

Brain Imaging Studies of Reading and Dyslexia

Guinevere Eden
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Gallaudet
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Supported by the NIH and the NSF

Reading is Important

- Reading skills provide the foundation for children's academic success.
- Children who read well read more.
- They acquire more knowledge in numerous domains.

Reading is a Cultural Invention



First use of alphabet - 1800 B.C.

Divination Characters on Oracle Bones
Shang Dynasty 1400-1100 BC

Magnetic Resonance Imaging (MRI)





Magnetic Resonance Imaging (MRI)

MRI studies brain anatomy.

Functional MRI (fMRI) studies brain function.



What Brain Imaging Tells Us

- Identifies brain regions that are involved in reading
- What these look like in dyslexia
- How these change following intensive instruction
- Helps refine theoretical frameworks of dyslexia
- Provides insights into connections between reading and arithmetic

Reading Outcome Depends on:



Alphabetic Principle,
Phonological Awareness,
Background Knowledge,
Vocabulary
Familiarity with Sentence
Structure, etc.

Scarborough (2001)

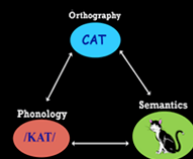
Reading Involves Mapping:

Understanding of how spelling patterns (orthography) correspond

to the sounds of words (phonology)

and link

to meaning (semantics)



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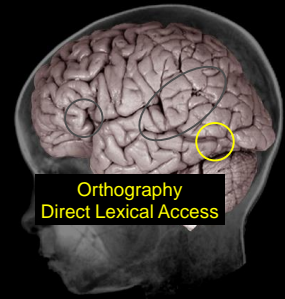
The Neural Basis of Reading

- Left inferior frontal gyrus
- Left temporo-parietal cortex
- Left infero-temporal cortex
- From Pugh et al., 2000



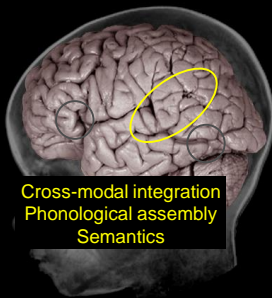
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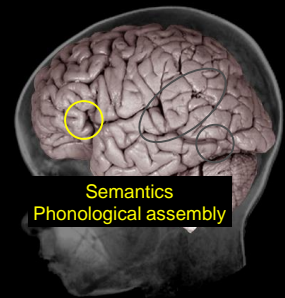
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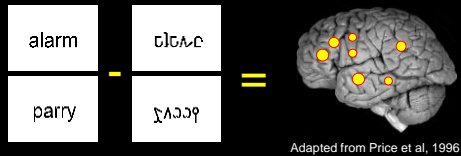


Center for the Study of Learning, Georgetown University

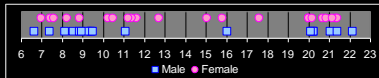
Research Questions

- How does the neural basis of word processing change during schooling in typical readers?
- What is the relationship between these neural systems and phonological skills?

Implicit Word Processing



41 normal subjects

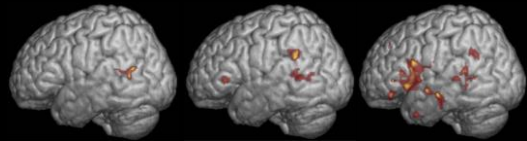


Implicit Reading Activity

6- 9.4 y
n=13

9.4- 18 y
n=13

20- 23 y
n=15



Turkeltaub et al. Nature Neuroscience, 2003

Phonological Processing and Reading

Three aspects of phonological processing predict reading (Wagner & Torgesen, 1987):

- Phonemic awareness
- Phonological Naming
- Working memory

Phonemic Awareness

Lindamood Auditory Conceptualization Test (LAC)



"Show me /p/ /t/ /p/"



"If this says 'eth', show me 'ith'"



Phonological Naming

Rapid Automatized Naming Test (RAN)

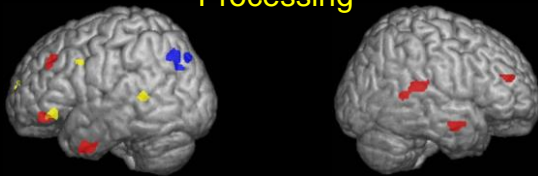
s a o c o f a f c o
s c a o a f s f c s
o p s f c o s a o f
a c o f s f a s c s
f o s d s f o a o c

