Imaging the Normal and Impaired Development of Reading.

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“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

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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

Linking anatomical measures to individual differences in reading development.
Unrestricted Flow, Isotropic Diffusion
Restricted Flow
Anisotropic Diffusion
The Diffusion Tensor

Tensor derived from directional diffusivities (ADC's)

Eigenvalues

Matrix of 3 eigenvectors

Jellison 2004
Direction of Diffusion

cingulum
corpus callosum
ILF
SLF
Diffusion tensor imaging segmentation of white matter structures using a Reproducible Objective Quantification Scheme (ROQS)

Sumit N. Niogi, Pratik Mukherjee, and Bruce D. McCandliss
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

Lateralization Index

![Graph showing the lateralization index of SCR and Word ID with a regression line and a coefficient of determination \( R^2 = 0.38 \).]
Replication Across Studies

Correlation between Left SCR FA and Word ID in children

- Niogi and McCandliss (2006) Neuropsychologia
Bilateral Anterior Corona Radiata

CTOPP Standardized Digit Recall (Short Term Memory)

$R^2 = 0.4199$
"Double Dissociation" in Correlation Patterns

Standardized Word ID

Standardized Digit Recall

\[ y = 0.005x - 0.0332 \]

\[ R^2 = 0.3125 \]
“Double Dissociation” in Correlation Patterns

Standardized Word ID

Standardized Digit Recall
# Multiple Regression Analyses of Domain Specificity

**FA in Left Superior Corona Radiata**

<table>
<thead>
<tr>
<th>Model</th>
<th>Change $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Non-verbal IQ, age</td>
<td>.10</td>
</tr>
<tr>
<td>Model 2: Non-verbal IQ, age, <em>Digit Recall</em></td>
<td>.00</td>
</tr>
<tr>
<td>Model 3: Non-verbal IQ, age, <em>Digit Recall</em>, <strong>Word ID</strong></td>
<td>.40 *** ($p&lt;.0001$)</td>
</tr>
</tbody>
</table>
### Multiple Regression Analyses of Domain Specificity and Tract Specificity

**FA in Left Superior Corona Radiata**

<table>
<thead>
<tr>
<th>Model</th>
<th>Change R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Non-verbal IQ, age</td>
<td>.10</td>
</tr>
<tr>
<td>Model 2: Non-verbal IQ, age, <em>Digit Recall</em></td>
<td>.00</td>
</tr>
<tr>
<td>Model 3: Non-verbal IQ, age, <em>Digit Recall</em>, <strong>Word ID</strong></td>
<td>.40 *** (p&lt;.0001)</td>
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</tbody>
</table>

**FA in Bilateral ACR**

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<th>Model</th>
<th>Change R-square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: Non-verbal IQ, age</td>
<td>.005</td>
</tr>
<tr>
<td>Model 2: Non-verbal IQ, age, <strong>Word ID</strong></td>
<td>.001</td>
</tr>
<tr>
<td>Model 3: Non-verbal IQ, age, <strong>Word ID</strong>, <em>Digit Recall</em></td>
<td>.419 *** (p&lt;.0001)</td>
</tr>
</tbody>
</table>

(see also Nagy et al., 2004 JCN)
DTI Findings Summary: Left lateraledized 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

SLURB
STOLT
TROBS

Initial consonant
Final consonant
3rd consonant
2nd consonant
Child Training Study:

Prototype: Word Building
(Beck & Hamilton, 1996)
Software Based Intervention

Take the "a" away and put the "i" in the middle

h o t
hol
hit
hol
hit
hol
hat
had

h i d
had
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.

*Scientific Studies of Reading*
Word Building (McCandliss et al, 2003)
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Reading Novel Words

SLURB
STOLT
TROBS

Initial consonant

3rd consonant

Final consonant

2nd consonant
Change in Standardized Test Scores-- Reading Novel Words

Woodcock Johnson Psychoeducational Battery: Word Attack Scores

![Graph showing the change in standard scores for different groups.](image)

$n=24$
Phonological Processing Skills

Phonological Awareness
Percentile Rank
(Composite of Elision, Word Blending, Nonword Blending)

Training | Waiting List
---|---
Before | After

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

Increased activation

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)
Subtraction Images
(Mean differences MEAT, EAT, TREAT)

Normal

Slightly Impaired
Before Intervention

After Intervention

Harm, McCandliss & Seidenberg (2000)
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