

# Neurologie de la dyslexie : données récentes de la recherche

Michel Habib

# La partie visible : 3 groupes de symptômes

## VISUELS

- Confusion entre des lettres visuellement proches : b/d, m/n, n/u
- difficulté de reconnaissance globale des mots familiers

## AUDITIFS

- Confusion de sons proches : t/d, ch/j, c/g, f/v, etc... (surtout à l'écrit)  
+ le trouble "phonologique"

## SEQUENTIELS

- Inversions diverses (lettres, syllabes, etc..., en lecture, en écriture et même à l'oral)



impossibilité d'acquérir la conversion graphème-phonème

# Conversion grapho-phonémique

- Une procédure en apparence si simple
  - Chaque signe (graphème) représente un son (phonème), soit consonne, soit voyelle
- Mais il existe des exceptions à ce principe :
  - Digraphes : cheval
  - Lettres silencieuses : trop
- ...des inconsistances...
  - rhum vs rhume (même lettre, son différent)
  - sot, saut, sceau... (même son, lettres différentes )
- ...et des irrégularités et étrangetés
  - femme, écho (un graphème se prononce de façon singulière)
  - yacht, football (des mots étrangers adoptant des règles de la langue)

# Les mécanismes sous-jacents :

pourquoi l'incapacité à la conversion grapho-phonémique?

- Le trouble phonologique
  - Présent chez la grande majorité des dyslexiques
  - Considéré comme causal par la majorité des auteurs
  - Dériverait d'un trouble de la mise en place précoce des représentations phonémiques
- Le trouble visuo-attentionnel
  - Fréquent, surtout après plusieurs années d'évolution
  - Peut mettre l'enfant dans l'incapacité d'apprendre la conversion grapho-phonémique serait la cause unique que dans une minorité de cas



# Quelques épreuves de conscience phonologique

Épreuves de segmentation

Tapping, comptage, suppression, ajout,

Rech d'intrus

Spoonerism (acronymes auditifs)

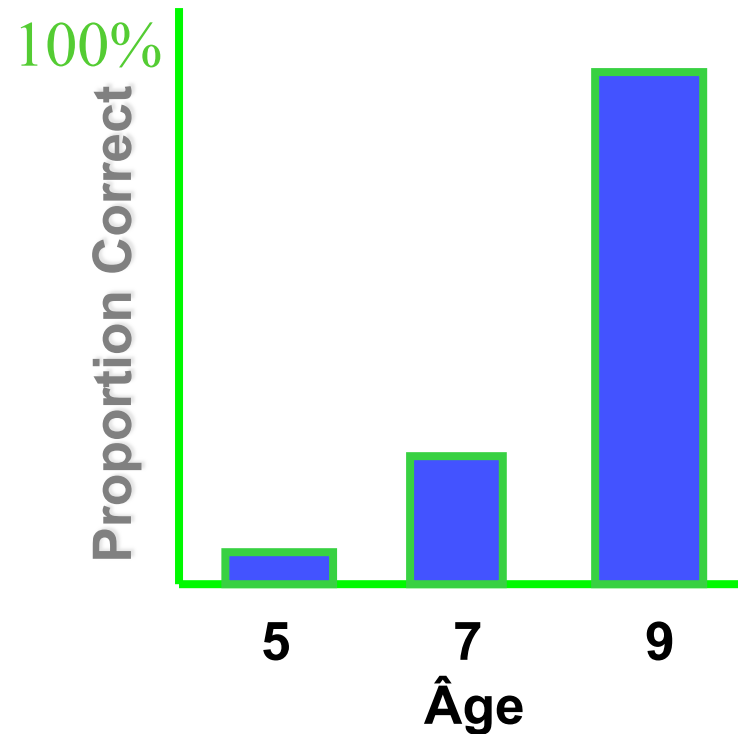
Épreuves de répétition

Mots, non-mots, chiffres, (endroit, envers)

Épreuves de lecture et dictée de non-mots

Manipulation plus ou moins explicite du contenu sonore des mots, se développant des unités les plus larges (syllabes) aux plus petites (phonèmes)

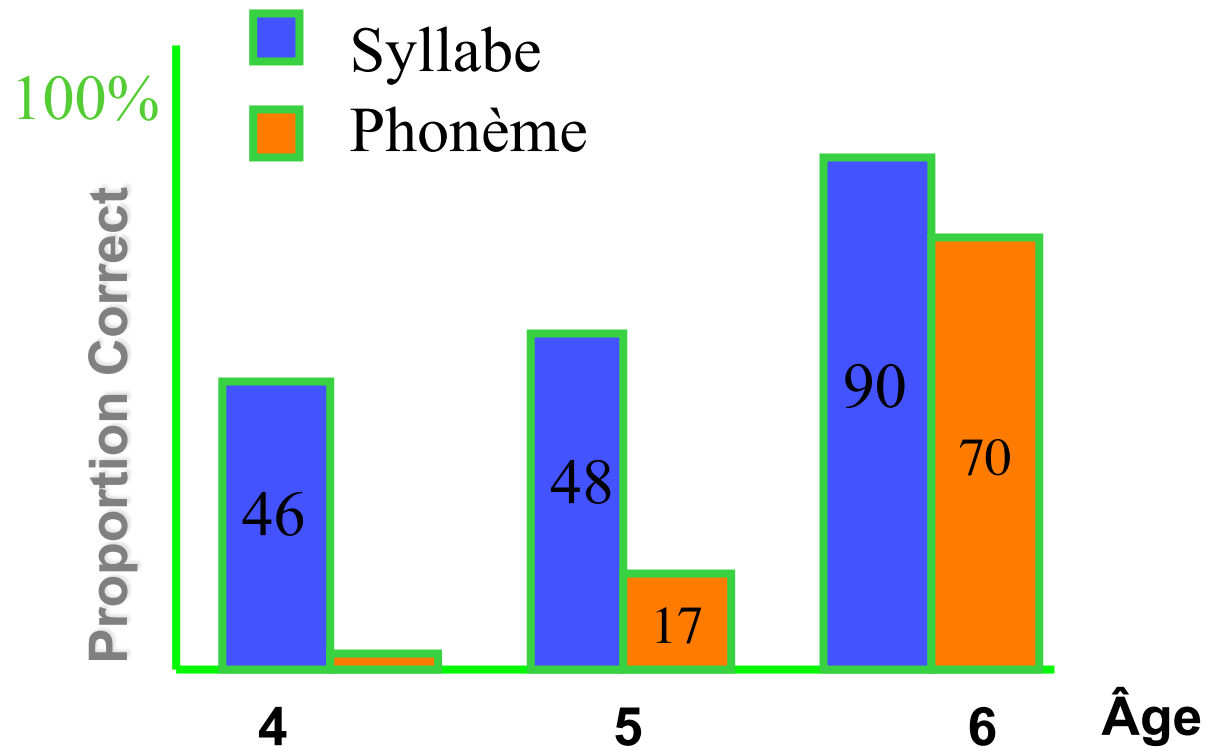
## Bruce (1964) : suppression de phonème



- /troi/ => /roi/ (début)
- /trou/ => tou (milieu)
- /tul/ => /tu/ (fin)

➤ Les enfants pré-lecteurs sont quasiment incapables de réaliser la tâche

# Liberman et al (1974)

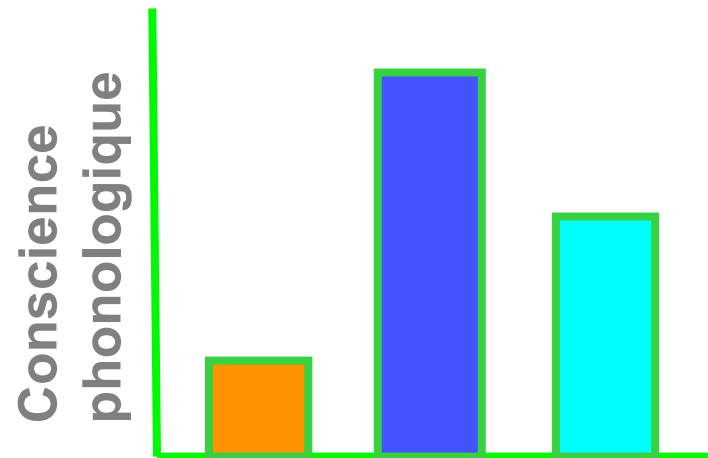


S' il existe une relation causale, les enfants en difficulté de lecture ont-ils un déficit de la conscience phonologique ?

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### 3. Enfants dyslexiques

- Bradley & Bryant (1978), Difficulties in auditory organisation as a possible cause of reading backwardness, *Nature*
  - Enfants de 10 ans en difficulté de lecture
  - Enfants de 10 ans sans difficultés
  - Enfants de 7 ans sans difficultés ayant le même niveau de lecture que les enfants en difficulté



# Entraînement phonologique et dyslexie

- Hatcher et al., 1994 : enfants de 7 ans 5 mois en moyenne, âge de lecture 5;9.
- 3 groupes expérimentaux :
  - lecture seule
  - Phonologie seule
  - Lecture / phono

- Le groupe phono améliore significativement la phonologie
- Seul le groupe phono/lecture améliore significativement la lecture par rapport au témoin

Wise, Ring & Olson, 2000 : 122 enfants 7 à 11 ans

Entraînement phono (40 heures) selon 3 modalités :

- classique manipulation des sons
- focus d'attention sur mouvements articulatoires
- combinaisons 1+2

- Amélioration très significative des 3 groupes
- Pas d'avantage de conditions articulatoires

# Trouble phonologique : répercussions langagières...

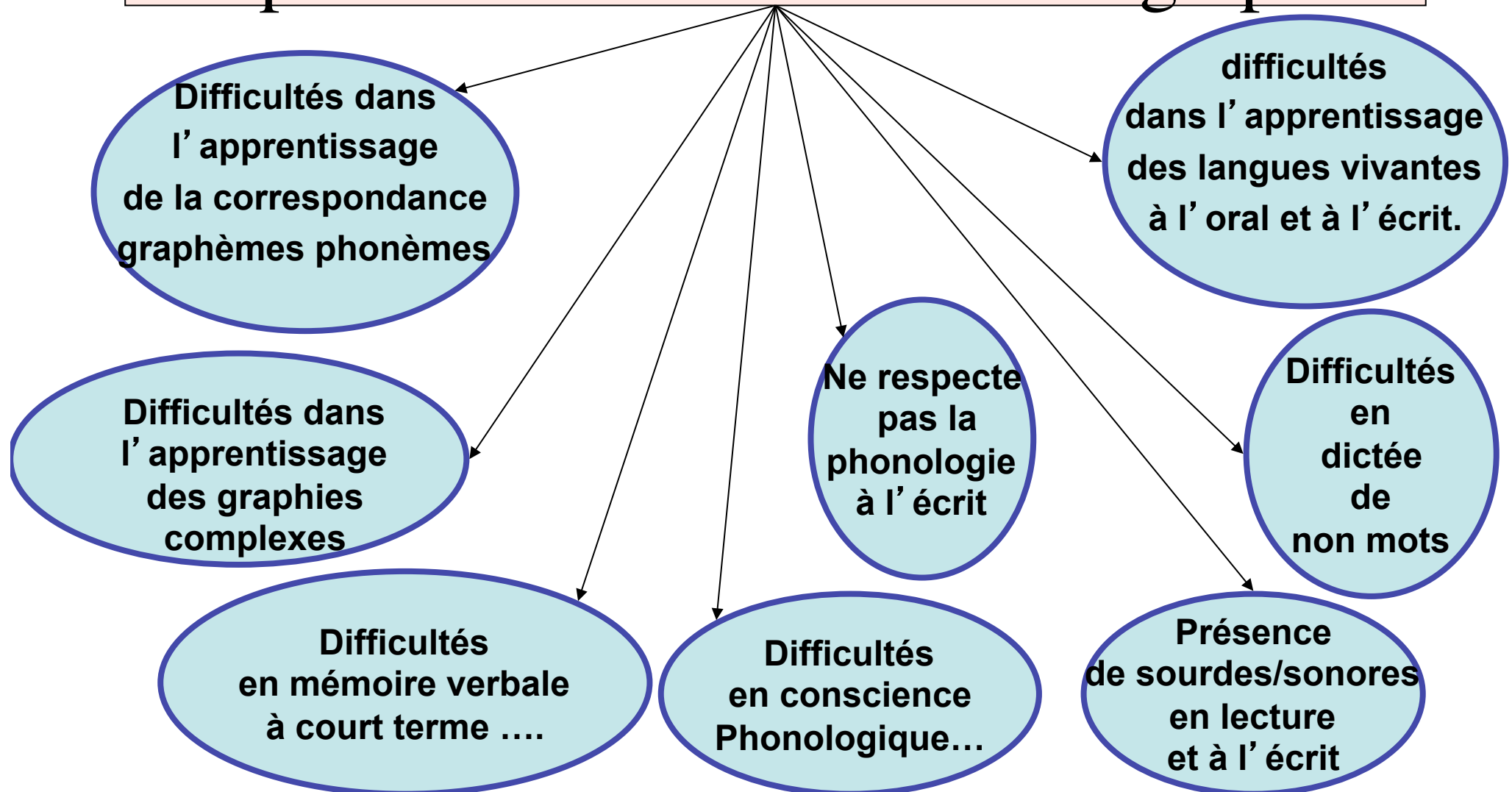
**Difficultés  
de répétition  
de mots  
et de  
non mots**

**Difficultés d'accès  
à la forme phonologique des mots :  
hésitations,  
manques du mot  
ou temps de latence élevés  
(Wolf, 1984; Snowling et al, 1988)**

**des difficultés  
quant à l'apprentissage  
de nouvelles formes sonores  
(médicaments, noms propres,  
sigles, termes techniques)  
→ apprentissage des leçons  
et des poésies**

**Performances déficitaires  
en évocation lexicale  
sur le critère formel  
(Frith et al, 1995).**

# Trouble phonologique : répercussions en lecture/orthographe



# Différentes formes de dyslexie

## - Les dyslexies phonologiques

Difficultés d'acquisition de la procédure analytique

## - Les dyslexies de surface

Difficultés d'acquisition de la procédure lexicale

## - Les dyslexies mixtes

Difficultés d'acquisition des procédures analytiques et lexicales



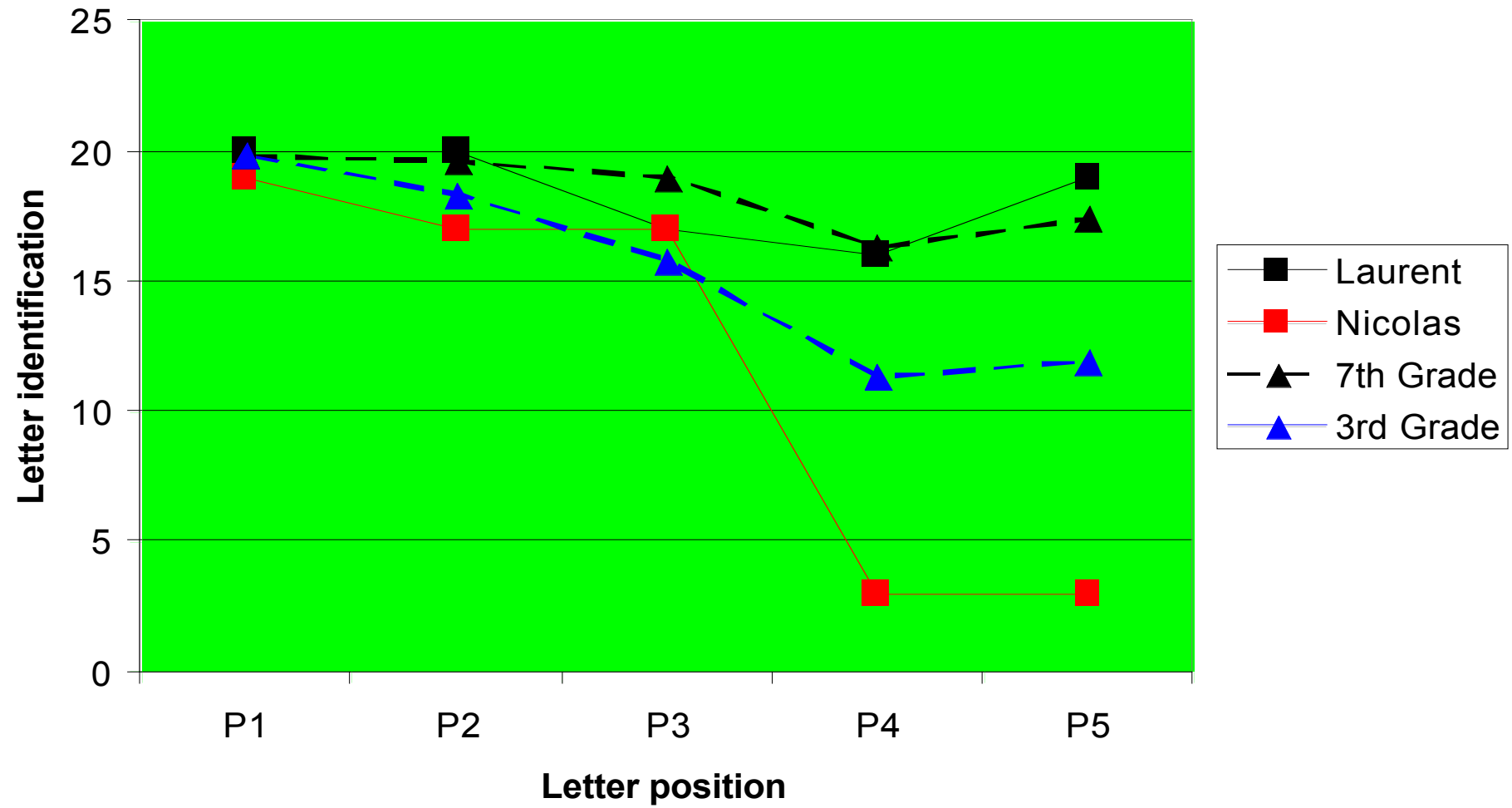
# Epreuve visuo-attentionnelle (S. Valdois)

## Report Global

**A V T.S R**

**Réponse**  **AVTSR**

## Whole report



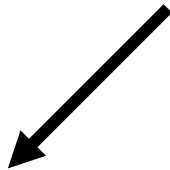
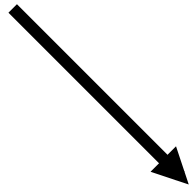
**Trouble  
phonologique**

**Trouble  
visuo-attentionnel**

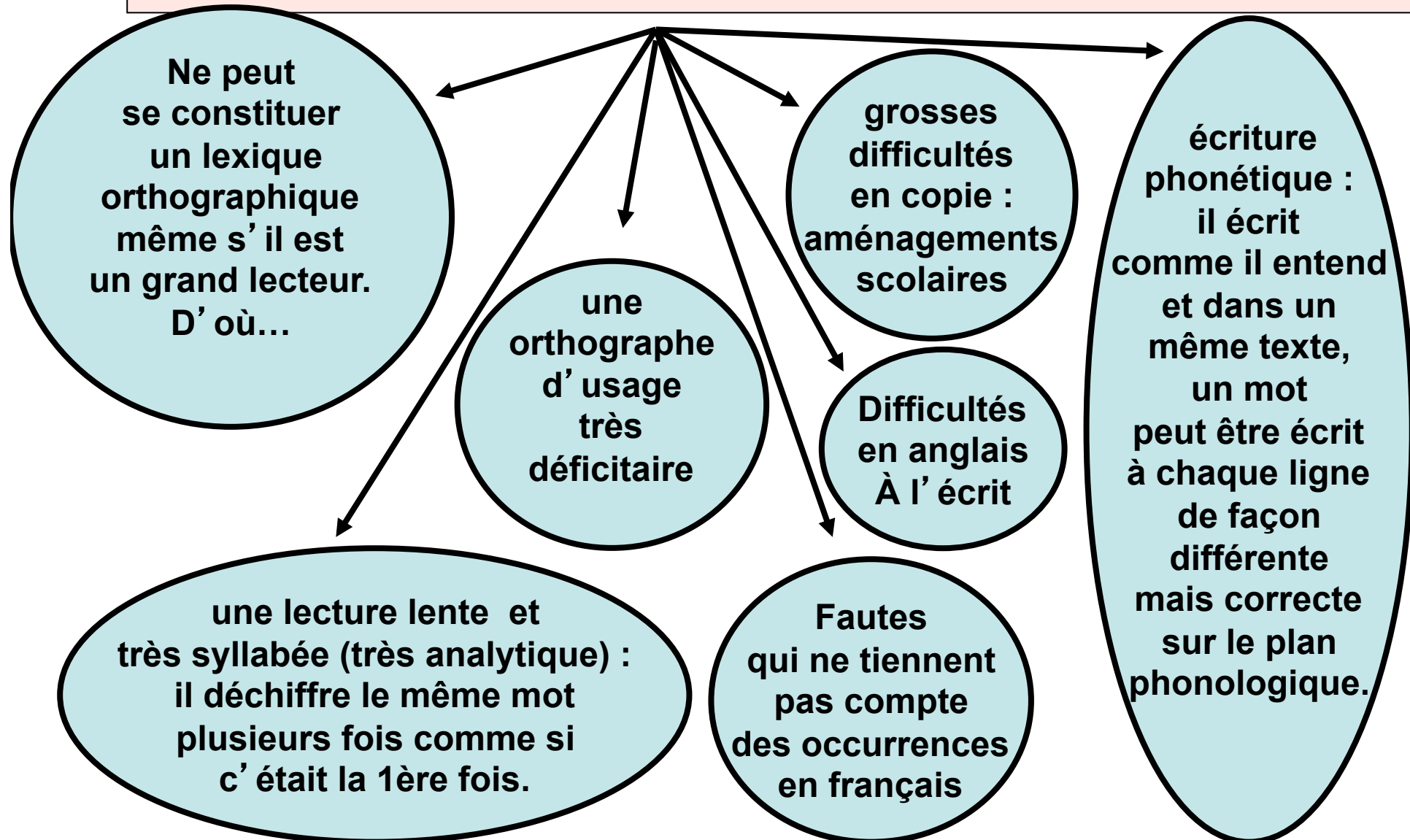
**Dyslexie Mixte**

**Dyslexie phonologique**

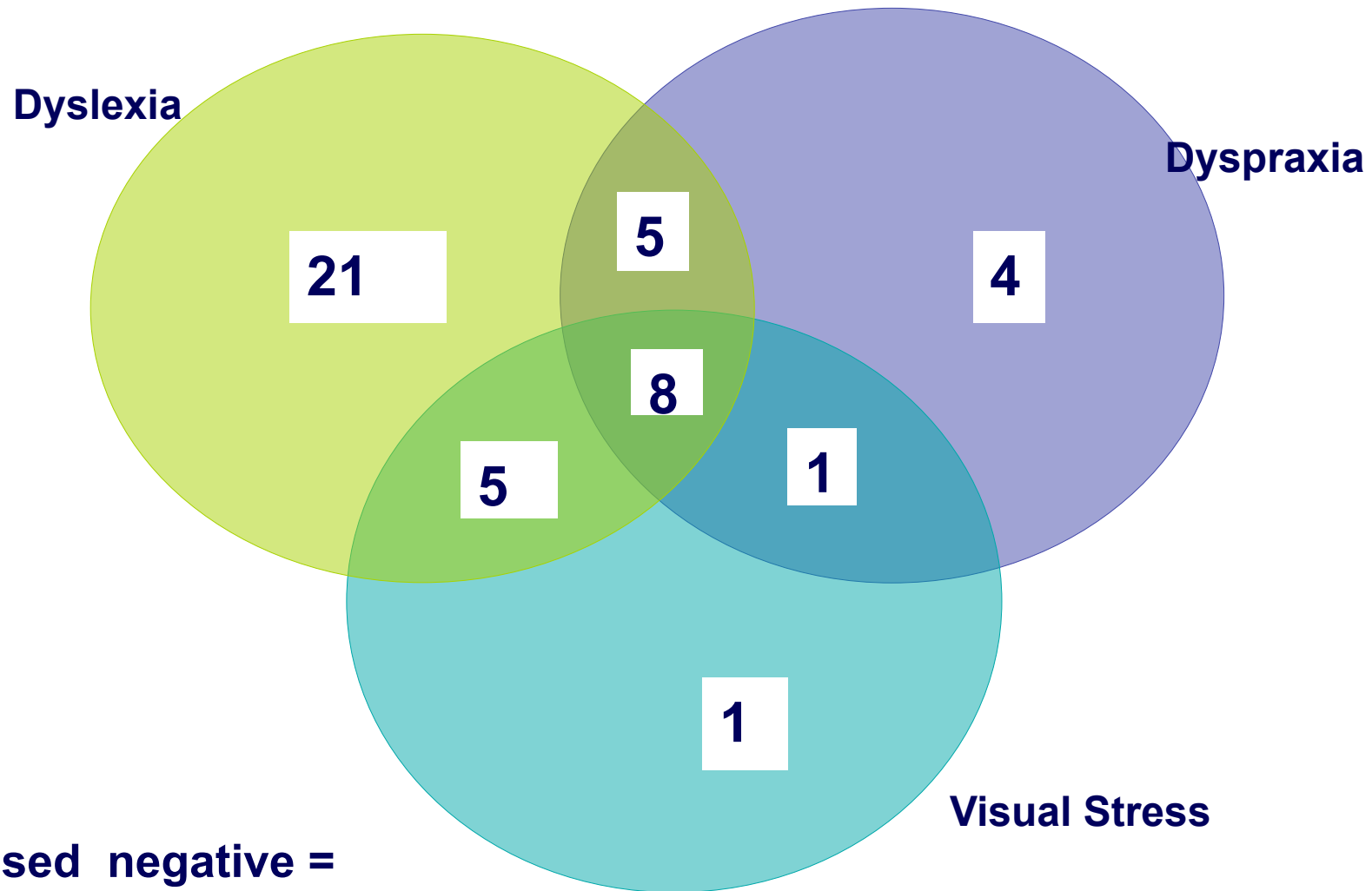
**Dyslexie de surface**



# Trouble visuo-attentionnel: conséquences

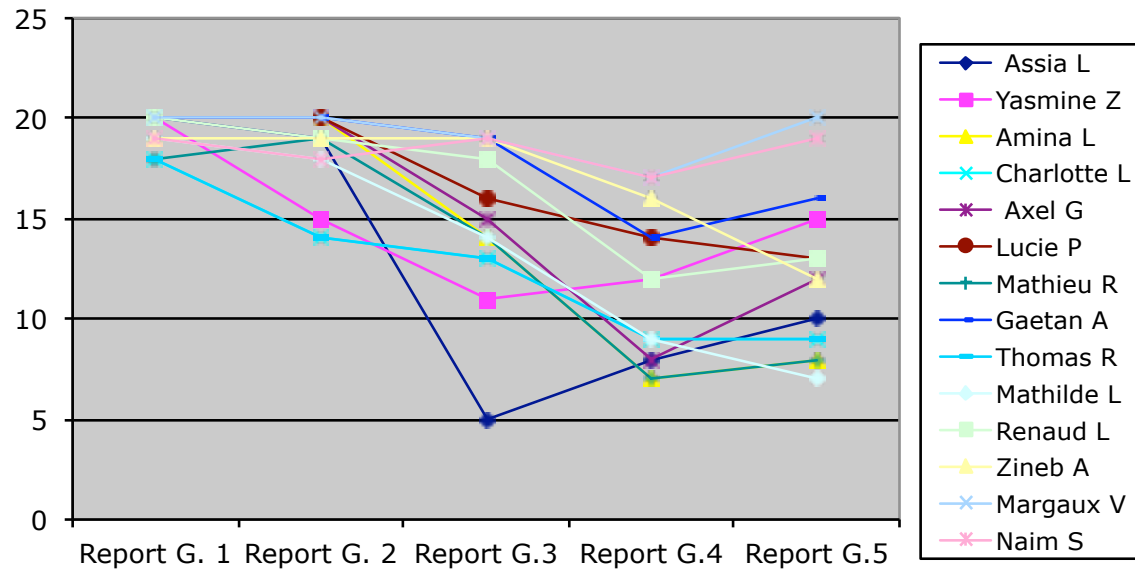


**Co-morbidity of dyslexia, dyspraxia and  
visual stress from the 60 assessments used.**

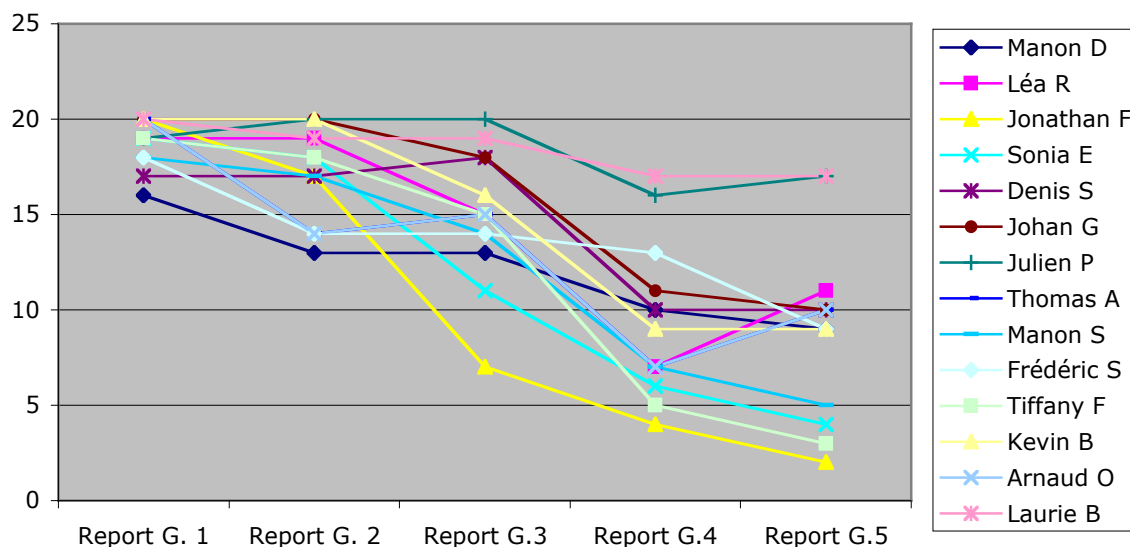


**Assessed negative =  
15**

### report global/ groupe "visuel"



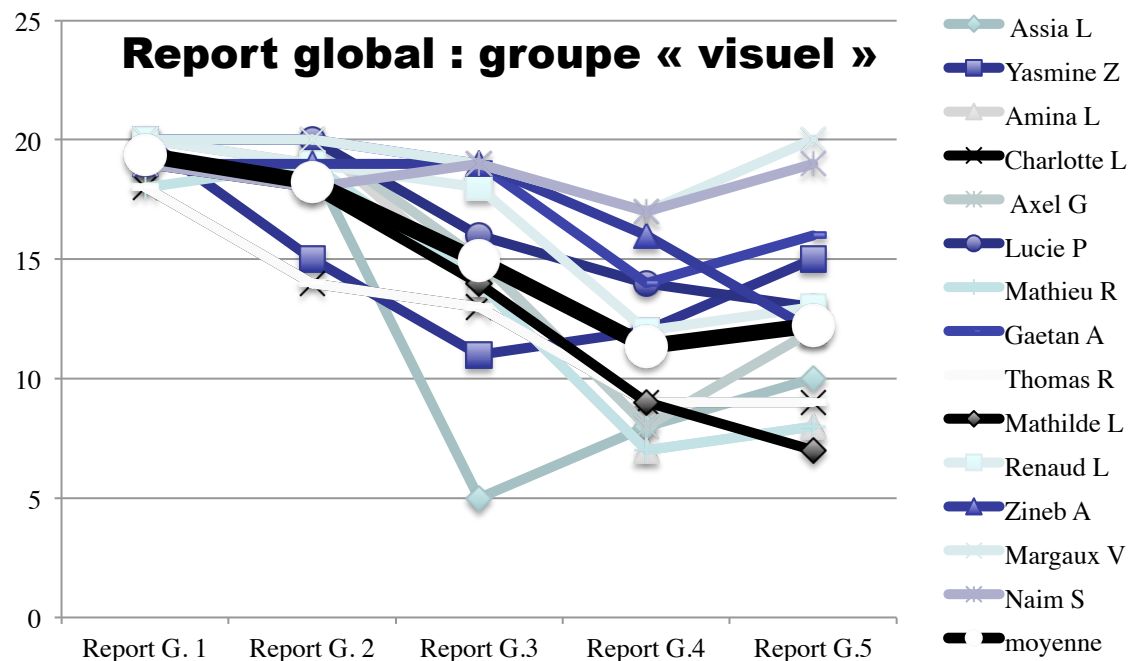
### report global / sujets contrôle



Comparaison de 14 dyslexiques ( $\mu=9a7m$ ) sans difficultés visuelles apparentes et 14 dyslexiques ( $\mu=10a2m$ ) suivis en orthoptie pour "trouble neurovisuel" ("visual stress")

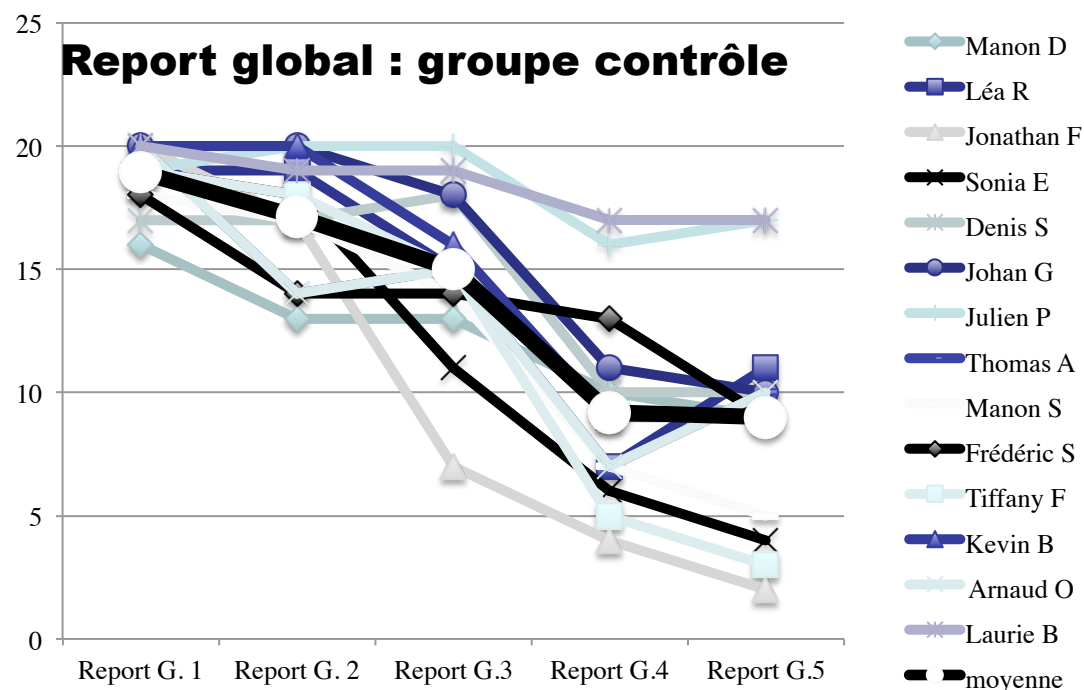
Même âge moyen, de lecture (Alouette)

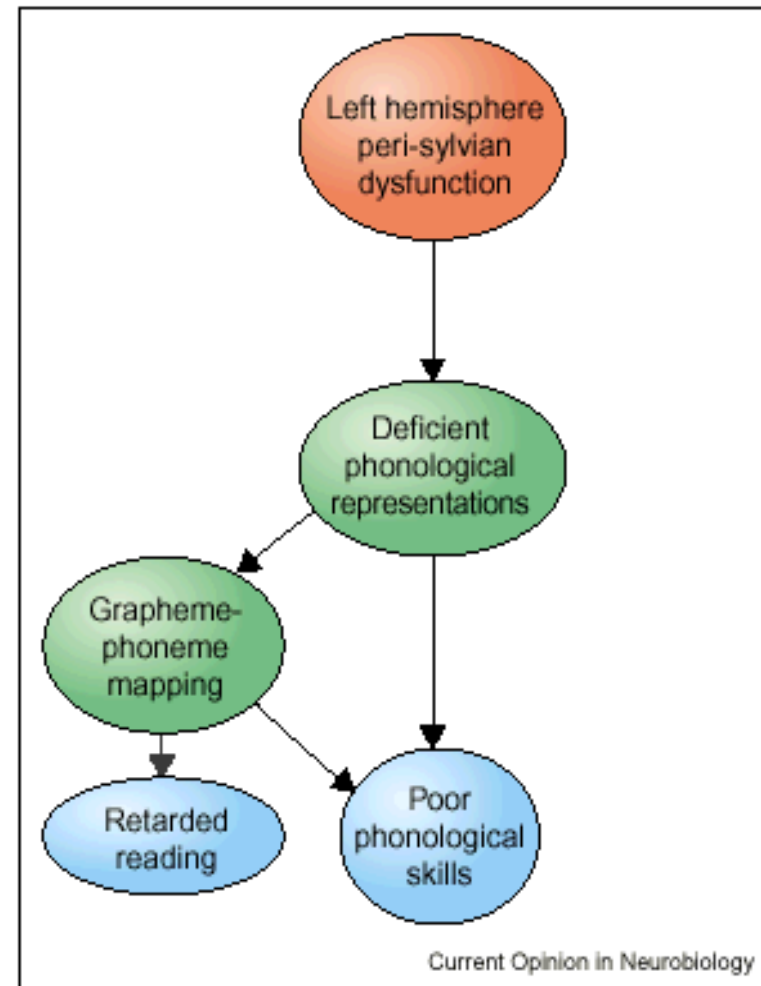
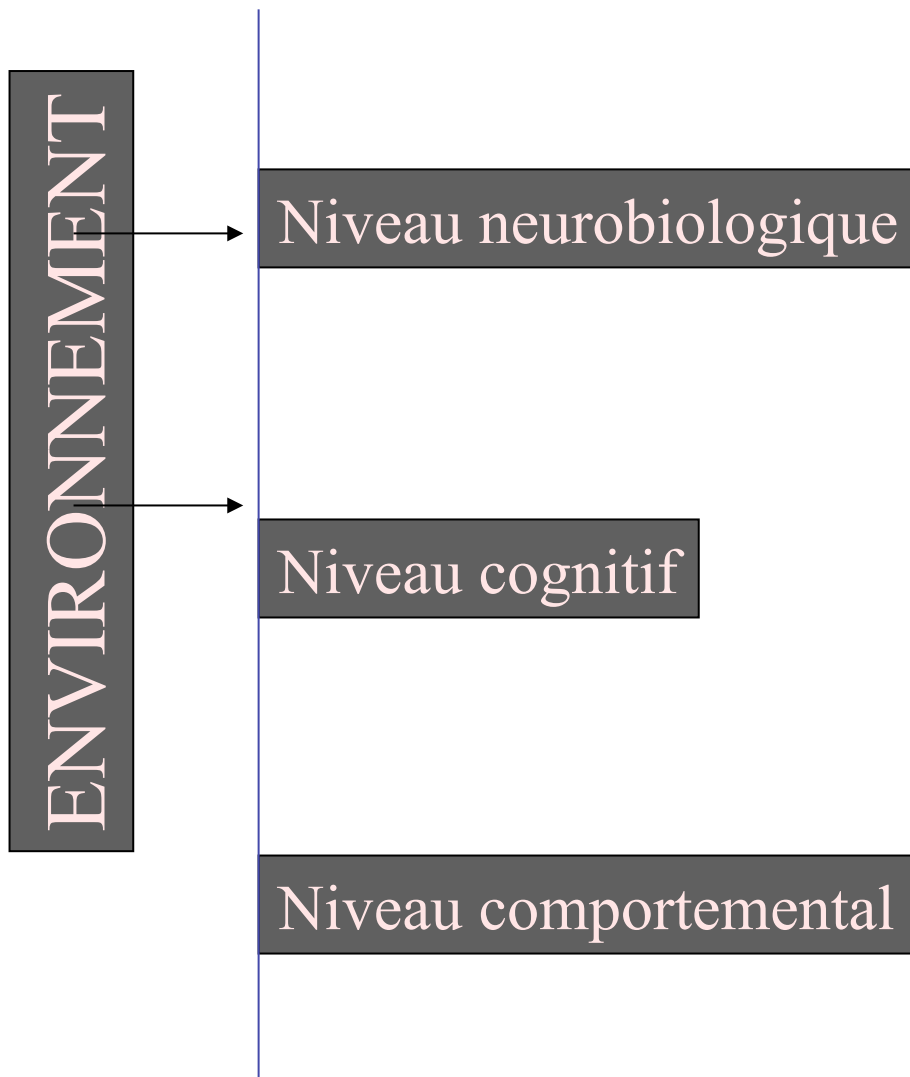
Trouble phonologique moins sévère dans le groupe "visuel"



Les deux groupes ont un profil visuo-attentionnel (plus d'erreurs sur les positions 4 et 5) mais pas de différence significative (sauf tendance sur position 5 : groupe « visuel » significativement meilleur que groupe contrôle ( $p=0.052$ ))

En conclusion : les dyslexiques présentant des troubles « neurovisuel » n'ont pas plus fréquemment que les autres un profil visuo-attentionnel.