Working Memory

Digit Span

"3 8 2 4"
"7 4 6 2 5"
"9 2 3 6 1 8"
"5 3 8 2 7 4 6"
"2 5 4 3 2 8 9 4"

Correlations with Phonological Processing

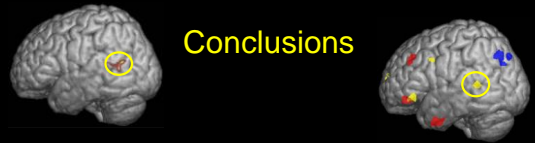


Phonemic Awareness
Phonological Recoding
Working Memory

$p < .005$, peak $p < .0005$

Turkeltaub et al., Nature Neuroscience, 2003

Conclusions



- Young readers activate left superior temporal cortex.
- Activity here is related to phonemic awareness.

What Brain Imaging Tells Us

- Identifies brain regions that are involved in reading
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The International Dyslexia Association / NICHD Research Definition of Dyslexia

Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and / or fluent word recognition and by poor spelling and decoding abilities...

The International Dyslexia Association / NICHD Research Definition of Dyslexia

... These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction...

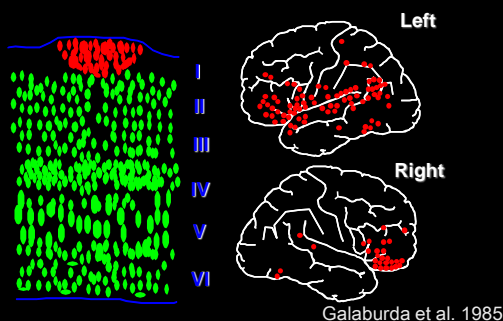
The International Dyslexia Association / NICHD Research Definition of Dyslexia

... Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge.

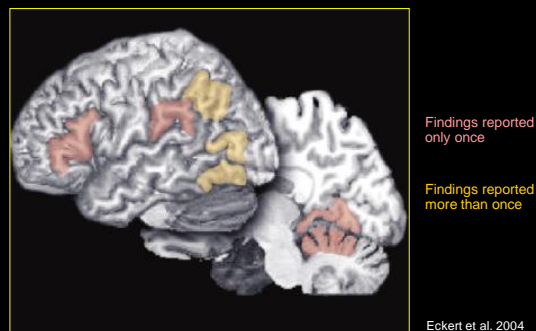
Developmental Dyslexia

- Highly heritable: 40% chance if one parent has dyslexia (Olson et al., 1989)
- Prevalence: 7-12% of population (Katusik et al. 2001; Rutter et al. 2004)
- 2-3 times more prevalent in males vs. females (Rutter et al. 2004)

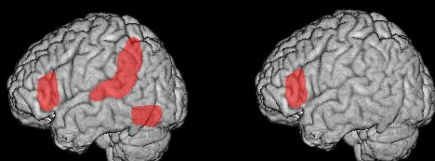
Dyslexia: Anatomical Variations - postmortem



Dyslexia: Anatomical Variations - in vivo



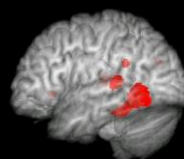
Neurobiological Basis of Reading and Dyslexia



