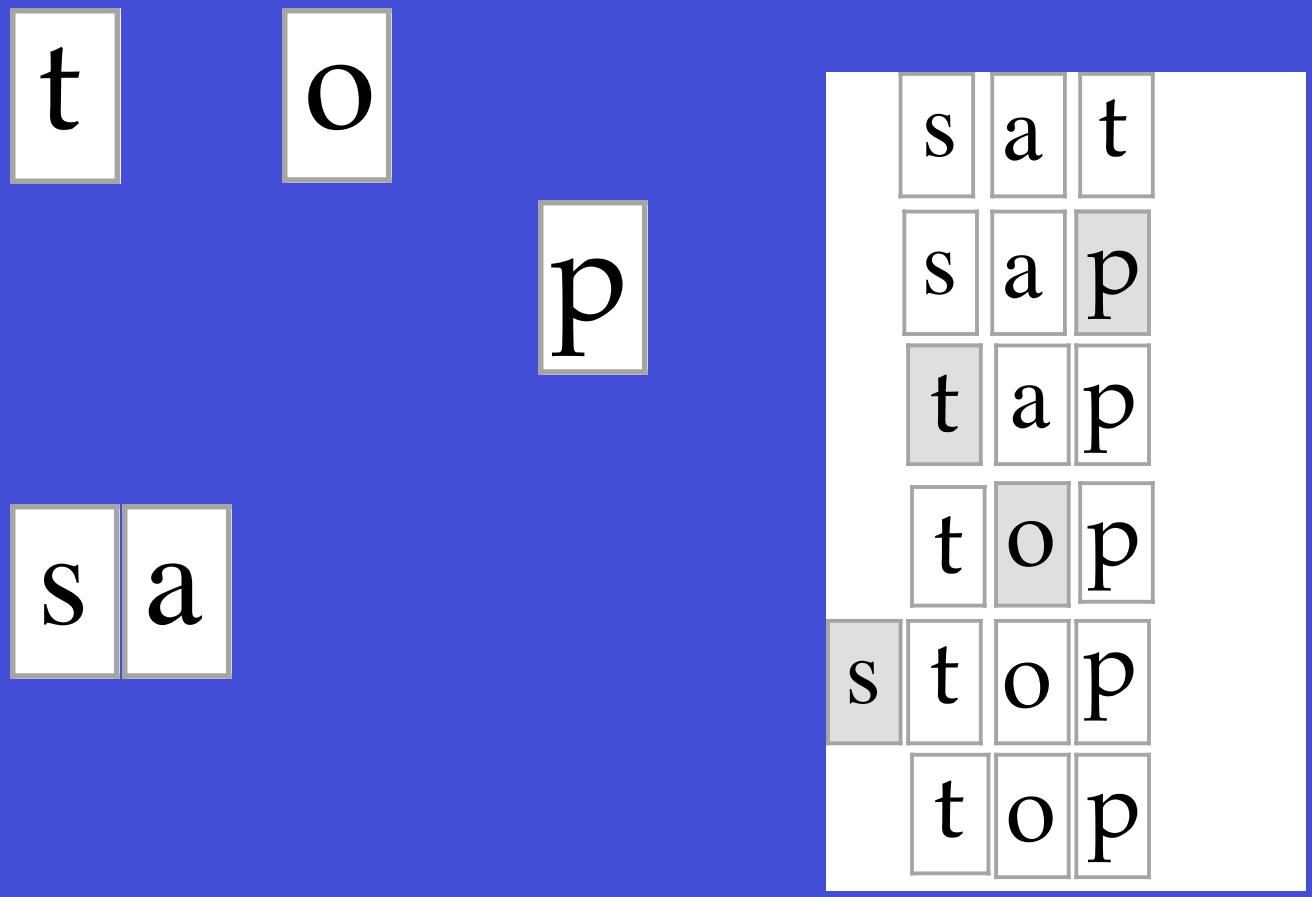
McCandliss, Beck, Sandak & Perfetti (2003)

Scientific Studies of Reading

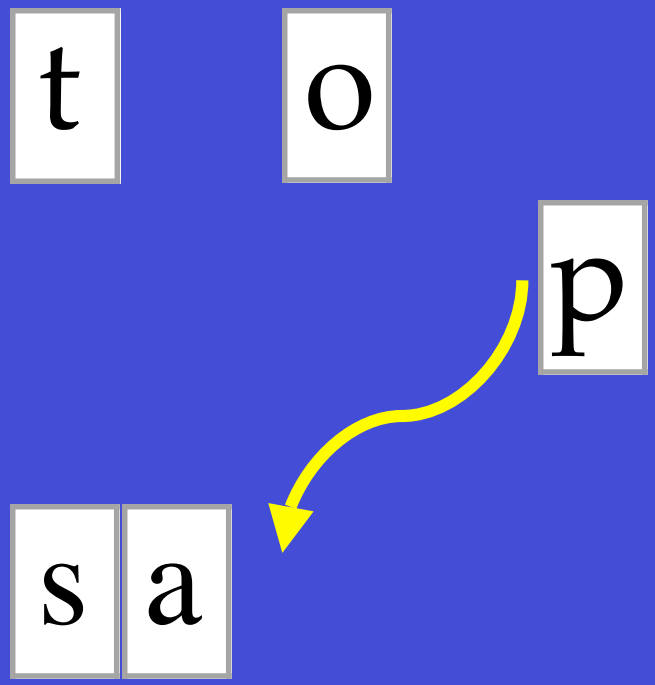
Word Building (McCandliss et al, 2003)



Word Building (McCandliss et al, 2003)



Word Building (McCandliss et al, 2003)

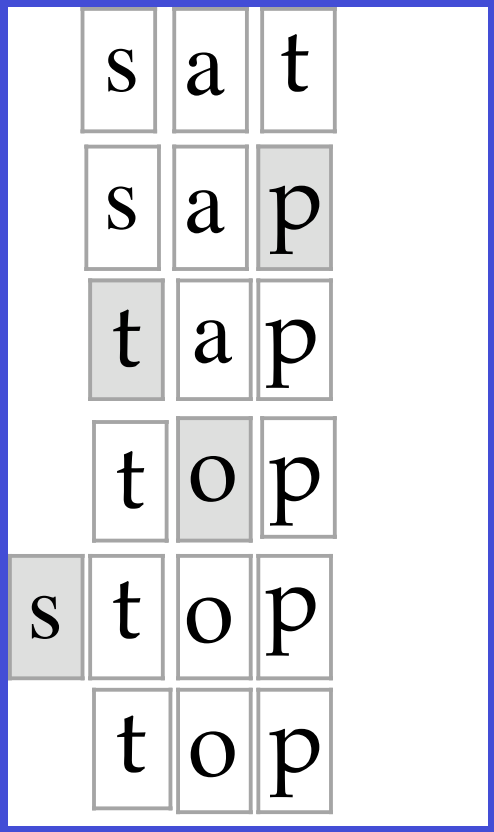


	s	a	t
	s	a	p
	t	a	p
	t	o	p
s	t	o	p
	t	o	p

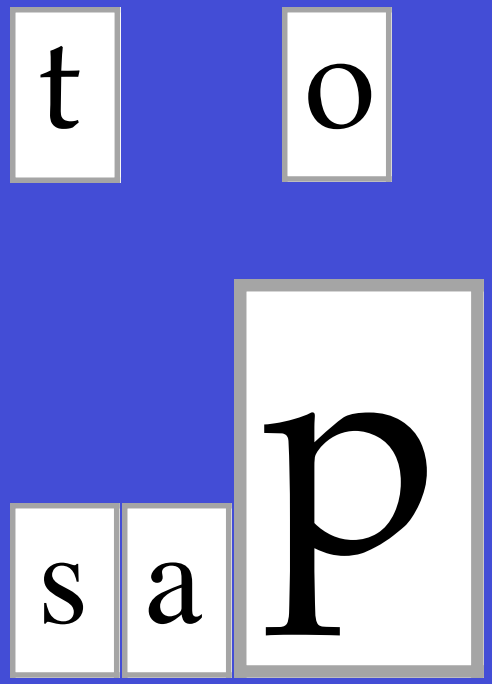
Word Building (McCandliss et al, 2003)

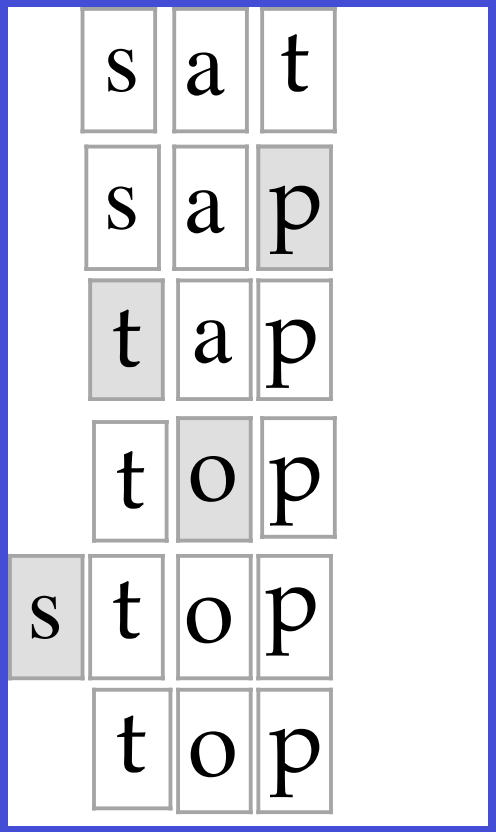
t o

s a p

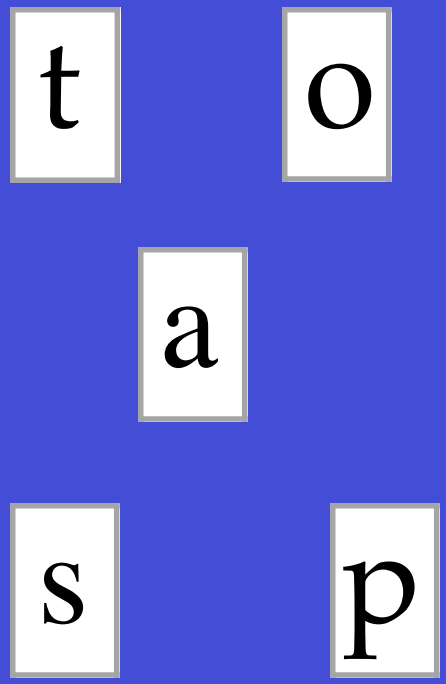


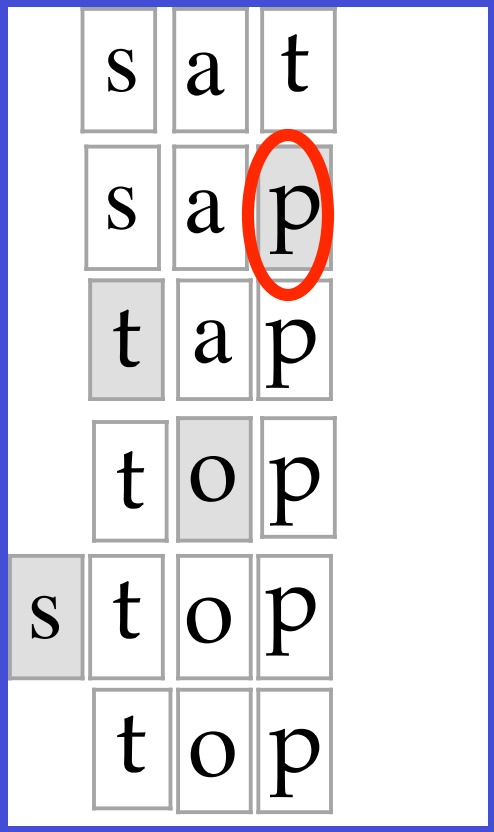
Word Building (McCandliss et al, 2003)