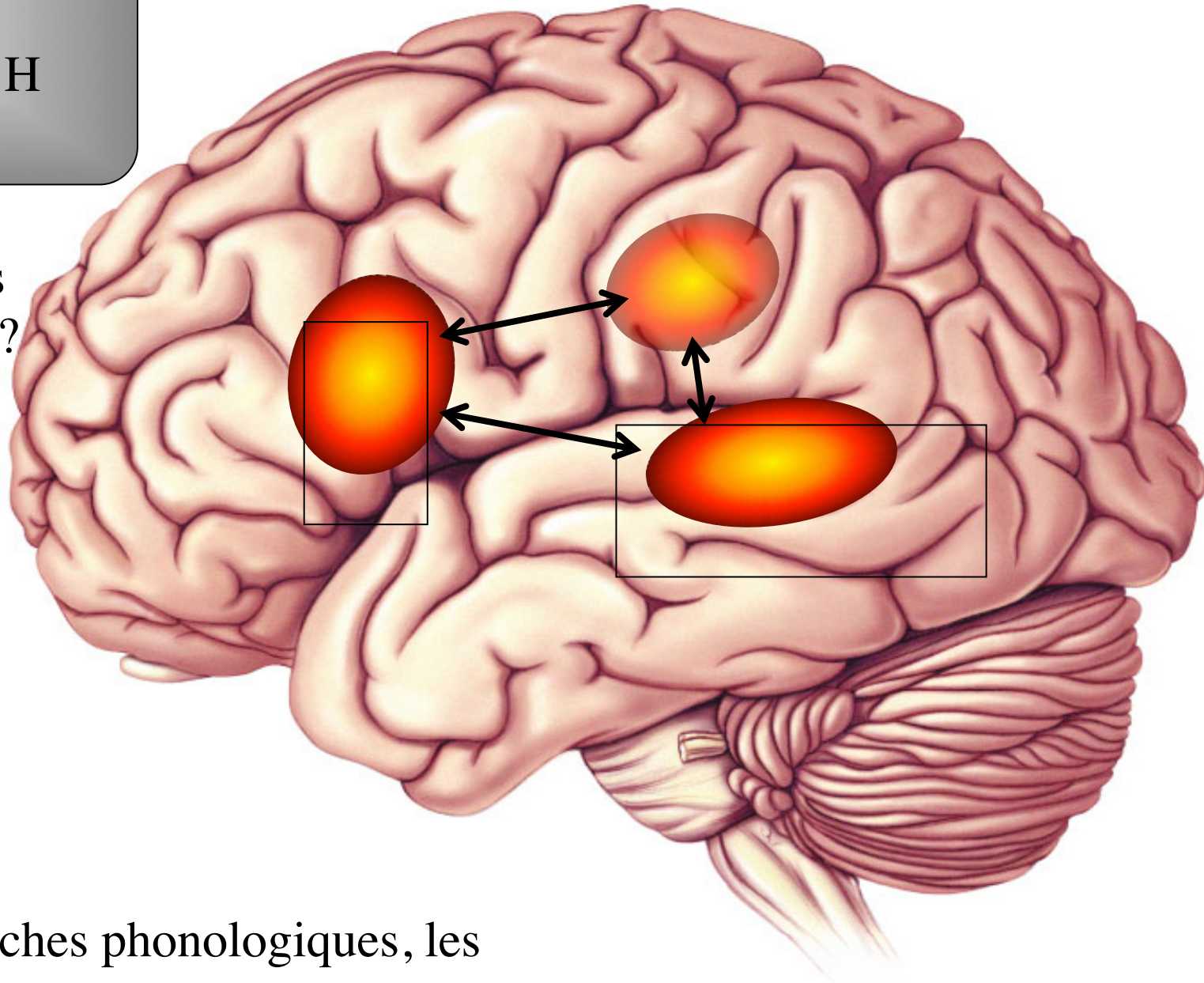






G H

Lettres  
riment?

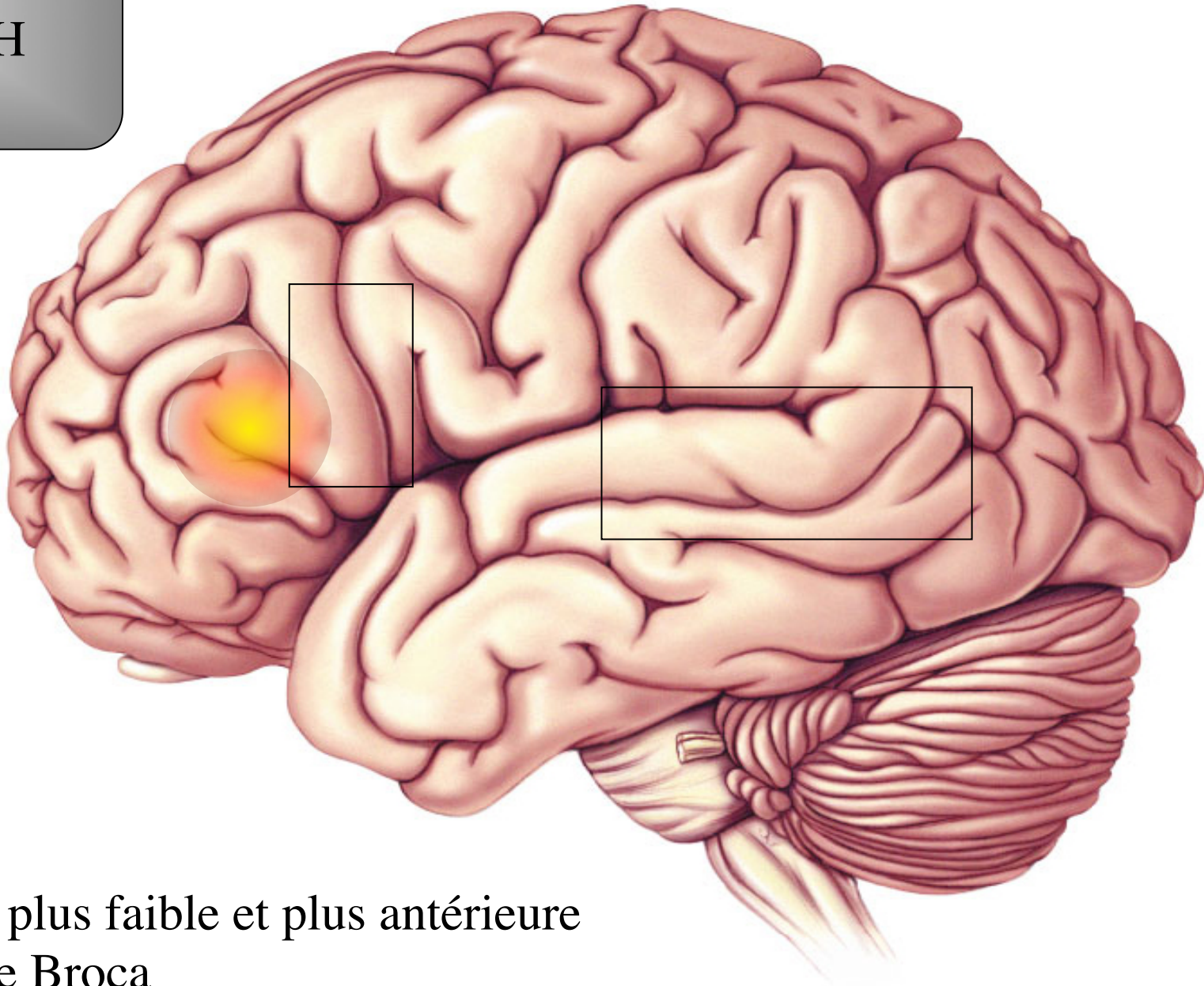


Lors de tâches phonologiques, les  
aires du langage ne peuvent  
s'activer correctement

Temple et al., *P.N.A.S.* (2003)

G H

## Enfant dyslexique



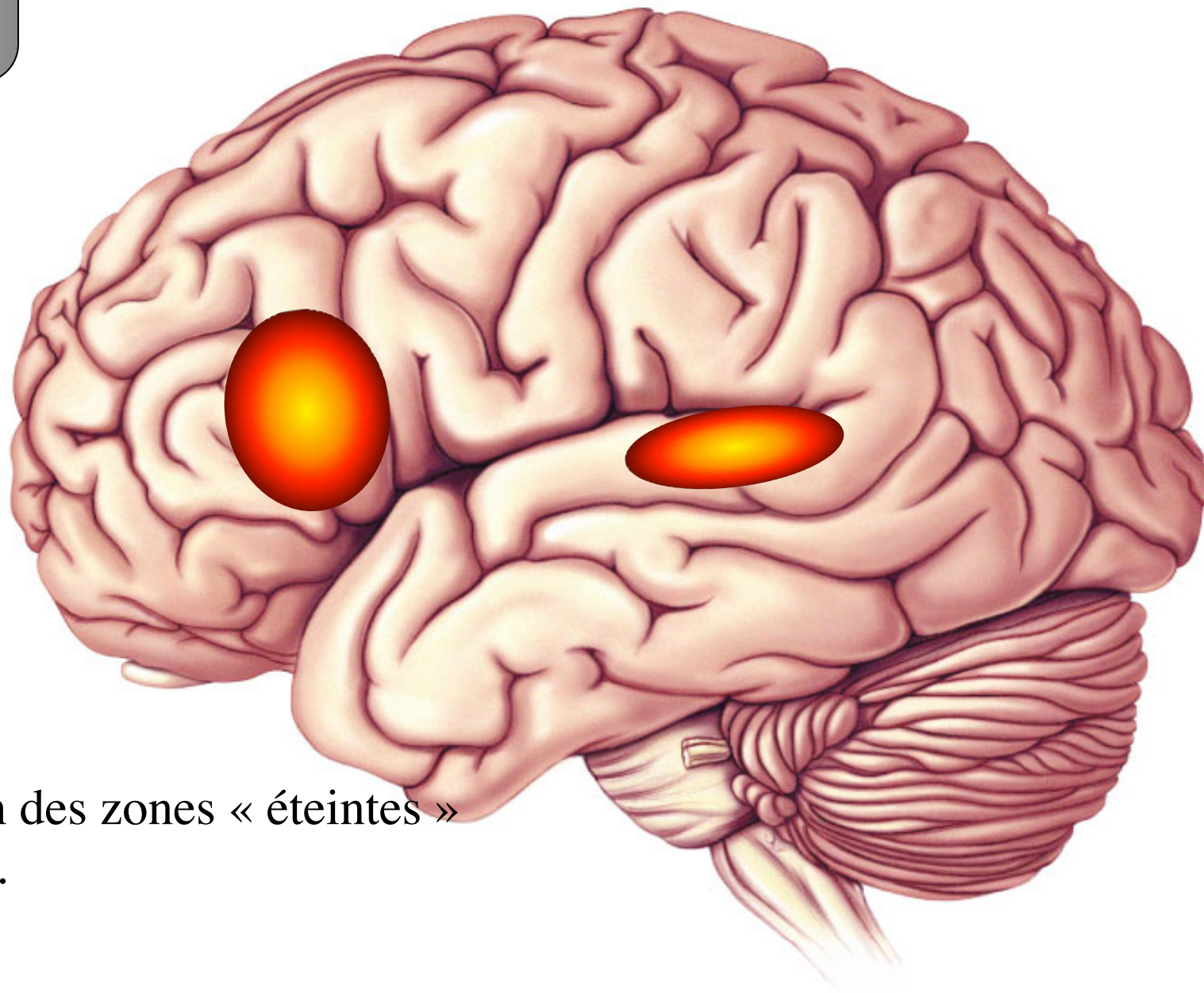
Activation plus faible et plus antérieure  
de l'aire de Broca  
Absence d'activation postérieure

Temple et al., *P.N.A.S.* (2003)

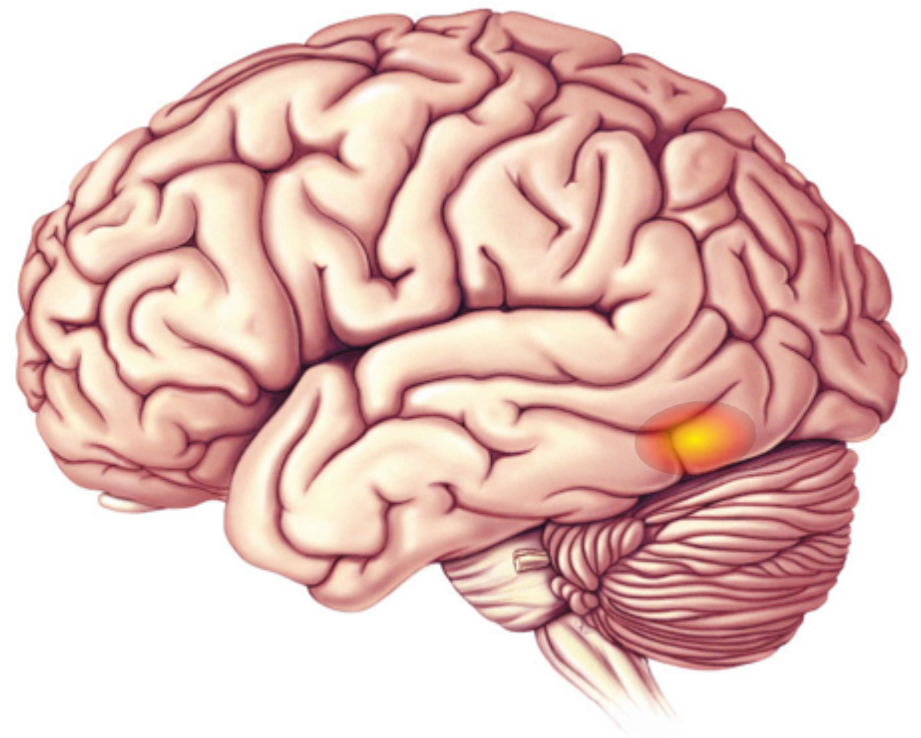


G H

Enfant dyslexique après entraînement (Fastforward®)



Réapparition des zones « éteintes »  
Mais aussi...



... apparition de zones non activées précédemment (et non activées chez le témoin) : mécanisme de compensation? réorganisation?

# Conclusion n°1

- Les processus phonologiques sont fortement liés à l'efficacité de la lecture, de manière causale, au moins pour les aptitudes concernant les unités de taille moyenne
- Les aires du langage sont insuffisamment activées chez le dyslexique lors d'exercices phonologiques, ce qui est généralement considéré comme la cause de leur difficulté en lecture
- Un entraînement intensif de quelques semaines, focalisé sur le système déficient, non seulement réactive les zones affaiblies mais sollicite des zones "muettes" des deux hémisphères
- En tout état de cause, l'apprentissage des règles de conversion grapho-phonémiques est, comme chez le normo-lecteur, l'étape cruciale de l'apprentissage

bol

confortablement

tambenefoneclor



**"CHAPEAU"**



**ANALYSE VISUELLE**  
(identité, position, etc...)

**"CHAPEAU"**



*lecture par  
adressage*

**chapeau**

**LEXIQUE VISUEL**  
(ORTHOGRAPHIQUE)  
reconnaissance  
globale du mot

**SYSTEME  
SEMANTIQUE**  
(sens du mot)



**SYSTEME DE  
CONVERSION  
DES GRAPHIES  
EN SONS**

*lecture par  
assemblage*

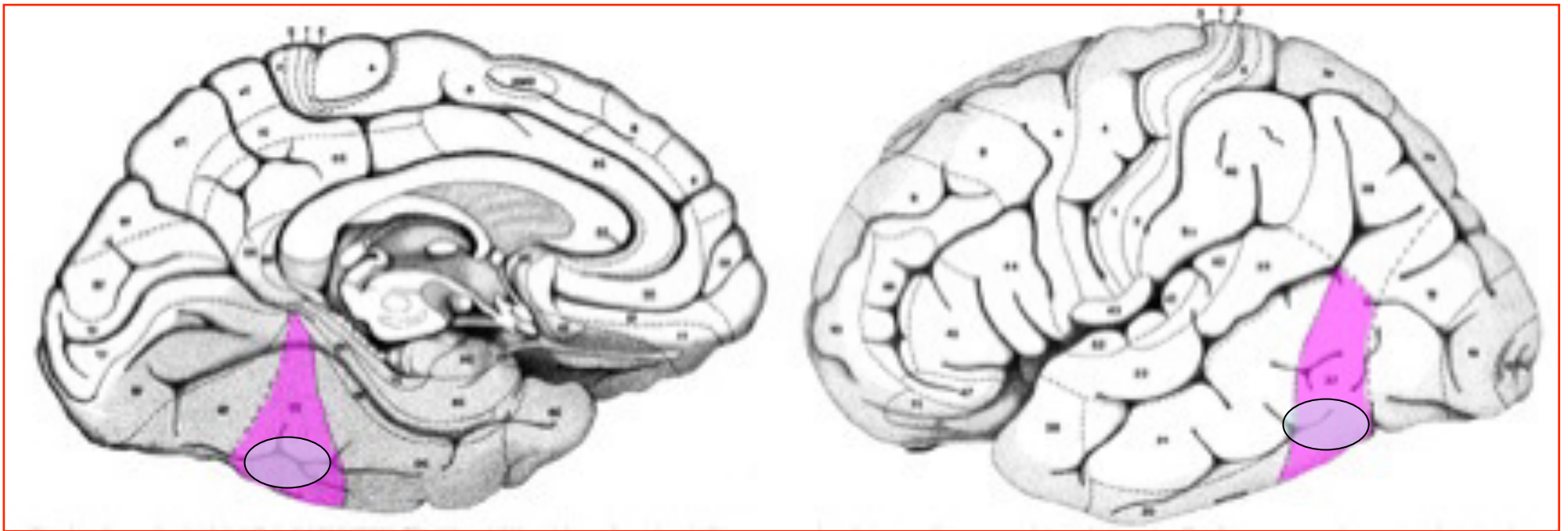
**ch a p eau**



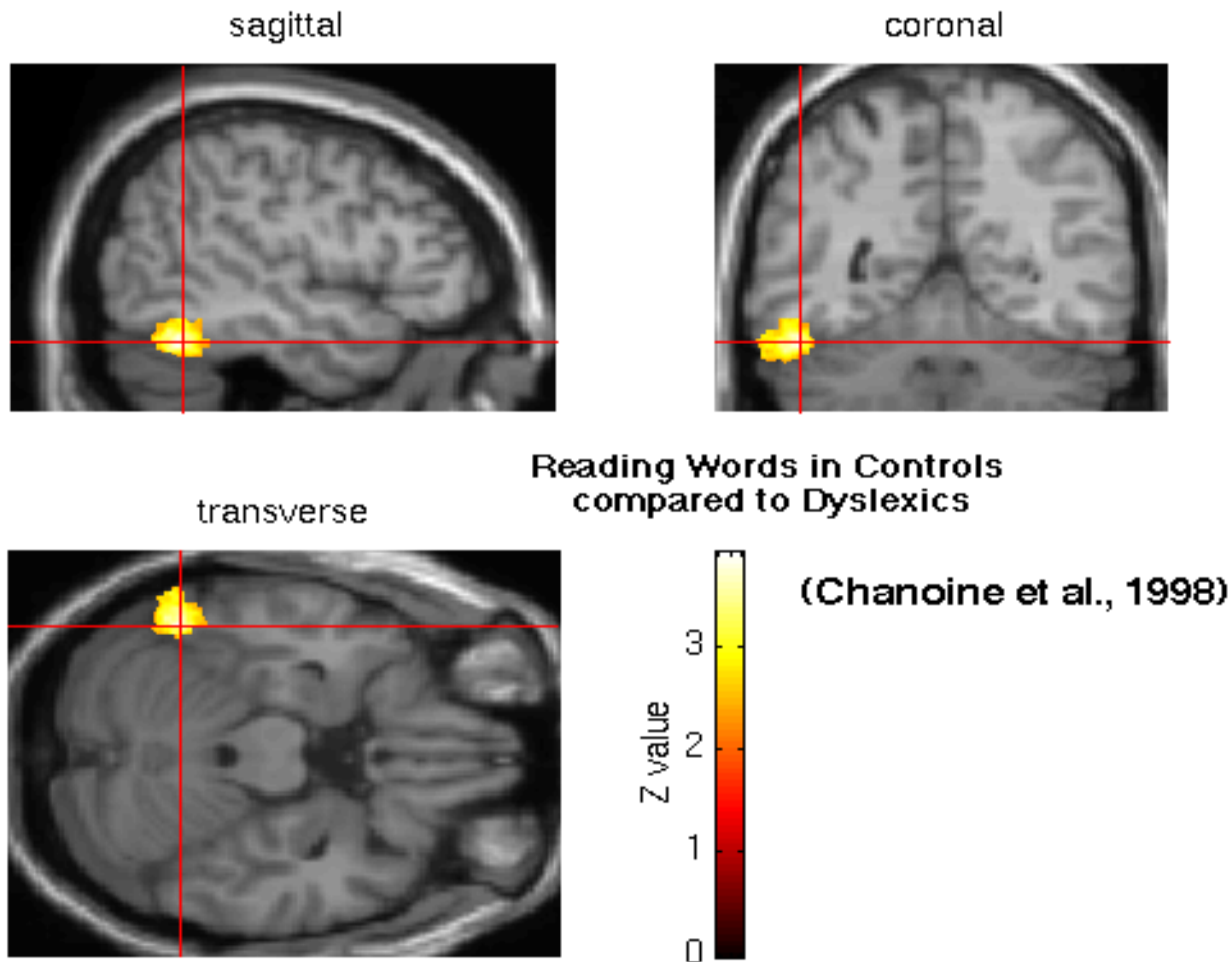
**/ʃa/po/**

**production  
orale**  
**/ʃa p o/**

# ILBA 37 : aire de la forme visuelle des mots



Attribue un statut linguistique à une suite de lettres



Most significant difference dyslexics/controls =  
left infero-lateral Brodman's area 37

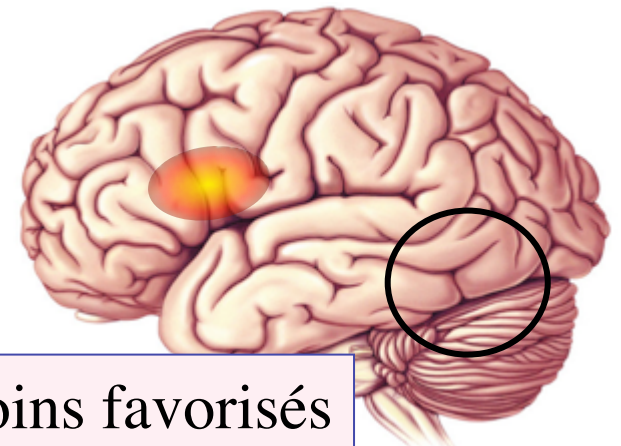
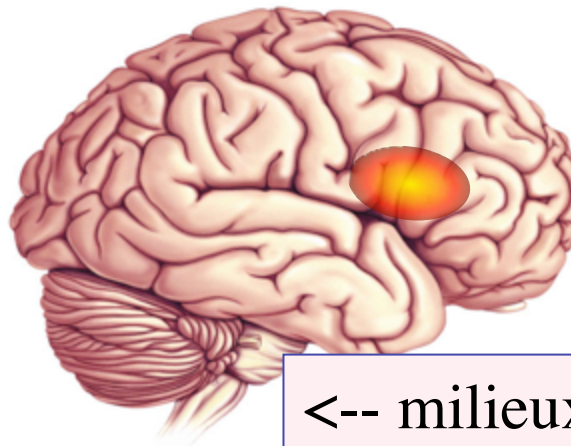
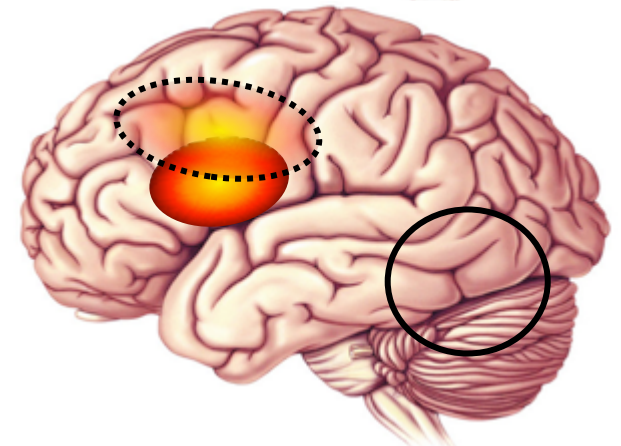
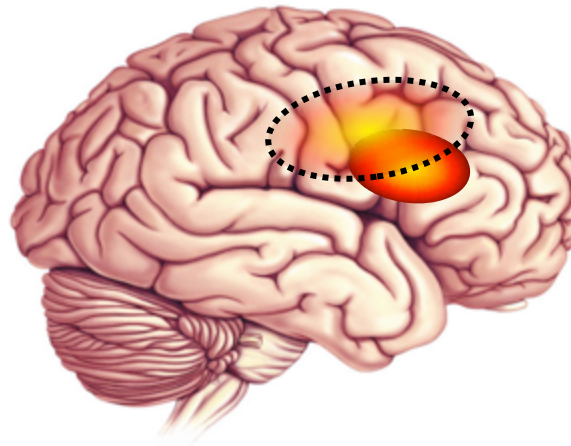
LEAT JETE

Témoins  
non dys

Riment?

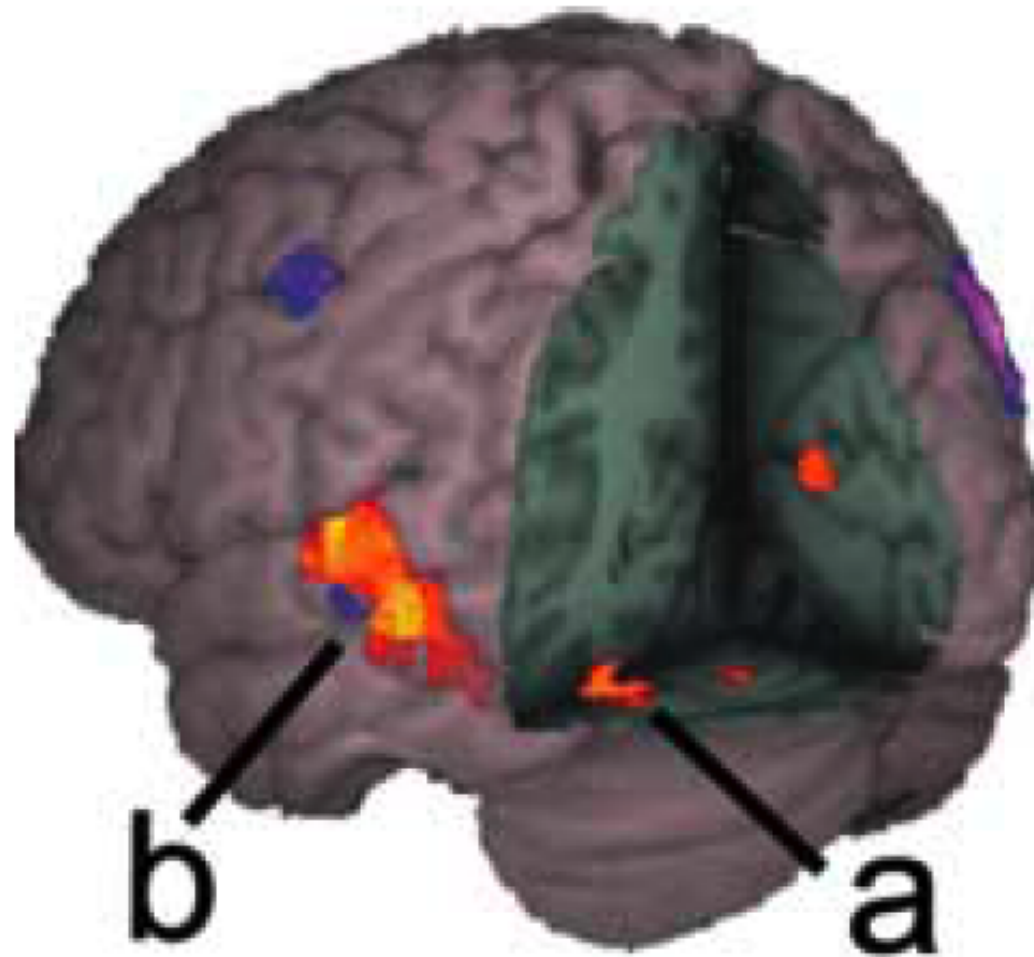
Dyslexiques  
"compensés"

Dyslexiques  
"persistants"



<-- milieux moins favorisés

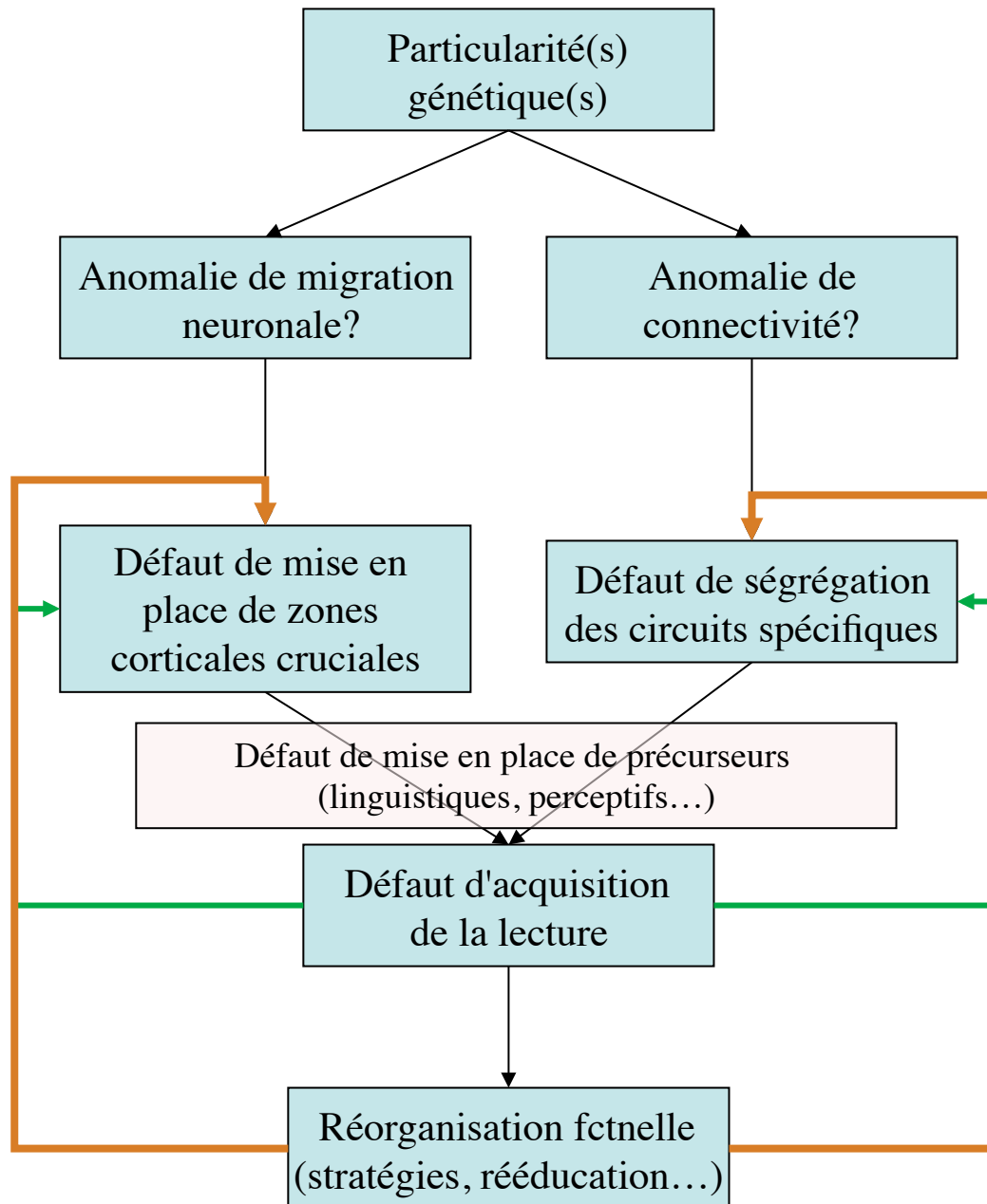
## Zones de corrélation entre le niveau de conscience phonologique et le statut socio-économique

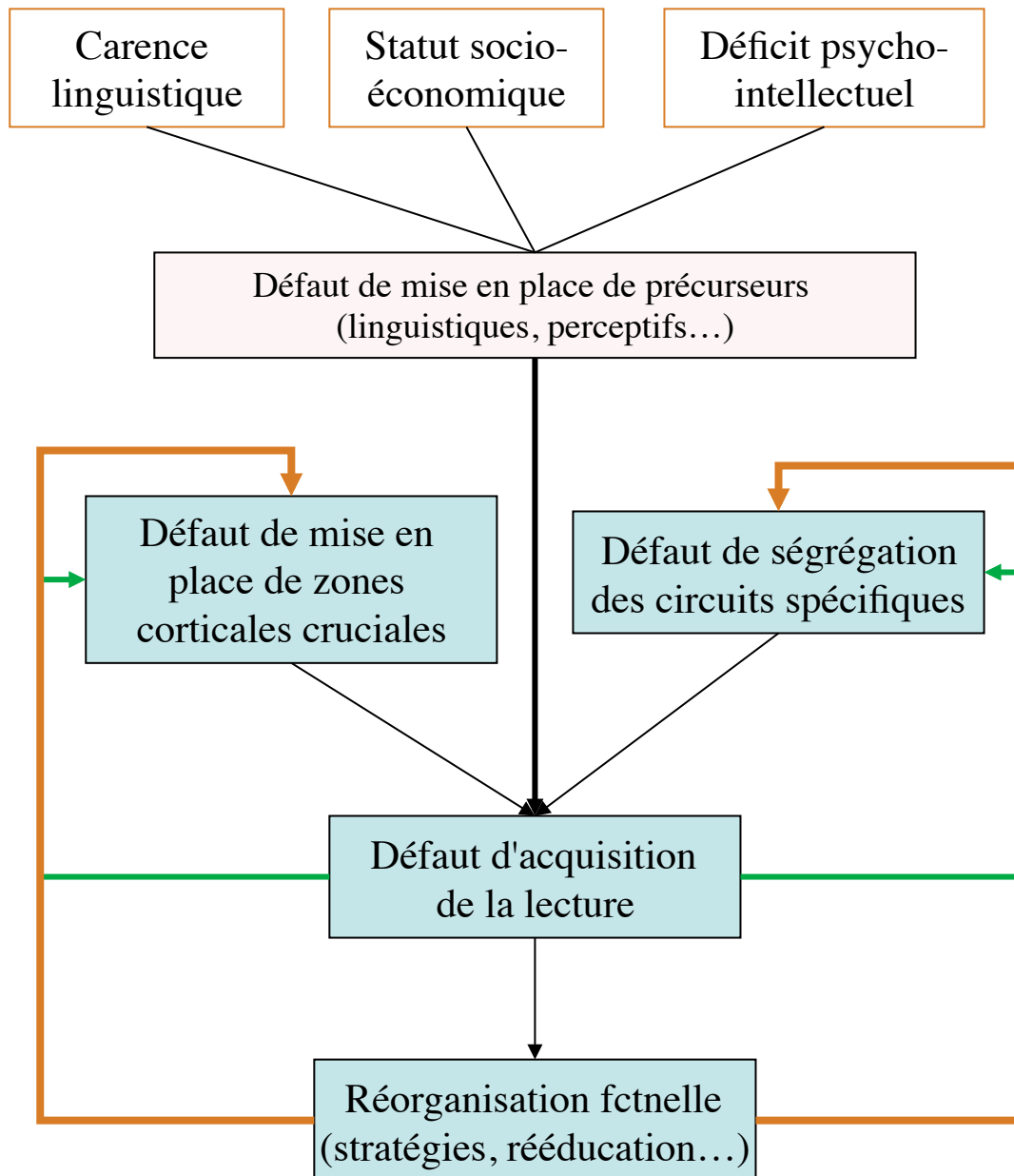


## Conclusion n°2

- A égalité de sévérité initiale, le milieu dans lequel évolue l'individu va déterminer au moins en partie non seulement sa capacité de récupération, mais également l'aptitude de son cerveau à recruter d'autres zones pour faciliter cette récupération
- La reconnaissance rapide des mots, finalité de la lecture, est sous la dépendance d'une aire spécialisée qui attribue un statut linguistique à une suite de lettres
- L'absence de mise en jeu de l'aire de la forme visuelle des mots est la conséquence commune à terme, mais variable selon divers facteurs d'environnement, incluant le statut socio-économique.