Typical Readers

Dyslexic Readers

Neurobiological Basis of Reading and Dyslexia

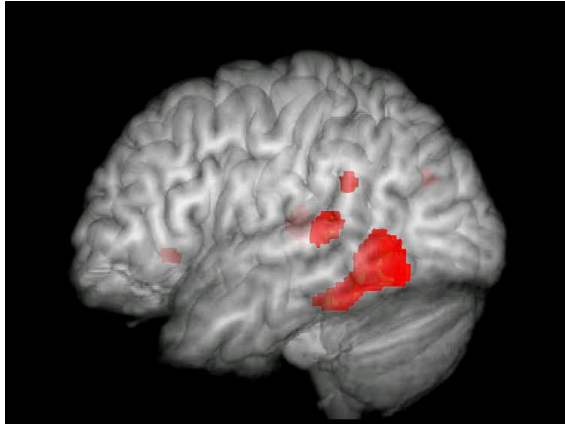


Typical Readers

>

Dyslexic Readers

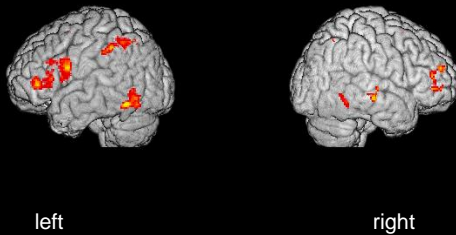
Maisog et al. PNYAS, 2008



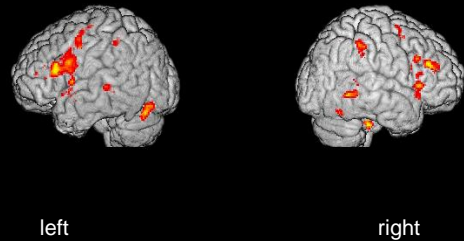
Phoneme Deletion

Task	fixate	repeat	delete
Stimulus	+	rat	rat
Response		rat	at
Processes	fixation	vocalization	vocalization + phonological manipulation

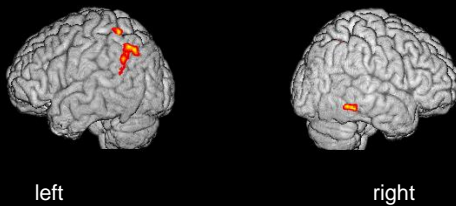
Typical Readers: Deletion versus Repetition



Dyslexic Readers: Deletion versus Repetition



Group Comparison: Controls > Dyslexics



Eden et al., Neuron 2004

What Brain Imaging Tells Us

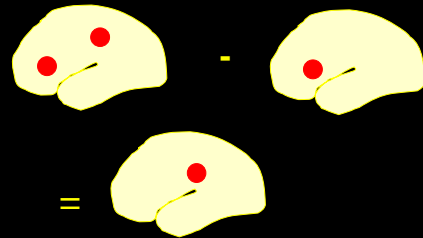
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Research Questions

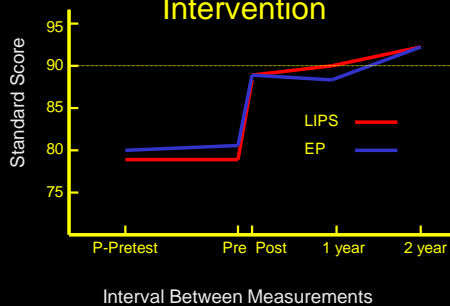
- What are the brain correlates of successful reading intervention in adults?

After
Intervention

Before
Intervention



Growth in Total Reading Skill Before, During, and Following Intensive Intervention



Torgesen, et al., 2001

Adult Reading Intervention Study

Subjects:

- 20 Adults from Orton Center

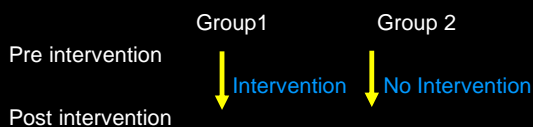


Intervention:

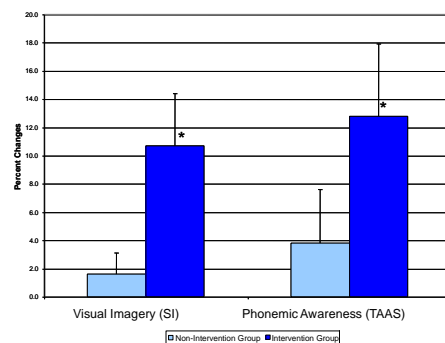
- 3 hours/day, over 8 weeks
- “Seeing Stars” and “Visualizing Verbalizing”