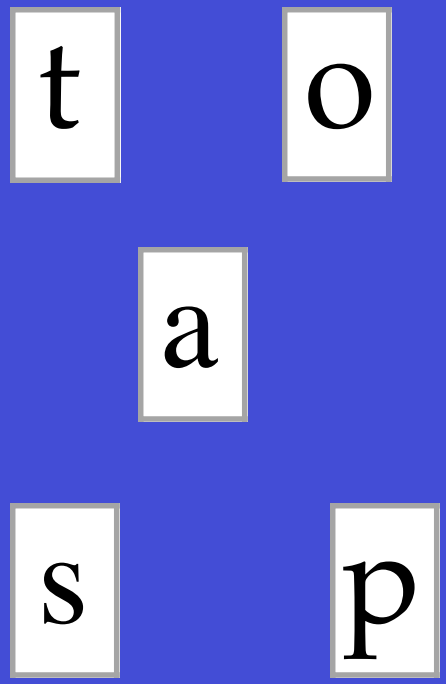


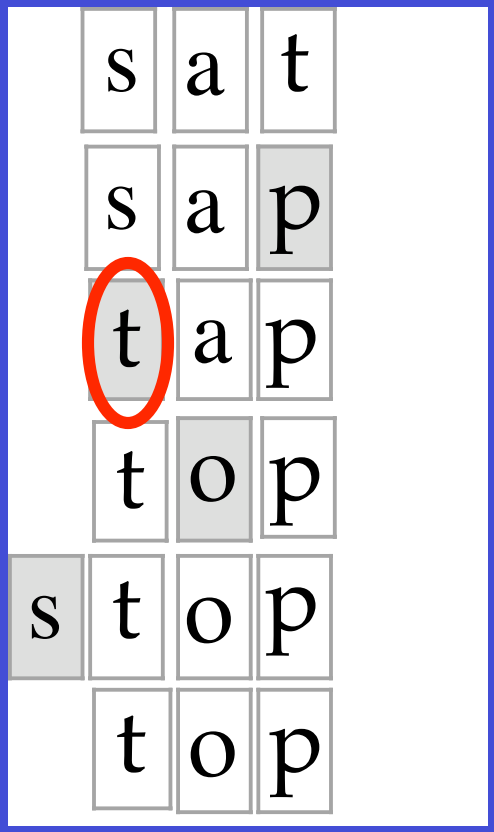
Word Building (McCandliss et al, 2003)



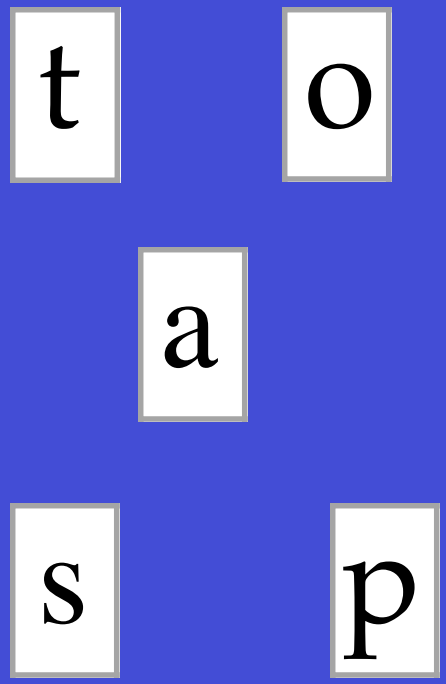


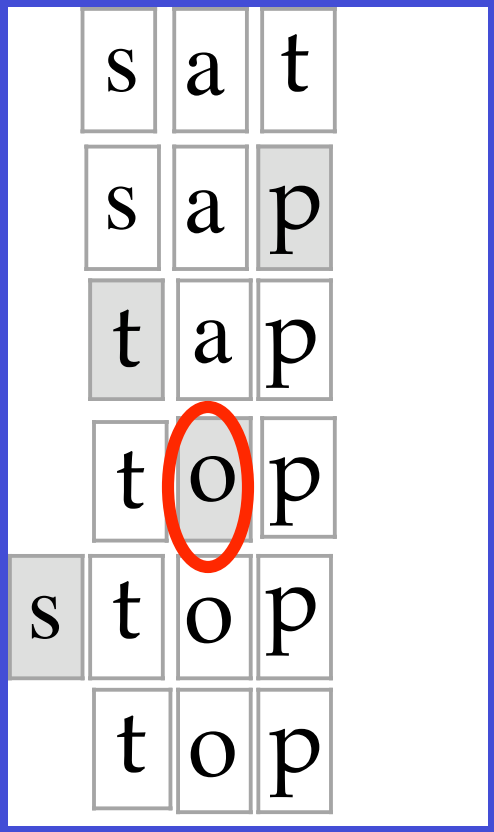
Word Building (McCandliss et al, 2003)



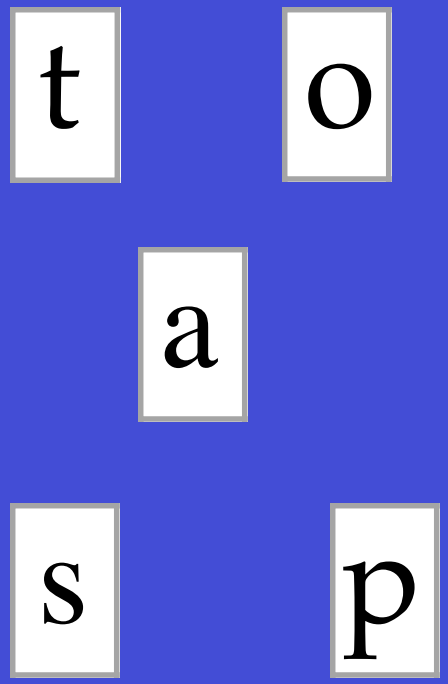


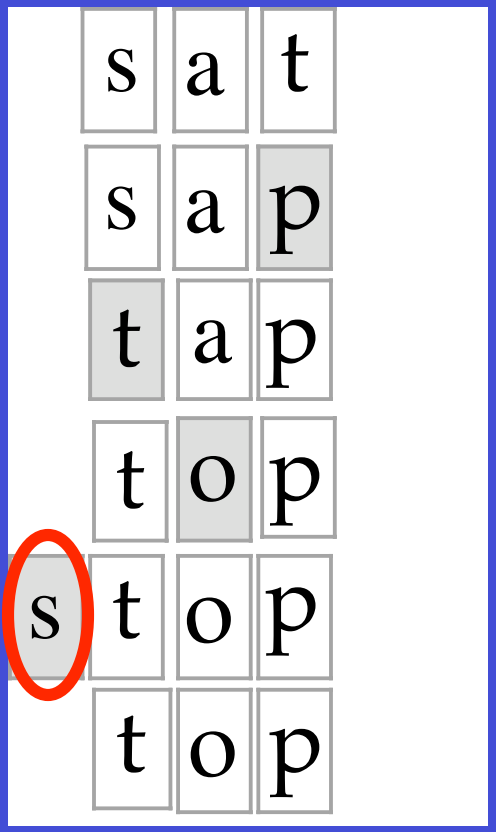
Word Building (McCandliss et al, 2003)



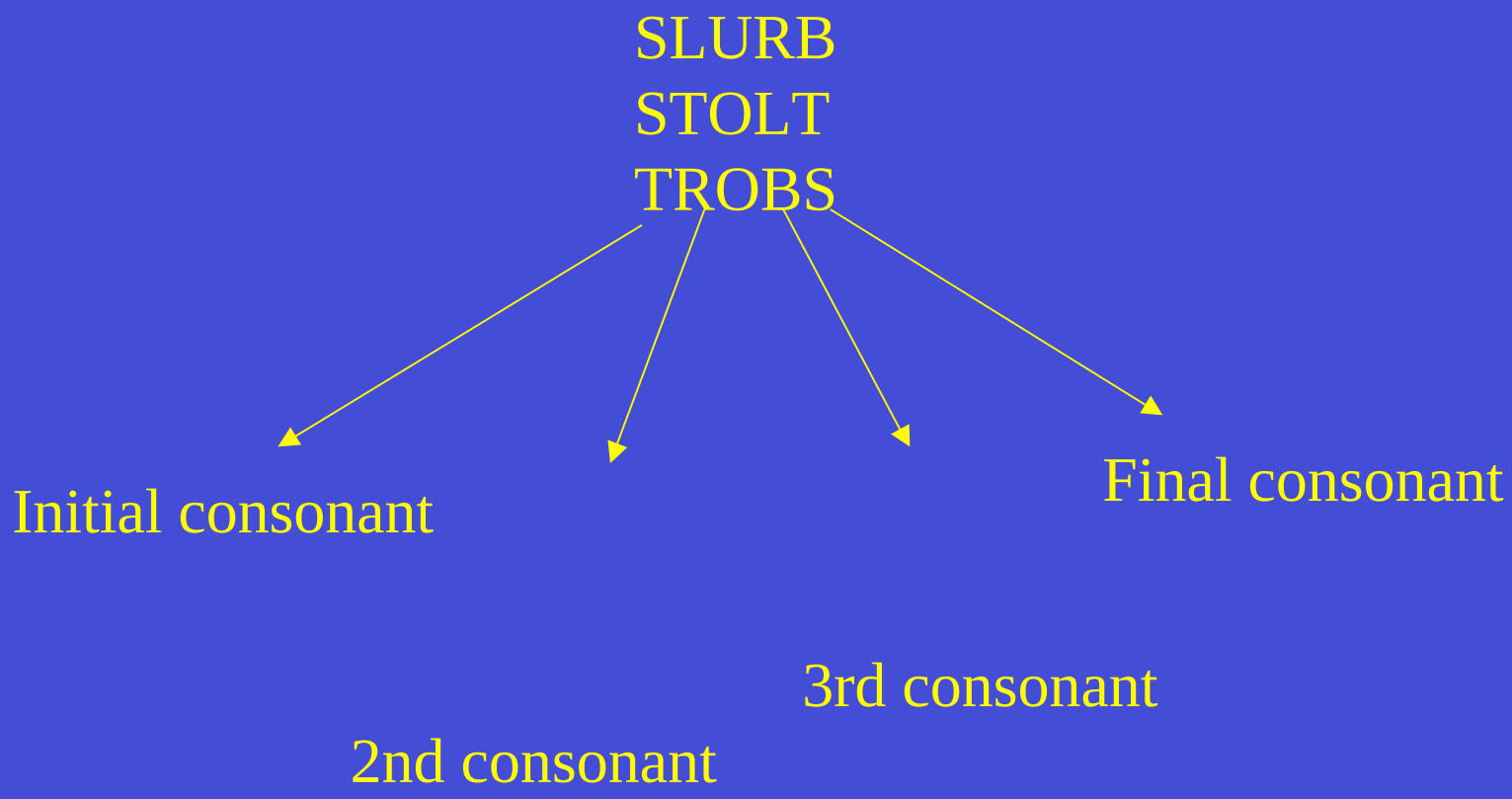


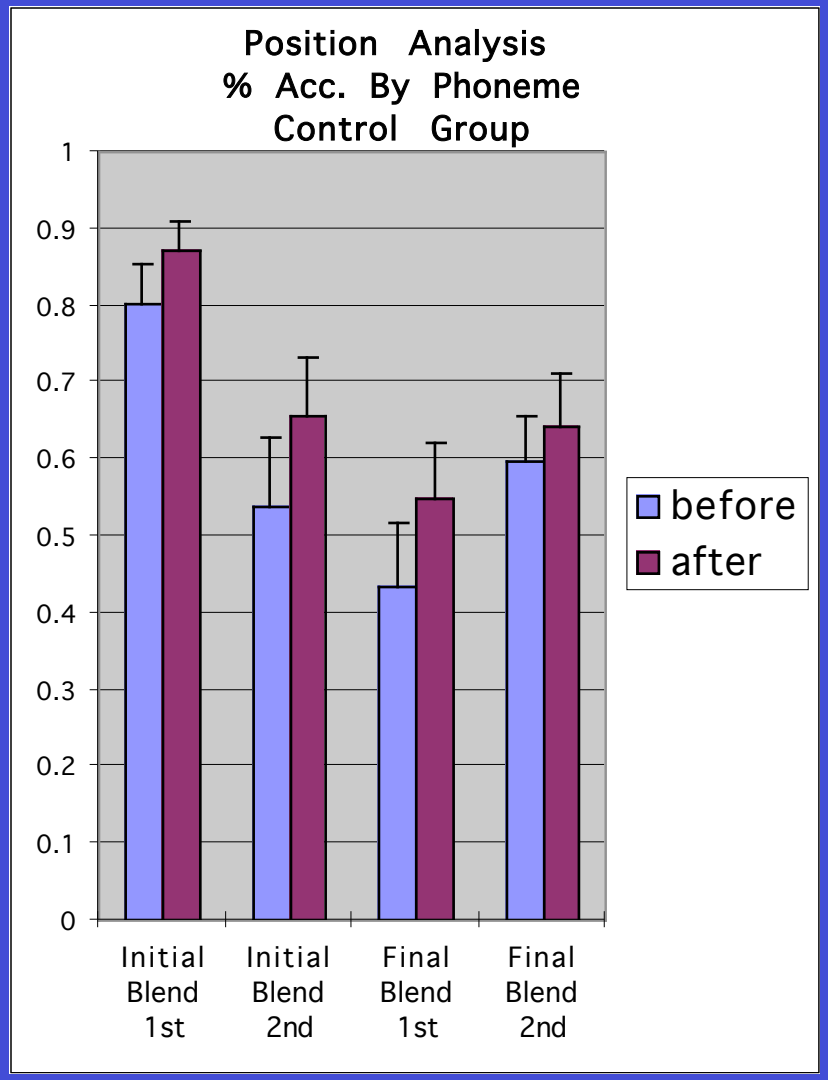
Word Building (McCandliss et al, 2003)