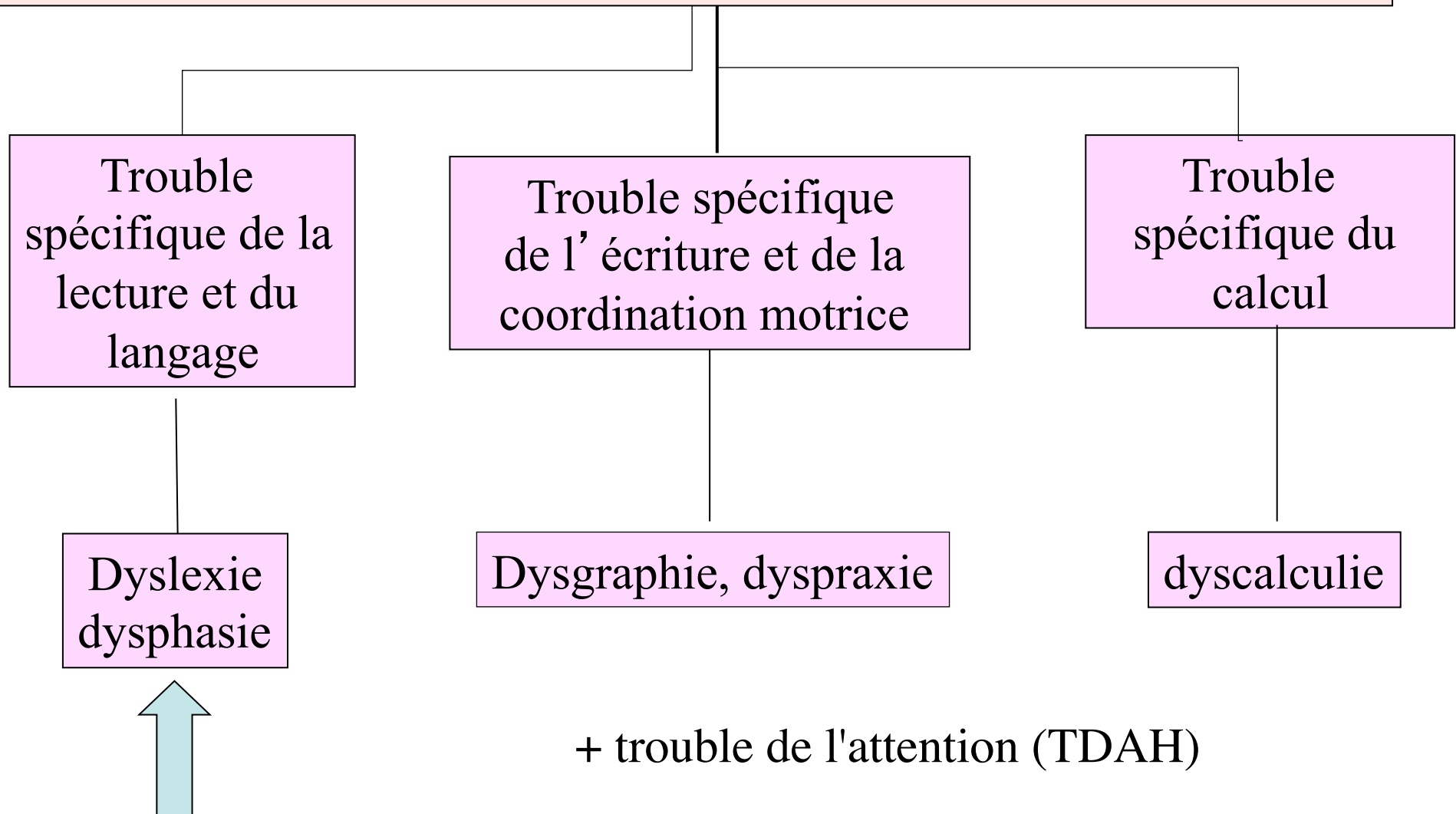


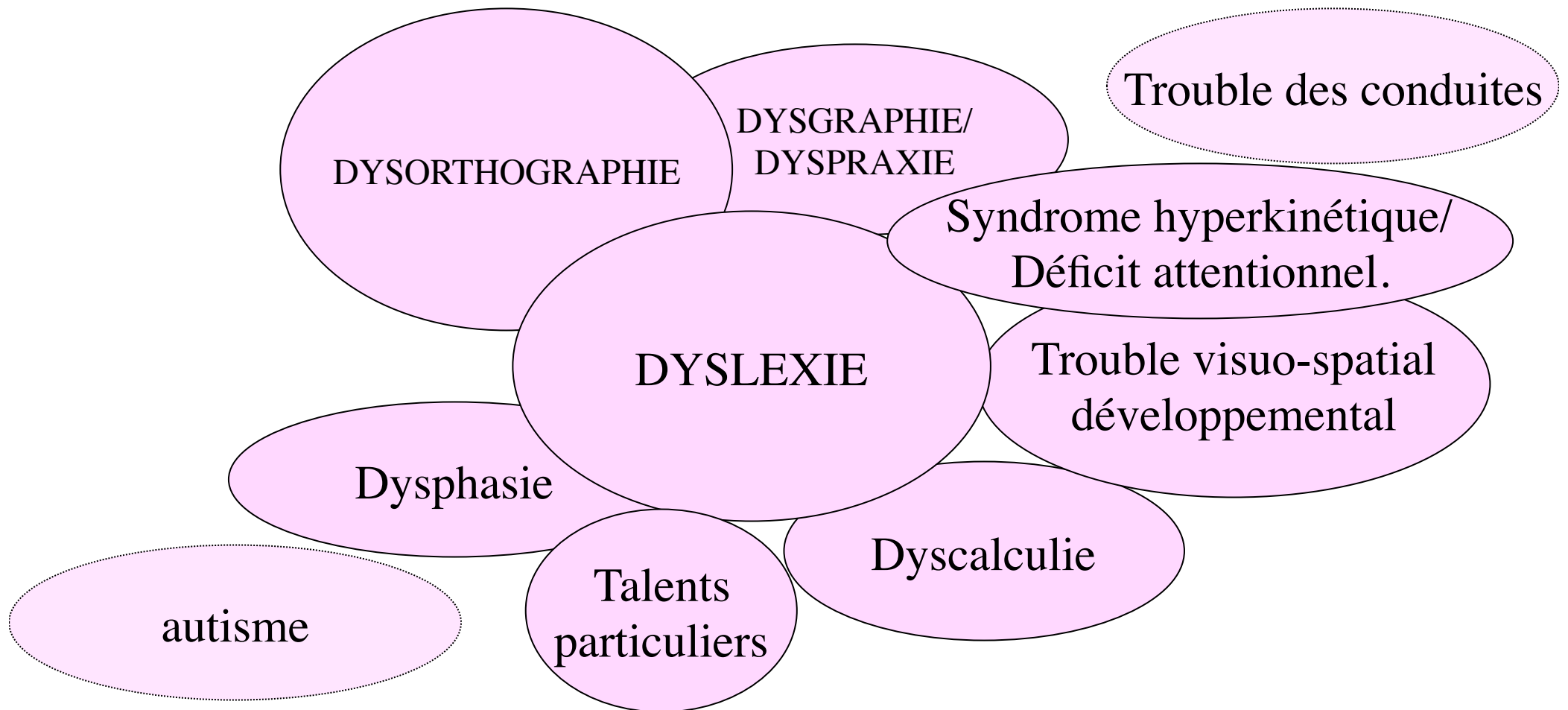






# Troubles spécifiques d'apprentissage ("learning disorders")

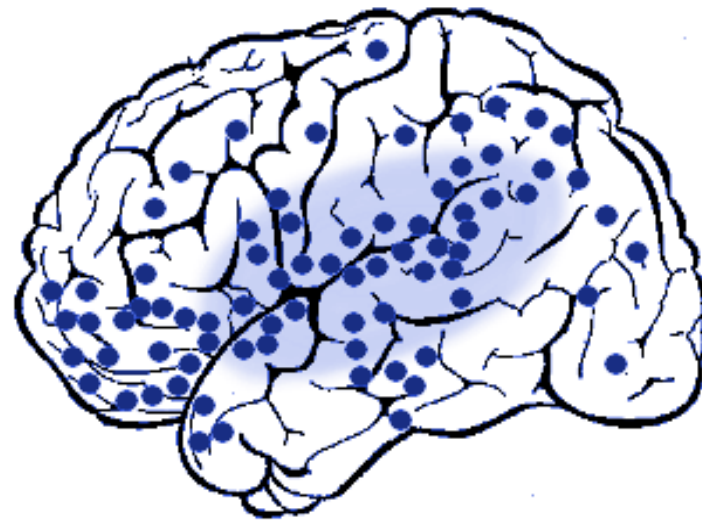
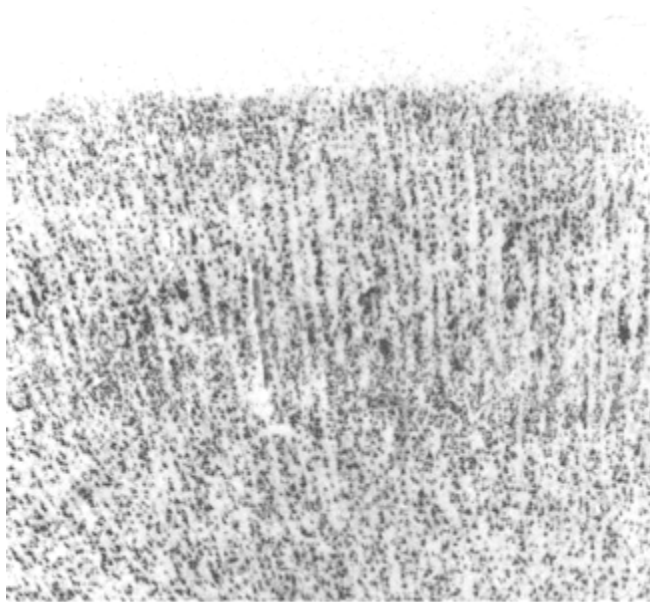




# Le cerveau du dyslexique

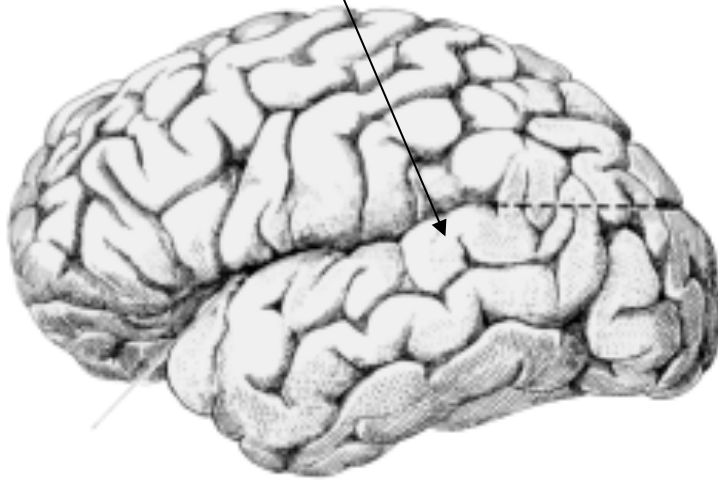
- Possède une organisation déficiente au niveau de l'aire du langage (génétique)
- Ne distingue pas parfaitement les phonèmes contenus dans la parole
- Ne peut manipuler volontairement les sons de la langue (conscience phonologique)
- Ne peut associer graphèmes et phonèmes
- Ne développe pas de procédure de reconnaissance globale des mots

# Données neuroanatomiques

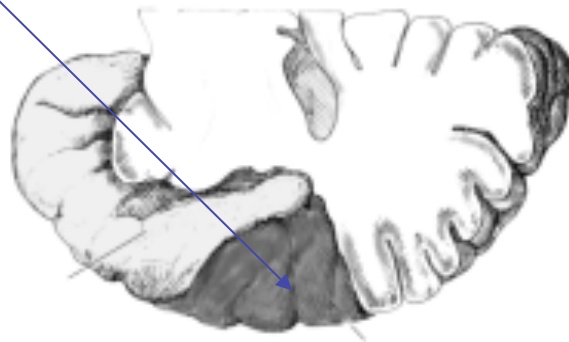


**Ectopies sur le cerveau dyslexique  
(Galaburda et al., 1979, 1985)**

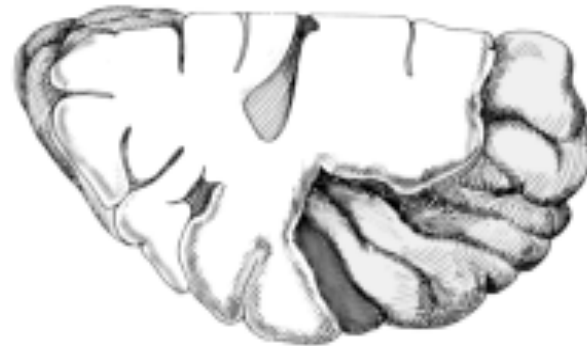
Aire de Wernicke



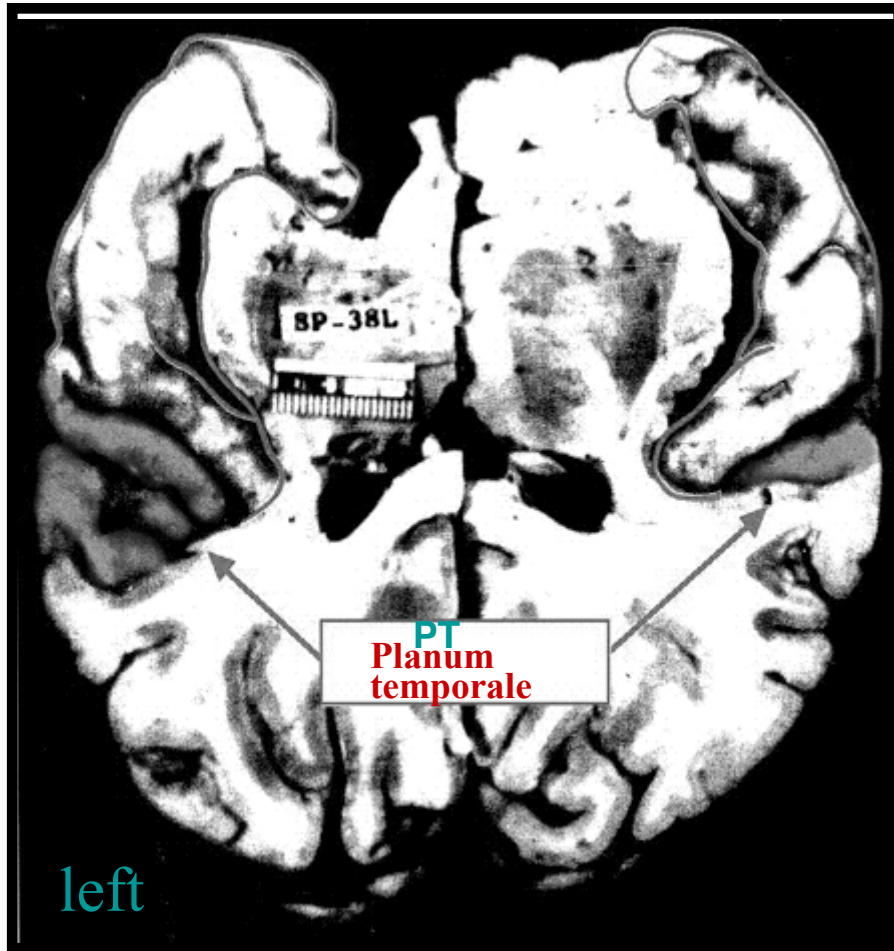
Planum temporale



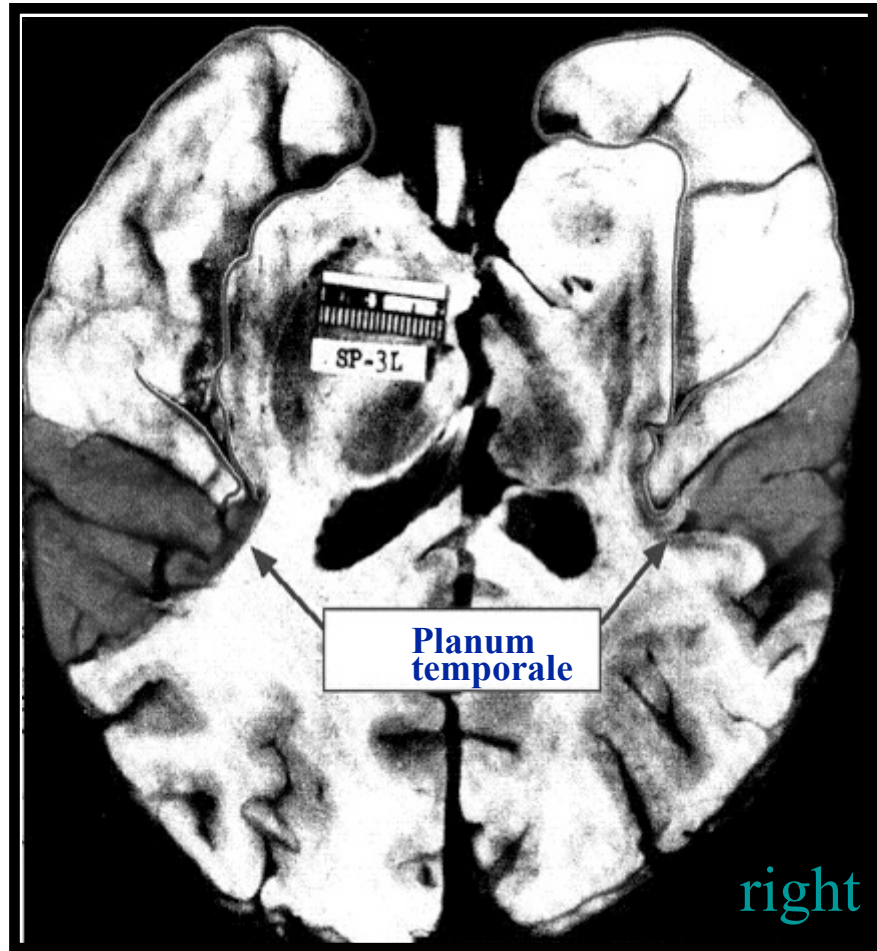
G



D



**NON DYSLEXIC**

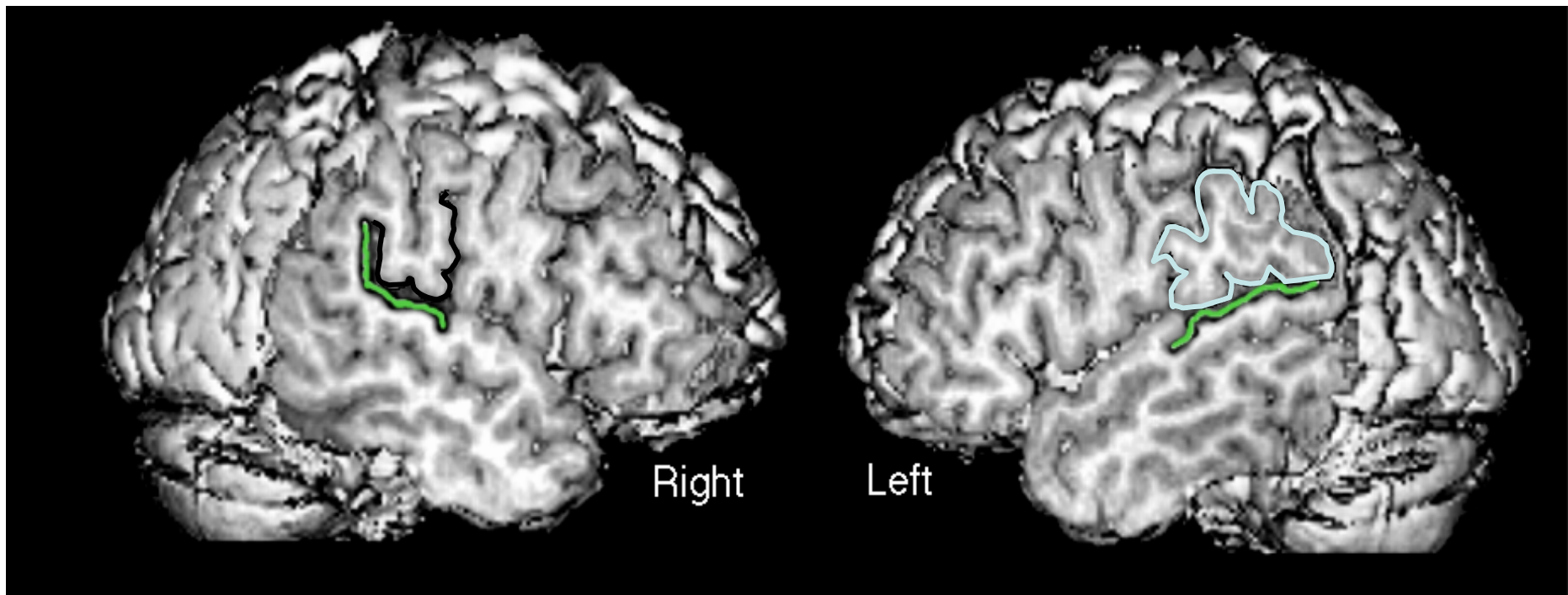


**DYSLEXIC**

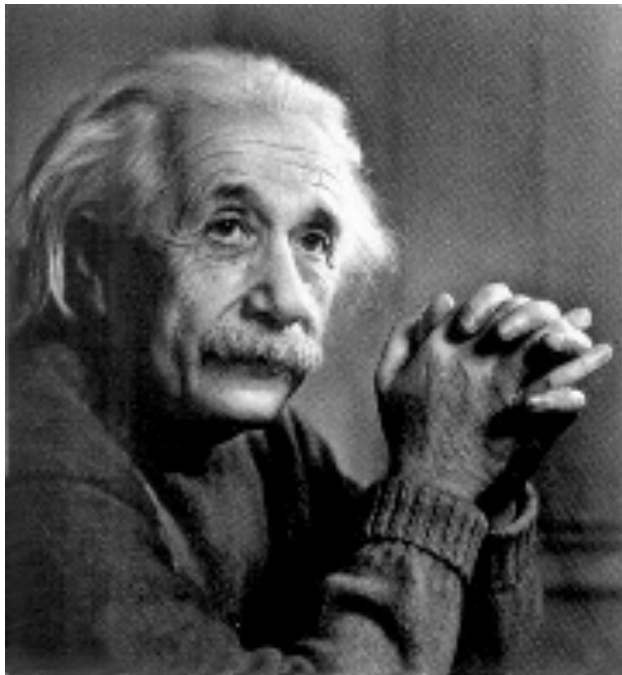
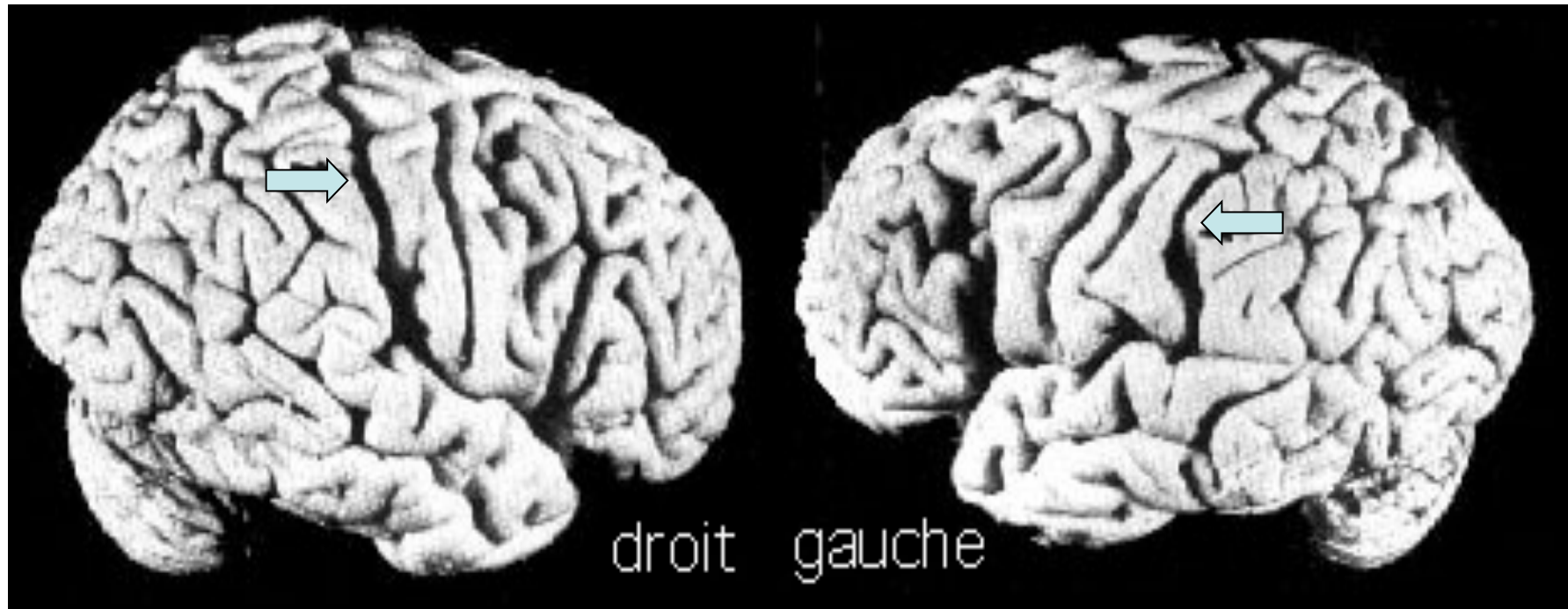
Absence of planum asymmetry in the dyslexic brain  
From Galaburda et al., 1979; 1985



# Dyslexie : opercule pariétal gauche plus vaste







**Einstein's brain : no parietal opercula  
(from Witelson et al., 1999)**

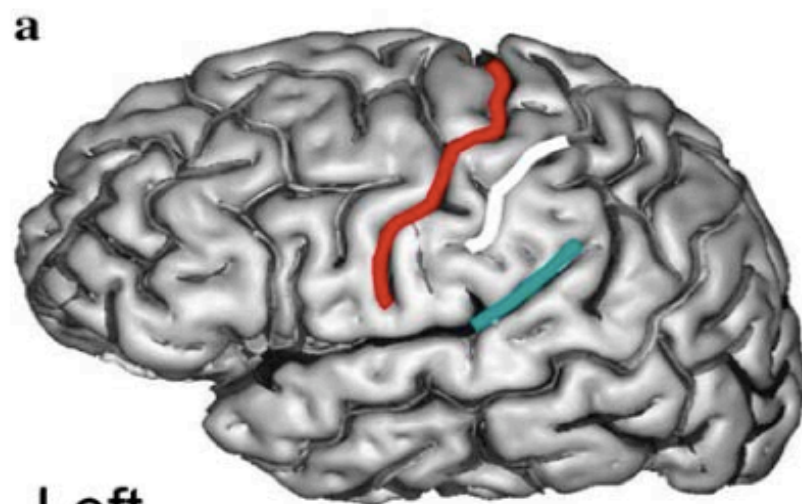
## Neuroanatomical and behavioral asymmetry in an adult compensated dyslexic <sup>☆</sup>

Christine Chiarello <sup>a,\*</sup>, Linda J. Lombardino <sup>b</sup>, Natalie A. Kacinik <sup>a,c</sup>,  
Ronald Otto <sup>d</sup>, Christiana M. Leonard <sup>b</sup>

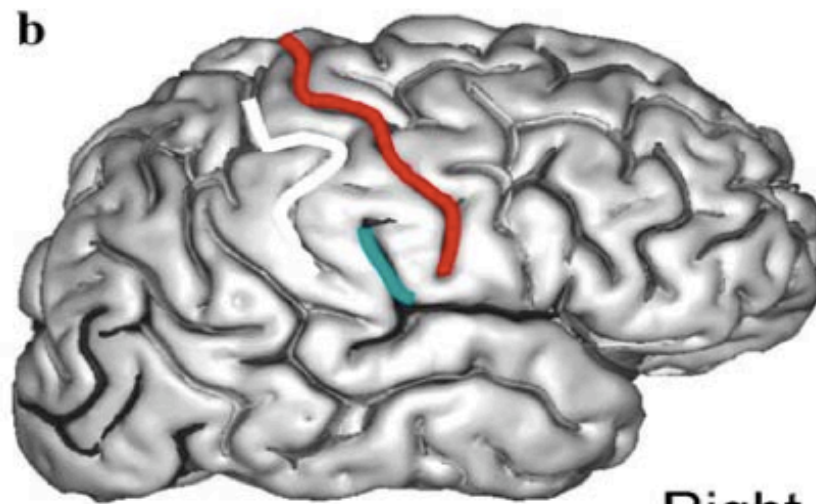
Table 1  
Standardized test results for T.F.

| Category     | Skill (measure)                                                     | Score <sup>*</sup> | Percentile |
|--------------|---------------------------------------------------------------------|--------------------|------------|
| Nonverbal IQ | (Ravens Advanced Progressive Matrices)                              | 29                 | 86         |
| Reading      | Untimed word reading aloud (WRMT-R Word Identification)             | 93                 | 32         |
|              | Timed word reading aloud (TOWRE Sight Word Efficiency)              | 83                 | 13         |
|              | Untimed nonword reading aloud (WRMT-R Word Attack)                  | 92                 | 29         |
|              | Timed nonword reading aloud (TOWRE Phonemic Decoding Efficiency)    | 94                 | 35         |
|              | Word comprehension (WRMT-R Word Comprehension)                      | 109                | 72         |
|              | Text comprehension (WRMT-R Passage Comprehension)                   | 124                | 95         |
| Spelling     | Untimed written spelling of spoken words (WRAT3)                    | 104                | 61         |
| Grammar      | Grammaticality judgment (CASL Grammaticality Judgment)              | 92                 | 30         |
|              | Syntax Construction (CASL Syntax Construction)                      | 100                | 50         |
| Rapid naming | Letter naming (CTOPP Rapid Letter Naming)                           | 10                 | 50         |
|              | Digit naming (CTOPP Rapid Digit Naming)                             | 10                 | 50         |
| Span memory  | (WAIS-R Digits Forward)                                             | 11                 | 52         |
|              | (WAIS-R Digits Backward)                                            | 6                  | 14         |
| Math         | Timed arithmetic computations (WJ COG III Math Fluency)             | 96                 | 39         |
|              | Untimed computations and solving equations (WJ COG III Calculation) | 112                | 78         |

<sup>\*</sup> Note: Scores listed are standard scores for all tests except WAIS digit spans, and Raven's Matrices.