Intervention Trial: Study Design

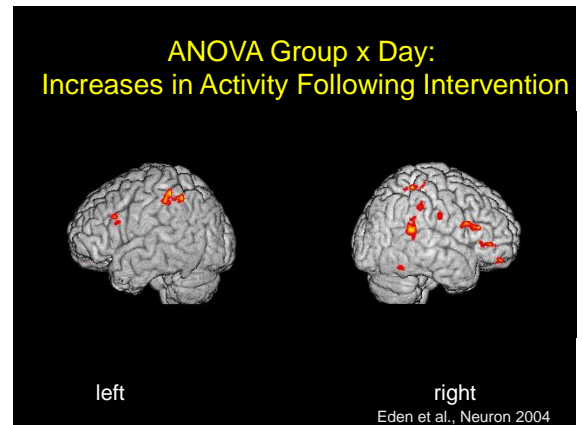
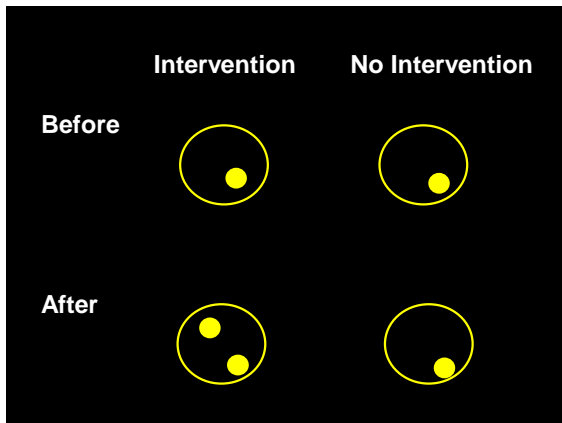
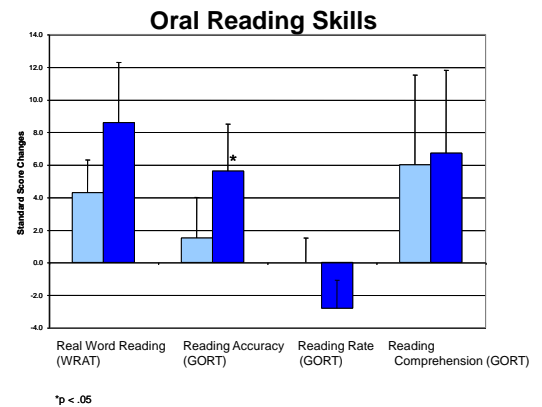
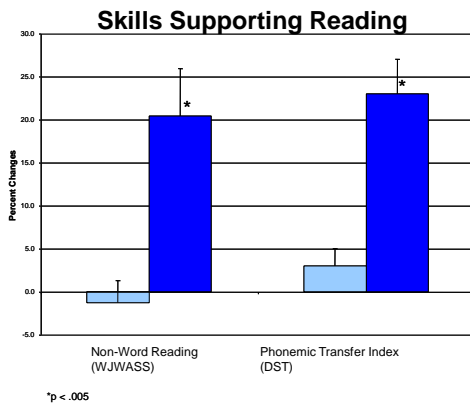
- Randomized assignment into two groups
- Groups equal in reading prior to intervention



Skills Targeted by Intervention

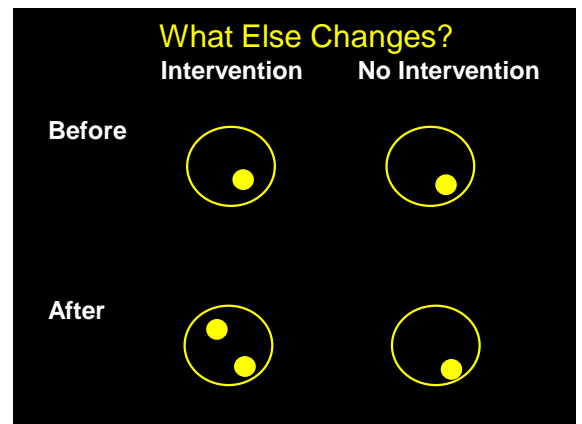


*p < .05

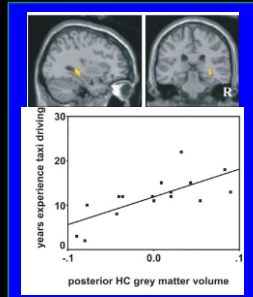


Conclusions

- Following intervention adults with dyslexia show increased activation in the left and right hemispheres.
- The right hemisphere areas are similar to those in the left hemisphere involved in phonological processing in good readers.

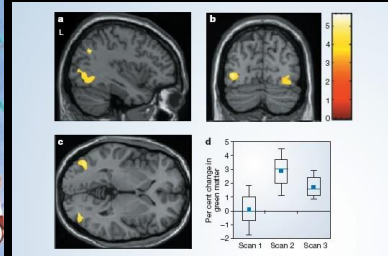


Training Changes the Brain



Maguire et al., 2006

Changes in Gray Matter Volume After Training



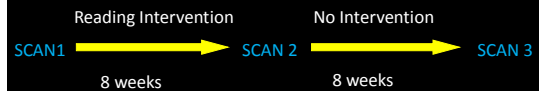
Draganski et al. (2004)

Research Question

- Are there changes in gray matter volume (GMV) following successful reading intervention in children?