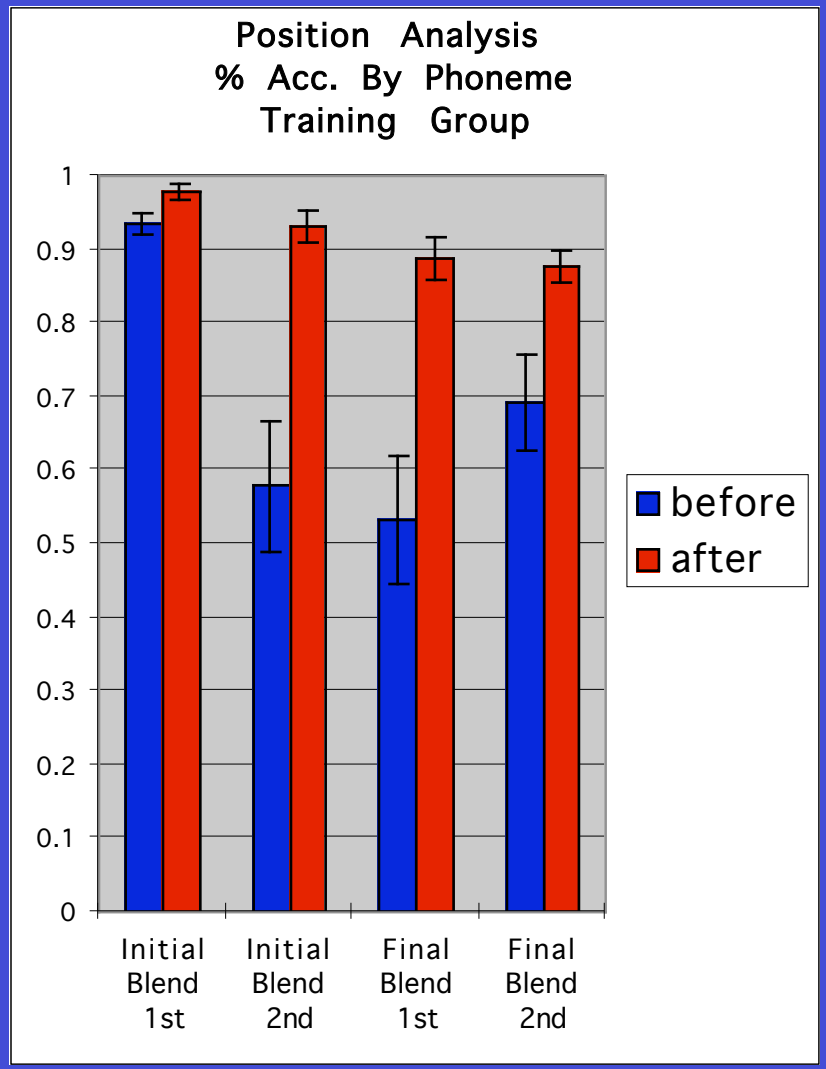


Reading Novel Words





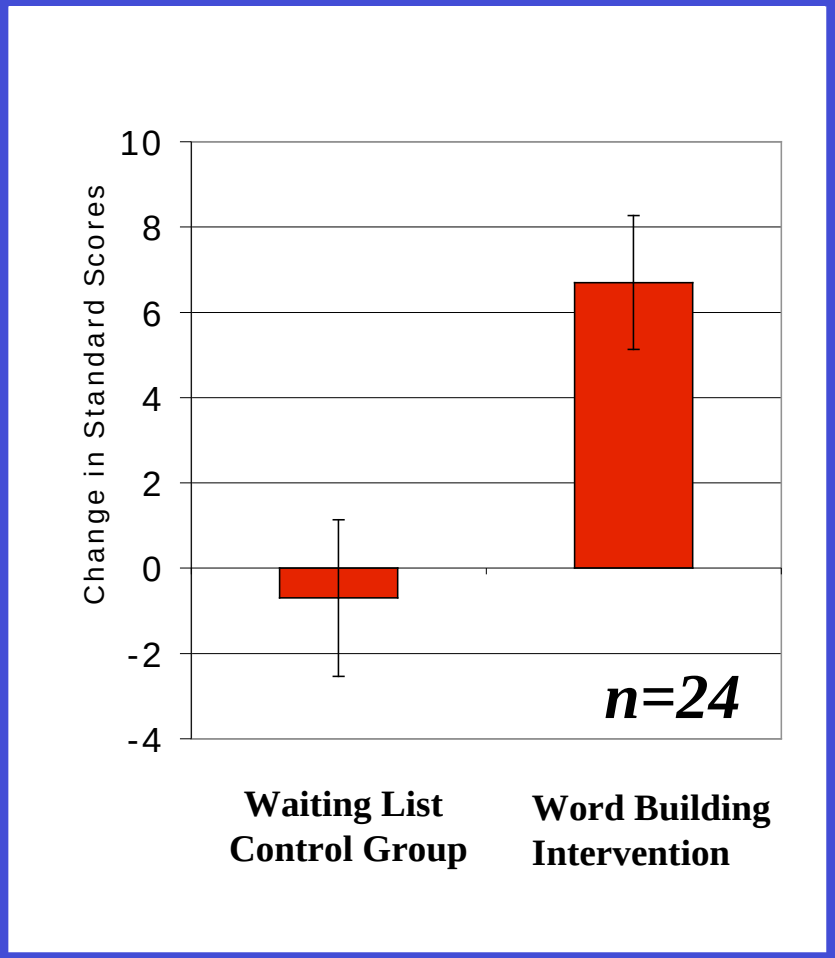
McCandliss et al, (2003) Scientific Studies of Reading



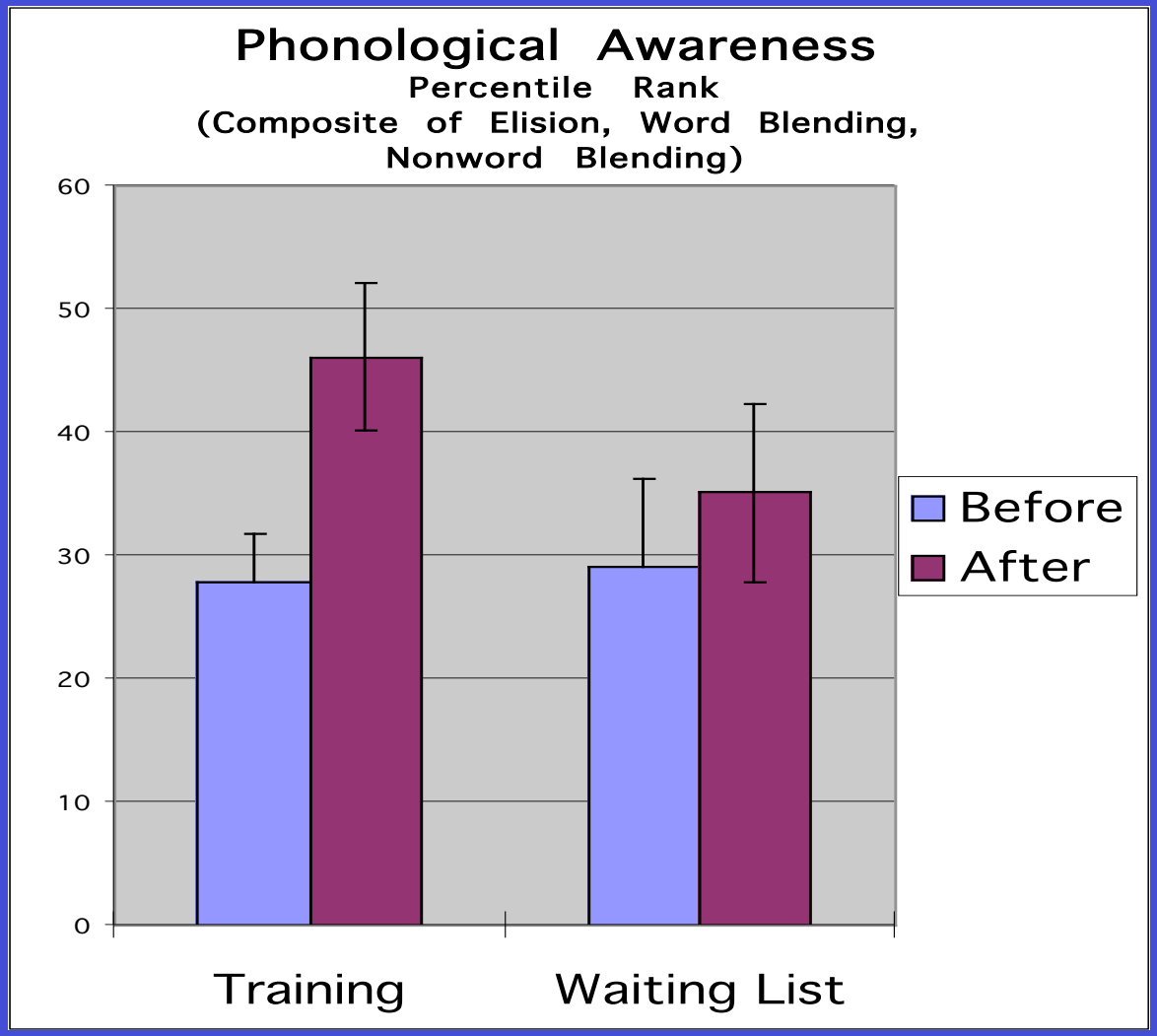
McCandliss et al, (2003) Scientific Studies of Reading

Change in Standardized Test Scores-- Reading Novel Words

Woodcock Johnson Psychoeducational Battery: Word Attack Scores



Phonological Processing Skills



McCandliss et al, (2003) Scientific Studies of Reading

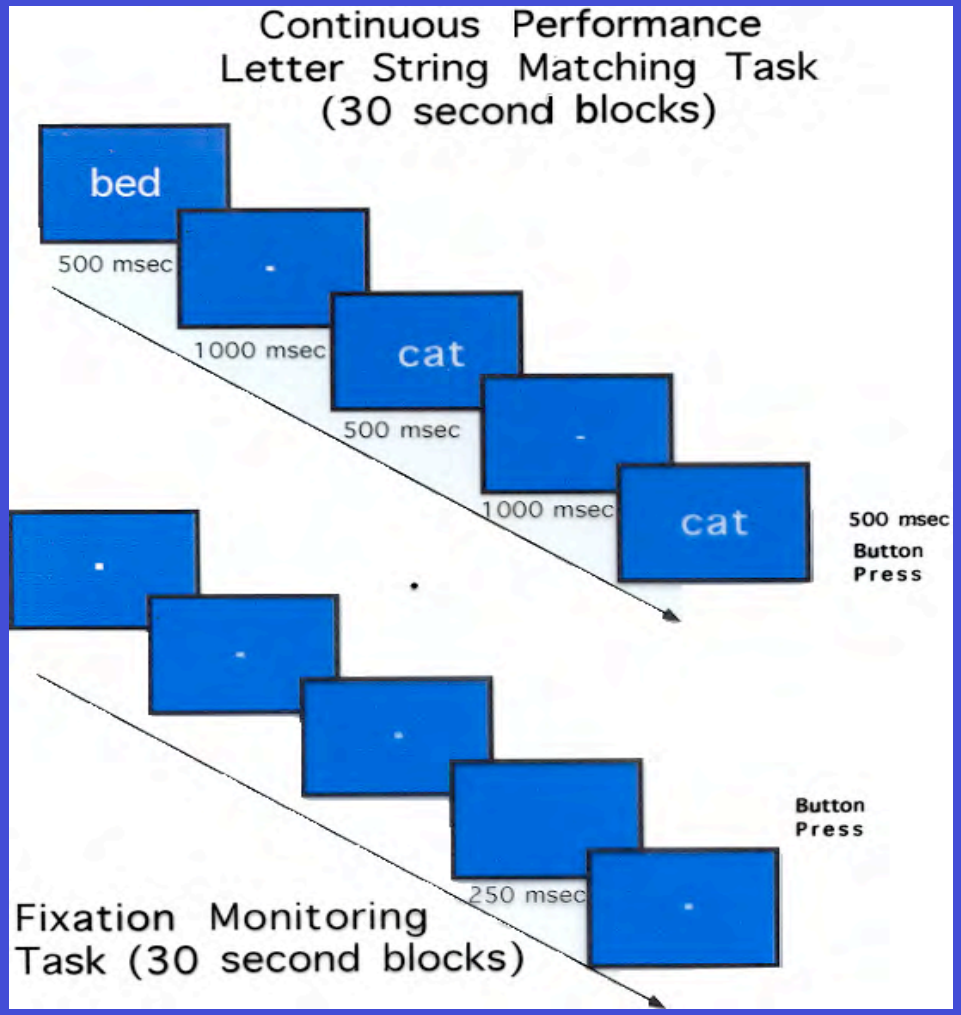
Cognitive Intervention

Before

20 Sessions of Intervention

After

fMRI Activation Task



6 cycles/run

2 runs of each stimulus type:

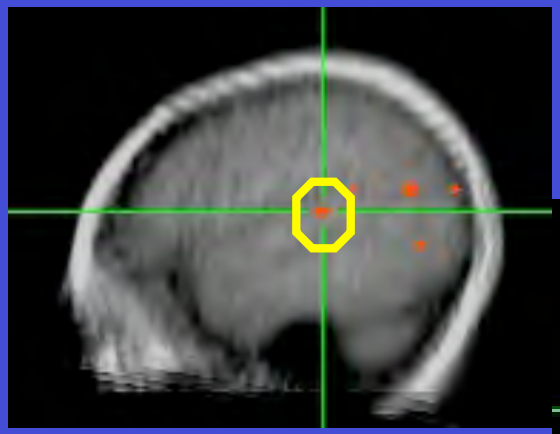
- Familiar Words
- Novel Words

- Control Letter Strings

Areas of significant training effects

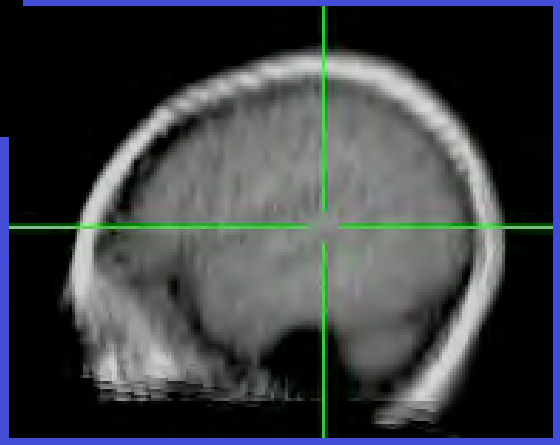
McCandliss et al., (2001)

Familiar Words

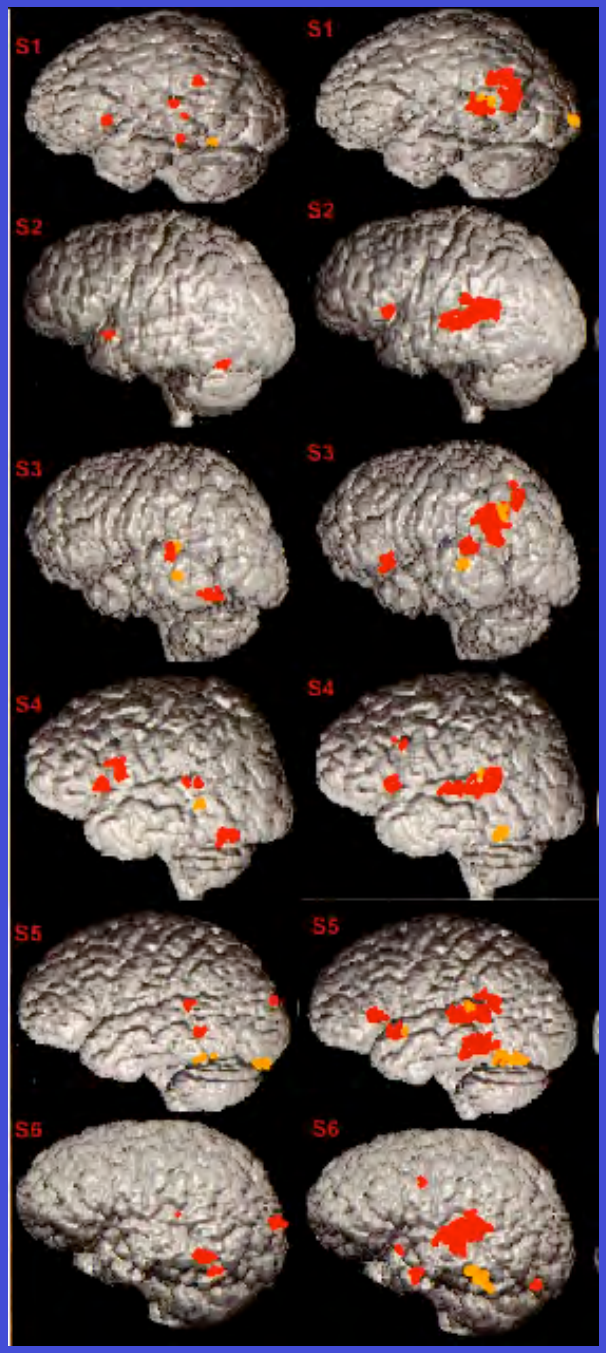


Novel Words

Control Letters



Left STG
BA 22
-43 -30 8
p<.01 n=8



Training Effects

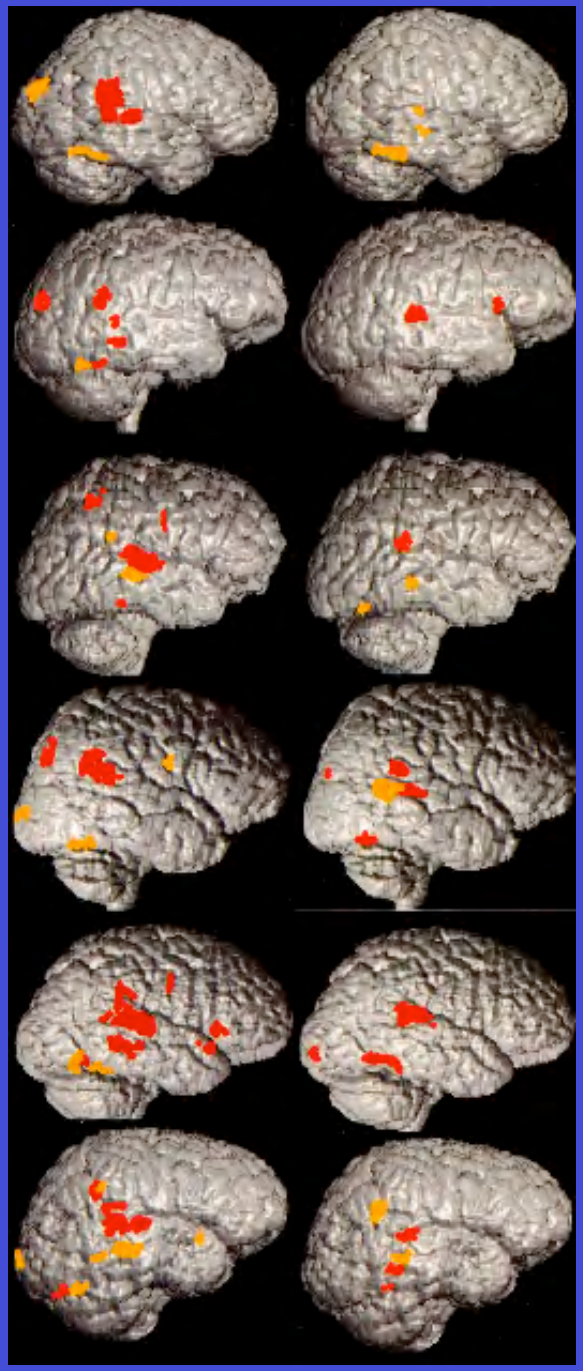
<u>Increased activation</u>

Left
Superior Temporal
Gyrus

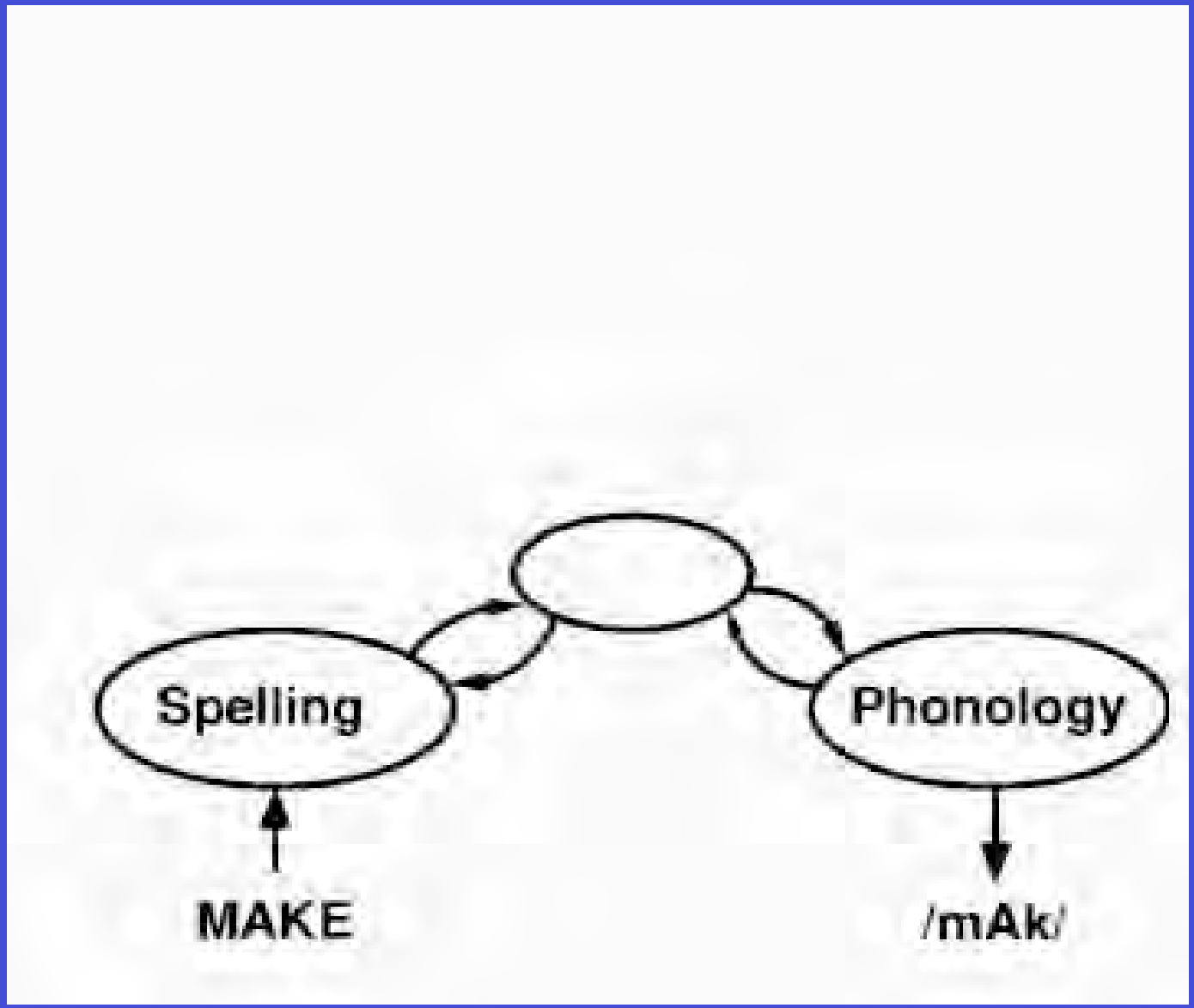
Simos et al. (2002)

Training Reductions

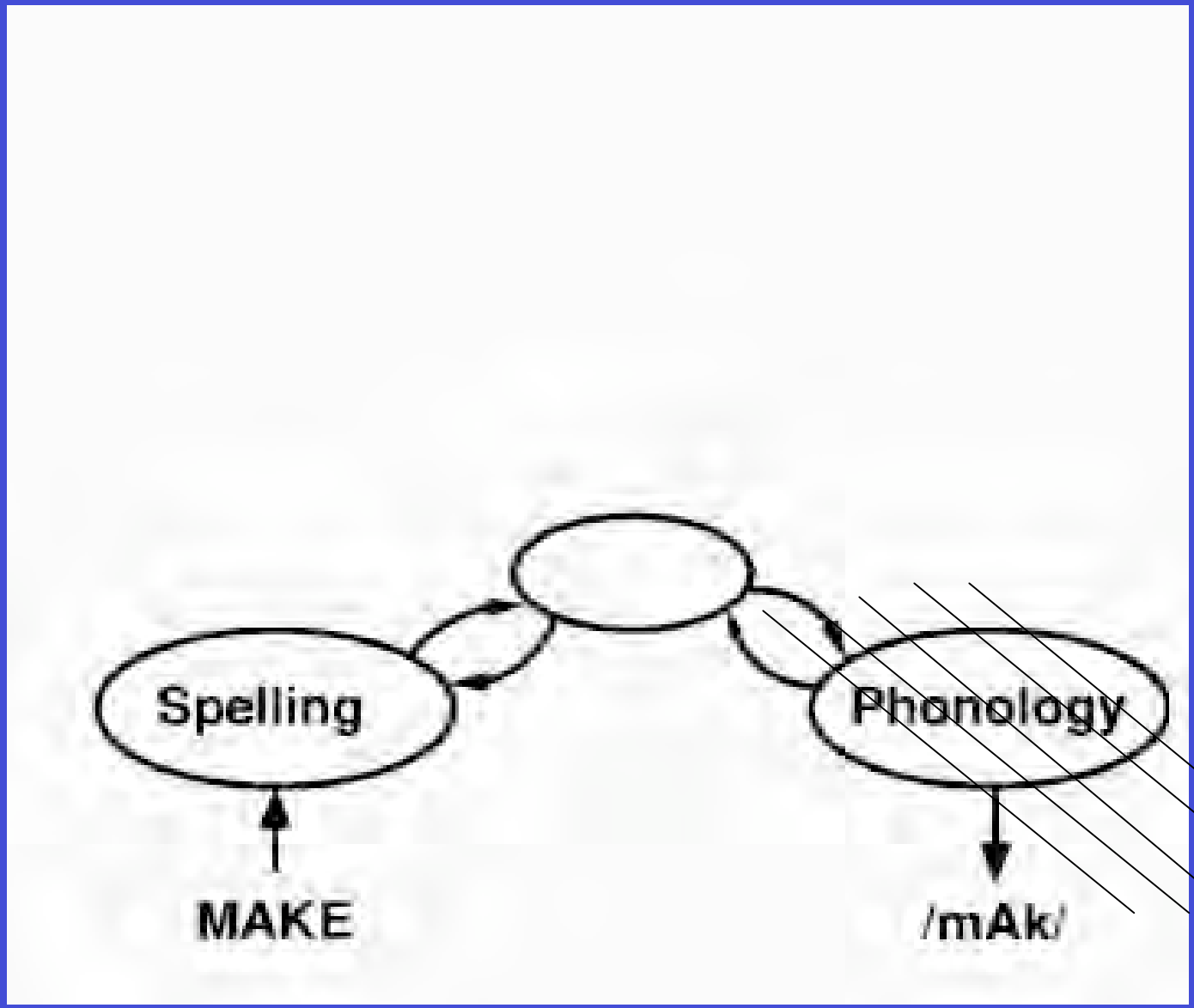
Reductions in Right Superior Temporal Gyrus