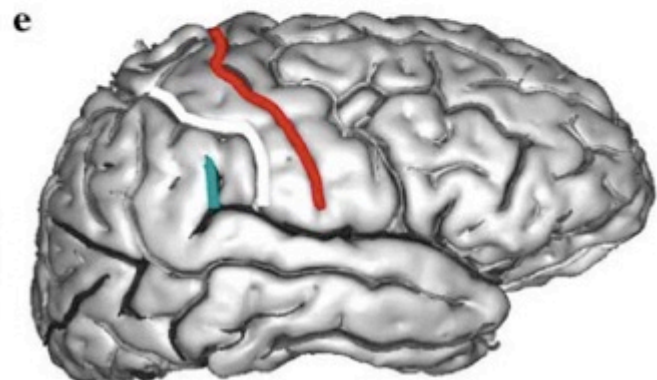
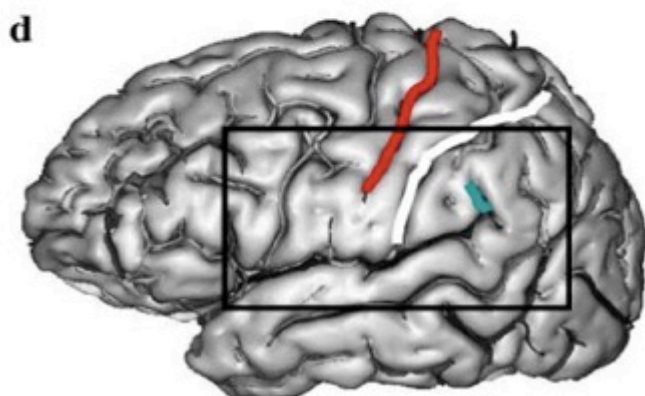
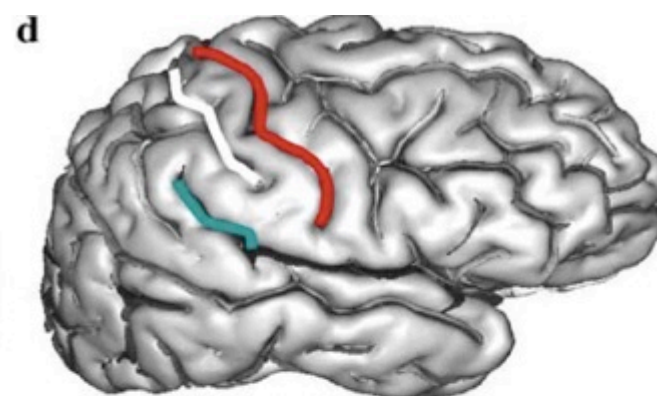
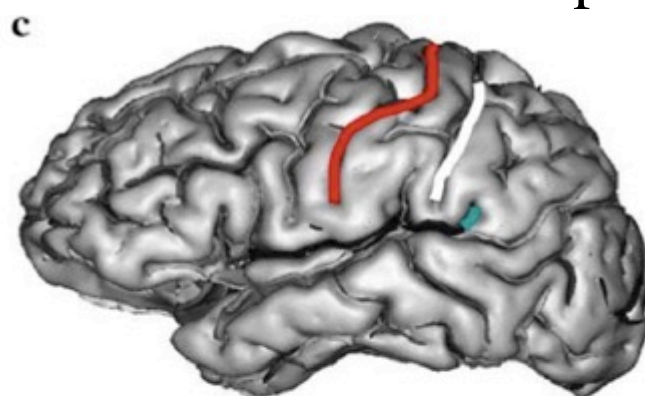


Left



Right

patient



témoins

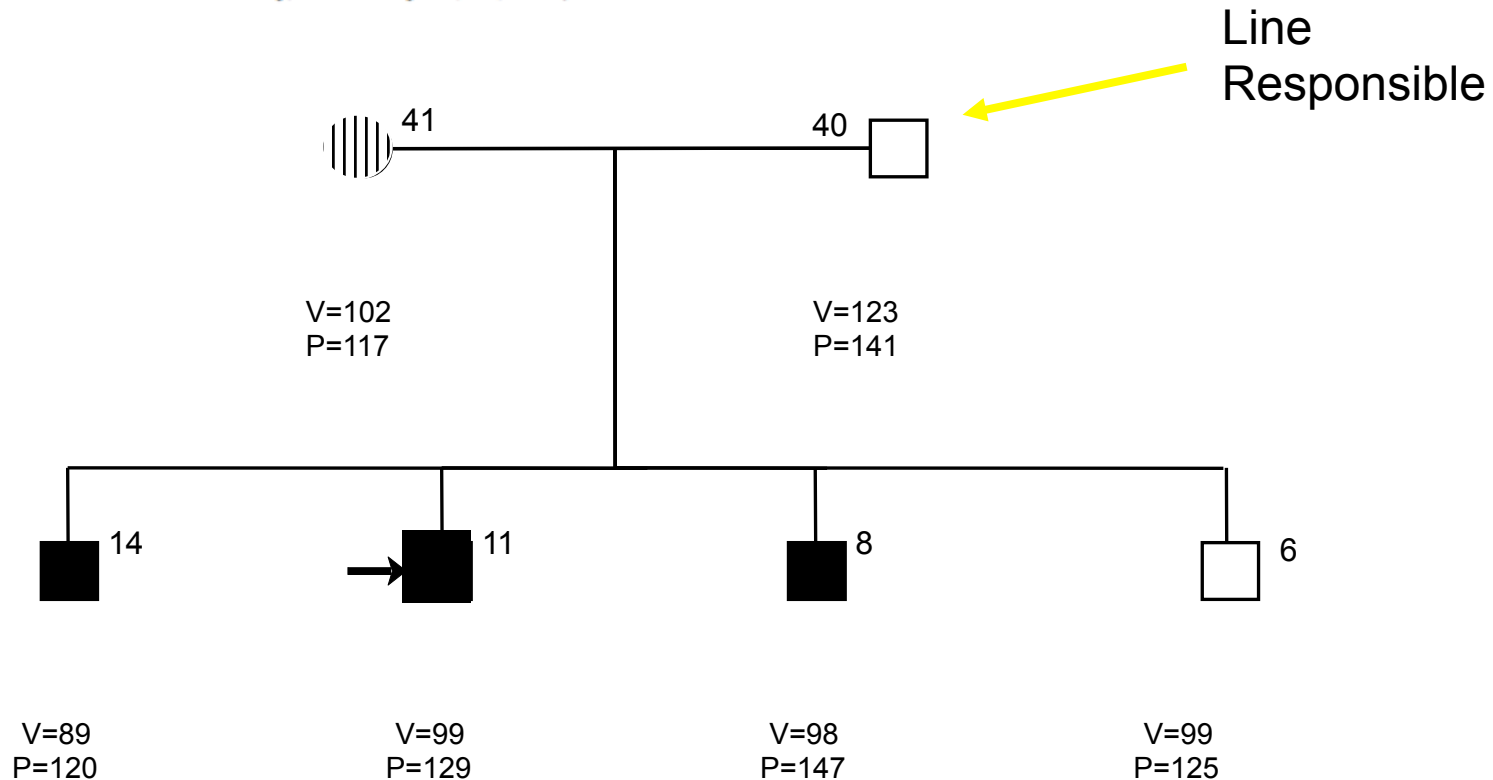
BRAIN MORPHOLOGY AND NEUROPSYCHOLOGICAL PROFILES  
IN A FAMILY DISPLAYING DYSLLEXIA  
AND SUPERIOR NONVERBAL INTELLIGENCE

Jason G. Craggs<sup>1</sup>, Juliana Sanchez<sup>1</sup>, Michelle Y. Kibby<sup>2</sup>, Jeffrey W. Gilger<sup>3</sup> and George W. Hynd<sup>4</sup>

(<sup>1</sup>Center for Clinical and Developmental Neuropsychology, University of Georgia, Athens, GA, USA;

<sup>2</sup>Washington State University, Pullman, WA, USA; <sup>3</sup>California State University, Los Angeles, CA, USA;

<sup>4</sup>Purdue University, West Lafayette, IN, USA)



V = Verbal IQ

P = Performance IQ



Unaffected – No linguistic deficit



RD status unclear



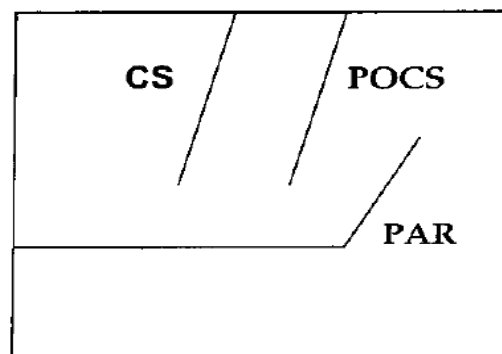
RD



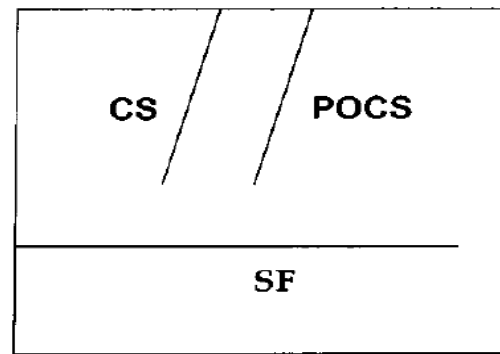
TABLE II  
Frequency of typology presentation in Steinmetz et al.'s (1990) sample

| Type | Left hemisphere (62) | Right hemisphere (58) | Overall (120) |
|------|----------------------|-----------------------|---------------|
| I    | 41 (66%)             | 48 (83%)              | 89 (74.16%)   |
| II   | 9 (15%)              | —                     | 9 (7.5%)      |
| III  | 10 (16%)             | 2 (3%)                | 12 (10%)      |
| IV   | 2 (3%)               | 8 (14%)               | 10 (8.33%)    |

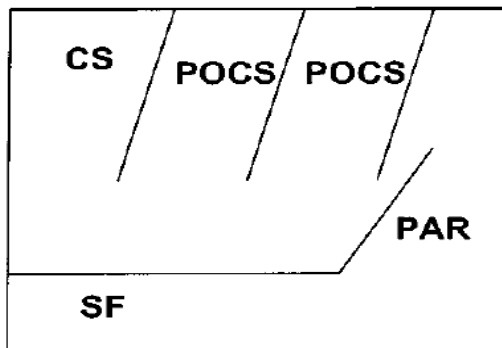
Note: Reported frequencies are combined from post-mortem and MRI data.  
Parentheses indicate number of hemispheres used.



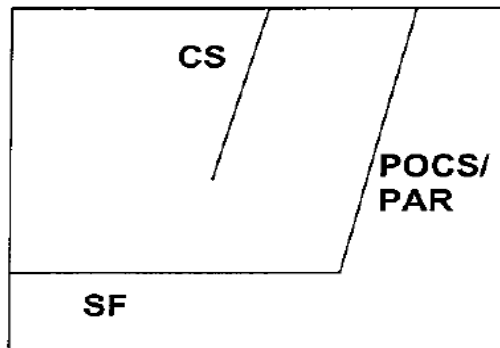
Type I



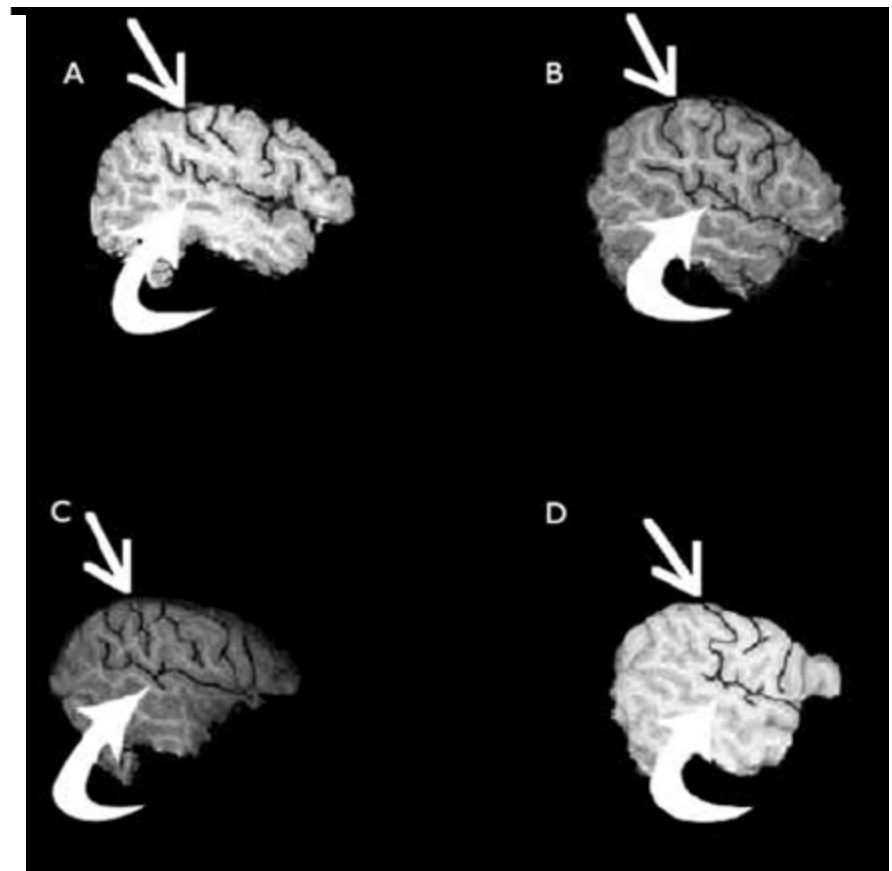
Type II



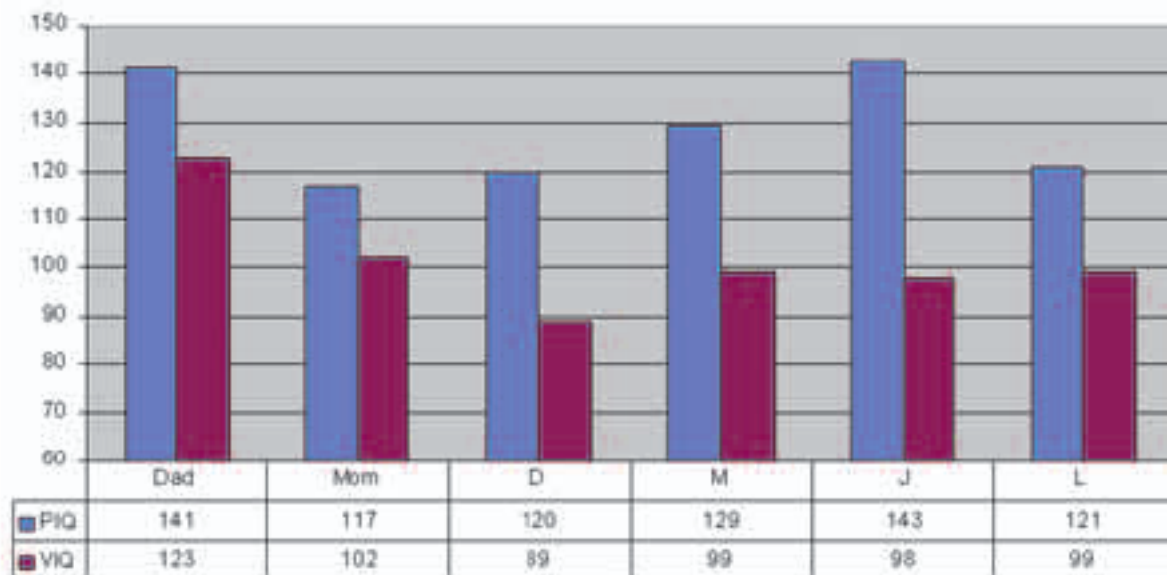
Type III



Type IV



WASI IQ



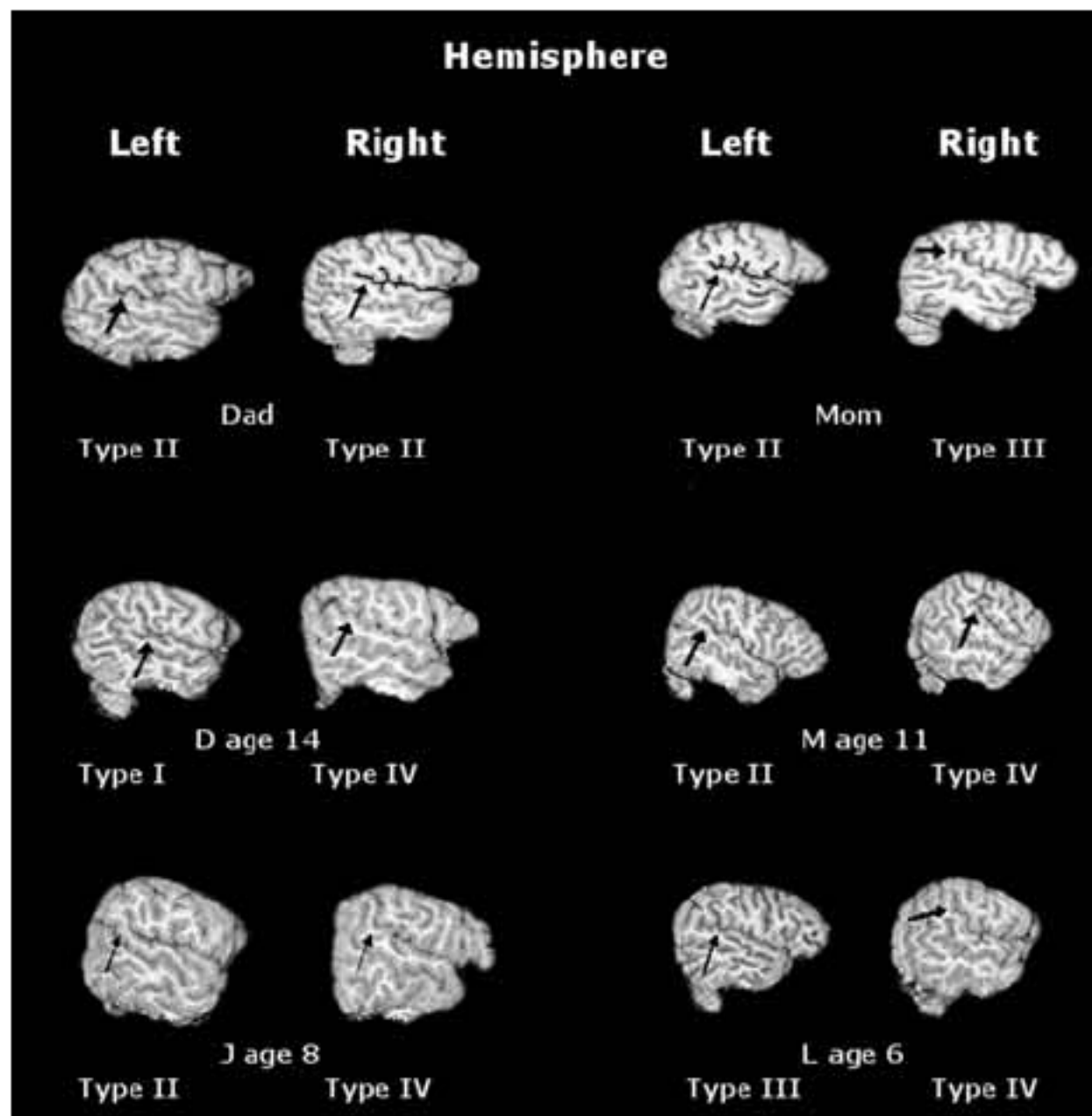
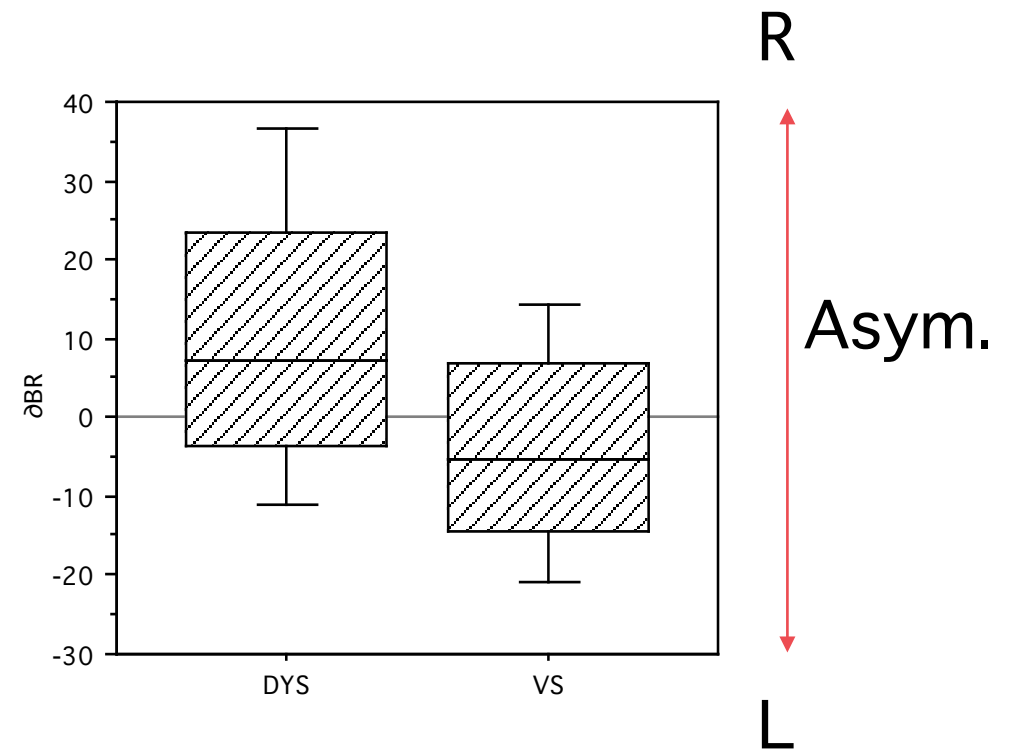
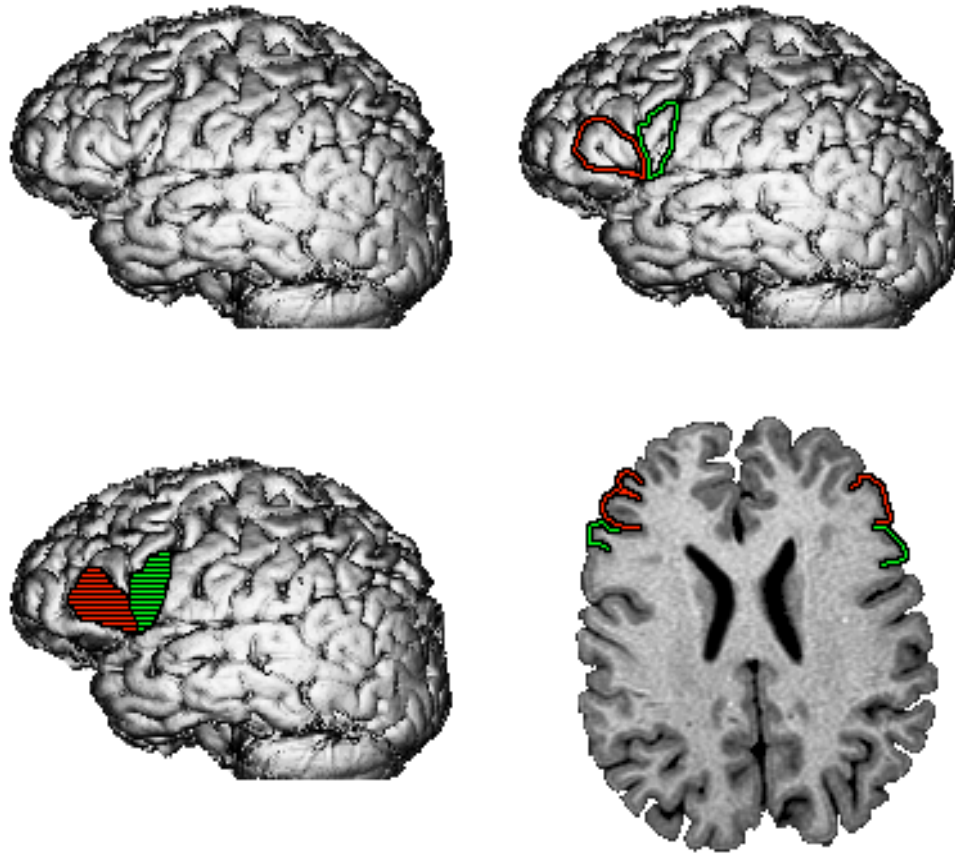


TABLE X  
*Steinmetz et al. (1990) prevalence rates in the current family*

|          | Left hemisphere | Right hemisphere | Overall |
|----------|-----------------|------------------|---------|
| Type I   | 16%             | 0                | 8%      |
| Type II  | 67%             | 16%              | 42%     |
| Type III | 16%             | 16%              | 17%     |
| Type IV  | 0               | 67%              | 33%     |



Robichon et al. (2000) : réduction (inversion)  
d'asymétrie de l'aire de Broca chez les adultes  
dyslexiques



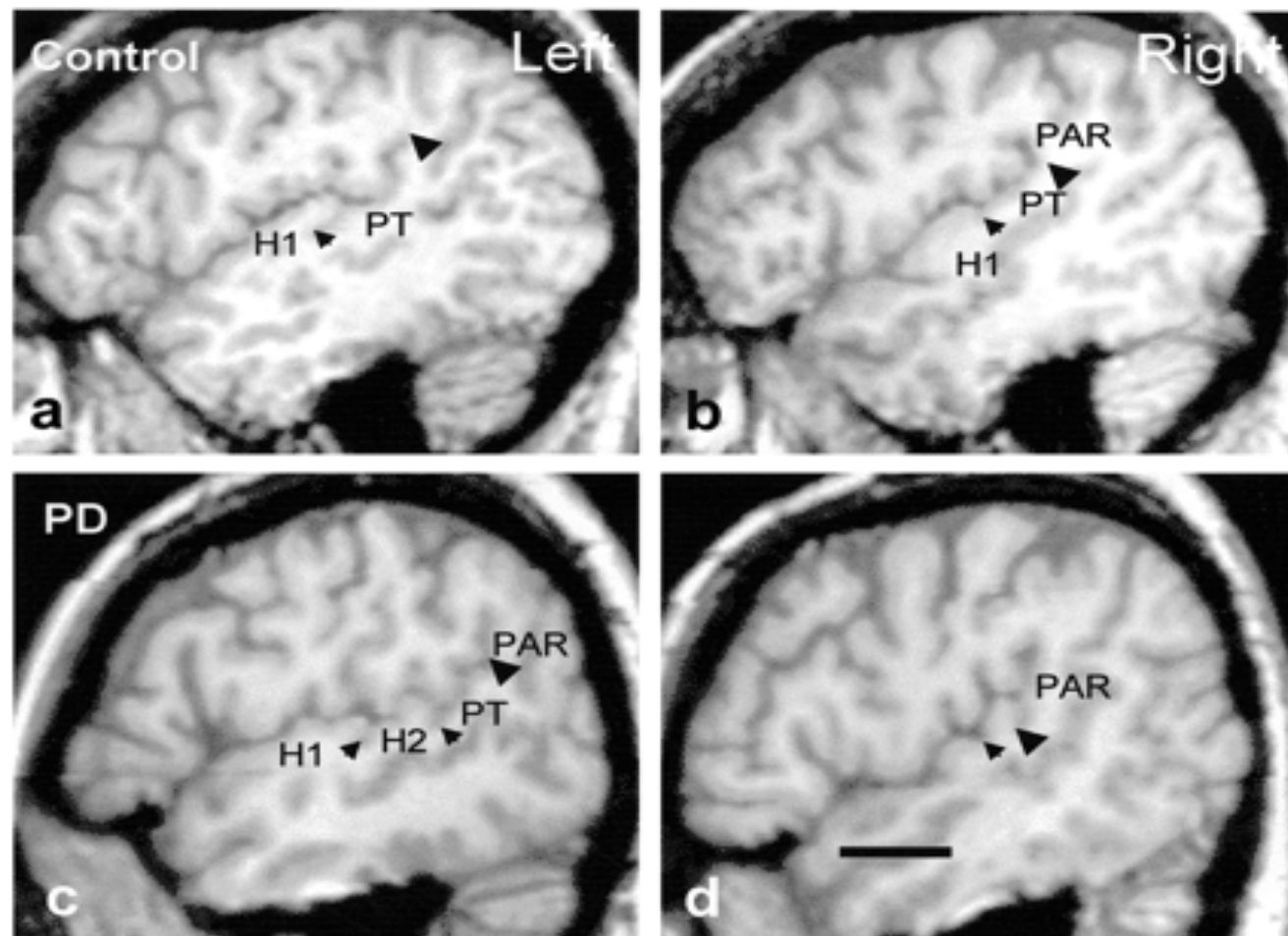
## Anatomical Risk Factors for Phonological Dyslexia

Christiana M. Leonard, Mark A. Eckert, Linda J. Lombardino<sup>1</sup>, Thomas Oakland<sup>2</sup>, John Kranzler<sup>2</sup>, Cecile M. Mohr, Wayne M. King and Alan Freeman

Department of Neuroscience, <sup>1</sup>Department of Communication Sciences and Disorders, and <sup>2</sup>Department of Education Foundations, University of Florida Brain Institute, Gainesville, FL 32611, USA

Leonard et al.  
(2001) : extreme  
leftward  
asymmetry of  
temporal and  
parietal cortices

(15 college students vs 15  
dyslexic adolescents)



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# Anatomical correlates of dyslexia: frontal and cerebellar findings

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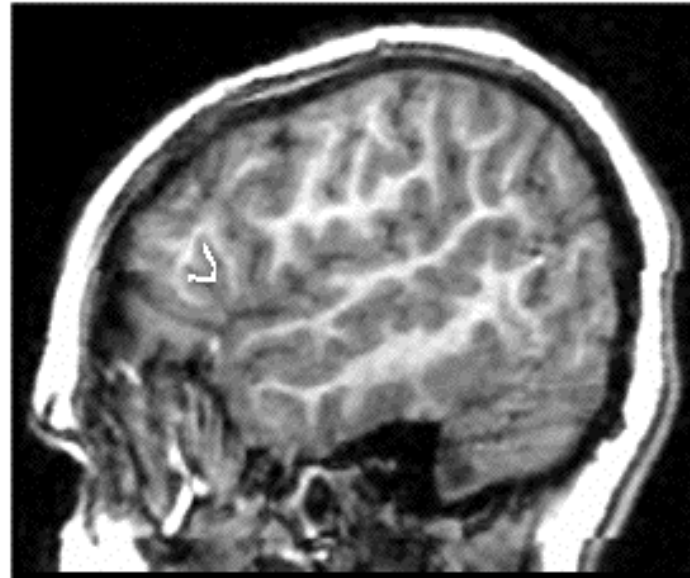
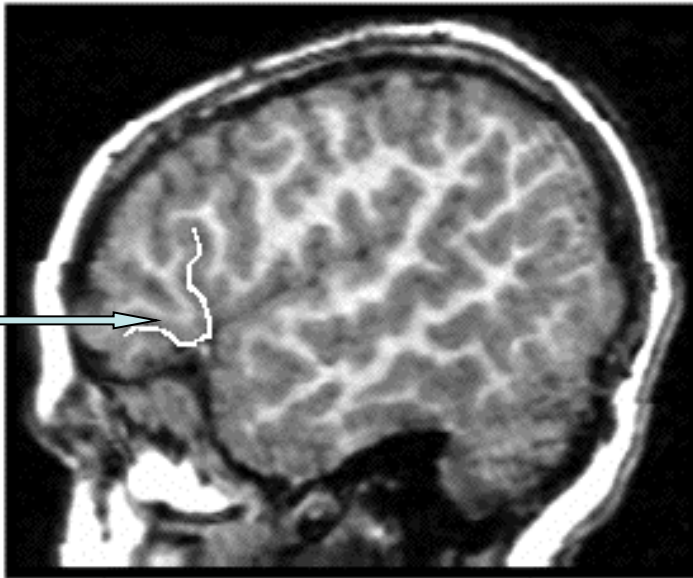
Mark A. Eckert,<sup>1</sup> Christiana M. Leonard,<sup>1</sup> Todd L. Richards,<sup>2</sup> Elizabeth H. Aylward,<sup>2</sup> Jennifer Thomson<sup>3</sup> and Virginia W. Berninger<sup>3</sup>

<sup>1</sup>*Department of Neuroscience, McKnight Brain Institute of the University of Florida, Gainesville, FL, Departments of*  
<sup>2</sup>*Radiology and* <sup>3</sup>*Education, University of Washington, Seattle, WA, USA*

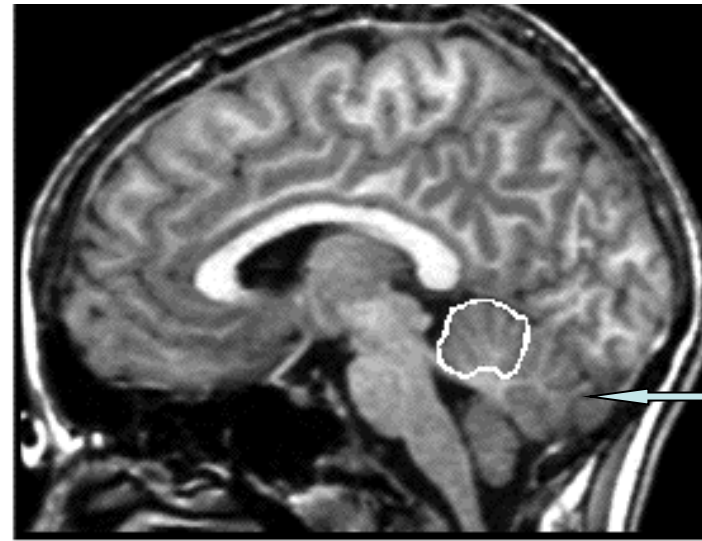
*Correspondence to: Mark Eckert, PO Box 100244, Department of Neuroscience, University of Florida McKnight Brain Institute, Gainesville, FL 32610, USA*  
*E-mail: eckert@ufl.edu*

Aire de  
Broca

témoin



dyslexique



cervelet

C.

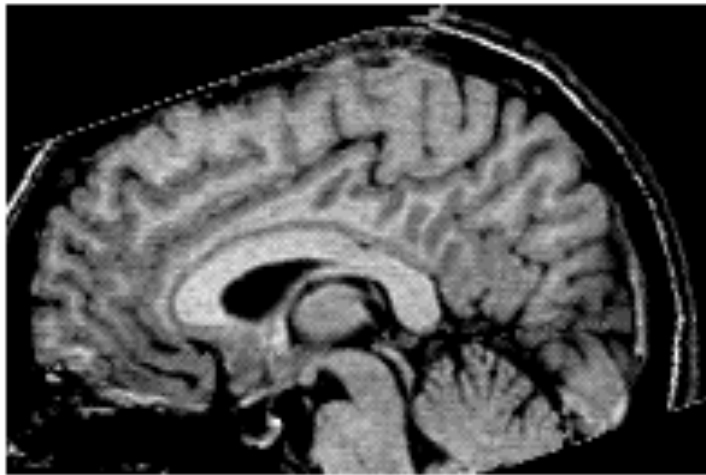
DOI: 10.1093/brain/awg026

*Brain* (2003), **126**, 482–494

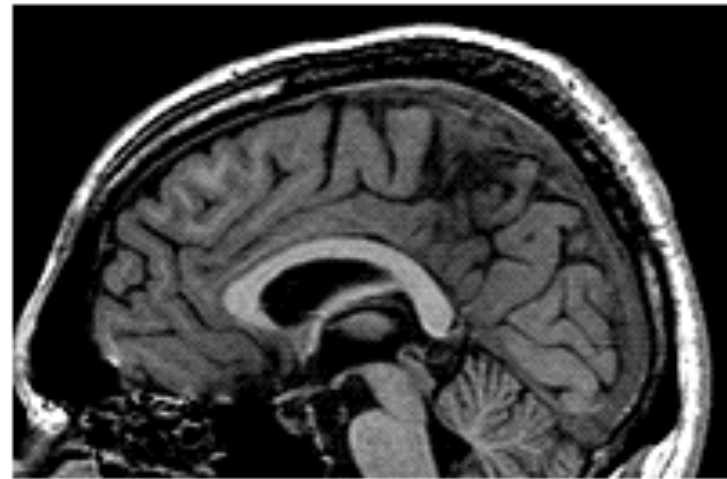
## Anatomical correlates of dyslexia: frontal and cerebellar findings

Mark A. Eckert,<sup>1</sup> Christiana M. Leonard,<sup>1</sup> Todd L. Richards,<sup>2</sup> Elizabeth H. Aylward,<sup>2</sup>  
Jennifer Thomson<sup>3</sup> and Virginia W. Berninger<sup>3</sup>

# Hypertrophie du corps calleux



**dyslexique (2136)**



**témoin**



PERGAMON

Neuropsychologia 40 (2002) 1035–1044

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

## Less developed corpus callosum in dyslexic subjects—a structural MRI study

Kerstin von Plessen<sup>a,\*</sup>, Arvid Lundervold<sup>b</sup>, Nicolae Duta<sup>c</sup>, Einar Heiervang<sup>a</sup>,  
Frederick Klauschen<sup>b</sup>, Alf Inge Smievoll<sup>d</sup>, Lars Ersland<sup>e</sup>, Kenneth Hugdahl<sup>f</sup>

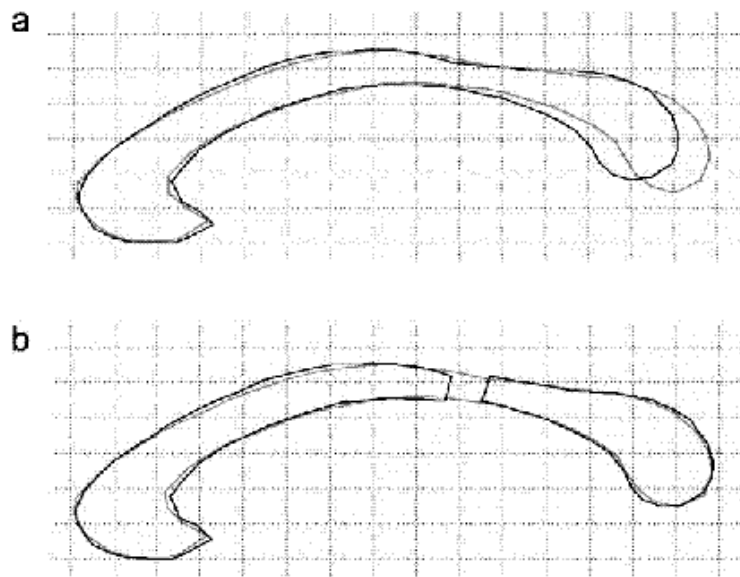


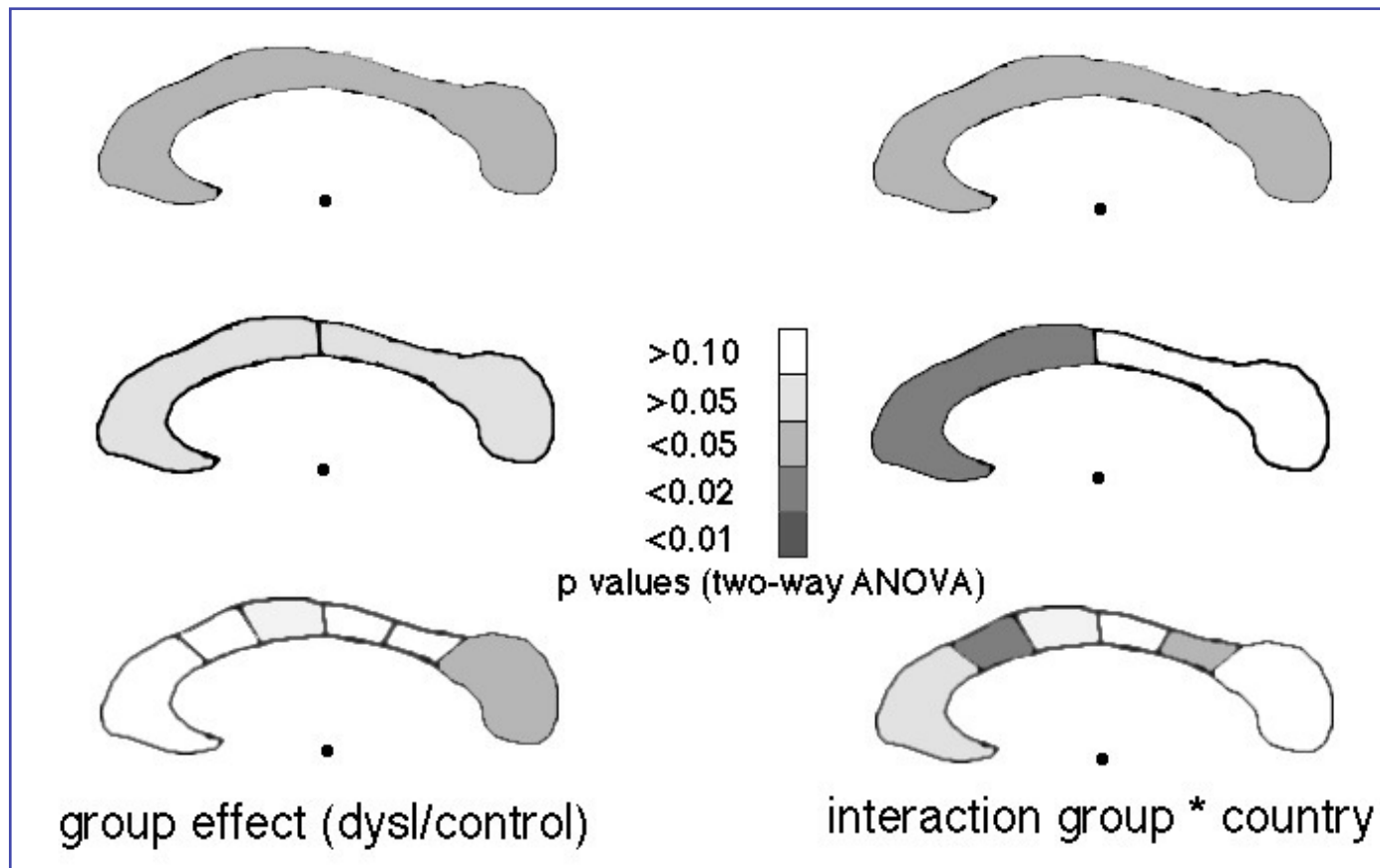
Fig. 4. Comparing the control (shown in grey) and dyslexic (shown in black) average CC shapes (prototypes) (a). The dyslexic prototype is cut into two pieces that are aligned separately at rostrum and splenium (b). The posterior midbody region in the dyslexic subjects is significantly shorter than in the control subjects.