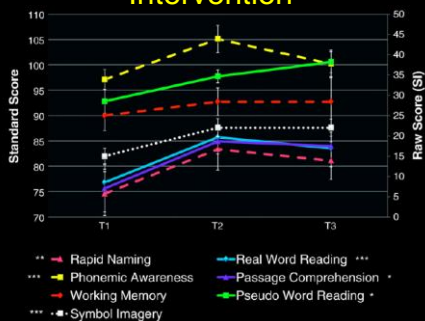
Research Design

- Children with dyslexia

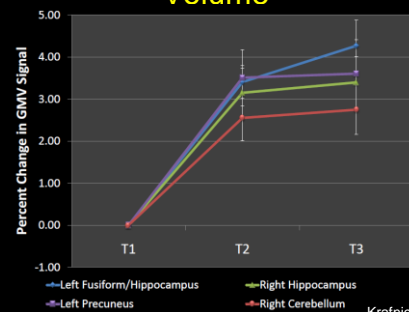


Anatomical scans obtained at 3 time points for analysis of gray matter volume (GMV)

Behavioral Changes After Intervention

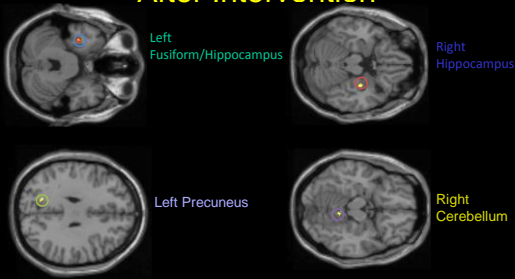


Percent Change in Gray Matter Volume



Krafnick et al., 2011

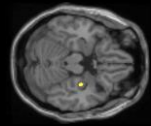
Gray Matter Volume Increases After Intervention



Krafnick et al., 2011

Conclusion

- After intervention, children with dyslexia show increased gray matter volume, including in bilateral hippocampus.
- These anatomical differences were maintained.



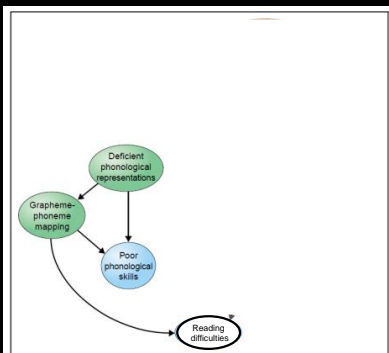
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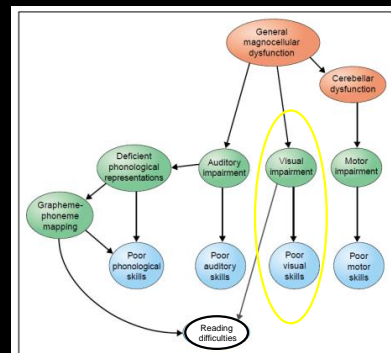
Debates about: Visual System Differences in Dyslexia



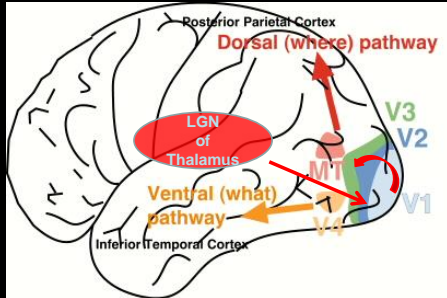
Phonological Theory of Dyslexia



Magnocellular Theory of Dyslexia



Visual Magnocellular Deficit Theory

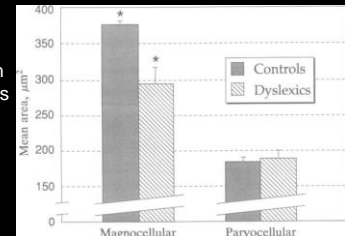


• <http://www.uwosh.edu/departments/psychology/Vreven/Lab/Images/brain.jpg>

Visual Magnocellular Deficit Theory

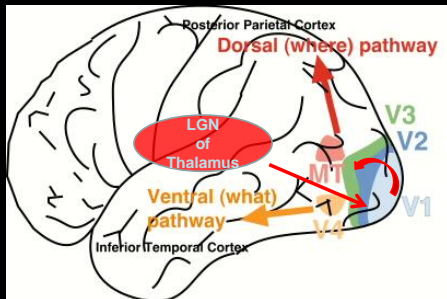
Anatomical Evidence:

Reduced cell size in magnocellular layers of the lateral geniculate nucleus



Livingstone et al., PNAS 1991

Visual Magnocellular Deficit Theory

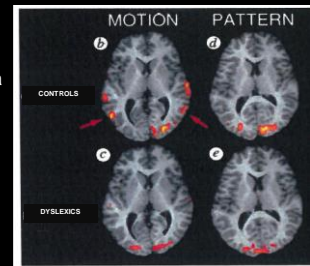


• <http://www.uwosh.edu/departments/psychology/Vreven/Lab/Images/brain.jpg>

Visual Magnocellular Deficit Theory

Functional Evidence:

Reduced activity in area V5/MT in dyslexia

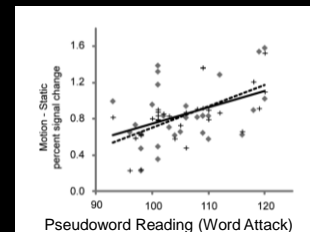
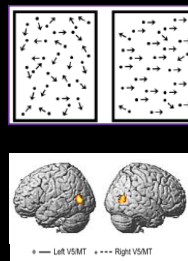


Eden et al., Nature 1996

Visual Magnocellular Deficit Theory

- does not exist (Vellutino et al.)
- is the cause of reading problems (Stein et al.)
- co-exists with other changes, which are the cause of the reading problems (Ramus et al.)
- is the consequence of reading problems

Correlation of V5/MT Activity with Reading in Typical Readers

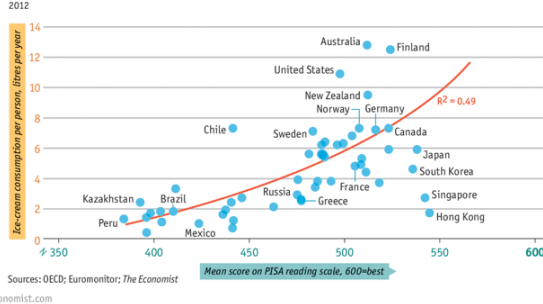


Left: $r = 0.41$; $p = 0.024$
Right: $r = 0.61$; $p = 0.0003$

Olulade et al, Neuron 2013

Correlation is not Causation

Ice-cream consumption and PISA educational performance scores

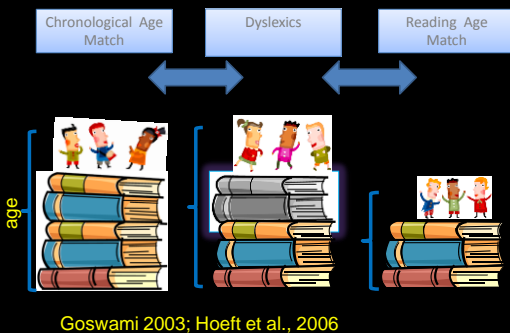


Addressing Causality in Dyslexia (Goswami, 2003)

Reading Level Match Study:

Do dyslexic individuals show deficits when compared with controls matched for reading ability?

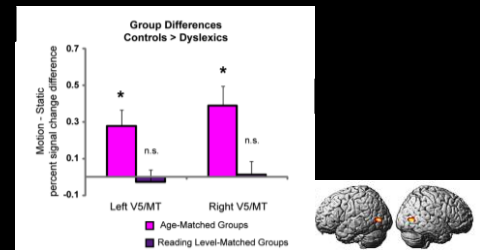
Cause vs. Consequence: Reading Level Match Design



Controls vs. Dyslexics V5/MT Activity

Age matched : Controls > dyslexics

Reading level matched: no difference



Addressing Causality in Dyslexia (Goswami, 2003)

Reading Level Match Study:

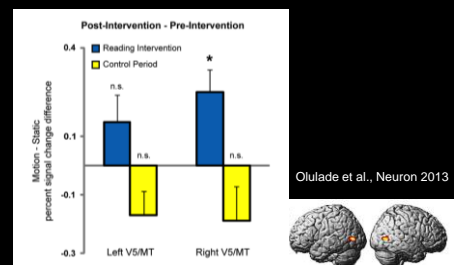
Do dyslexic individuals show deficits when compared with controls matched for reading ability?