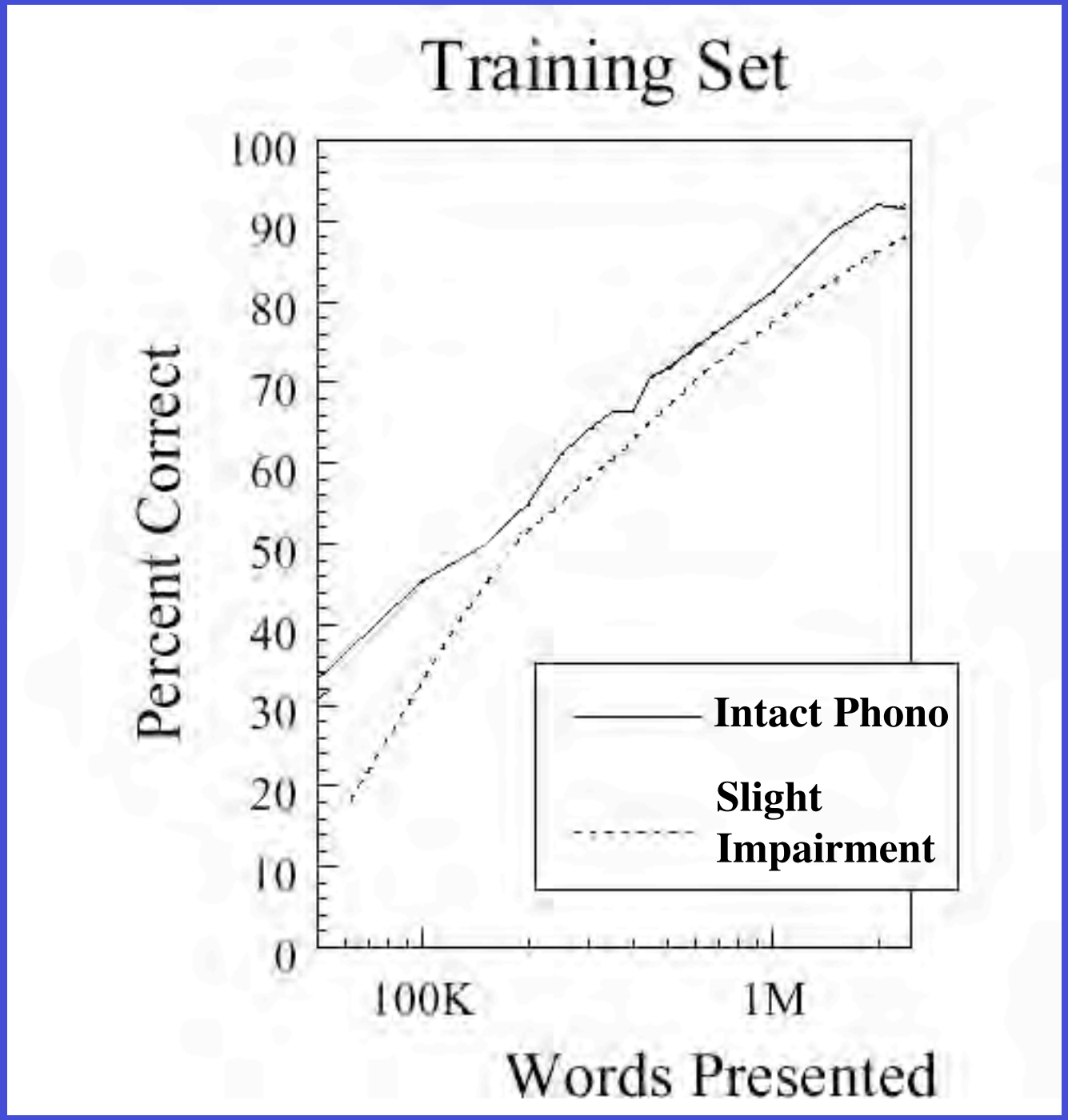
Simos et al. (2002)

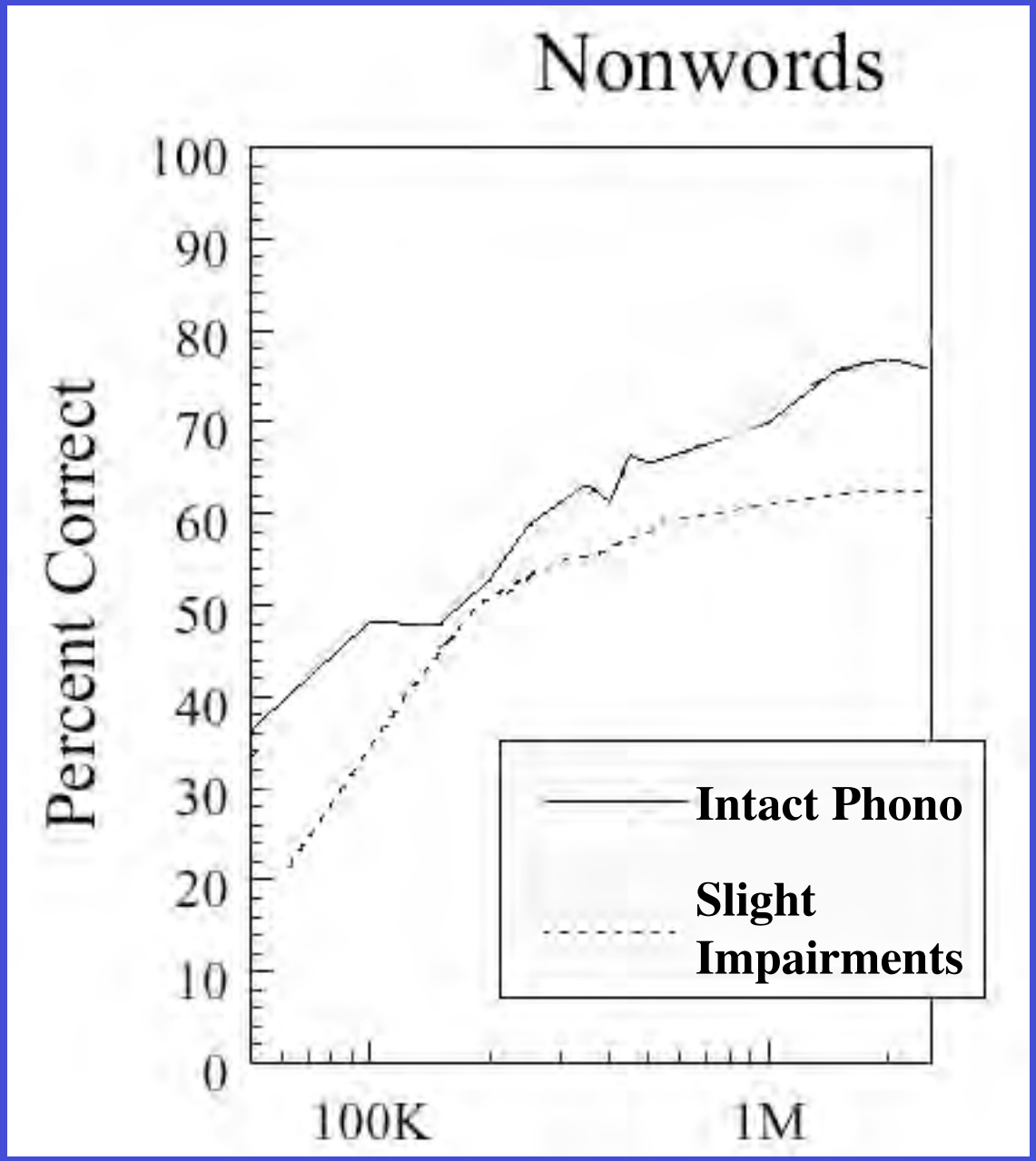


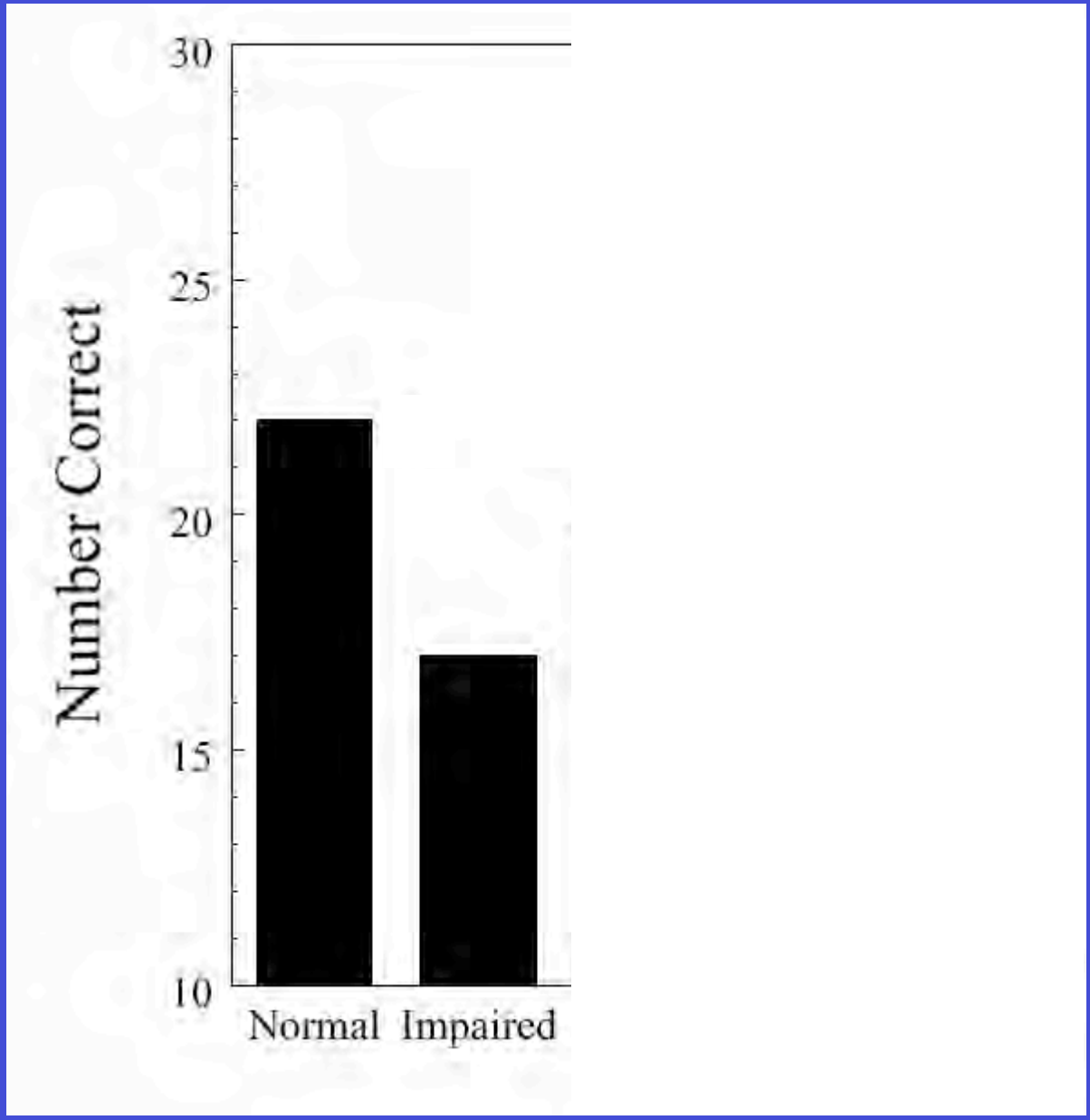
Harm, McCandliss, & Seidenberg (2003)