Areas analysis : No areal differences  
Shape analysis : shorter posterior midbody

Table 2  
Mean values (SD) for CC area measurements

|                                 | Dyslexic group,<br><i>n</i> = 20 (mm <sup>2</sup> ) | Control group,<br><i>n</i> = 20 (mm <sup>2</sup> ) |
|---------------------------------|-----------------------------------------------------|----------------------------------------------------|
| Total CC area                   | 662.6 (79.9)                                        | 659.85 (99.9)                                      |
| Midsagittal cortical brain area | 10582 (781)                                         | 10999 (838)                                        |
| Anterior third                  | 294.9 (41.9)                                        | 288.3 (49.1)                                       |
| Mid-third                       | 135.2 (20.1)                                        | 138.8 (23.7)                                       |
| Posterior third                 | 225.6 (34.5)                                        | 232.9 (38.5)                                       |

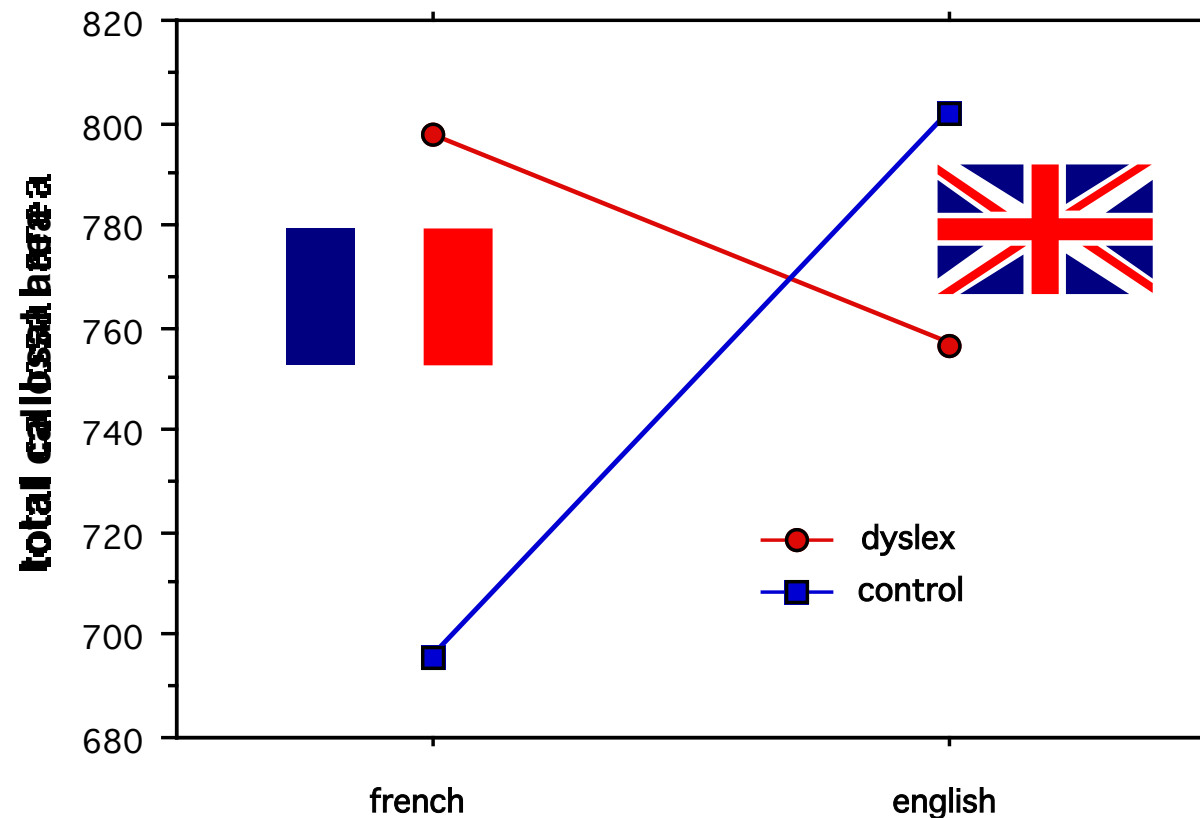
## Effect of group (DYS/CONT) and country (FR/ENGL) on callosal size





# Total callosal area : group x country interaction

$F(1,60)=9.337; p=0.033$





Modern morphological imaging (with MRI)

```
graph TD; A[Modern morphological imaging (with MRI)] --> B[Voxel-based morphometry]; A --> C[Diffusion tensor imaging]; B --> D[Whole-brain analysis (non R.O.I.) methods]; C --> D;
```

Voxel-based morphometry

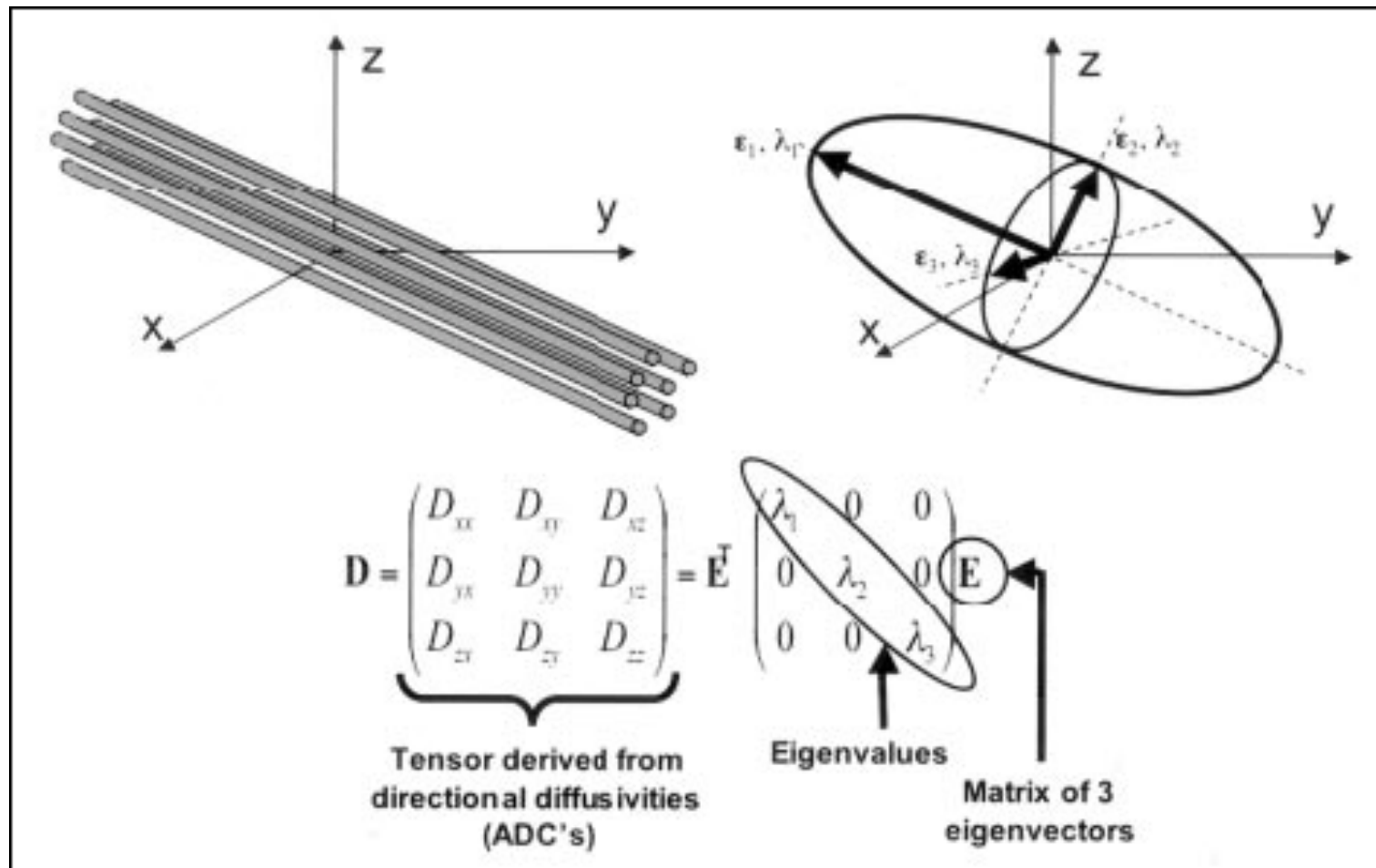
Averages grey and/or  
white matter density

Diffusion tensor imaging

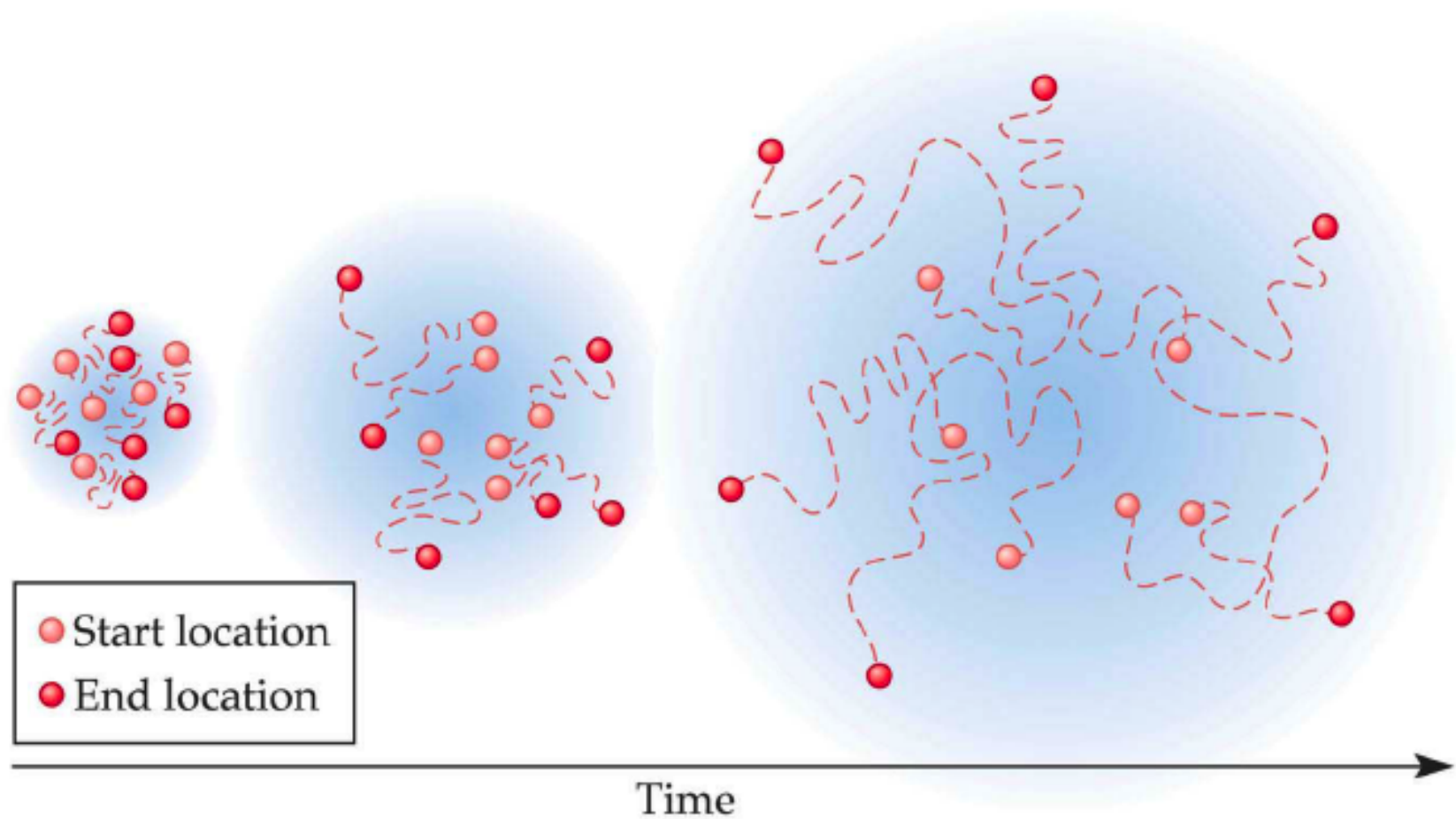
Looks at regions of  
different fibers orientation  
(anisotropy)

Whole-brain analysis (non R.O.I.) methods

# Diffusion Anisotropy

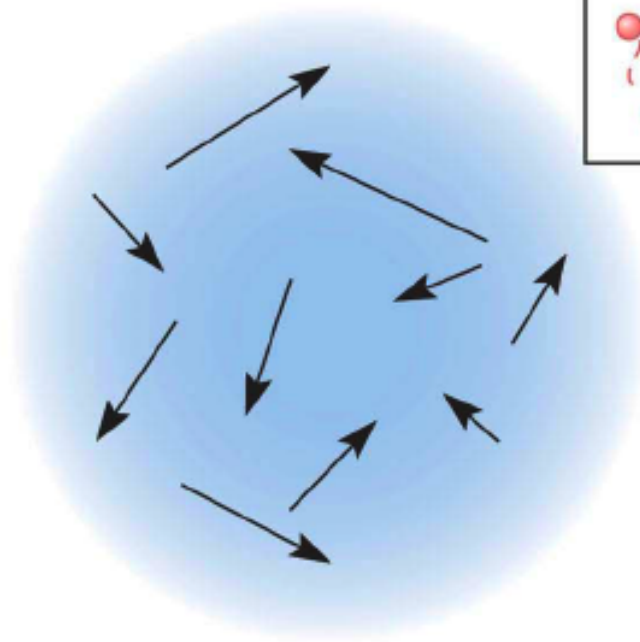


5.17 Diffusion. Over time, molecules within gases or liquids will move freely through the medium.

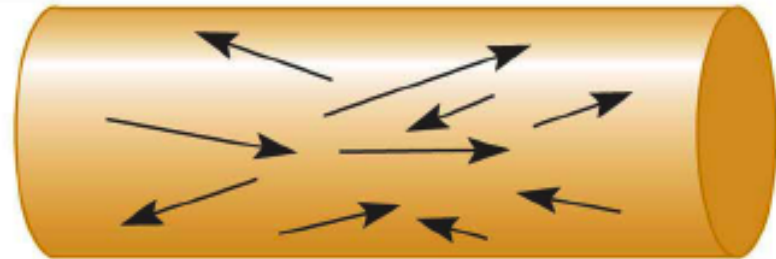
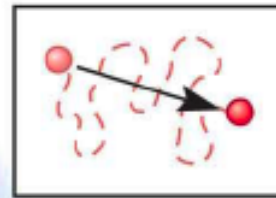


## 5.18 Isotropic and anisotropic diffusion.

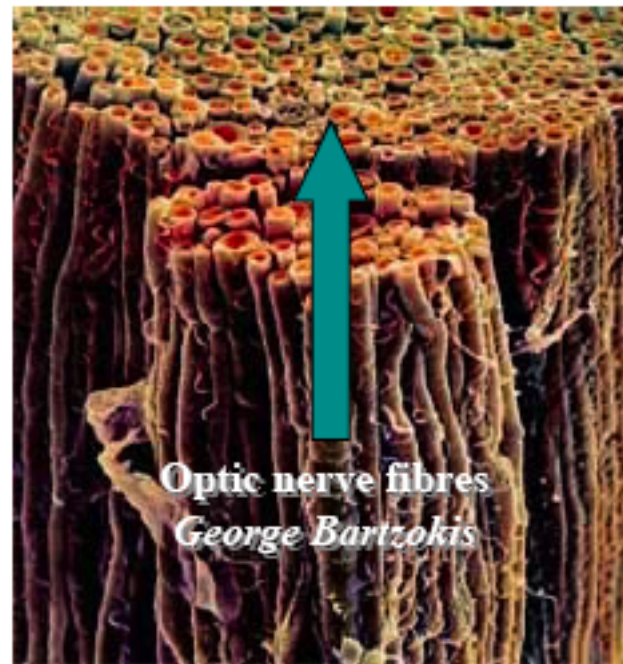
(A)



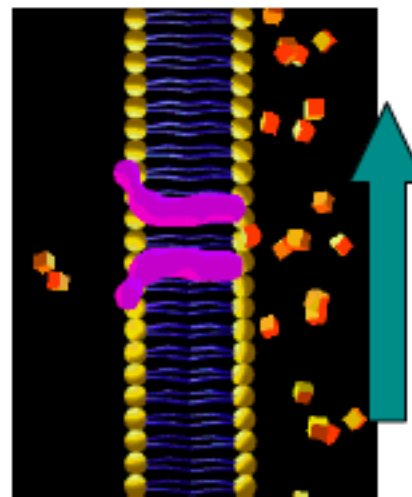
(B)



H<sub>2</sub>O  
Diffusion  
Probes  
Microscopic  
Structures  
In the Brain

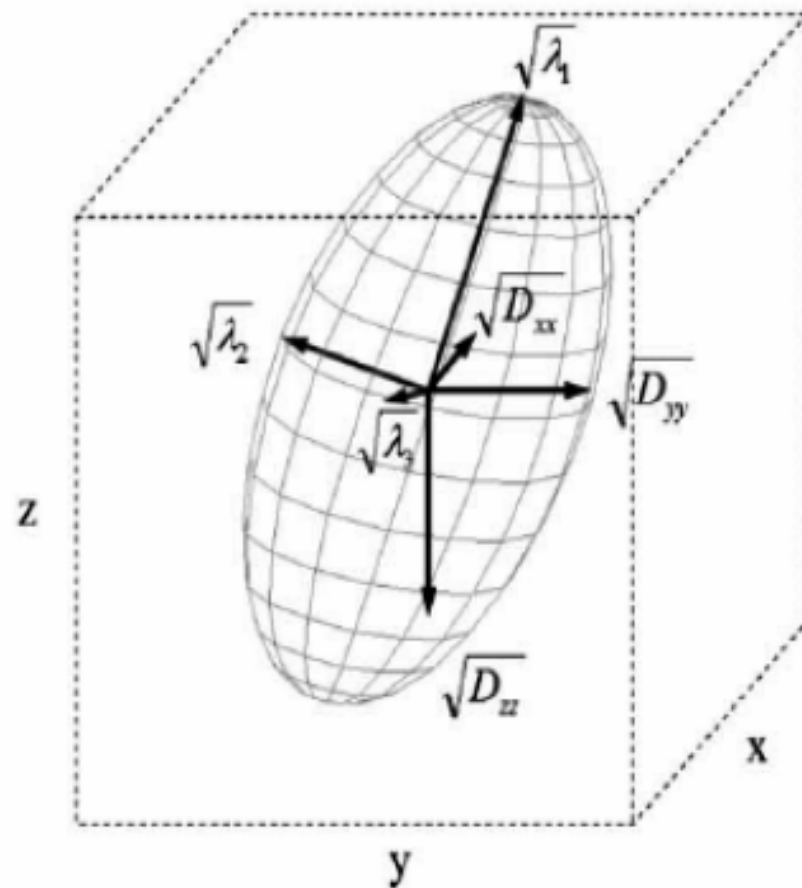


*Along the axon, within  
the cytoskeleton, there  
is a large  
Apparent Diffusion  
Coefficient (ADC)*



# Mathematical Description:

## An Ellipsoid (Diffusion Tensor)



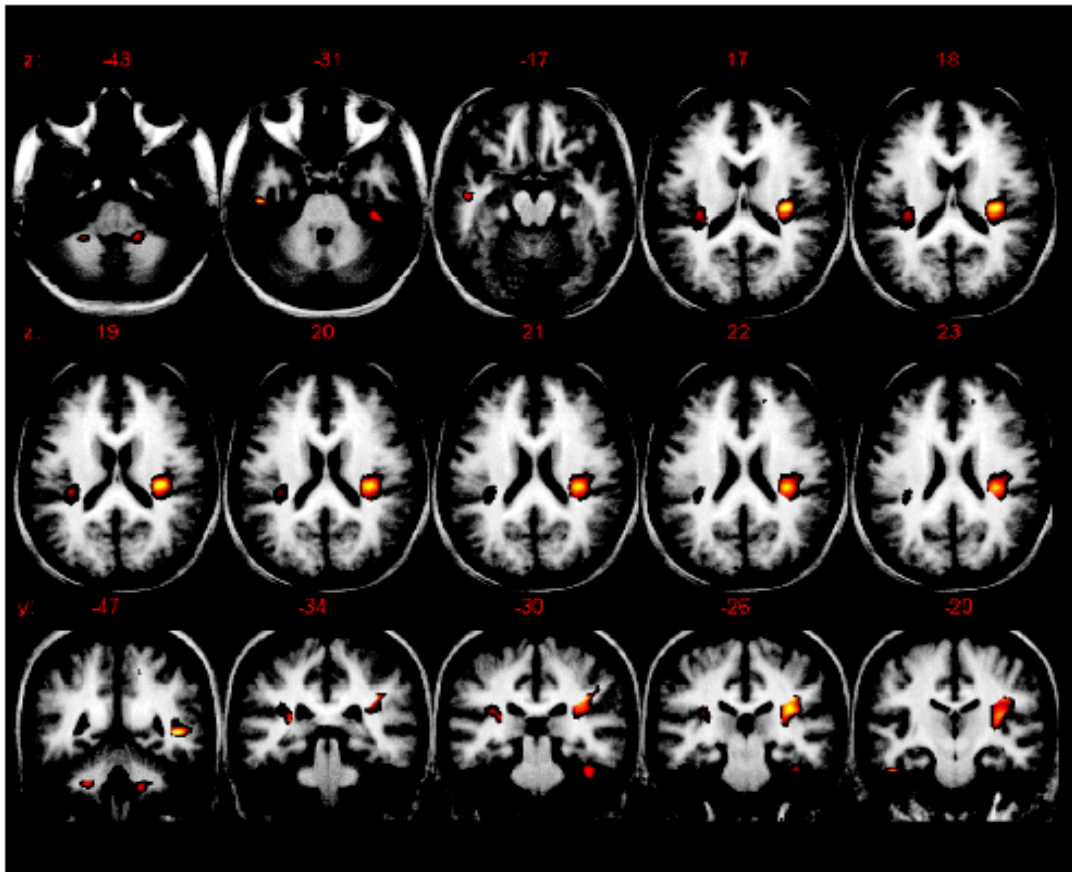
This surface summarizes the mean distance from the starting position that a typical particle (water molecule) will travel in diffusion time  $T = \frac{1}{2}$





# Regional reductions of gray matter volume in familial dyslexia

S.M. Brambati, BS; C. Termine, MD; M. Ruffino, BS; G. Stella, PhD; F. Fazio, MD; S.F. Cappa, MD; and D. Perani, MD



- 10 dyslexic subjects (5 females, 5 males; age range 13 to 57 years, mean 31.6 years) belonging to four different families characterized by the presence of a proband with persistent, severe developmental dyslexia
- 11 matched controls
- Regions of reduction in grey matter volume
  - PT bilat
  - inferior temporal bilat
  - Left sup and inf tempor gyrus

# Microstructure of Temporo-Parietal White Matter as a Basis for Reading Ability: Evidence from Diffusion Tensor Magnetic Resonance Imaging

Torkel Klingberg,<sup>\*§</sup> Maj Hedehus,<sup>†</sup> Elise Temple,<sup>\*</sup>

Talya Salz,<sup>\*‡</sup> John D. E. Gabrieli,<sup>\*†</sup>

Michael E. Moseley,<sup>†</sup> and Russell A. Poldrack<sup>\*</sup>

<sup>\*</sup>Department of Psychology

<sup>†</sup>Department of Radiology

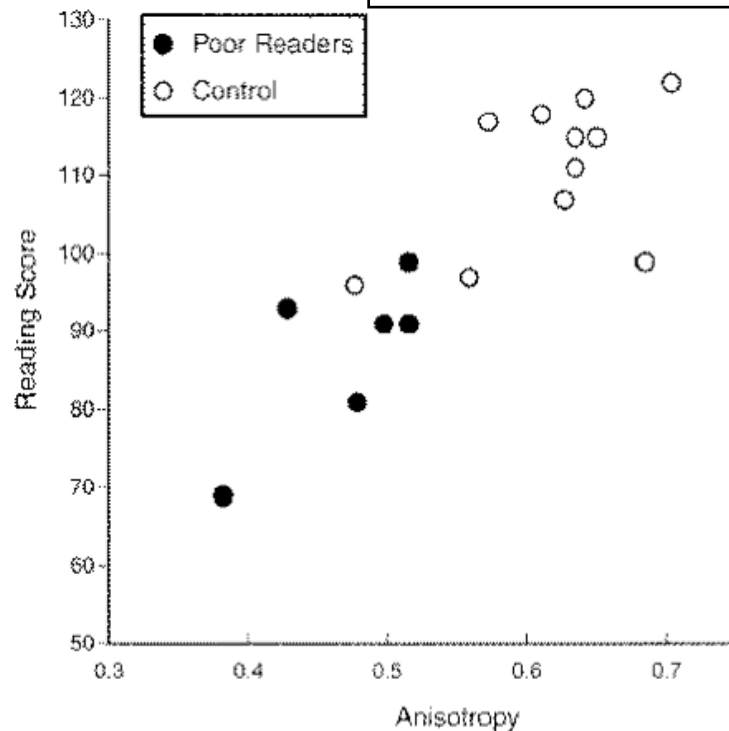
Stanford University

Stanford, California 94305

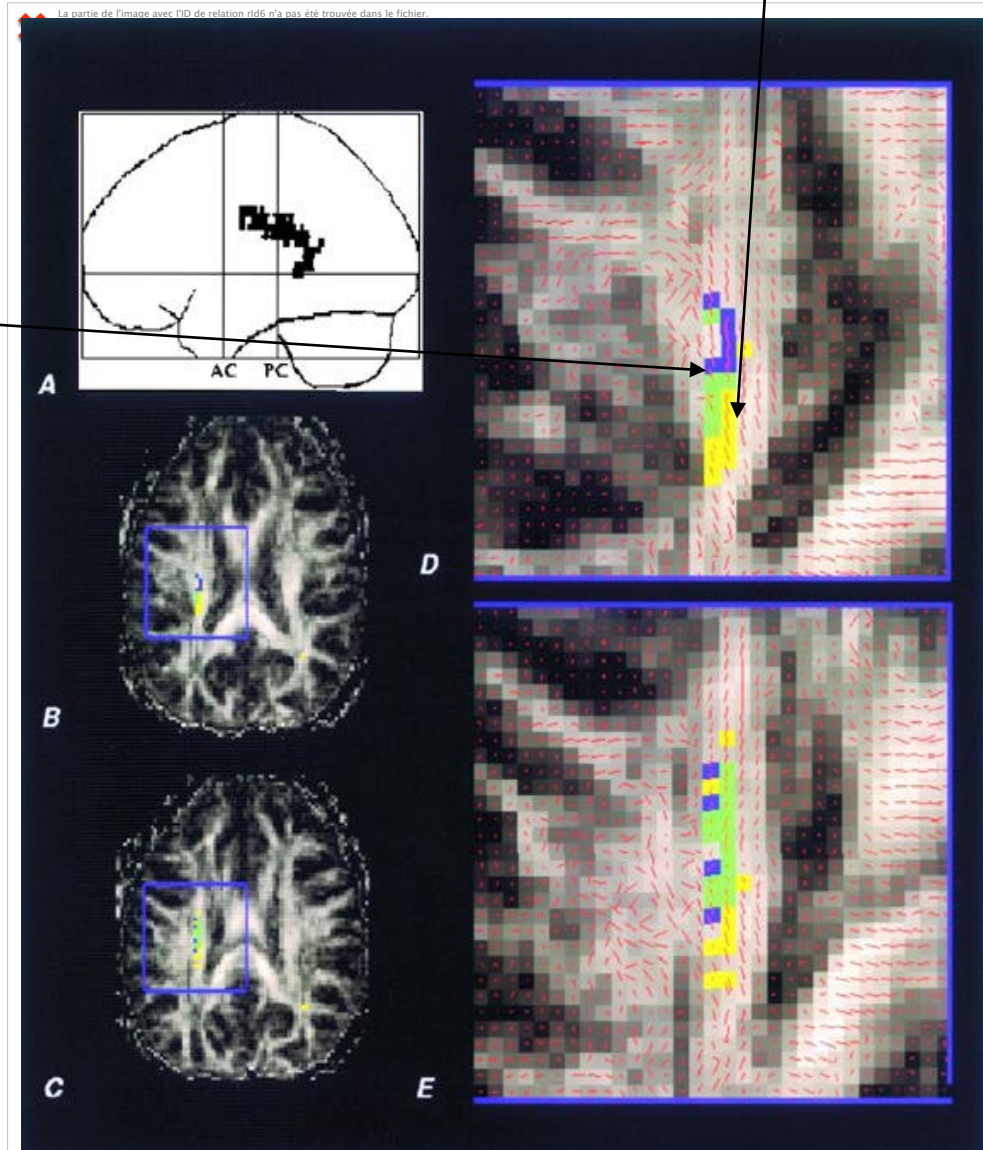
<sup>‡</sup>Scientific Learning Corporation

Berkeley, California 94704

Significant correlation with reading scores



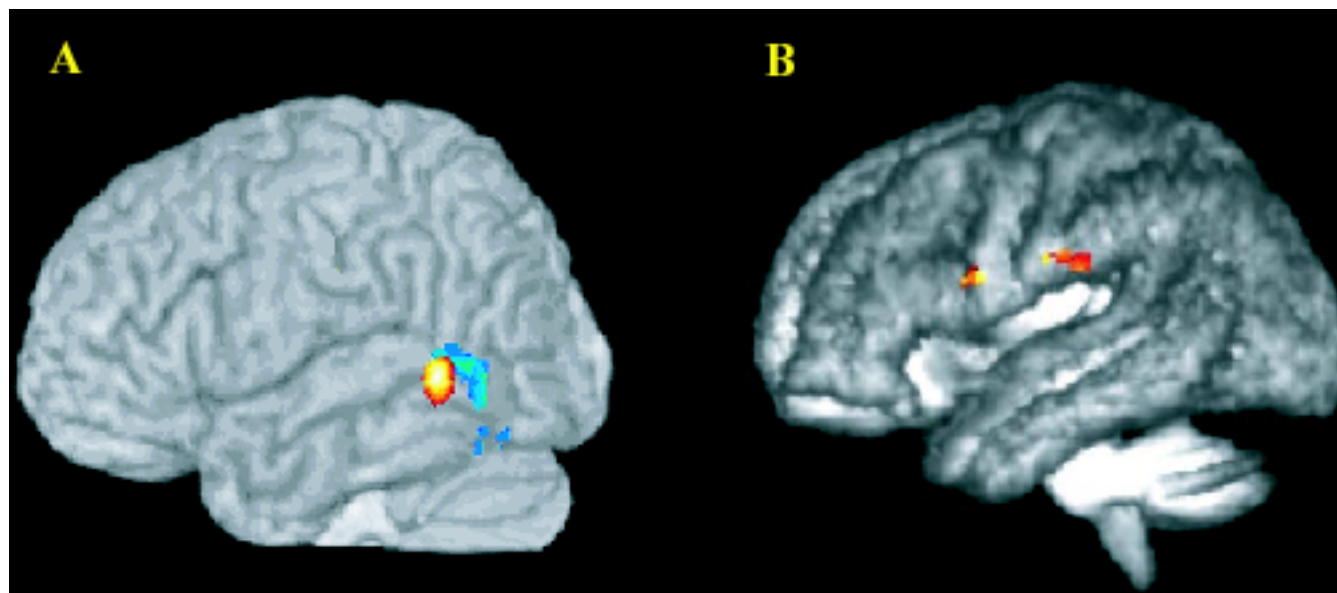
VOI of maximal anisotropy difference between 6 adult dyslexic and 11 controls



# Brain abnormalities underlying altered activation in dyslexia: a voxel based morphometry study

G. Silani,<sup>1</sup> U. Frith,<sup>2</sup> J.-F. Demonet,<sup>3</sup> F. Fazio,<sup>4,5,6</sup> D. Perani,<sup>7</sup> C. Price,<sup>8</sup> C. D. Frith<sup>8</sup> and E. Paulesu<sup>1</sup>

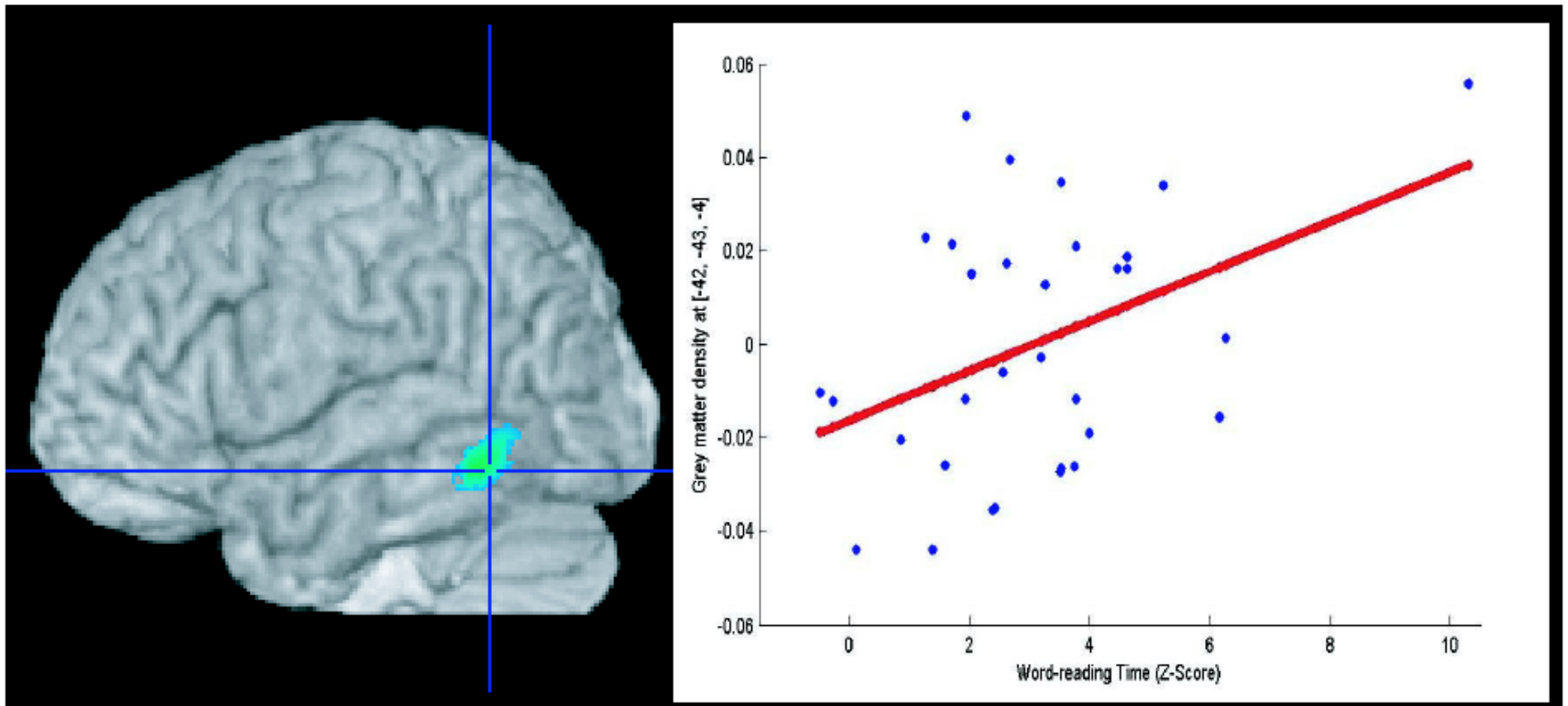
■ decrease  
■ increase



■ decrease

Gray matter dyslex/controls

White matter dyslex/controls



Silani et al. (2005) : a lateral temporal zone of increased voxel density correlates inversely with reading performance



# CHILDREN'S READING PERFORMANCE IS CORRELATED WITH WHITE MATTER STRUCTURE MEASURED BY DIFFUSION TENSOR IMAGING

Gayle K. Deutsch<sup>1\*</sup>, Robert F. Dougherty<sup>1</sup>, Roland Bammer<sup>2</sup>, Wai Ting Siok<sup>1</sup>, John D.E. Gabrieli<sup>1</sup>  
and Brian Wandell<sup>1</sup>

(<sup>1</sup>Department of Psychology, Stanford University, Stanford, CA, USA; <sup>2</sup>Department of Radiology, Stanford University, Stanford, CA, USA)