Intervention Study:

Perform phonological based intervention to improve reading and demonstrate improved function.

Increased V5/MT Activity following Reading Intervention

Increased right V5/MT activity following reading intervention (but not following the control period)



Conclusion



- There is a relationship between activity in V5/MT and reading.
- Dyslexics differed from chronological age but not reading age matched controls.
- Successful reading intervention resulted in increased right V5/MT activity
- Together this suggests that V5/MT underactivity is a consequence of reading disability rather than a cause.

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The Relationship Between Arithmetic ...

and Reading



Reading and Arithmetic

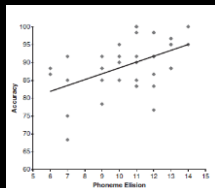
High comorbidity of dyslexia and dyscalculia (Lewis *et al.*, 1994).

Phonological awareness skills predict reading and math outcome (Hecht *et al.*, 2001)

Phonological awareness skills are related to retrieval-based arithmetic problem solving (DeSmedt *et al.*, 2010).

Reading and Arithmetic

Retrieval-Based Arithmetic



Phonological Coding

$$4 + 5 = 9$$

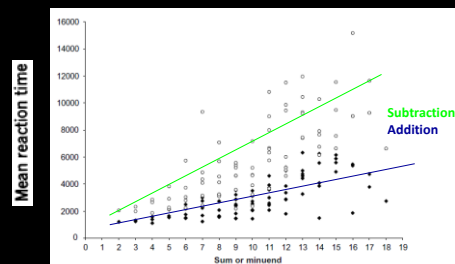
For retrieval-based problems

NOT for procedural problems

$$7 - 2 = 5$$

DeSmedt *et al.*, 2010

Subtraction and Addition Reaction Times



Barrouillet *J Exp Child Psych* 2008

Subtraction and Addition

Procedural-based

Retrieval-based

$$9 - 2 = 8$$

$$4 + 5 = 9$$

Subtraction and Addition

Procedural-based

Retrieval-based

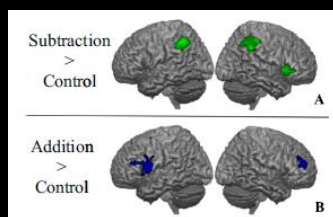
$$9 - 2 = 8$$

$$4 + 5 = 9$$

$$1 - 5 = 1$$

$$4 + 1 = 2$$

Brain Bases for Arithmetic and Reading



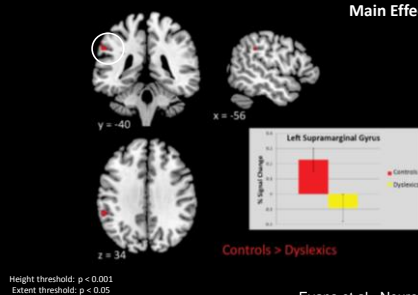
Evans et al., *Neuroimage* 2016

Research Questions

- Is the functional anatomy of arithmetic altered in dyslexia?

Brain Bases of Arithmetic in Dyslexia

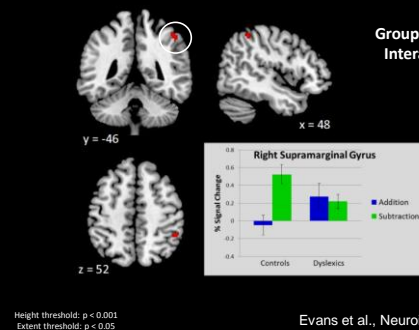
Main Effect of Group



Evans et al., *Neuroimage* 2014

Brain Bases of Arithmetic in Dyslexia

Group by Task Interaction



Evans et al., *Neuroimage* 2014

Conclusions

- Children with dyslexia show less activity during arithmetic tasks in left supramarginal gyrus.
- They also lack modulation by operation in right supramarginal gyrus.
- This supports earlier behavioral work showing differences in math performance specific to retrieval-based problems (De Smedt and Boets, 2010).

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Overall Summary



- Brain Imaging is a research tool

-it is not used for diagnostic purposes

-beware of it's use for marketing purposes

Georgetown
UNIVERSITY



Tanya Evans
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Jose Maisog
Olumide Olulade
Peter Turkeltaub
John VanMeter

Wake Forest University

Lynn Flowers
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