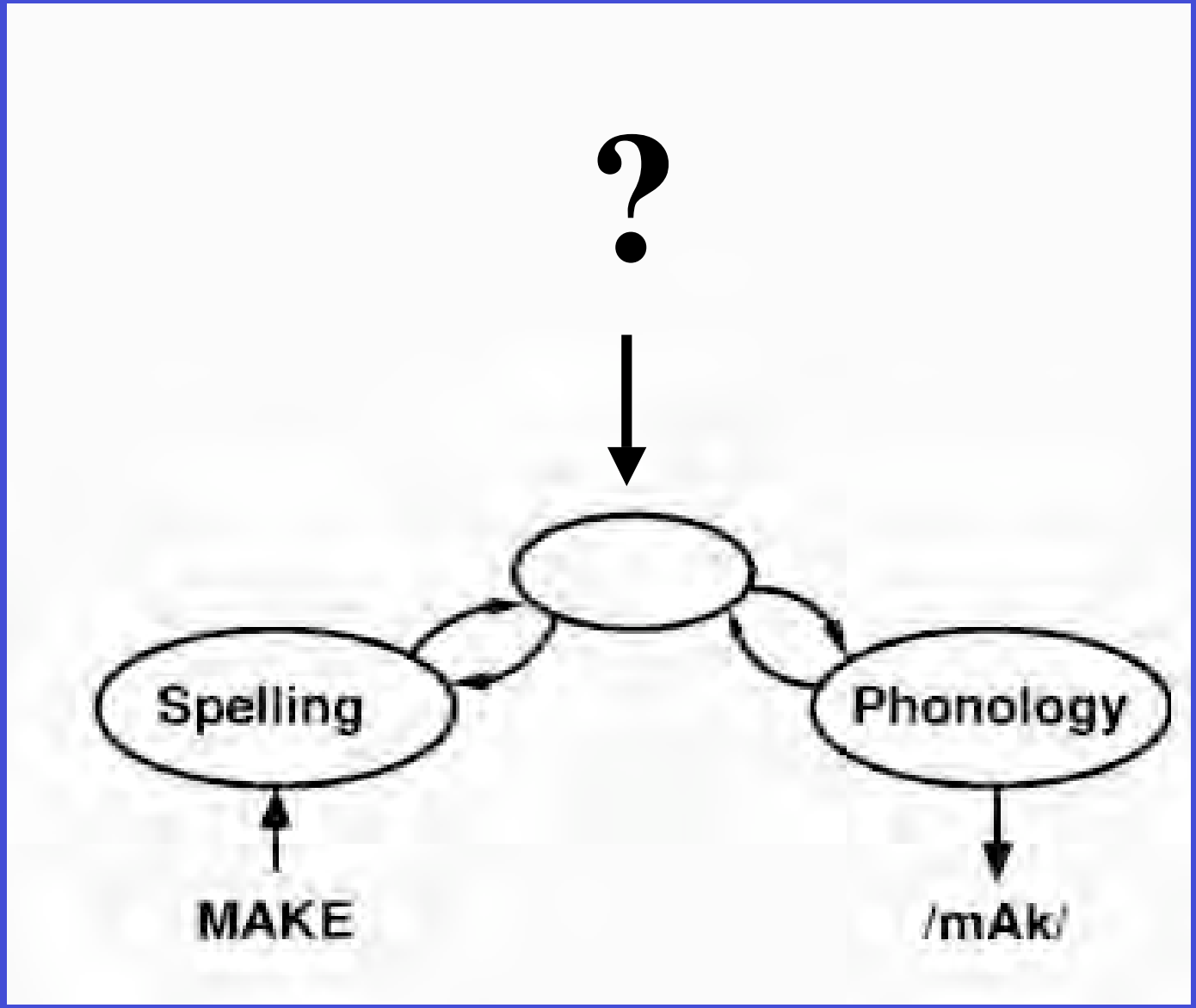
Harm, McCandliss, & Seidenberg (2003)


Training Set
Percent Correct
100
90
80
70
60
50
40
30
20
10
0
100K
1M
Words Presented
Intact Phono
Slight Impairment


Nonwords
Percent Correct
100
90
80
70
60
50
40
30
20
10
0
100K
1M
Intact Phono
Slight Impairments

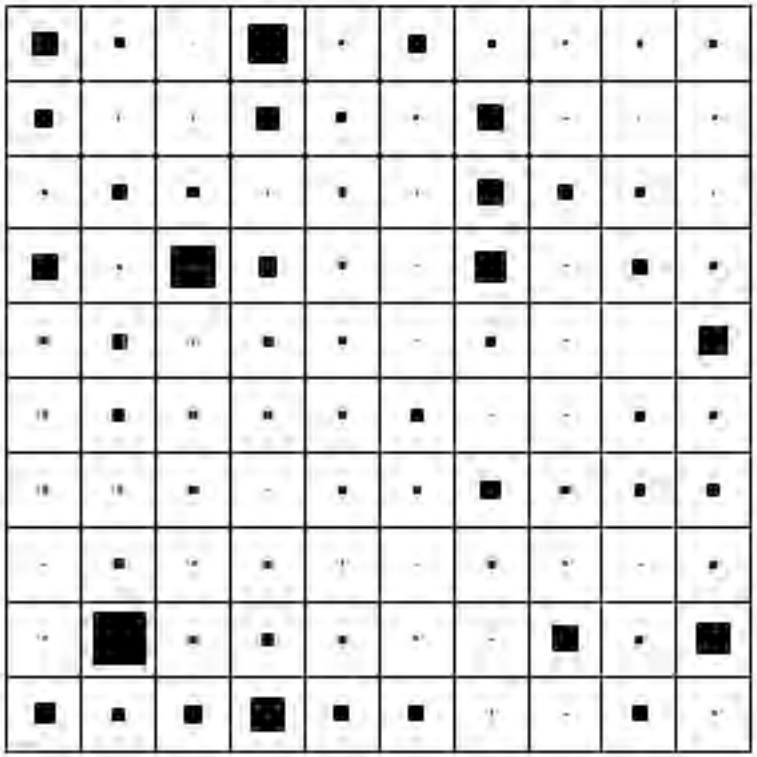


Harm, McCandliss, & Seidenberg (2003)

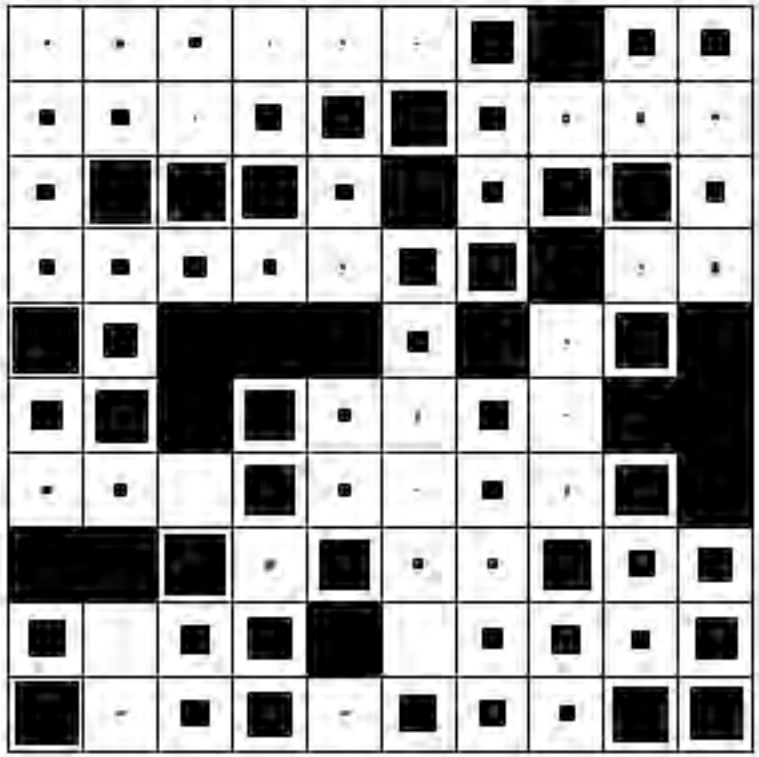

?
Spelling
Phonology
MAKE
/mAk/

Subtraction Images
(Mean differences MEAT, EAT, TREAT)