358

Gayle K. Deutsch and Others

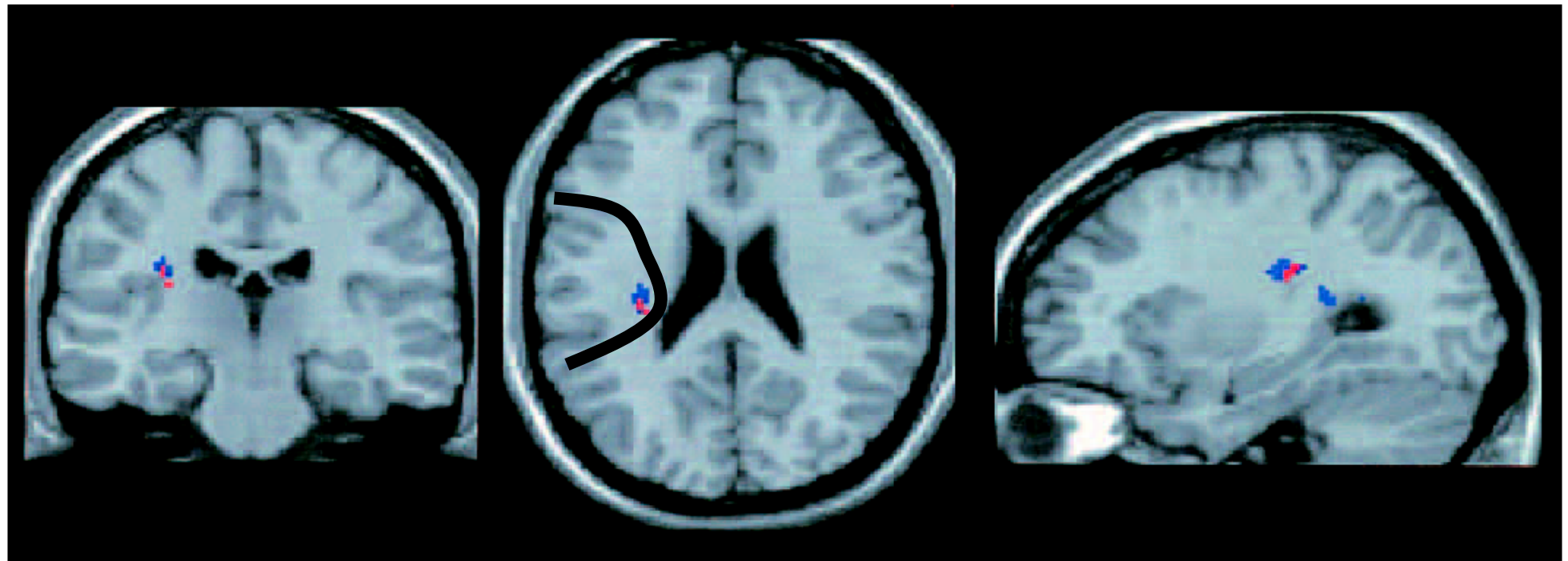
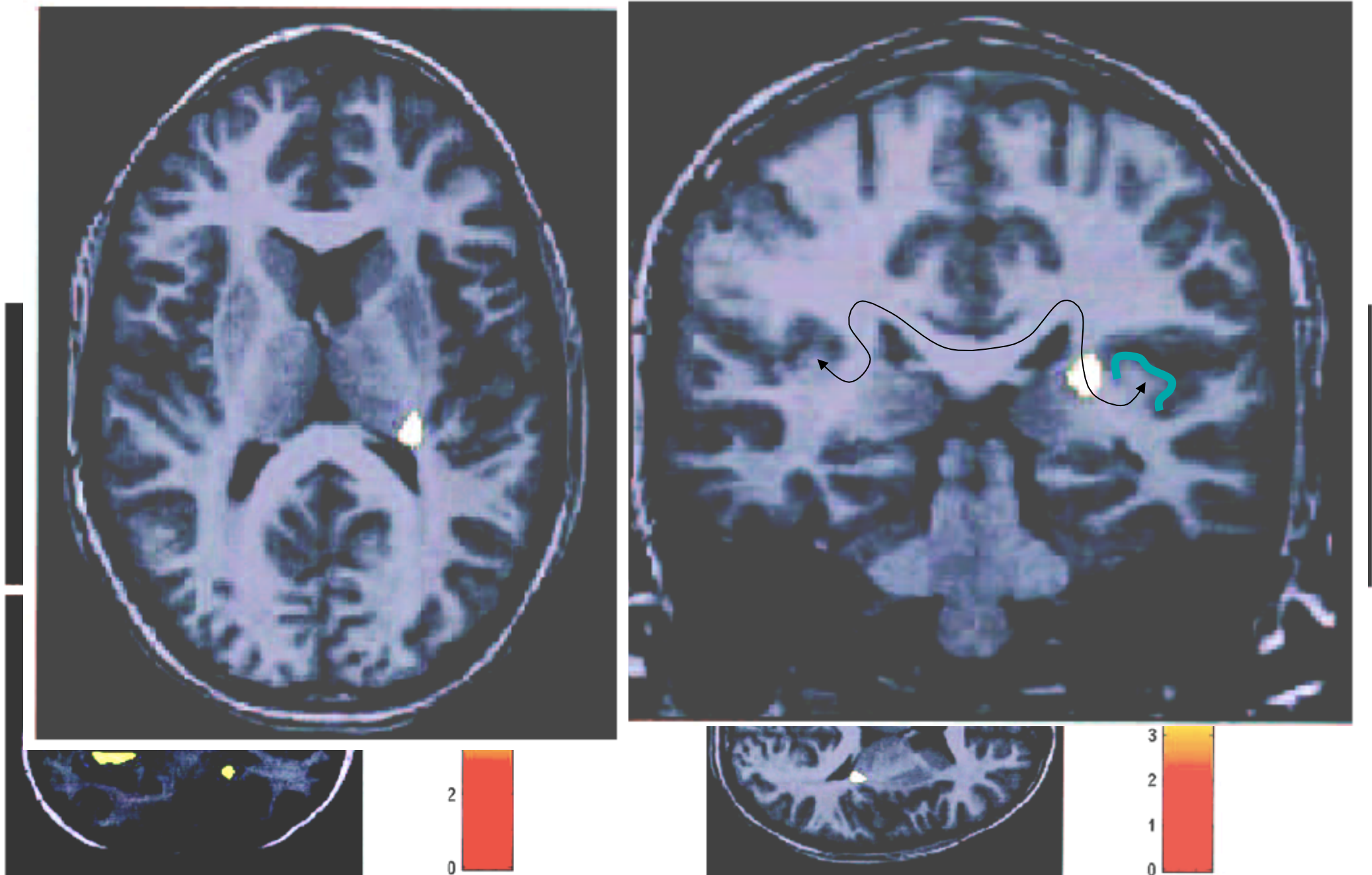


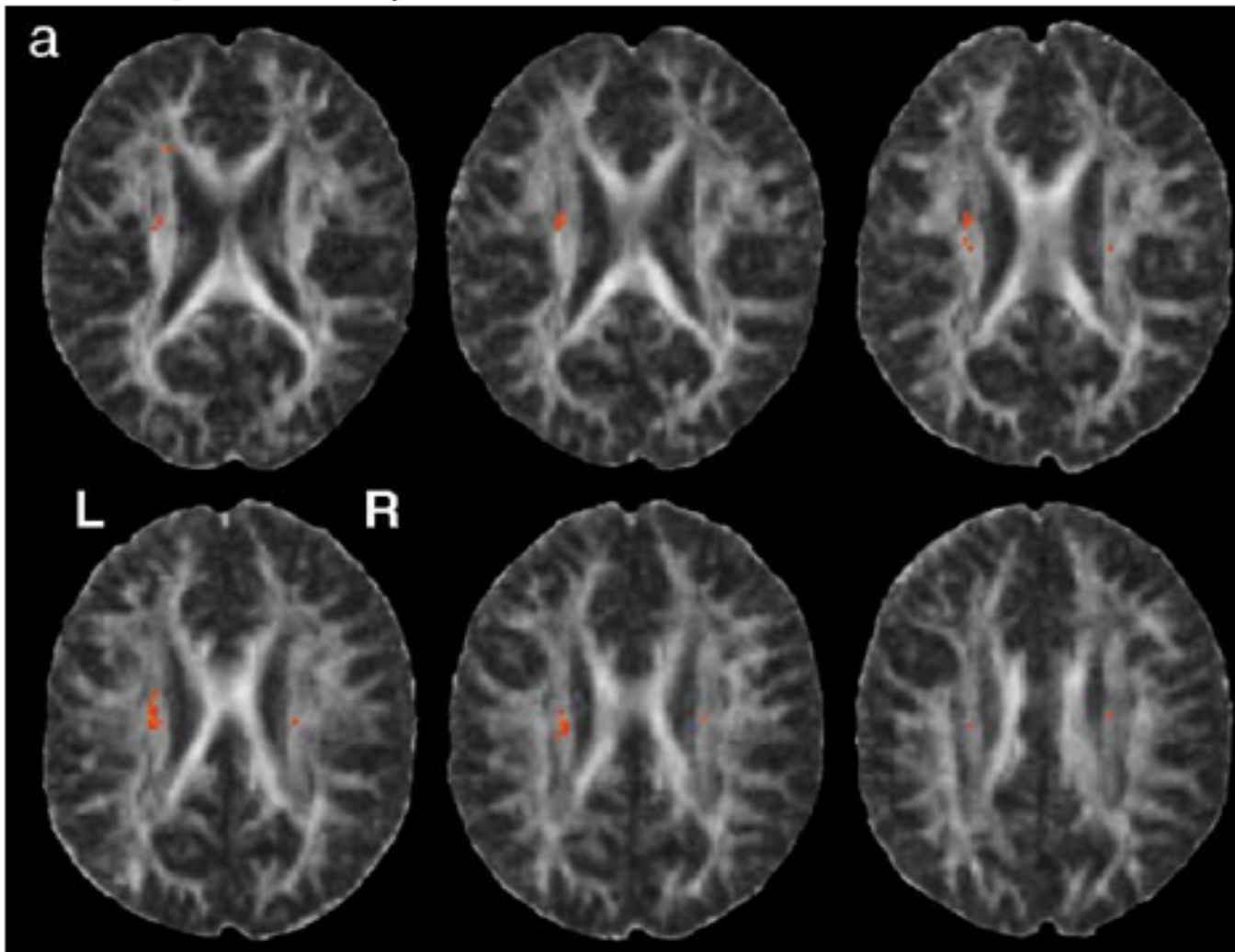
Fig. 1 – Brain regions that showed significant differences in normal and poor reading children are presented. Left temporo-parietal regions are shown in three slices of the SPM99 T1 canonical brain. Red indicates voxels with significant group differences in FA and blue indicates voxels with significant differences in CI.

ANATOMICAL SIGNATURES OF DYSLEXIA IN CHILDREN



## Imaging brain connectivity in children with diverse reading ability

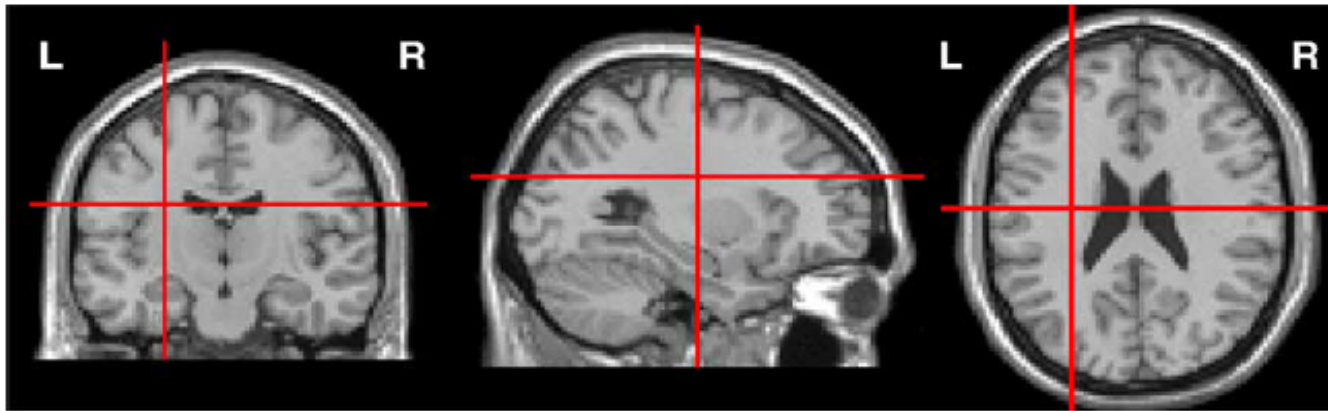
Christian Beaulieu,<sup>a,\*</sup> Christopher Plewes,<sup>a</sup> Lori Anne Paulson,<sup>a</sup> Dawne Roy,<sup>b</sup> Lindsay Snook,<sup>a</sup> Luis Concha,<sup>a</sup> and Linda Phillips<sup>b</sup>



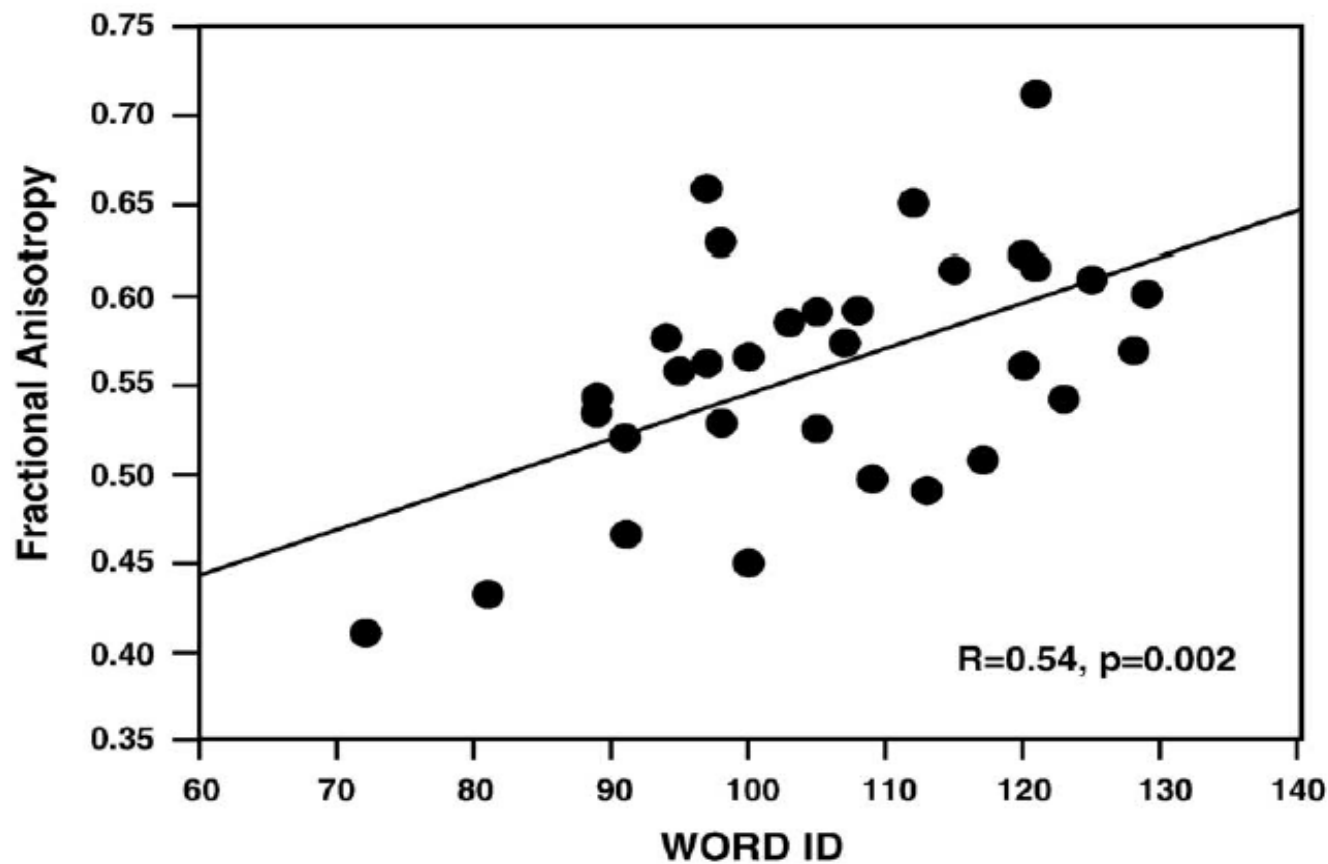
- 32 volunteers (14 male, 18 female).
- 8.3–12.9 years mean  $11.1 \pm 1.3$  years
- 30/32 right handed.
- aptitudes en lecture variables évaluées par un test d'identification de mots

Corrélation avec performance en lecture : voxels de plus forte corrélation





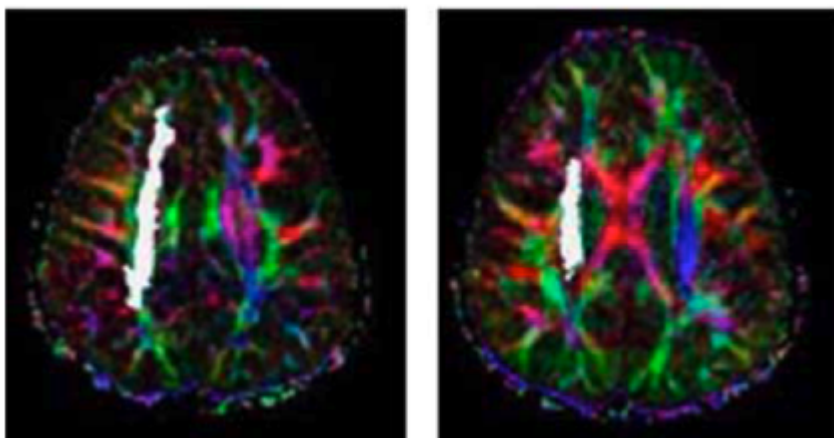
Voxel with Highest Correlation : (X, Y, Z) = (- 28, -14, 24)



Voxel of higher correlation with word identification rate

# Left lateralized white matter microstructure accounts for individual differences in reading ability and disability<sup>☆</sup>

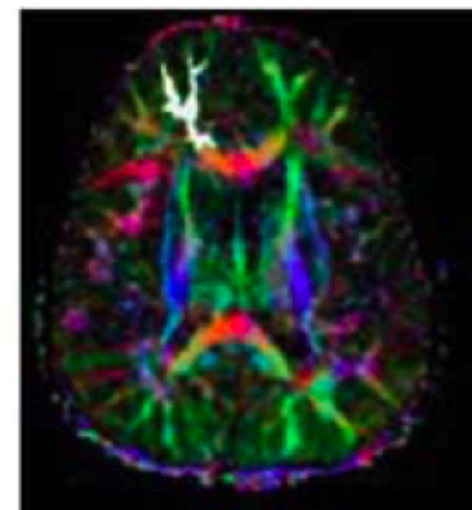
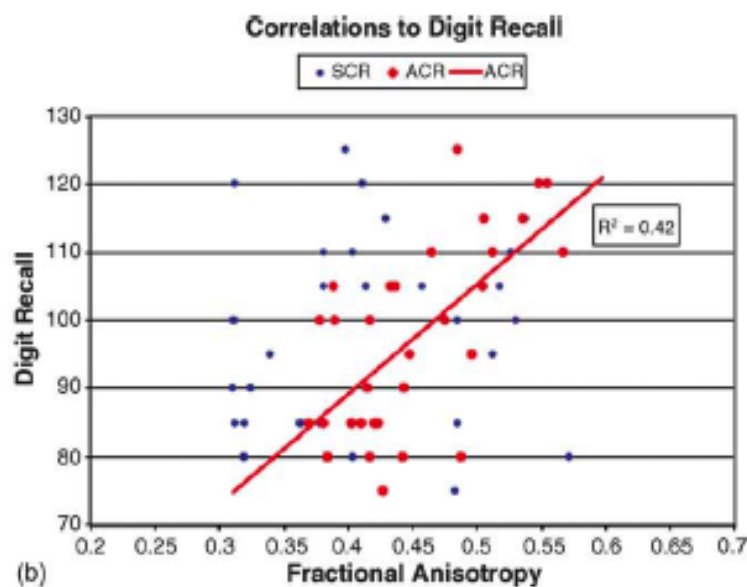
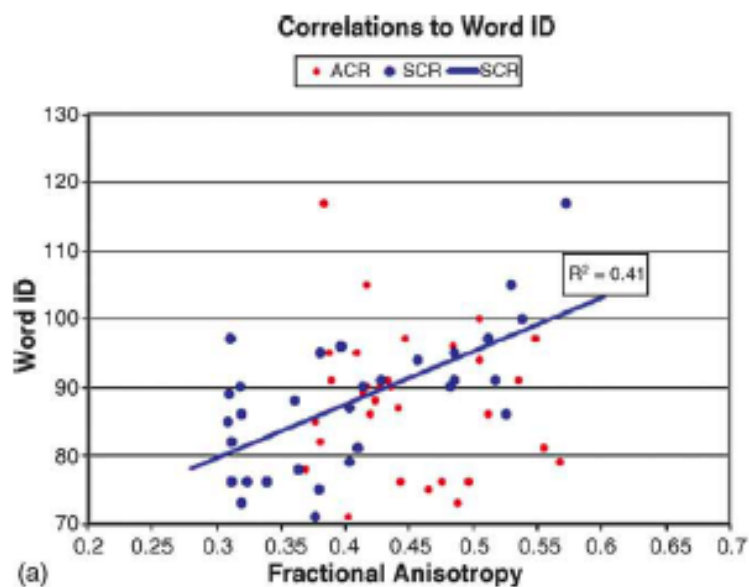
Sumit N. Niogi, Bruce D. McCandliss<sup>\*</sup>



Centrum semi-ovale

| Structure  | Word ID | Word Attack | Digit Recall |
|------------|---------|-------------|--------------|
| CS right   | 0.38    | 0.14        | 0.35         |
| CS left    | 0.58    | 0.25        | -0.11        |
| SCR right  | -0.18   | -0.02       | -0.22        |
| SCR left   | 0.64    | 0.37*       | 0.15         |
| SLF right  | -0.22   | 0.10        | 0.16         |
| SLF left   | -0.12   | 0.03        | -0.16        |
| ACR right  | -0.18   | -0.30       | 0.66         |
| ACR left   | -0.08   | -0.11       | 0.61         |
| PLIC right | 0.28    | 0.05        | 0.17         |
| PLIC left  | -0.21   | 0.02        | -0.19        |
| LAT SCR    | -0.61   | -0.28       | -0.26        |
| LAT CS     | -0.23   | -0.12       | 0.32         |

DTI : 31 children, 6-10yr  
21 Nl, 10 dlx

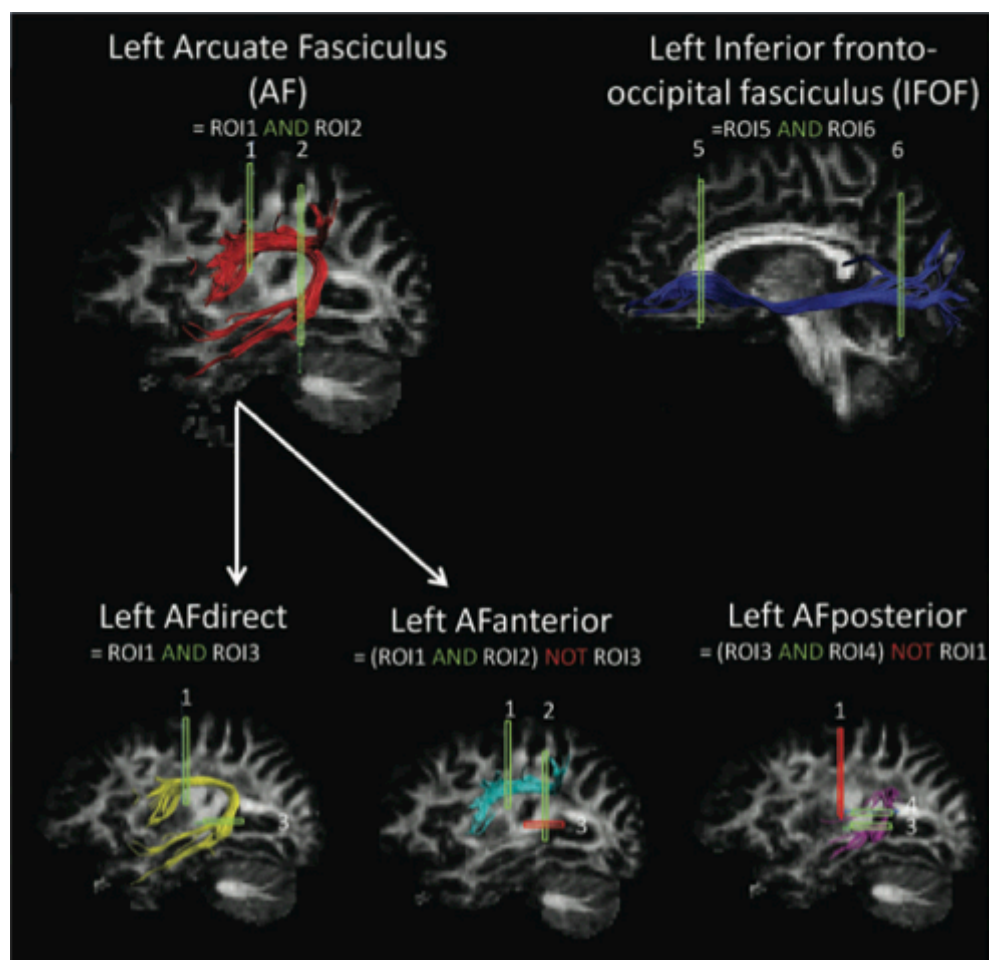


anterior corona radiata

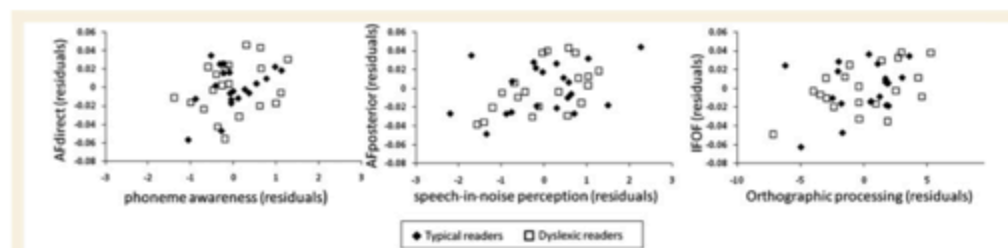
# A tractography study in dyslexia: neuroanatomic correlates of orthographic, phonological and speech processing

Maaïke Vandermosten,<sup>1,2,3</sup> Bart Boets,<sup>1,2,4</sup> Hanne Poelmans,<sup>1,2</sup> Stefan Sunaert,<sup>3</sup> Jan Wouters<sup>2</sup> and Pol Ghesquière<sup>1</sup>

<sup>1</sup> Parenting and Special Education Research Unit, Katholieke Universiteit Leuven, A. Vesaliusstraat 2, PO Box 3765, 3000 Leuven, Belgium



Correlational analyses (controlled for reading status) demonstrated a specific relation between performance on phoneme awareness and speech perception and the integrity of left arcuate fasciculus as indexed by fractional anisotropy, and between orthographic processing (flashed word identification task) and fractional anisotropy values in left inferior fronto-occipital fasciculus.



**Figure 2** Correlations between (residual) fractional anisotropy values and (residual) reading-related behavioural measures after controlling for group, IQ and quality index of DTI acquisition. AFdirect = arcuate fasciculus-direct; AFposterior = arcuate fasciculus-posterior; IFOF = inferior fronto-occipital fasciculus.

**Table 4** Unique variance ( $R^2$ ) in fractional anisotropy explained by individual differences in phoneme awareness and orthographic processing

| Predicting variables             | Fractional anisotropy left IFOF | Fractional anisotropy left AFdirect |
|----------------------------------|---------------------------------|-------------------------------------|
| Step 1: control variables        | 0.04                            | 0.04                                |
| Step 2: group variable           | 0.00                            | 0.10*                               |
| Step 3a: phoneme awareness       | 0.02                            | 0.10*                               |
| Step 3b: orthographic processing | 0.16**                          | 0.00                                |
| Total $R^2$                      | 0.21                            | 0.24                                |

Step 1 = Control variables (IQ and quality index of DTI acquisition); Step 2 = Control variables + Group variable; Step 3a = Control variables + Group variable + Orthographic processing + Phoneme awareness; Step 3b = Control variables + Group variable + Phoneme awareness + Orthographic processing. \* $P < 0.05$ , \*\* $P < 0.01$ .

AFdirect = arcuate fasciculus-direct; IFOF = inferior fronto-occipital fasciculus.

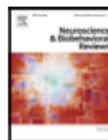
**Table 5** Unique variance ( $R^2$ ) in fractional anisotropy explained by individual differences in speech-in-noise perception and orthographic processing

| Predicting variables                | Fractional anisotropy left IFOF | Fractional anisotropy left AFposterior |
|-------------------------------------|---------------------------------|----------------------------------------|
| Step 1: control variables           | 0.04                            | 0.02                                   |
| Step 2: group variable              | 0.00                            | 0.06                                   |
| Step 3a: speech-in-noise perception | 0.01                            | 0.18**                                 |
| Step 3b: orthographic processing    | 0.12*                           | 0.01                                   |
| Total $R^2$                         | 0.19                            | 0.26                                   |

Step 1 = Control variables (IQ and quality index of DTI acquisition); Step 2 = Control variables + Group variable; Step 3a = Control variables + Group variable + Orthographic processing + Speech-in-noise perception; Step 3b = Control variables + Group variable + Speech-in-noise perception + Orthographic processing. \* $P < 0.05$ , \*\* $P < 0.01$ .

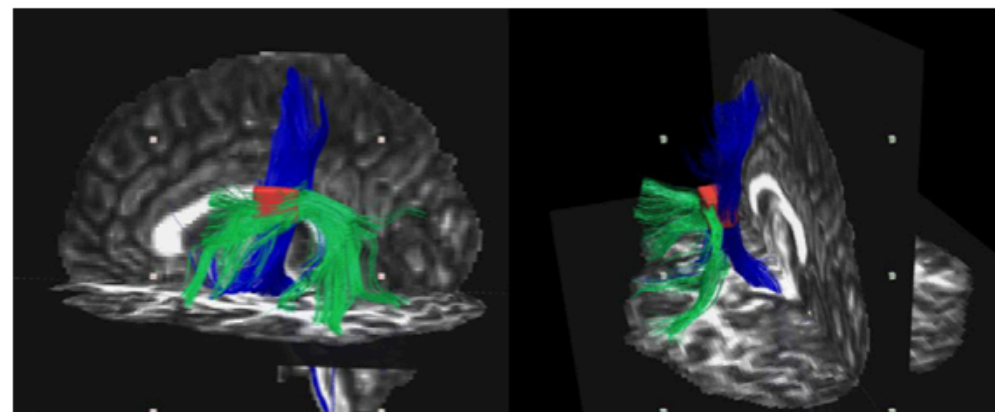
AFposterior = arcuate fasciculus-posterior; IFOF = inferior fronto-occipital fasciculus.



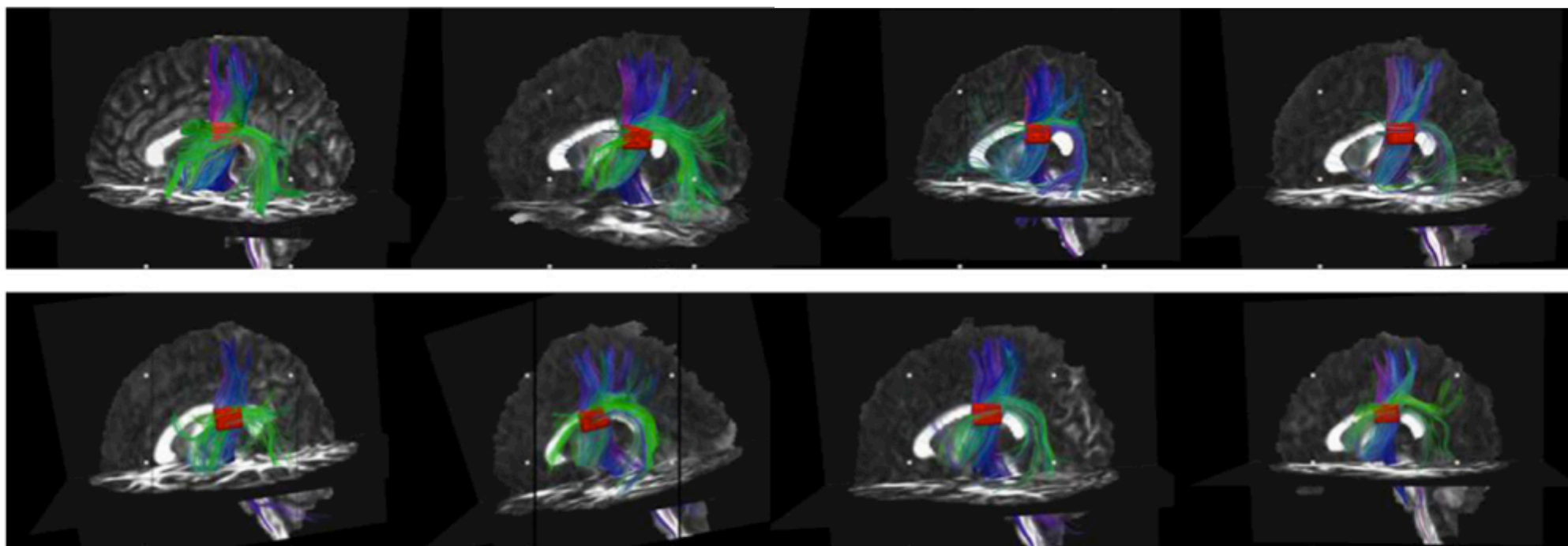


## Review

## A qualitative and quantitative review of diffusion tensor imaging studies in reading and dyslexia

Maaïke Vandermosten<sup>a,b,c,\*</sup>, Bart Boets<sup>a,b,d</sup>, Jan Wouters<sup>b</sup>, Pol Ghesquière<sup>a</sup>

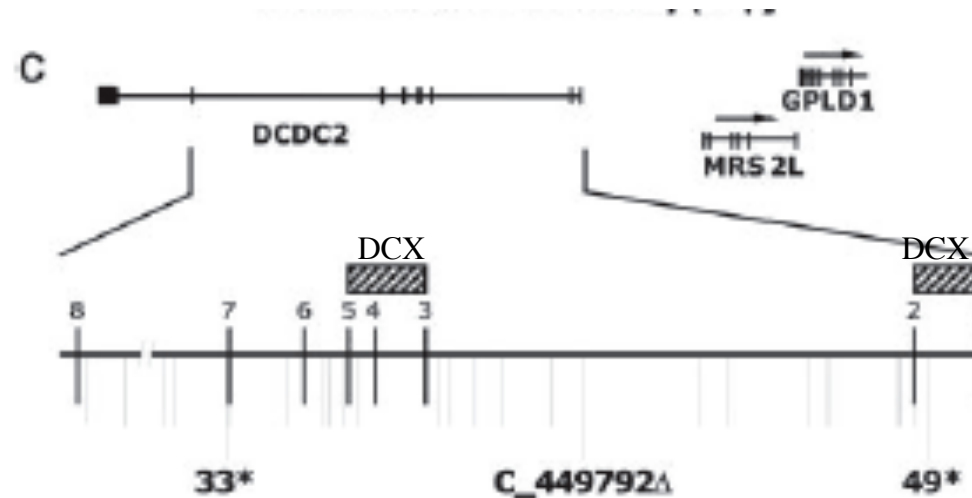
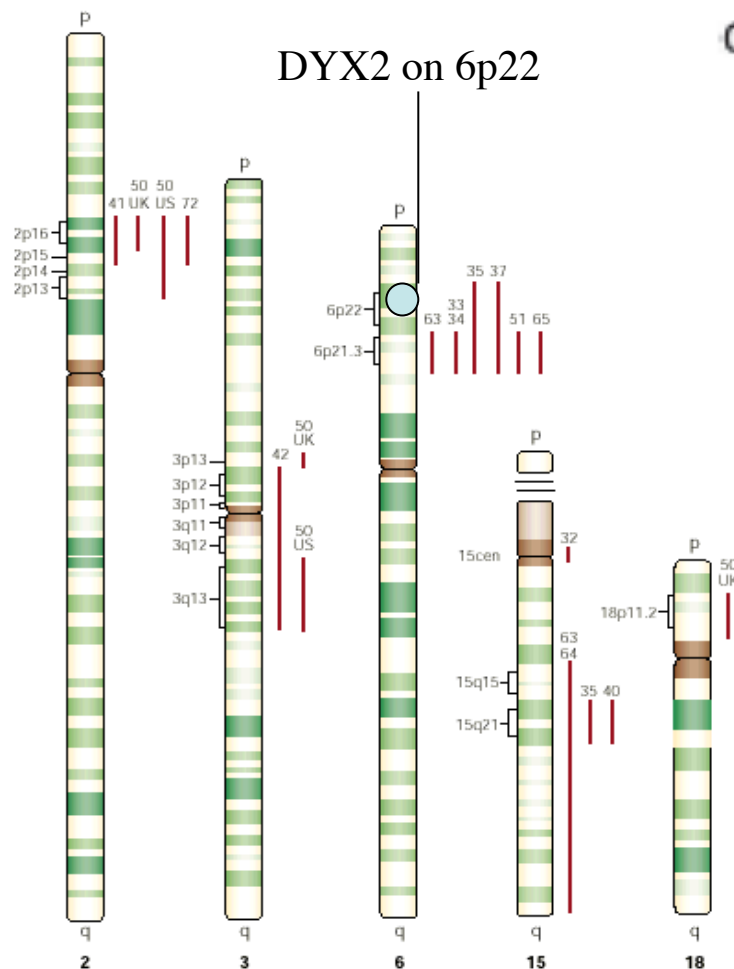
**Fig. 3.** Fibertracking through the temporoparietal cluster defined by the ALE-meta-analysis (cluster depicted in red). Two major pathways, the left AF (depicted in green) and left CR (depicted in blue), cross this cluster. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Fig. 4.** Fibertracking through the temporoparietal cluster defined by the ALE-meta-analysis (cluster depicted in red) in eight subjects. The upper row represents four normal reading subjects and the lower row four dyslexic readers. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