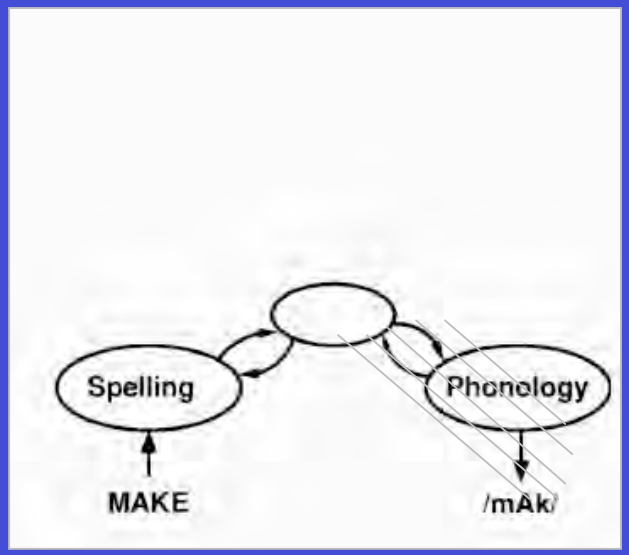
Normal



Slightly Impaired

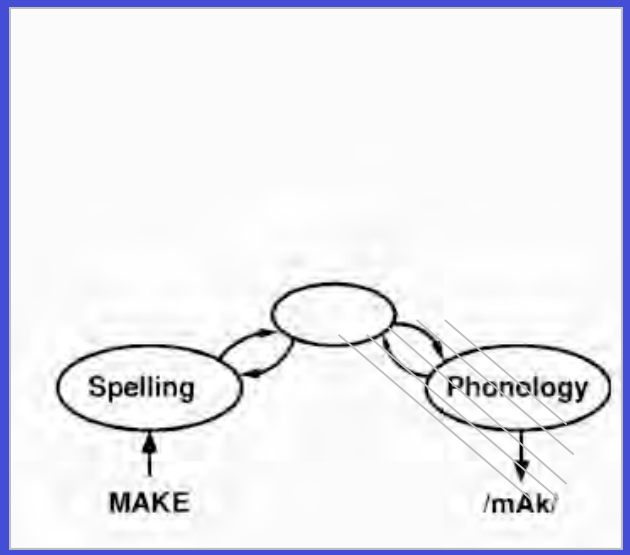


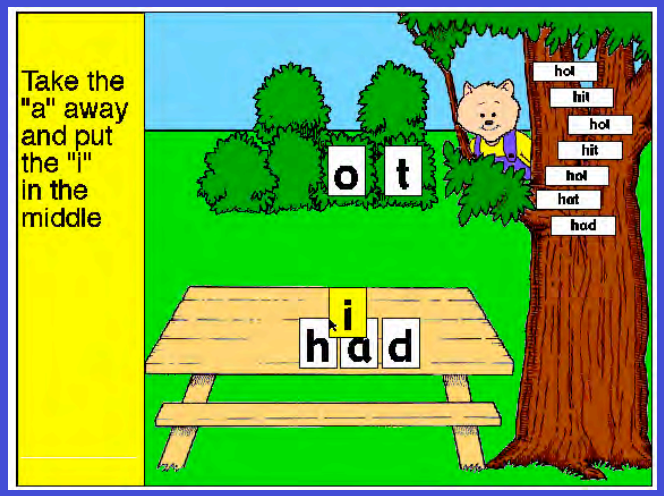
Before Intervention



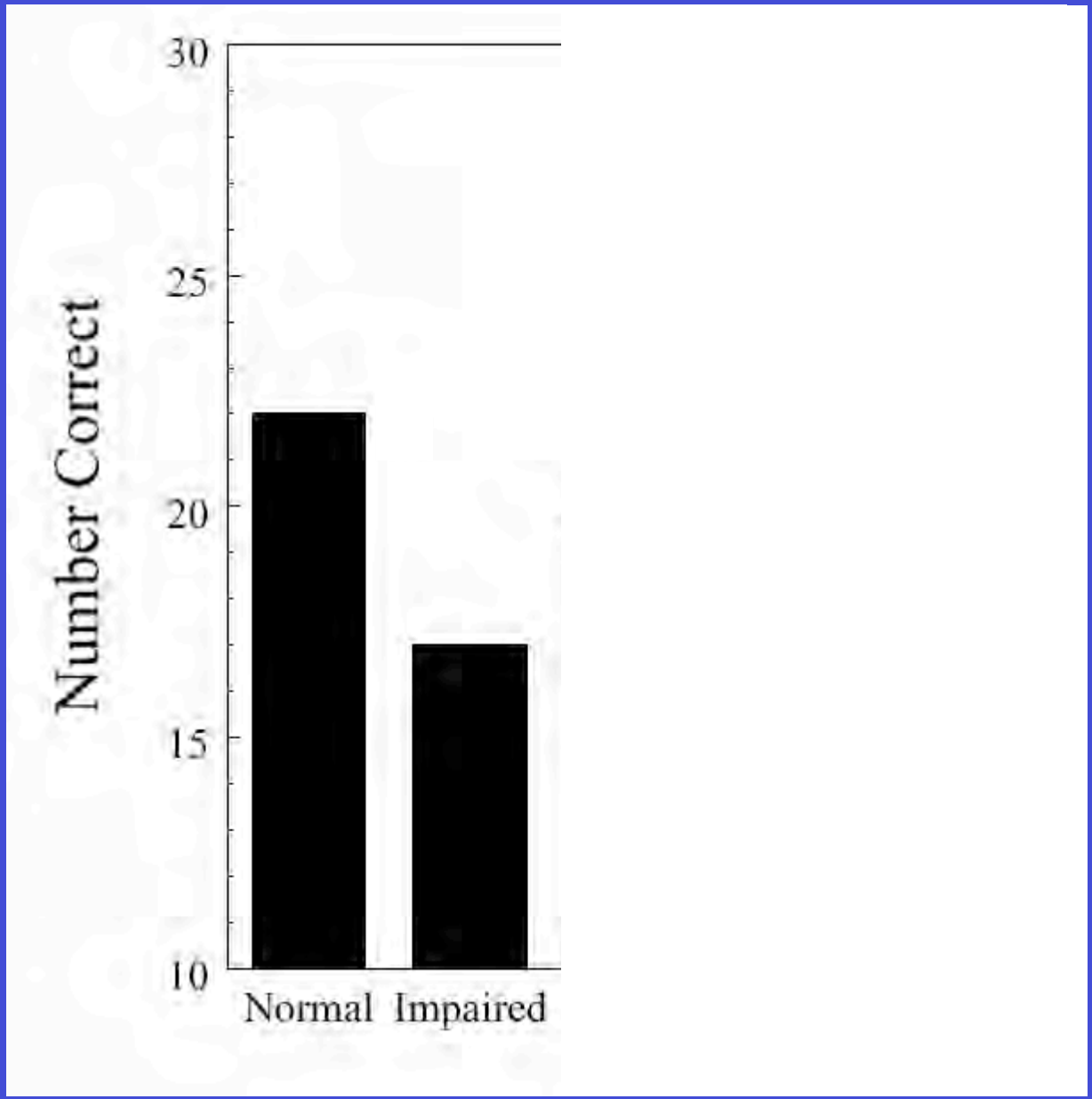
?

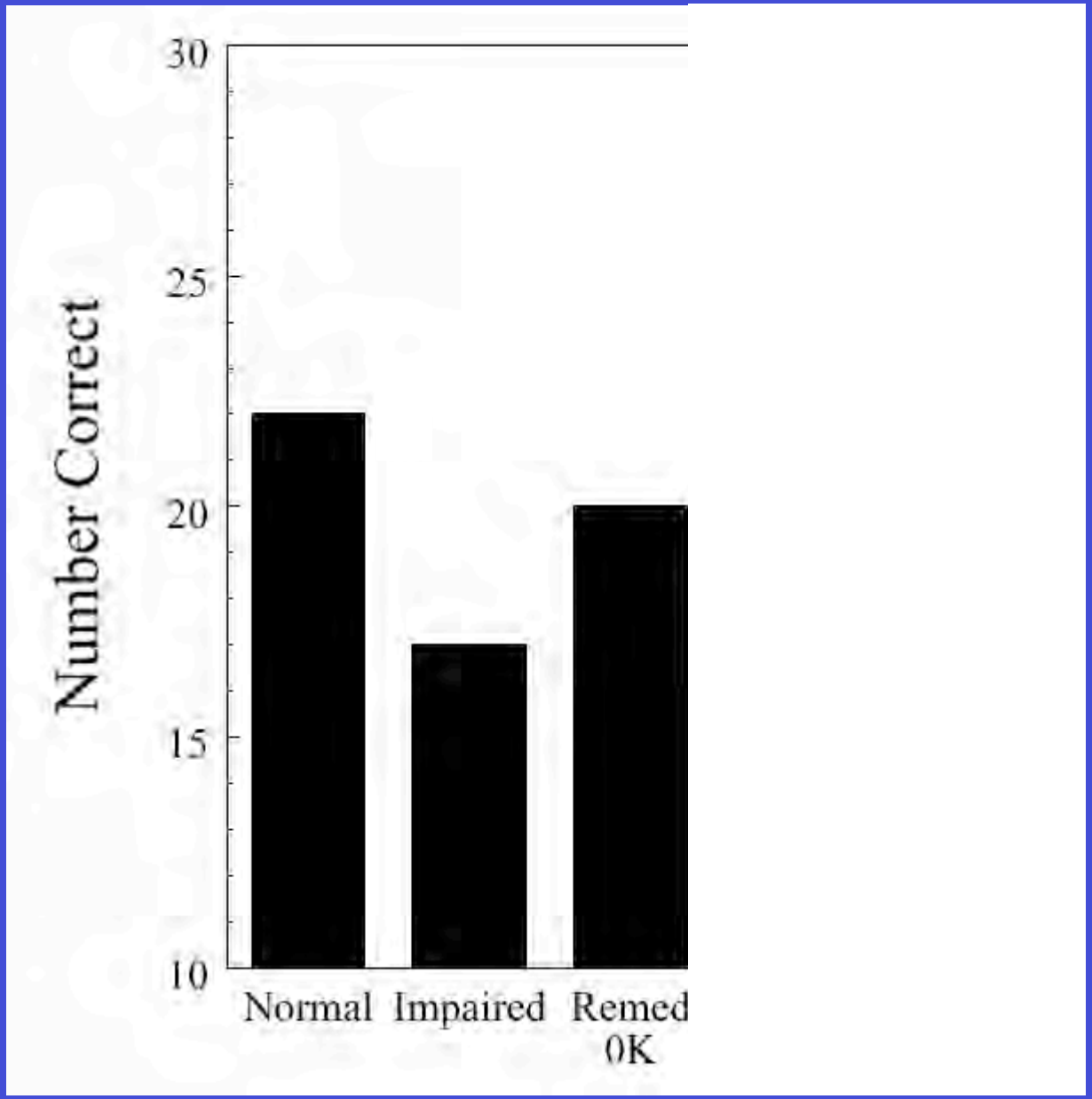
After Intervention

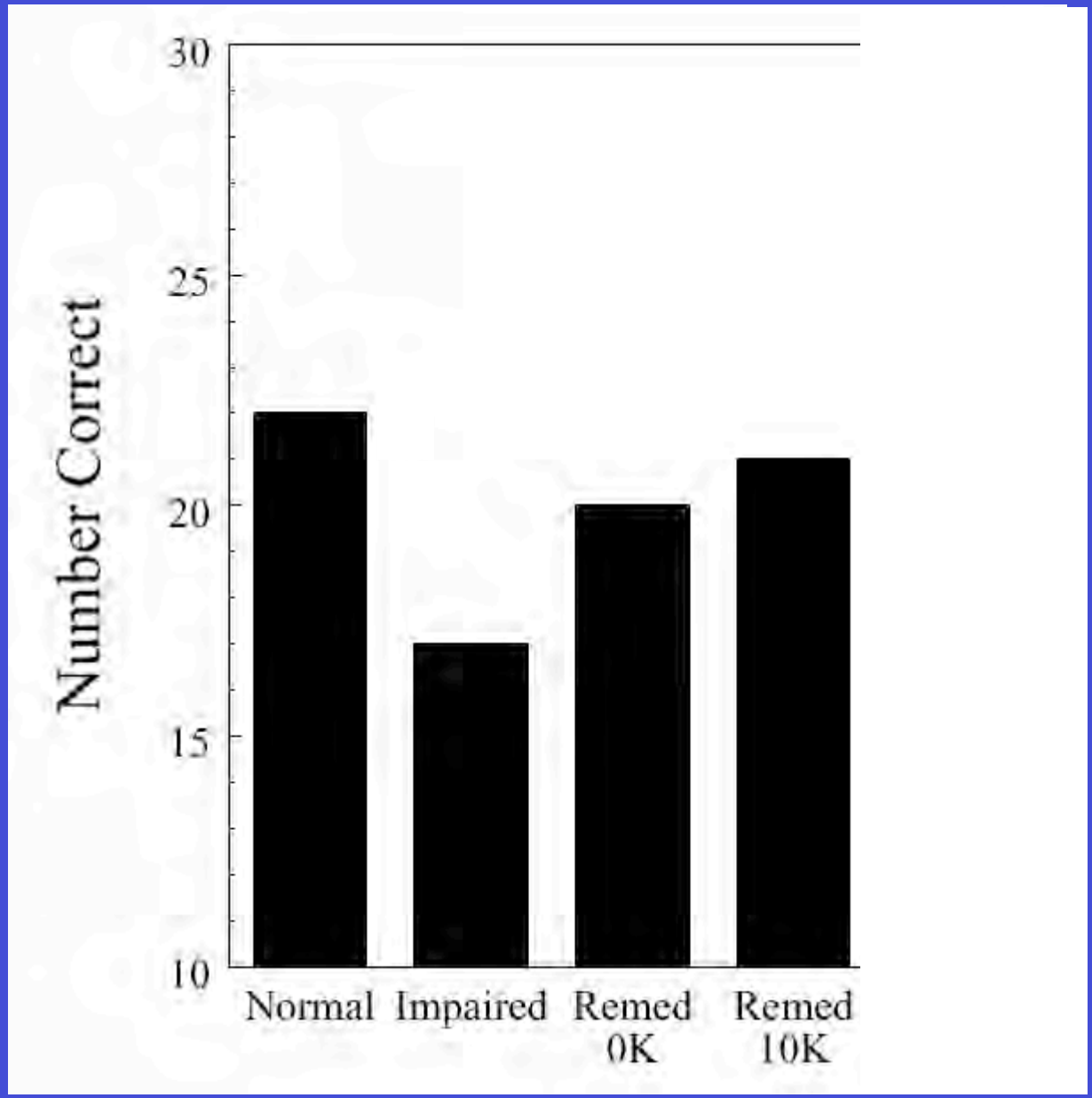


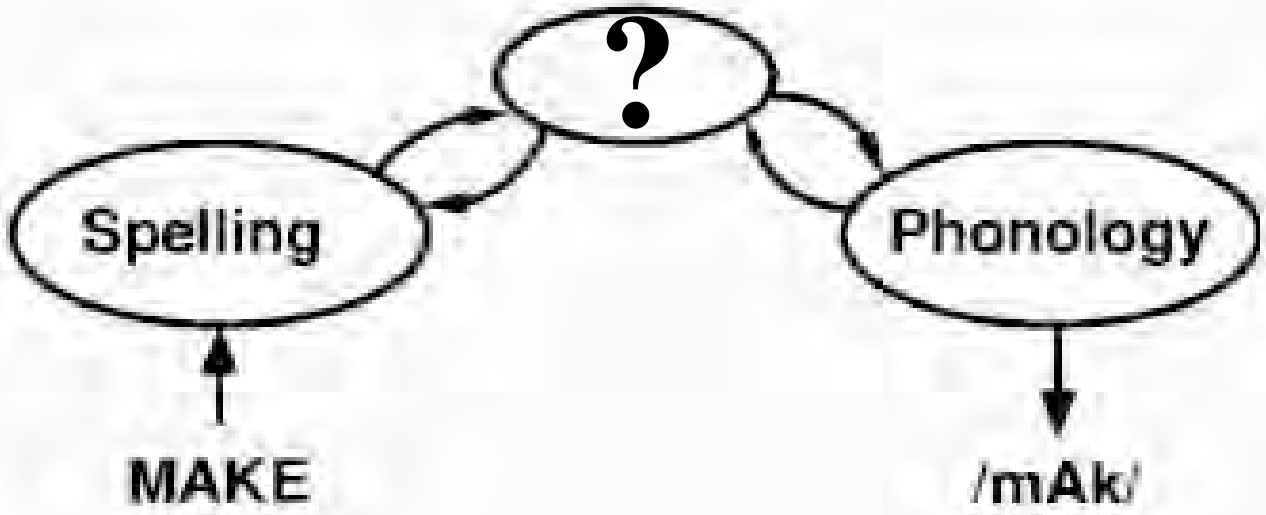


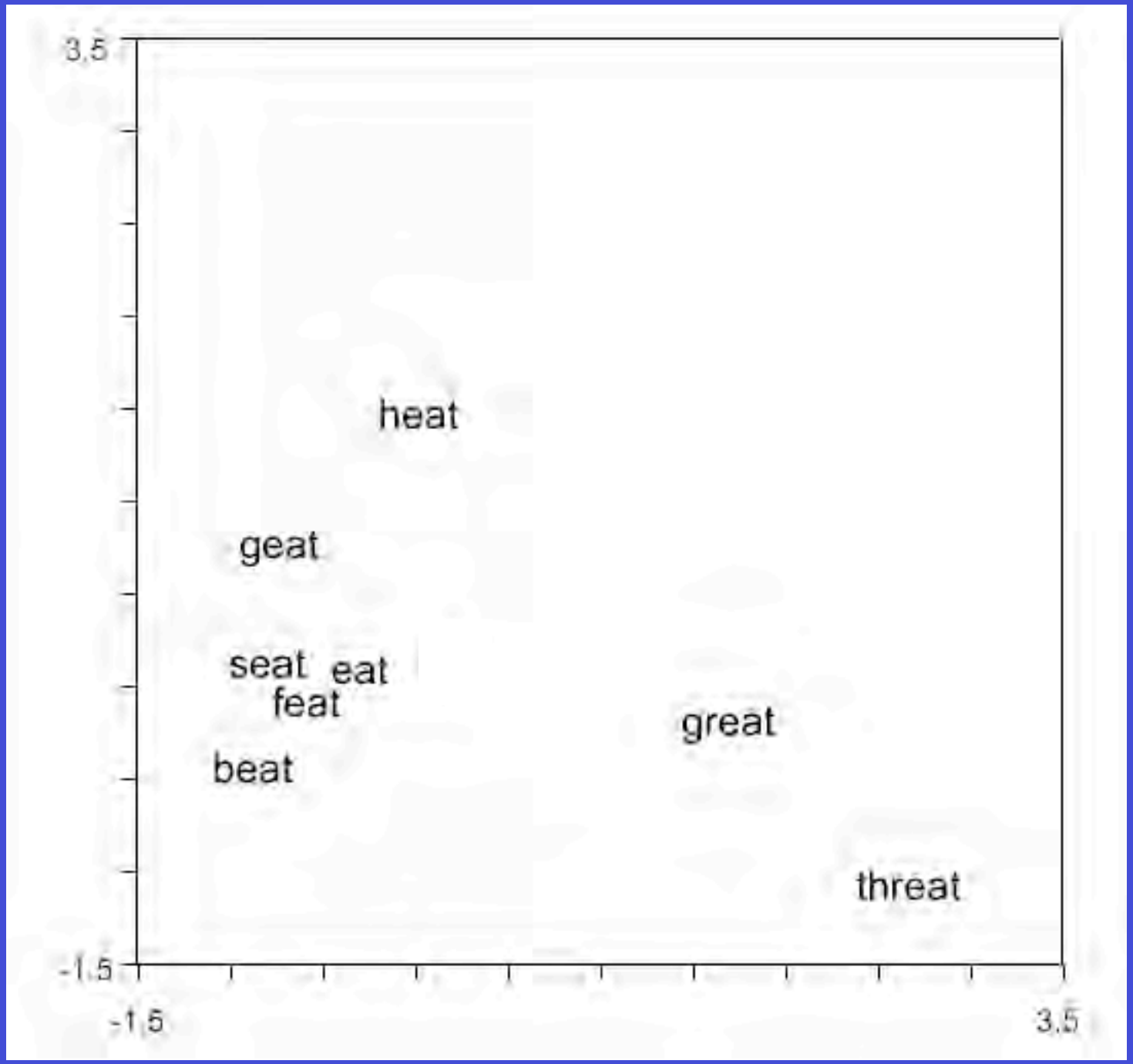
Harm, McCandliss & Seidenberg (2000)

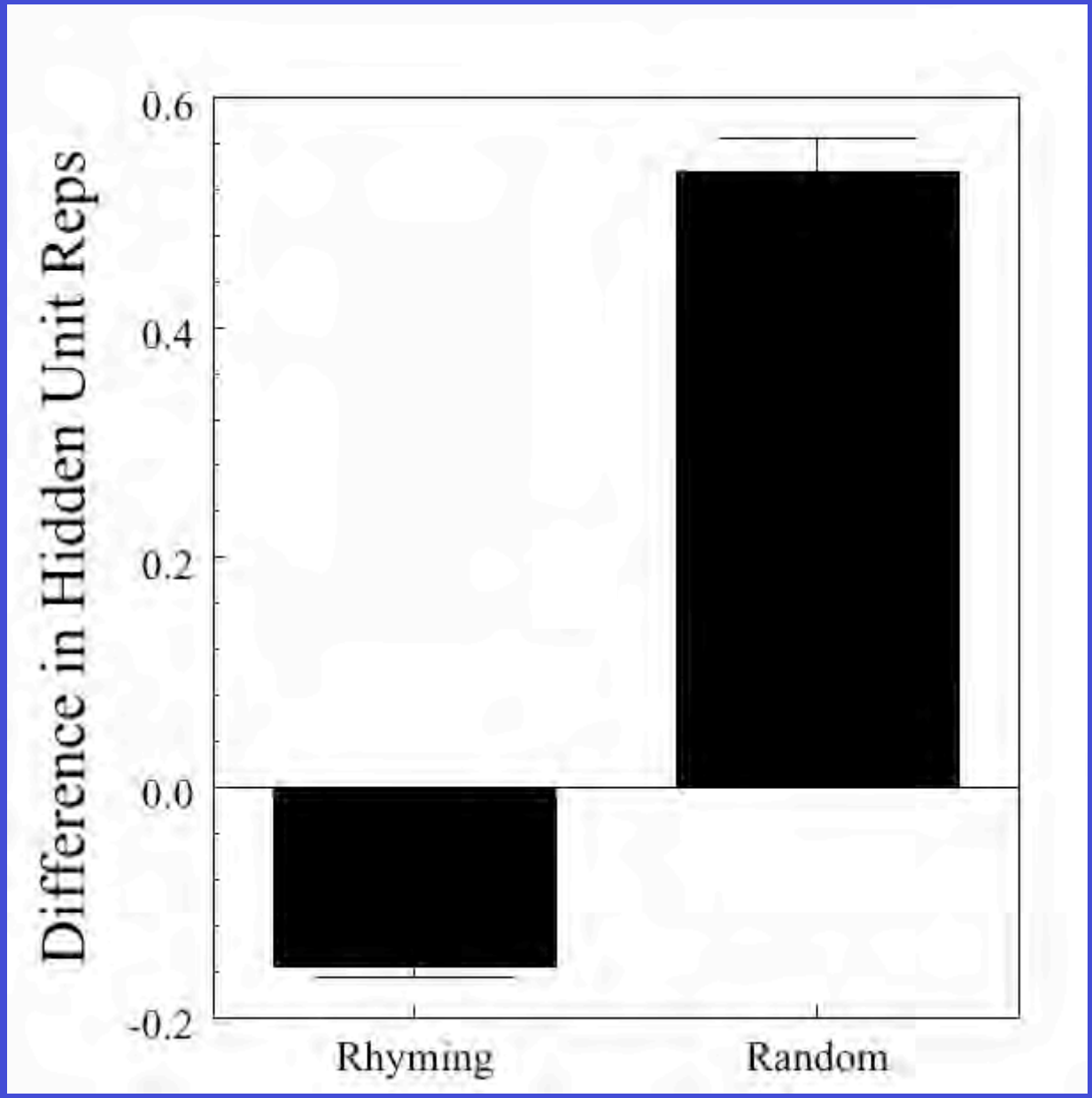

Number Correct
30
25
20
15
10
Normal
Impaired

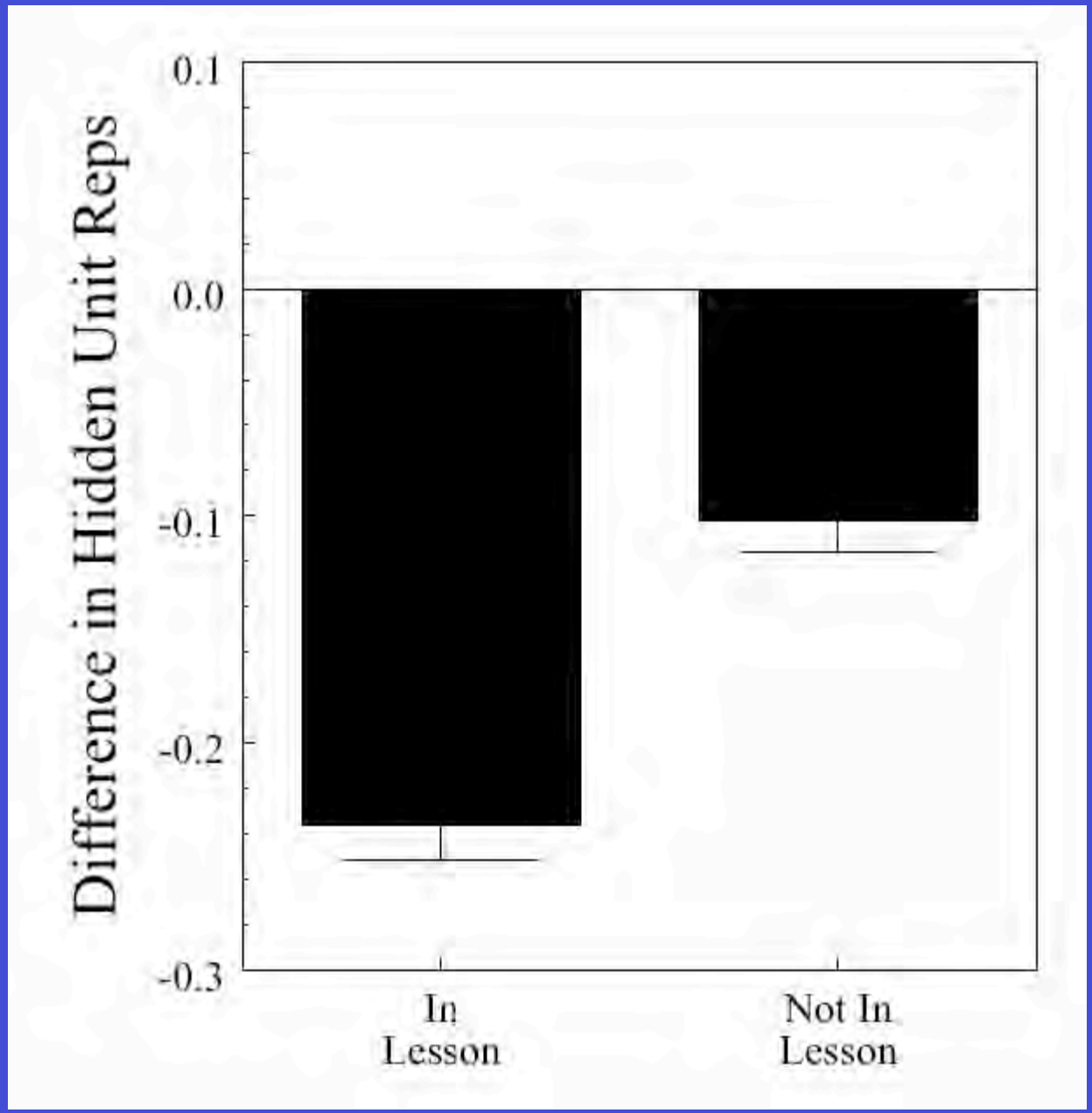

Number Correct
30
25
20
15
10
Normal
Impaired
Remed
0K


Number Correct
30
25
20
15
10
Normal
Impaired
Remed 0K
Remed 10K


?
Spelling
Phonology
MAKE
/mAk/


3.5
heat
geat
seat
eat
feat
great
beat
threat
-1.5
-1.5
3.5


Difference in Hidden Unit Reps
0.6
0.4
0.2
0.0
-0.2
Rhyming
Random


Difference in Hidden Unit Reps
0.1
0.0
-0.1
-0.2
-0.3
In Lesson
Not In Lesson

Cognitive Neuroscience of Reading Ability/Disability

- Functional organization in experts
- Organization of function during development
- Physiological and anatomical correlates of individual differences
- Functional plasticity related to reorganization during intervention

"We cannot understand how the mature system works until we understand how it is constructed in development, and we cannot fully understand that process of normal construction without understanding how development can go awry."

– Johnson & Pennington (1999)

Collaborators

Sackler Institute Fellows

Urs Maurer
Yuliya Yoncheva
Sumit Niogi
Jason Zevin
Michael Wolmetz
Courtney Stevens

Sackler Research Assistants

Alpana Choudhury
Eva Hulse
Rebecca Gottlieb
Jamie Ferri
Cathy Yun

Univ. Pittsburgh

Isabel Beck
Charles Perfetti
Rebecca Sandak
Walter Schnieder

Weill Medical-CBIC

Richard Watts
Aziz Ulug
Henning Voss