# DCDC2 is associated with reading disability and modulates neuronal development in the brain

Haiying Meng<sup>a</sup>, Shelley D. Smith<sup>b</sup>, Karl Hager<sup>c</sup>, Matthew Held<sup>a</sup>, Jonathan Liu<sup>d</sup>, Richard K. Olson<sup>a</sup>, Bruce F. Pennington<sup>f</sup>, John C. DeFries<sup>g</sup>, Joel Gelernter<sup>h,i</sup>, Thomas O'Reilly-Pol<sup>a</sup>, Stefan Somlo<sup>j</sup>, Pawel Skudlarski<sup>a</sup>, Sally E. Shaywitz<sup>a</sup>, Bennett A. Shaywitz<sup>a</sup>, Karen Marchione<sup>a</sup>, Yu Wang<sup>k</sup>, Murugan Paramasivam<sup>k</sup>, Joseph J. LoTurco<sup>k</sup>, Grier P. Page<sup>l</sup>, and Jeffrey R. Gruen<sup>a,m</sup>



DCDC2 : deletion in strong linkage with reading performance

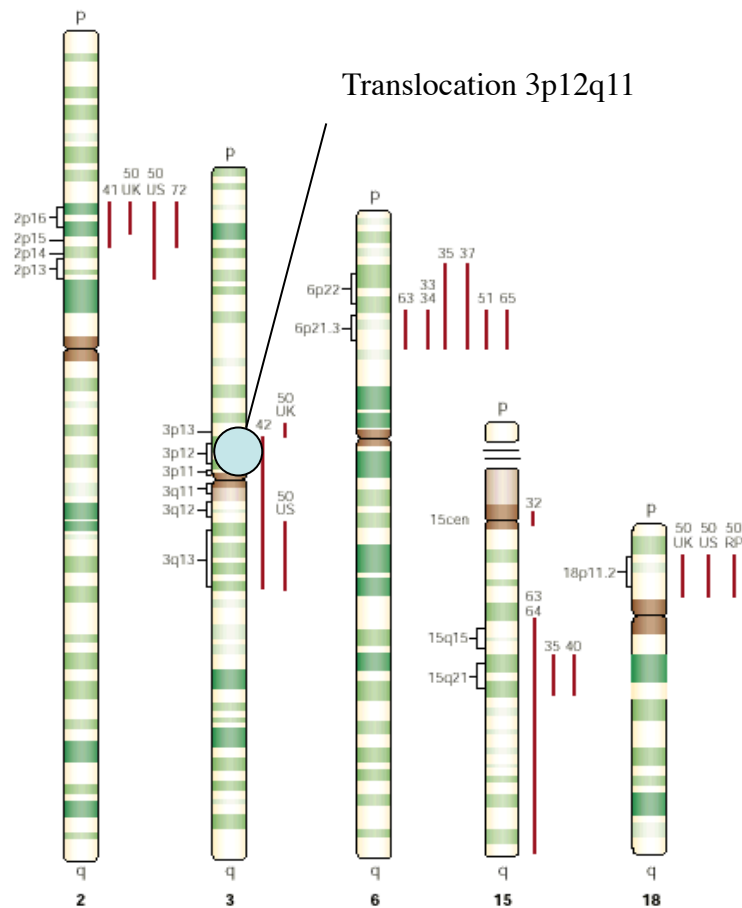
Contains doublecortine (DCX) gene domain (responsible for lissencephaly & double cortex syndrome)

RNA present in cerebral tissue from reading-associated regions

Thus should be associated to abnormal migration

# The Axon Guidance Receptor Gene *ROBO1* Is a Candidate Gene for Developmental Dyslexia

Katariina Hannula-Jouppi<sup>1</sup>, Nina Kaminen-Ahola<sup>1</sup>, Mikko Taipale<sup>1,2</sup>, Ranja Eklund<sup>1</sup>, Jaana Nopola-Hemmi<sup>1,3</sup>, Helena Kääriäinen<sup>4,5</sup>, Juha Kere<sup>1,6\*</sup>



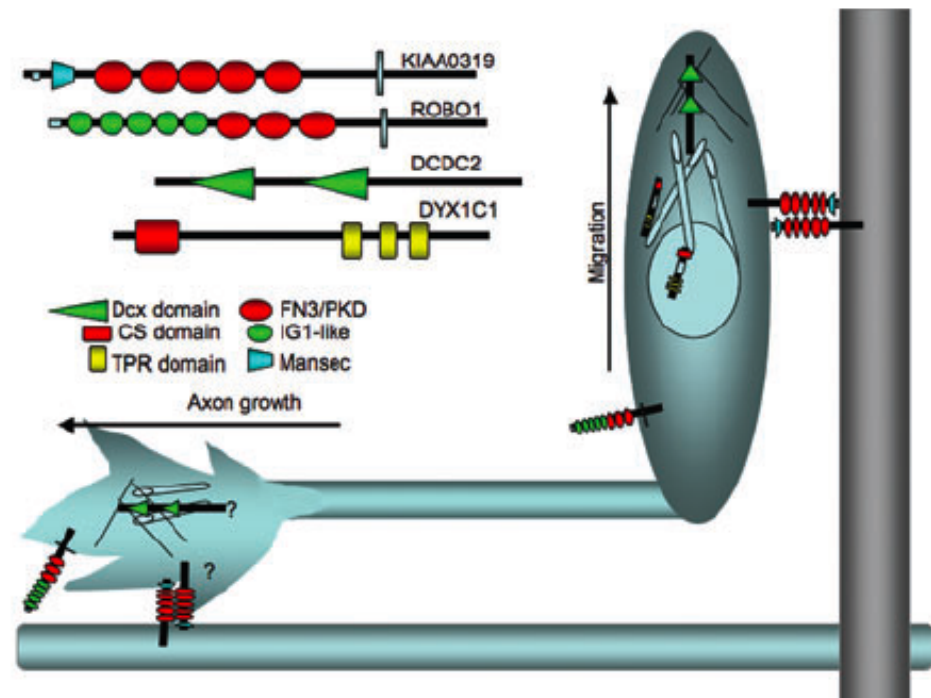
*ROBO1* has a role in regulating axon crossing across the midline between brain hemispheres and guidance of neuronal dendrites





## From genes to behavior in developmental dyslexia

Albert M Galaburda, Joseph LoTurco, Franck Ramus, R Holly Fitch & Glenn D Rosen



**Figure 1** Protein domains and possible functions. KIAA0319 and ROBO1 serve as transmembrane adhesion molecules and receptors that guide axons to appropriate targets. DCDC2, and perhaps DYX1C1, are proposed to act as downstream targets that then serve to modulate changes in cytoskeletal dynamic processes involved in the motility of developing neurons. Critical future studies must now address whether there are links between the functions of these proteins in migration and axonal pathfinding.

# Three Dyslexia Susceptibility Genes, *DYX1C1*, *DCDC2*, and *KIAA0319*, Affect Temporo-Parietal White Matter Structure

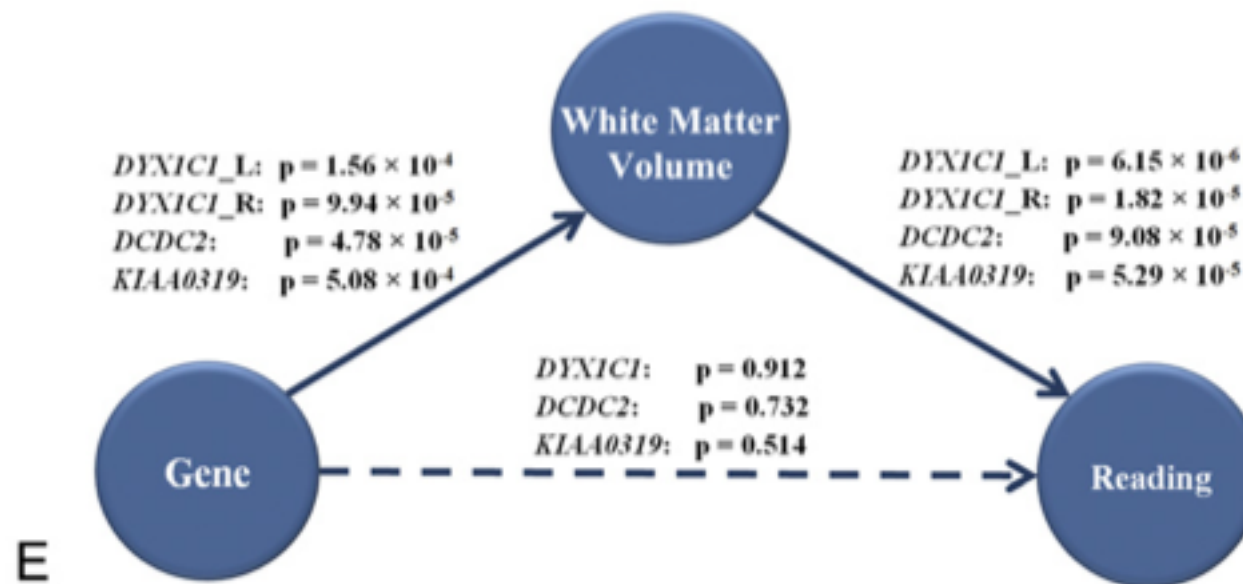
Fahimeh Darki, Myriam Peyrard-Janvid, Hans Matsson, Juha Kere, and Torkel Klingberg

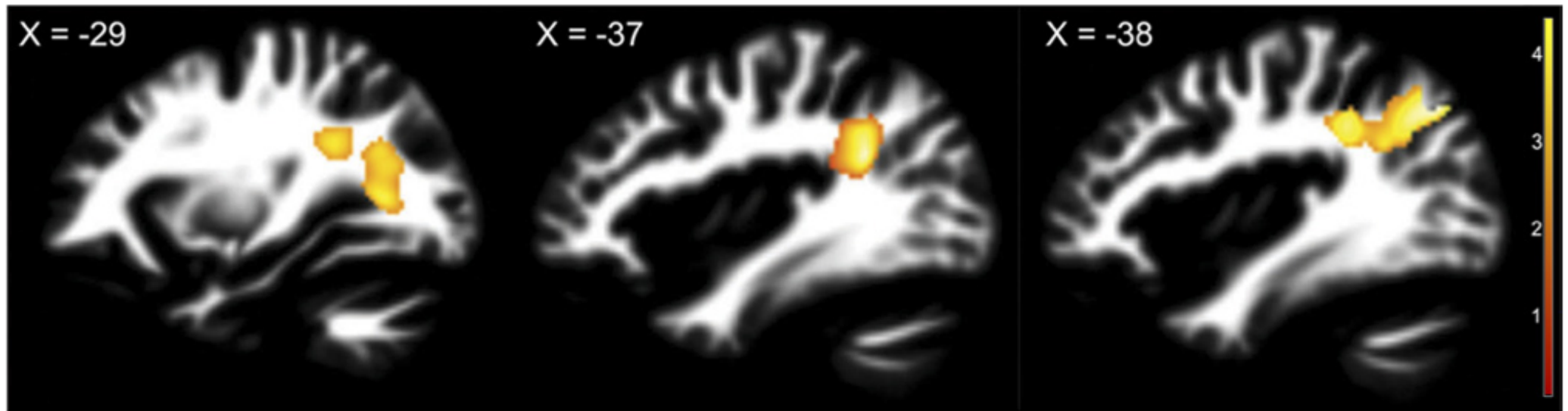
**Background:** Volume and integrity of white matter correlate with reading ability, but the underlying factors contributing to this variability are unknown.

**Methods:** We investigated single nucleotide polymorphisms in three genes previously associated with dyslexia and implicated in neuronal migration (*DYX1C1*, *DCDC2*, *KIAA0319*) and white matter volume in a cohort of 76 children and young adults from the general population.

**Results:** We found that all three genes contained polymorphisms that were significantly associated with white matter volume in the left temporo-parietal region and that white matter volume influenced reading ability.

**Conclusions:** The identified region contained white matter pathways connecting the middle temporal gyrus with the inferior parietal lobe. The finding links previous neuroimaging and genetic results and proposes a mechanism underlying variability in reading ability in both normal and impaired readers.





DYX1C1

DCDC2

KIAA0319

3 gènes impliqués dans la migration neuronale et liés à l'efficacité en lecture

**Results:** We found that all three genes contained polymorphisms that were significantly associated with white matter volume in the left temporo-parietal region and that white matter volume influenced reading ability.



## Brain connectivity in non-reading impaired children and children diagnosed with developmental dyslexia

Timothy N. Odegard<sup>a,c,\*</sup>, Emily A. Farris<sup>a</sup>, Jeremiah Ring<sup>b</sup>, Roderick McColl<sup>c</sup>, Jeffrey Black<sup>b,c</sup>

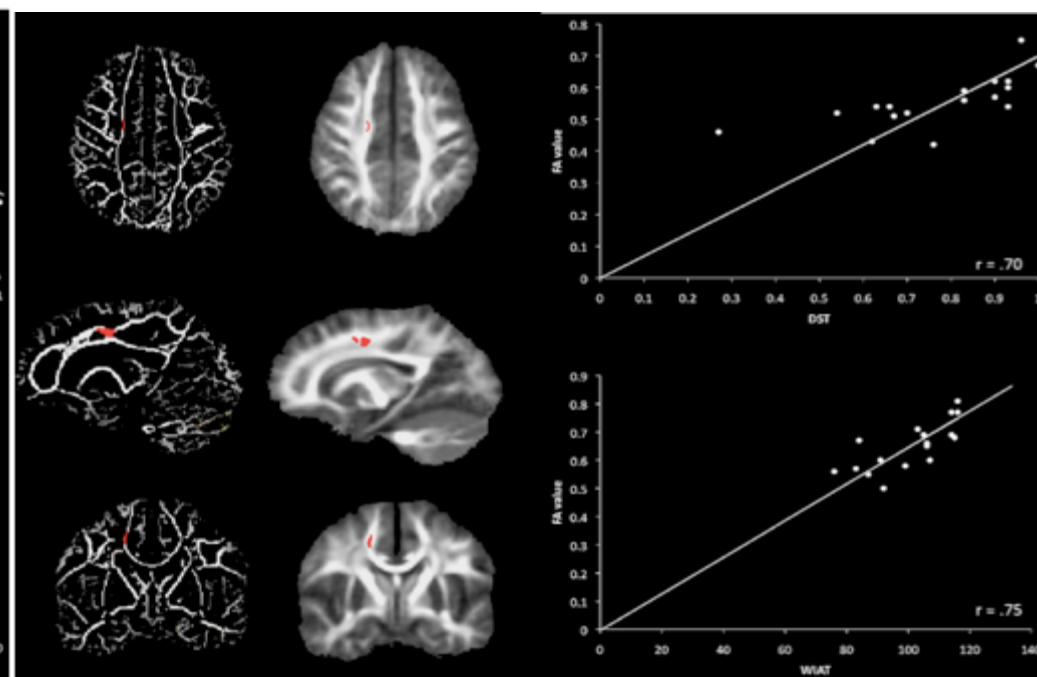
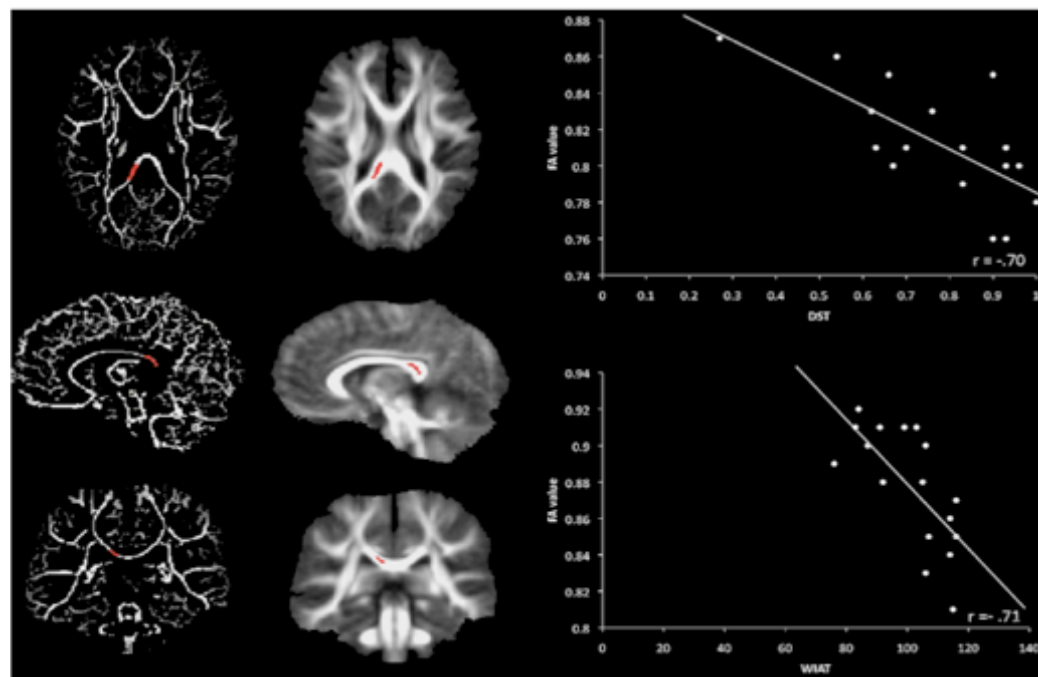
<sup>a</sup> University of Texas Arlington, United States

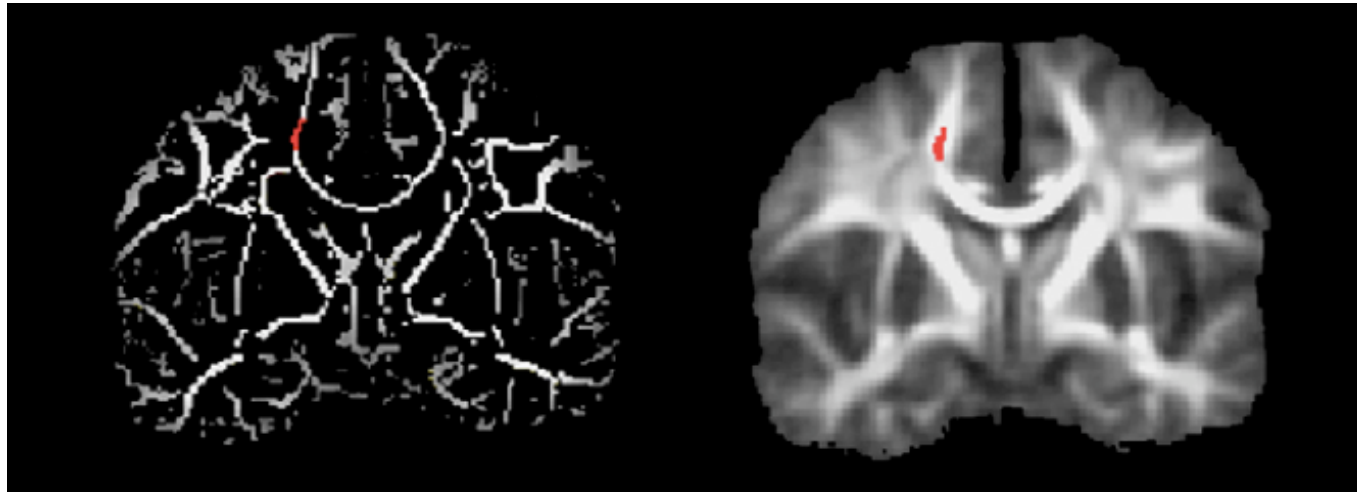
<sup>b</sup> Texas Children's Hospital, United States

<sup>c</sup> Texas Children's Hospital, United States

Corrélations entre F.A. et décodage en lecture pour des voxels situés dans le corps calleux postérieur gauche

Corrélations entre F.A. et décodage en lecture pour des voxels situés dans la corona radiata supérieure gauche





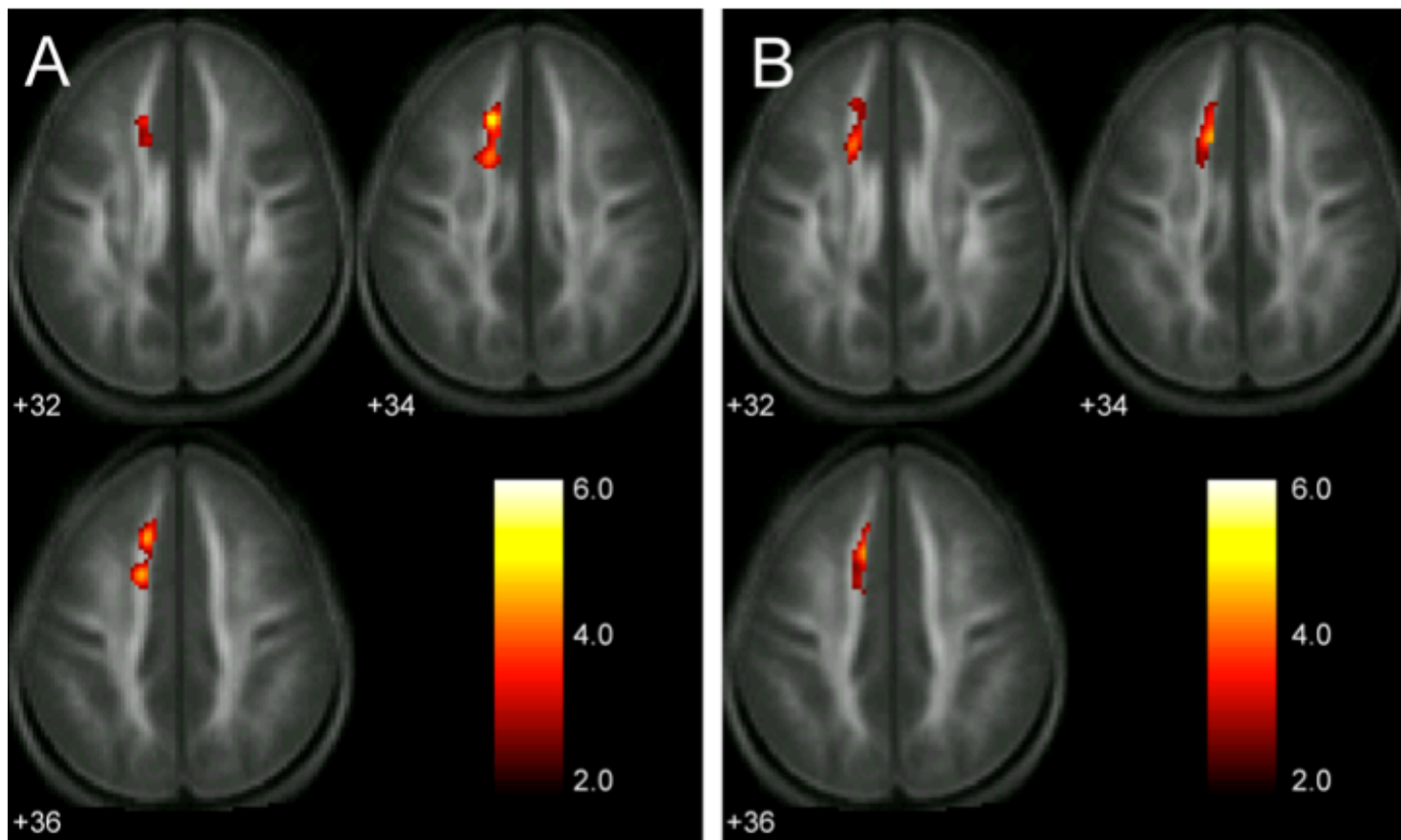
these data replicate the positive correlations observed between reading ability and FA values in left hemisphere white matter tracts that project along the superior–inferior axis opposed to the anterior–posterior axis (Beaulieu et al., 2005; Dougherty et al., 2007; Niogi & McCandliss, 2006). The main areas observed to be positively correlated with reading ability in the present study were located on the left superior corona radiata, which is a white matter tract that projects from the thalamus to the sensory cortices



## Altering cortical connectivity: Remediation-induced changes in the white matter of poor readers

Timothy A. Keller<sup>1</sup> and Marcel Adam Just<sup>1</sup>

<sup>1</sup>Center for Cognitive Brain Imaging, Department of Psychology, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA



72 participants : 35 poor readers that received the treatment, 12 poor readers that did not receive the treatment, and 25 good readers that did not receive the treatment

Treatment : 100 hours of intensive reading instruction (one of 4 classical reading remediation programmes)

(A) Region where the poor reader group showed an increase in FA between the pre-remediation and post-remediation scans (peak  $t(34) = 5.12$ , at Montreal Neurological Institute (MNI) coordinates  $-2\ 28\ 36$ , spatial extent = 450 voxels,  $p < .05$  corrected for multiple comparisons). There were no areas where poor readers showed a decrease in FA between phases, nor were there any areas where the control group of good readers or the control group of unremediated poor readers showed either an increase or decrease in FA. (B) Region showing a significant difference in FA between good readers and all poor readers at the first scan (peak  $t(70) = 4.66$ , at MNI coordinates  $-0\ 20\ 38$ , spatial extent = 418 voxels,  $p < .05$  corrected for multiple comparisons).



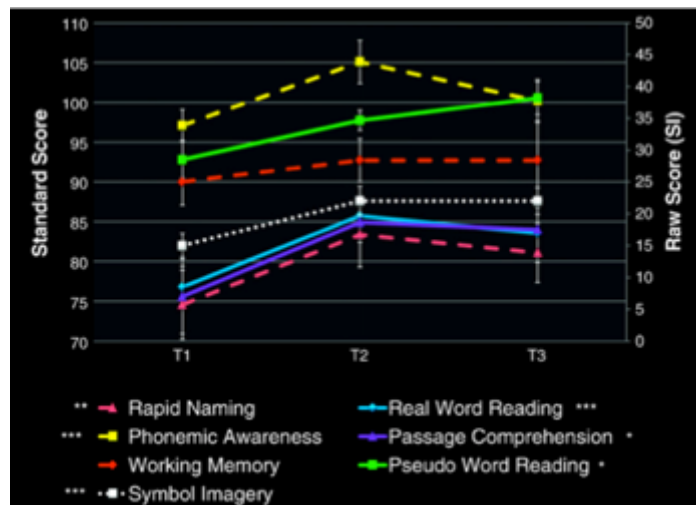


## Gray matter volume changes following reading intervention in dyslexic children

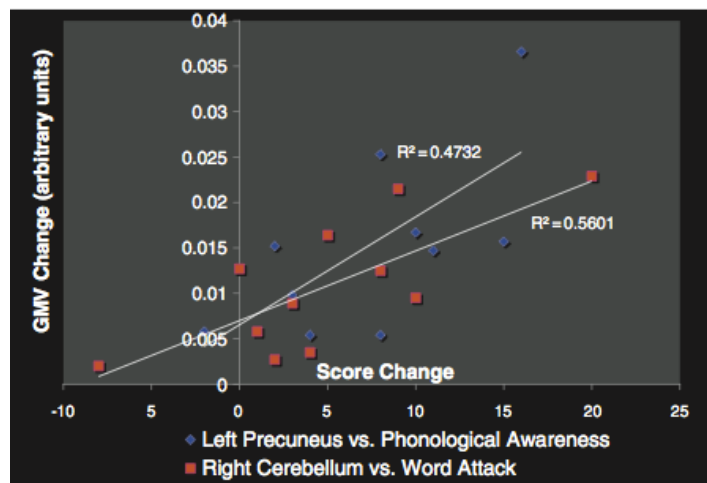
Anthony J. Krafnick<sup>a</sup>, D. Lynn Flowers<sup>a,b</sup>, Eileen M. Napoliello<sup>a</sup>, Guinevere F. Eden<sup>a,\*</sup>

<sup>a</sup> Center for the Study of Learning, Georgetown University Medical Center, 4000 Reservoir Road, Building D Suite 150, Washington, DC 20057, USA

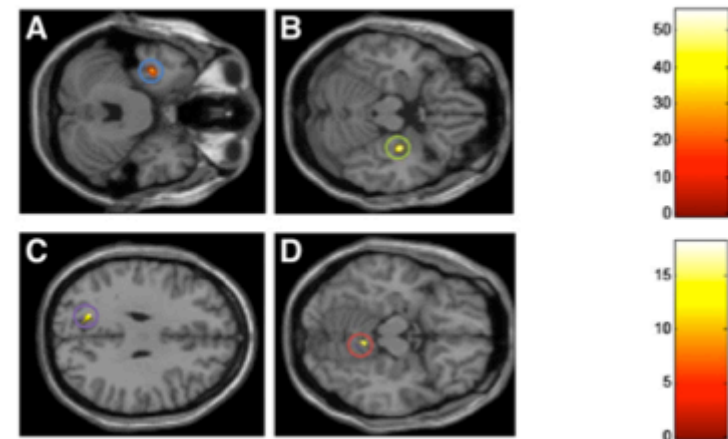
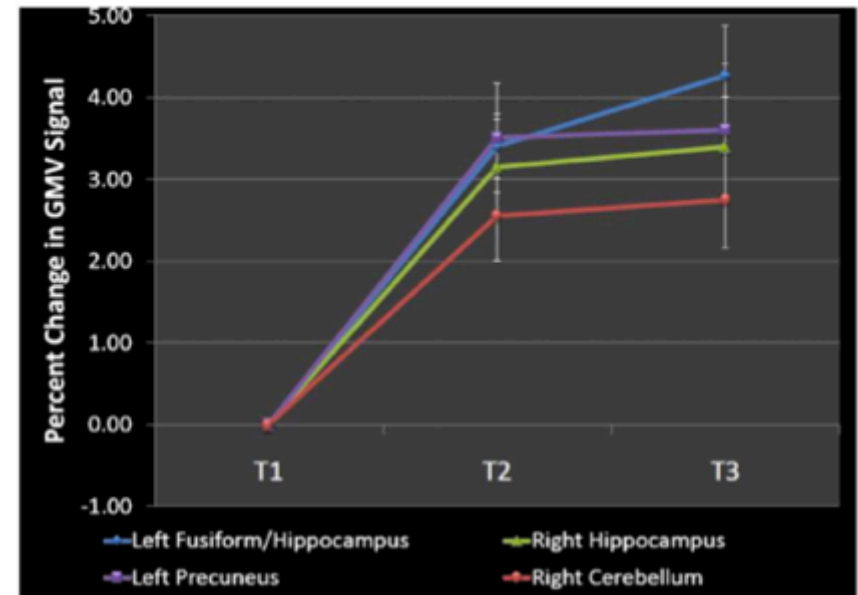
<sup>b</sup> Wake Forest University Baptist Medical Center, Winston Salem, NC, 27157



3 scans : before the reading intervention (T1), after the reading intervention (T2) and after the period of no intervention (T3)



11 children, mean age 9,5y, 8 week reading intervention, Seeing Stars (Lindamood-Bell Learning Processes ©), focuses heavily on imaging/visualization starting with single letters and increasing in difficulty to image one syllable and up to two and three syllable words. Then 8 week : no intervention

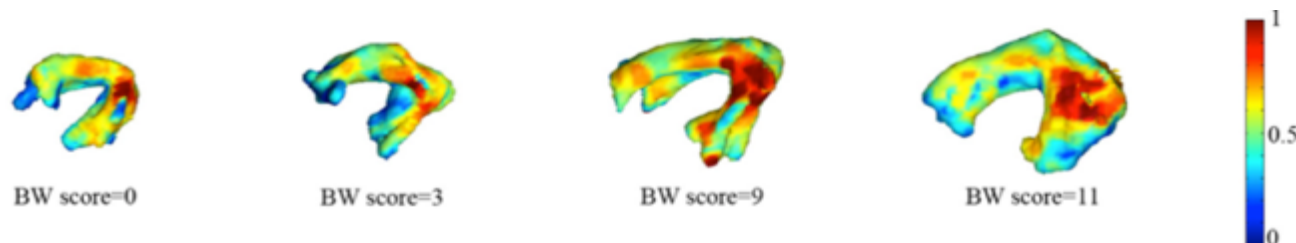
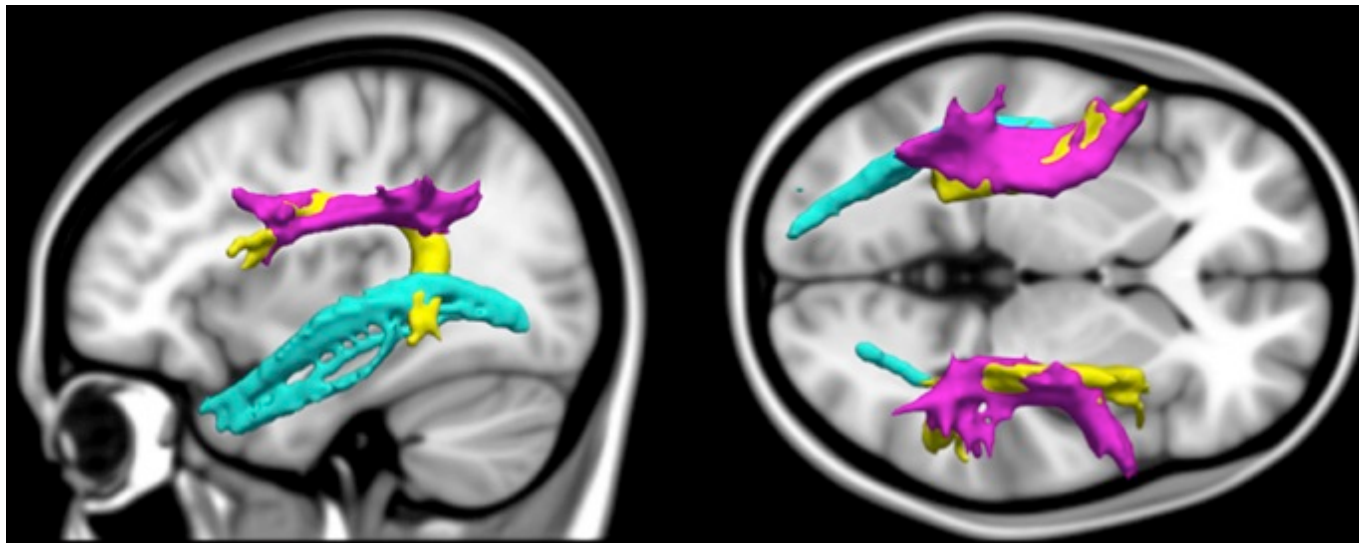


Behavioral/Cognitive

## 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,<sup>1\*</sup> Elizabeth S. Norton,<sup>1\*</sup> David E. Osher,<sup>1</sup> Sara D. Beach,<sup>1</sup> Abigail B. Cyr,<sup>1</sup> Ola Ozernov-Palchik,<sup>3</sup> Anastasia Yendiki,<sup>4</sup> Bruce Fischl,<sup>2,4</sup> Nadine Gaab,<sup>3</sup> and John D.E. Gabrieli<sup>1</sup>

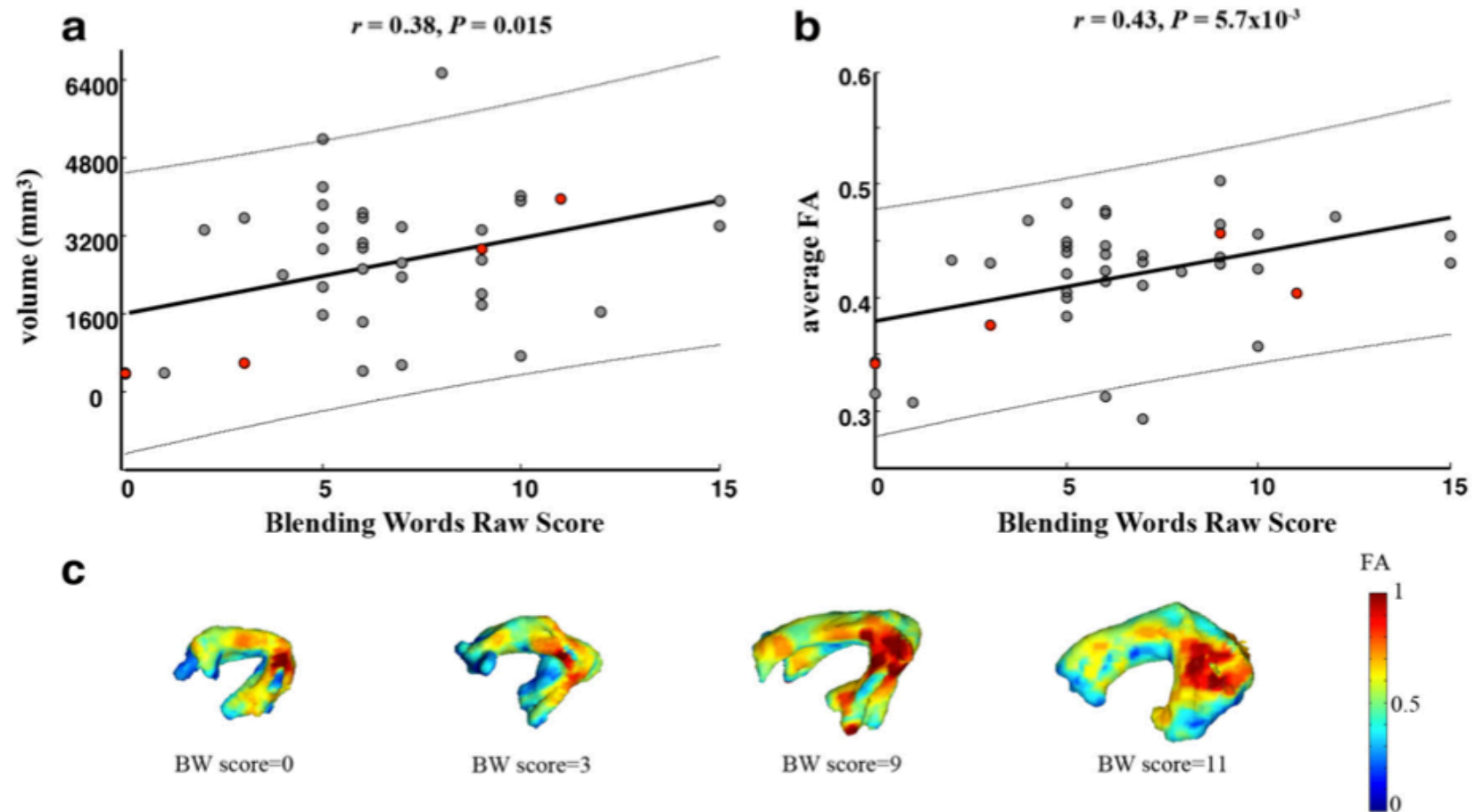
<sup>1</sup>McGovern Institute for Brain Research and Department of Brain and Cognitive Sciences and <sup>2</sup>Computer Science and Artificial Intelligence Laboratory



40 enfants de différents niveaux de capacités de conscience phonologique en première moitié de maternelle et 18 pré-lecteurs. Corrélation avec l'organisation (taille et anisotropie) du faisceau arqué dans les deux populations :

- les différences d'organisation du FA ne sont pas la conséquence de l'acquisition de la lecture.
- Pas de telle corrélation avec les autres faisceaux

Corrélation entre le score de conscience phonologique en maternelle et la morphologie du faisceau arqué (volume et anisotropie)



**Figure 2.** Greater volume and FA of the left arcuate fasciculus are associated with superior phonological awareness. **a**, Volume of the left arcuate fasciculus plotted against individual raw scores of the Blending Words subtest. **b**, Phonological awareness, illustrated by Blending Words raw scores, was significantly correlated with average FA of the left arcuate fasciculus. In **a** and **b**, thick lines represent the best fits and thin outer lines represent the 95% confidence intervals. **c**, To illustrate the relation between the behavioral phonological awareness scores with left arcuate volume and FA, this tract was rendered from example participants (filled red circles in **a** and **b**) and colored according to FA. The tracts are ordered by Blending Words raw score increasing from left to right.

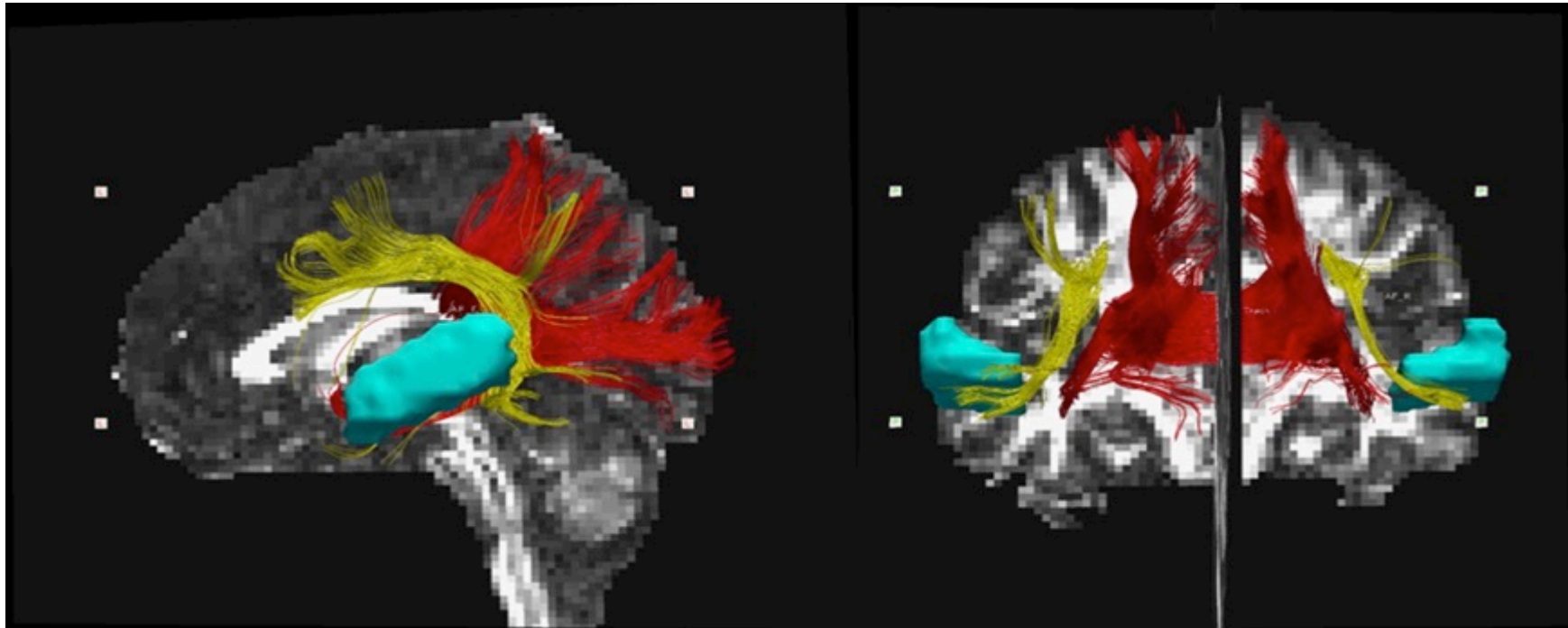


Fig. 1 Left arcuate fasciculus (depicted in yellow), STGp (depicted in light blue), and CCsplenium (depicted in red). Left panel: sagittal view from the left. Right panel: coronal view from posterior. (For interpretation of the references to color in this ...

Maaïke Vandermosten , Hanne Poelmans , Stefan Sunaert , Pol Ghesquière , Jan Wouters

**White matter lateralization and interhemispheric coherence to auditory modulations in normal reading and dyslexic adults**

Neuropsychologia Volume 51, Issue 11 2013 2087 - 2099

<http://dx.doi.org/10.1016/j.neuropsychologia.2013.07.008>

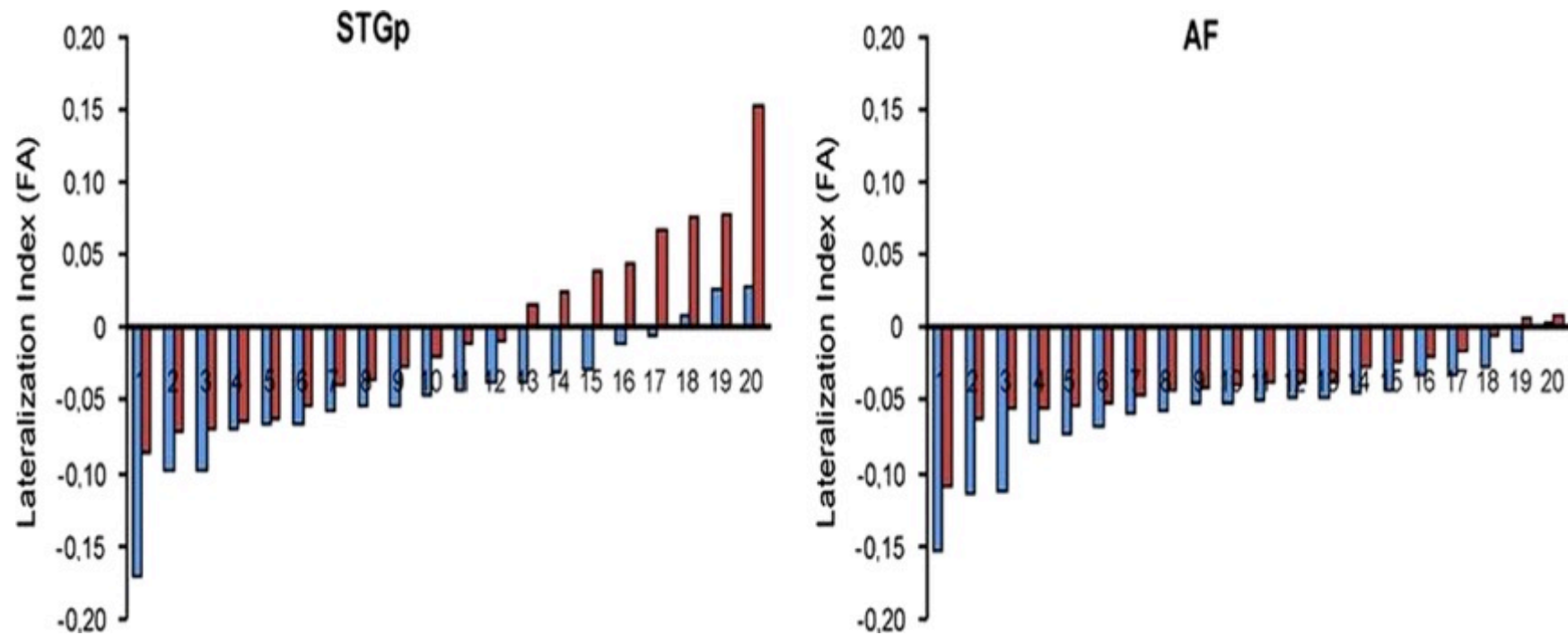


Fig. 3 Individual distribution of the lateralization indices of the STGp and arcuate fasciculus for normal (blue bars) and dyslexic (red bars) readers. (For interpretation of the references to color in this figure legend, the reader is referred to the web ...

Maaïke Vandermosten , Hanne Poelmans , Stefan Sunaert , Pol Ghesquière , Jan Wouters

**White matter lateralization and interhemispheric coherence to auditory modulations in normal reading and dyslexic adults**

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# En résumé : neurobiologie de la dyslexie

- Les découvertes initiales de Galaburda sur le cortex d'humains dyslexiques ont été ravivées par les études génétiques montrant des altérations de gènes impliqués dans le développement cérébral précoce.
- Les techniques modernes de traitement du signal IRM ont montré de façon convergente une anomalie structurale fine de la connectivité entre diverses régions cérébrales, en particulier hémisphériques gauches
- Il reste que ces anomalies, aussi robustes soient-elles, ne peuvent être tenues comme à coup sûr responsables du trouble de la fonction (e.g. lecture) dont elles peuvent tout aussi bien représenter la conséquence (plutôt que la cause)



# Données neurofonctionnelles

# Developmental dyslexia

Jean-François Démonet, Margot J Taylor, Yves Chaix

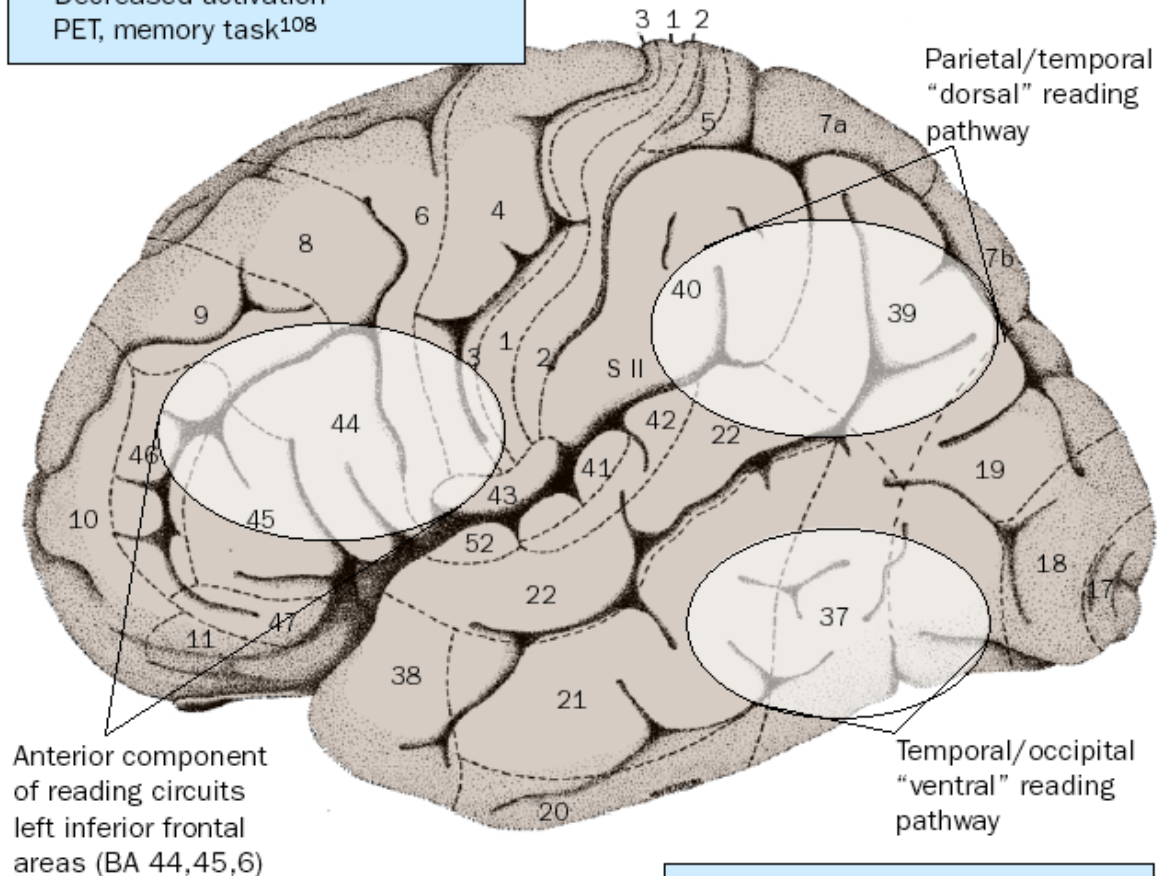
## Dysfunction of left inferior frontal area

Increased activation:  
fMRI, hierarchically organised tasks with phonological process;<sup>106</sup>  
PET, implicit and explicit word and pseudoword reading<sup>107</sup>

Decreased activation  
PET, memory task<sup>108</sup>

## Reduced activity in left parietal/temporal regions

PET, rhyming task;<sup>108,109</sup>  
PET, pronunciation and decision making tasks;<sup>110</sup>  
fMRI, hierarchically organised tasks with phonological process<sup>106</sup>  
PET, reading<sup>111</sup>



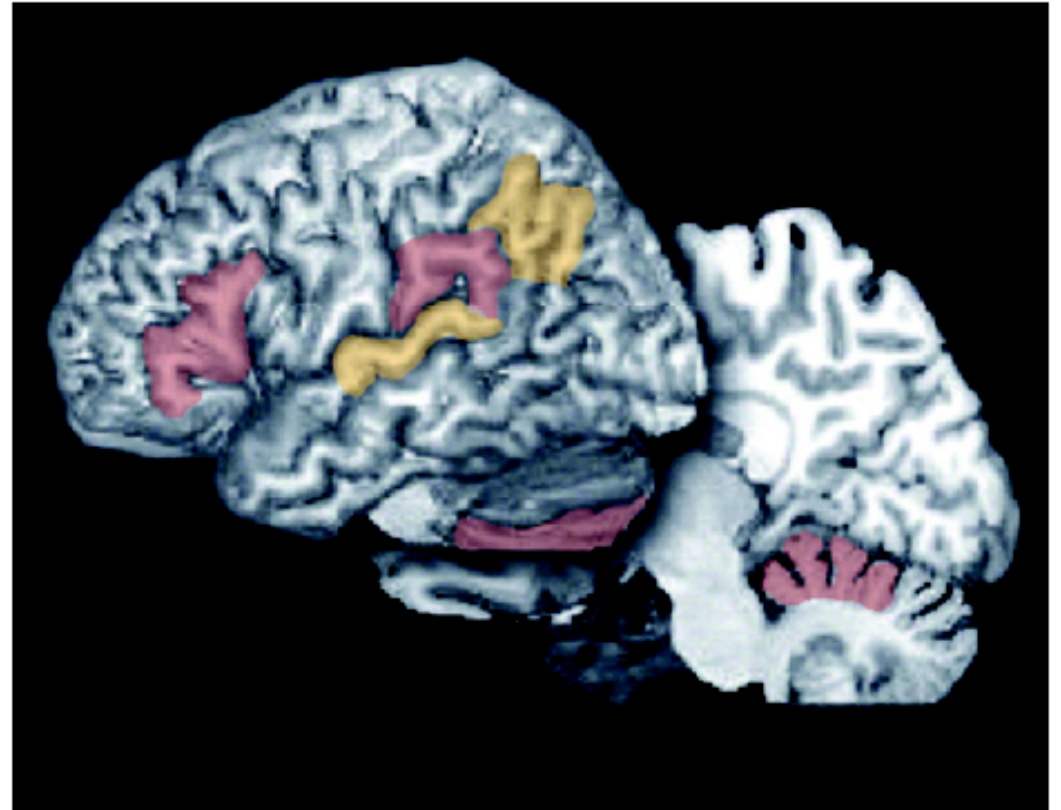
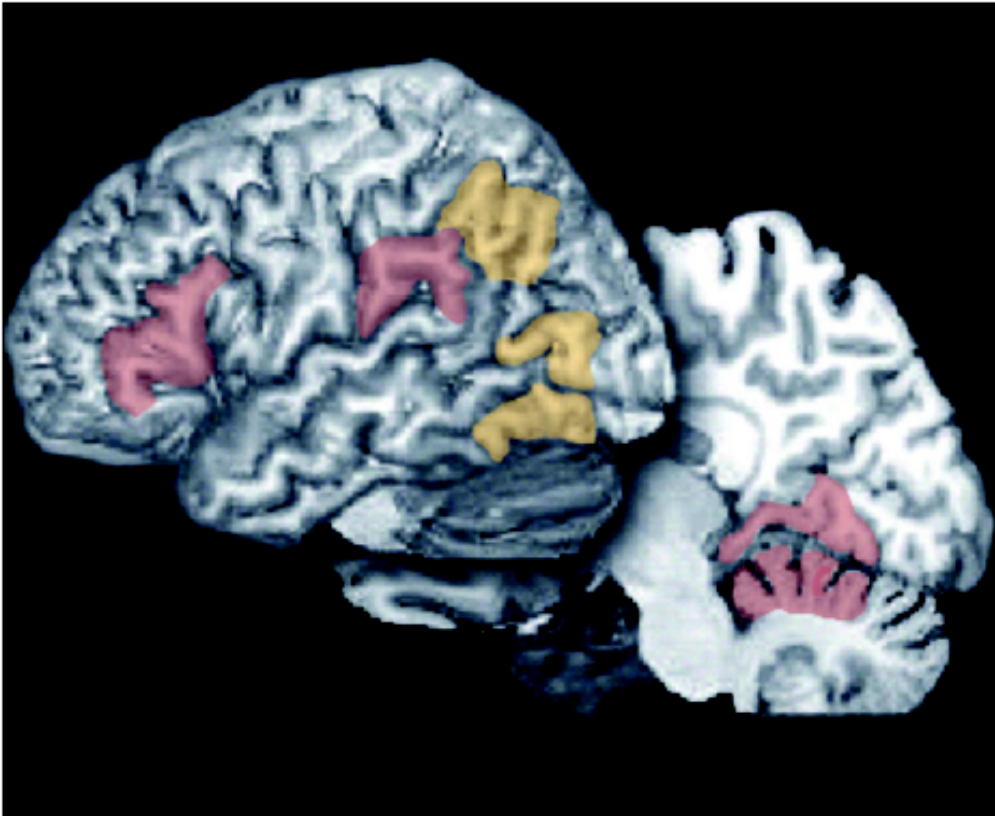
## Reduced activity in left inferior temporal/occipital area

MEG, letter perception<sup>101</sup>  
PET, implicit and explicit word and pseudoword reading<sup>107,112</sup>

*Lancet* 2004; **363**: 1451–60

**INSERM U455, Hôpital Purpan, IFR 96, Toulouse, France** (J-F Démonet MD); **CNRS UMR 5549, Faculté de Médecine de Toulouse-Rangueil, IFR 96, Toulouse, France** (M J Taylor PhD); and **Unité de Neuro-Pédiatrie, Hôpital des Enfants, Toulouse, France** (Y Chaix MD)

**Correspondence to:** Dr J-F Démonet  
(e-mail: demonet@toulouse.inserm.fr)



Anatomical areas activated during written language tasks and that exhibit significant differences from controls in studies of dyslexia

Anatomical areas activated during oral language tasks and that exhibit significant differences from controls in studies of dyslexia

REVIEW ■

## Neuroanatomical Markers for Dyslexia: A Review of Dyslexia Structural Imaging Studies

MARK ECKERT

NEUROSCIENTIST. 10(3):000-000, 2004.

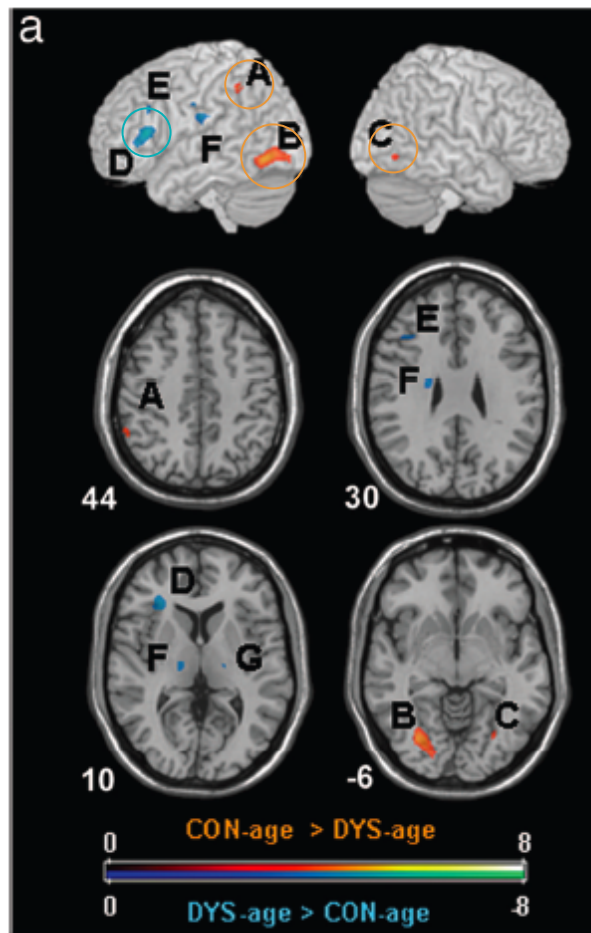
# Functional and morphometric brain dissociation between dyslexia and reading ability

Fumiko Hoeft<sup>\*,†</sup>, Ann Meyler<sup>§</sup>, Arvel Hernandez<sup>\*</sup>, Connie Juel<sup>¶</sup>, Heather Taylor-Hill<sup>\*</sup>, Jennifer L. Martindale<sup>\*</sup>, Glenn McMillon<sup>\*</sup>, Galena Kolchugina<sup>\*</sup>, Jessica M. Black<sup>¶</sup>, Afroz Faizi<sup>\*</sup>, Gayle K. Deutsch<sup>\*</sup>, Wai Ting Siok<sup>¶</sup>, Allan L. Reiss<sup>†</sup>, Susan Whitfield-Gabrieli<sup>\*,\*\*</sup>, and John D. E. Gabrieli<sup>\*,\*\*</sup>

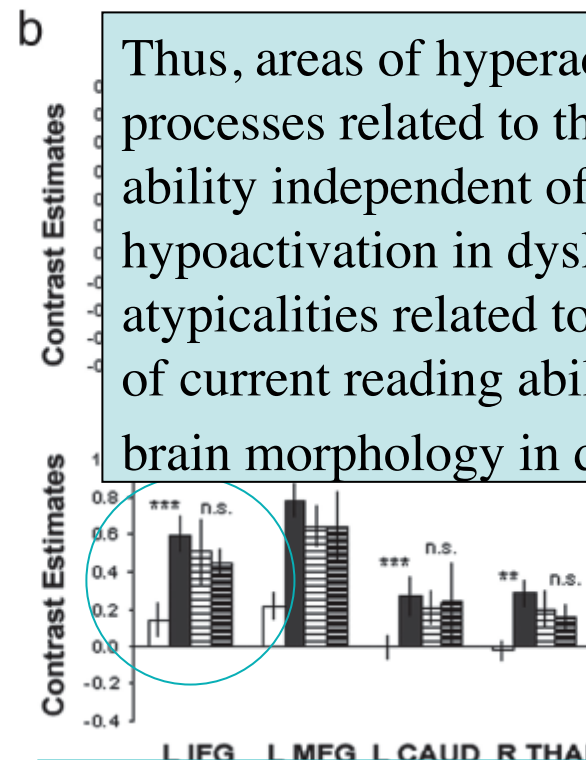
<sup>\*</sup>Department of Psychology, Stanford University, Building 420, m/c 2130, Palo Alto, CA 94305-2130; <sup>†</sup>Center for Interdisciplinary Brain Sciences Research (CIBSR), Department of Psychiatry and Behavioral Sciences, Stanford University School of Medicine, 401 Quarry Road, Palo Alto, CA 94305-5795; <sup>§</sup>Department of Psychology, Carnegie Mellon University, Baker Hall, Pittsburgh, PA 15213-3890; <sup>¶</sup>School of Education, Stanford University, 485 Lausen Mall, Palo Alto, CA 94305-3096

Edited by Michael M. Merzenich, University of California School of Medicine, San Francisco, CA, and approved December 27, 2006  
(received for review October 26, 2006)

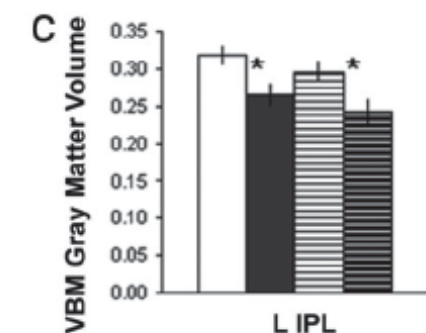
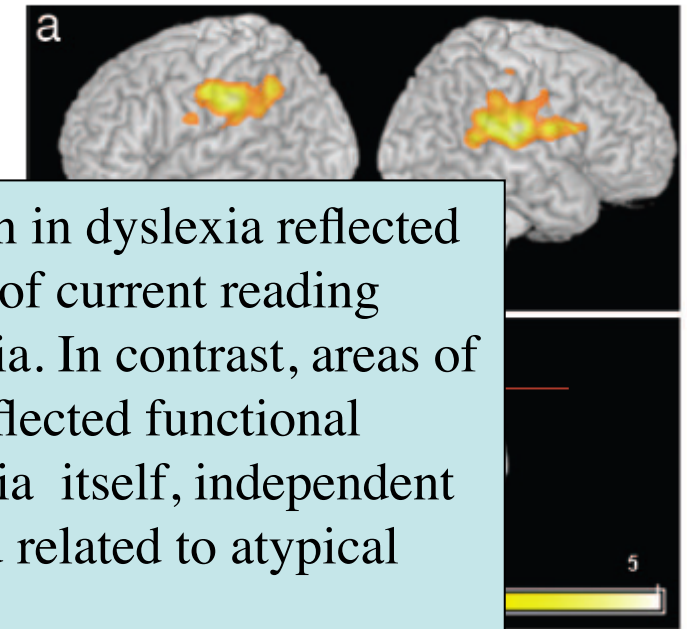
a) régions de diminution de volume  
b) idem pour zones d'activation réduite en fMRI (L IPL)



I/ IRMf



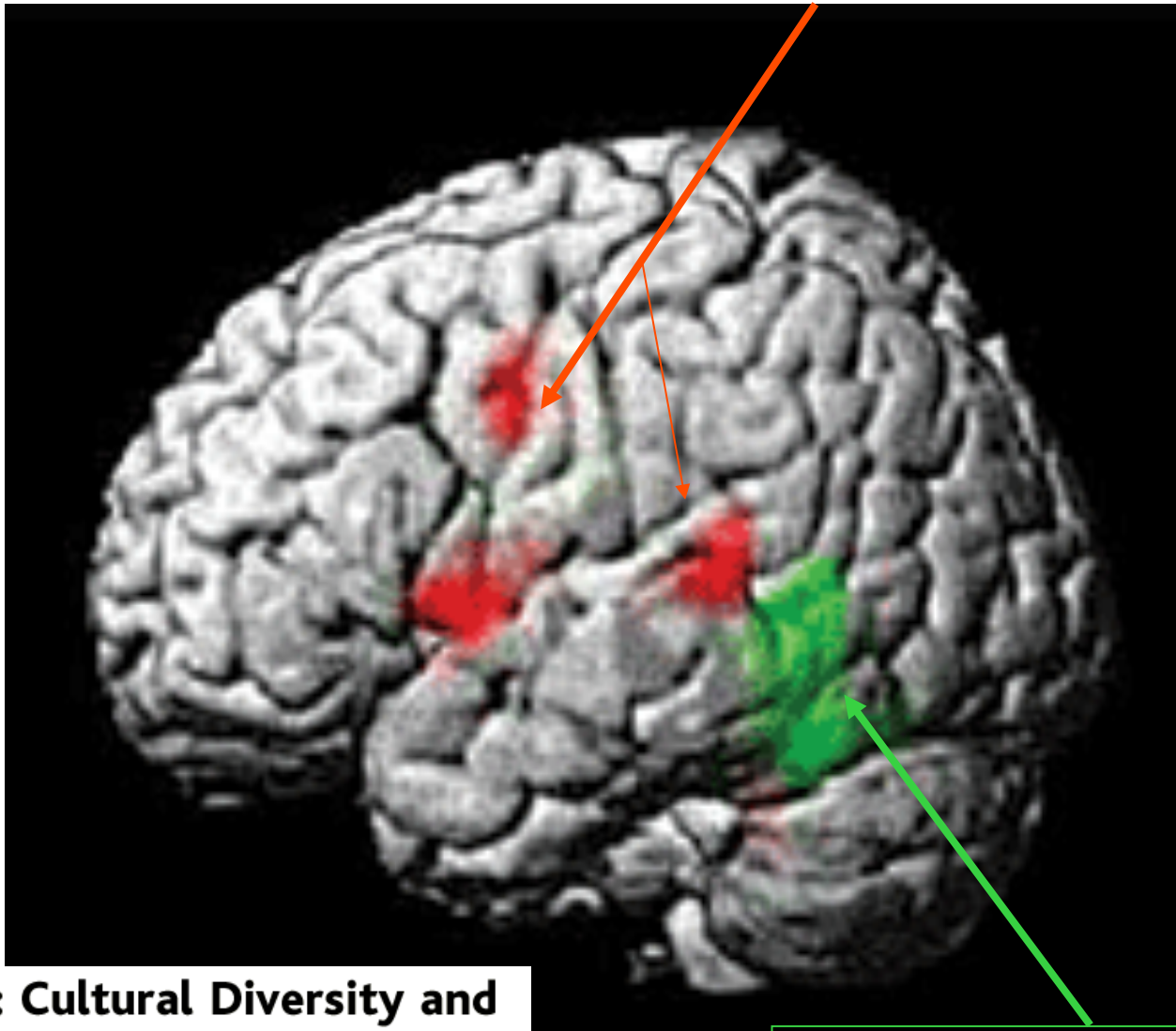
Hypoactivation significative pour les régions postérieures. Hyperactivation significative pour les régions antérieures, seulement par rapport aux témoins d'âge chronologique



II/ VBM



également activé chez les témoins et les dyslexiques

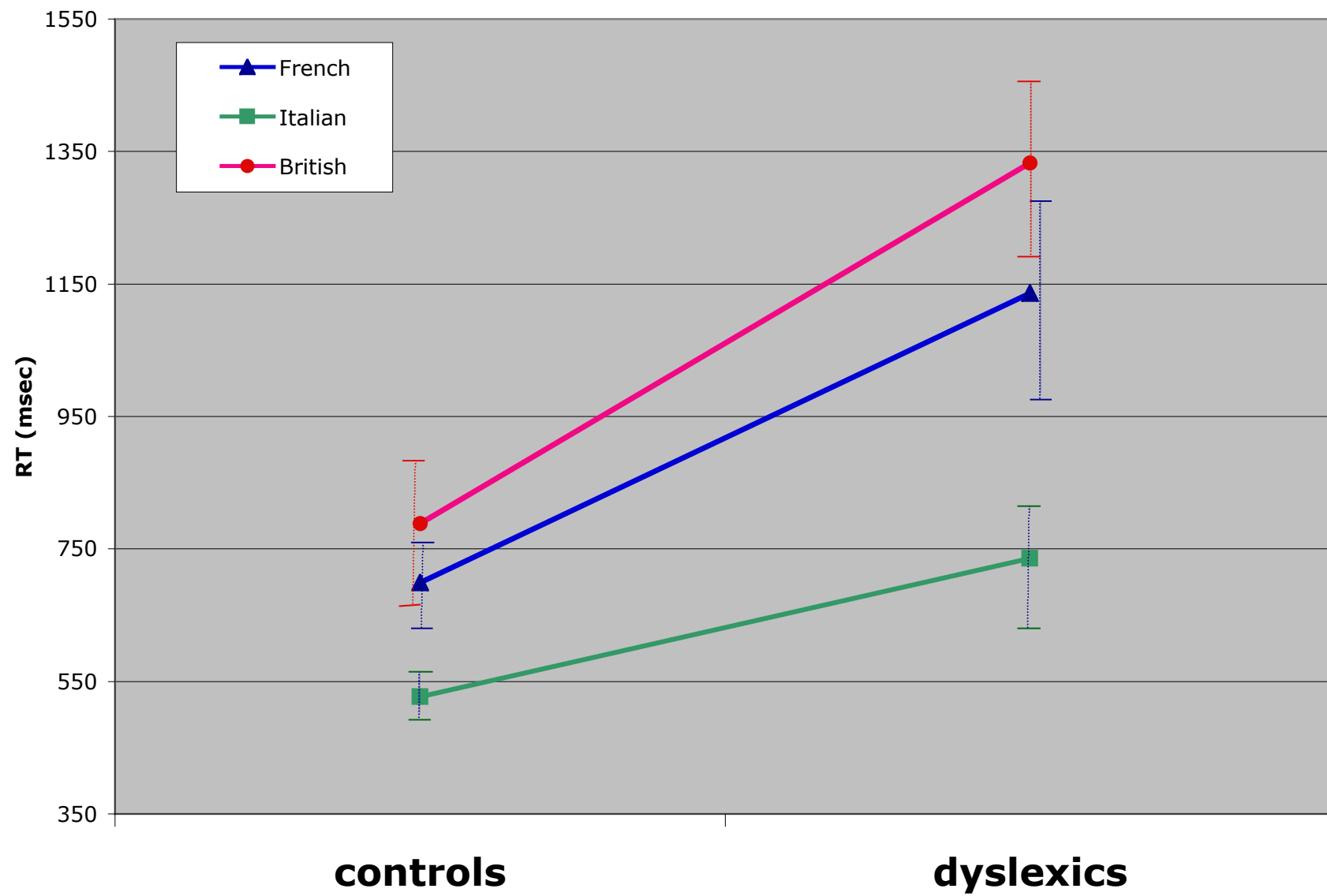


Paulesu et al., 2001

## Dyslexia: Cultural Diversity and Biological Unity

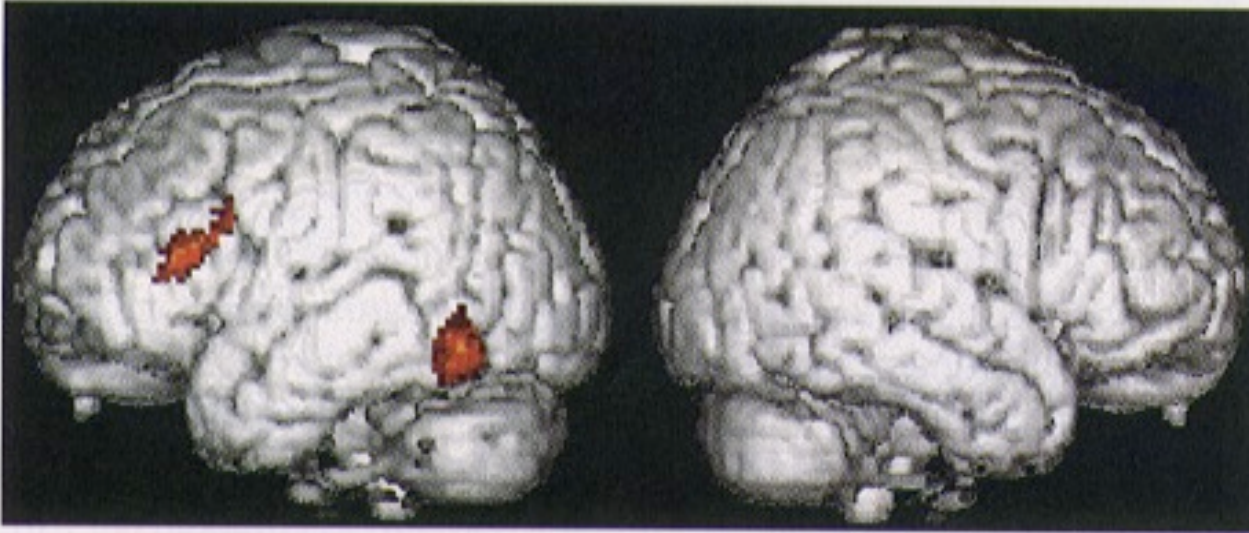
E. Paulesu,<sup>1,2\*</sup> J.-F. Démonet,<sup>3</sup> F. Fazio,<sup>2,4</sup> E. McCrory,<sup>5</sup>  
V. Chanoine,<sup>3</sup> N. Brunswick,<sup>6</sup> S. F. Cappa,<sup>7</sup> G. Cossu,<sup>8</sup> M. Habib,<sup>9</sup>  
C. D. Frith,<sup>6</sup> U. Frith<sup>5</sup>

significativement moins  
activé chez les dyslexiques

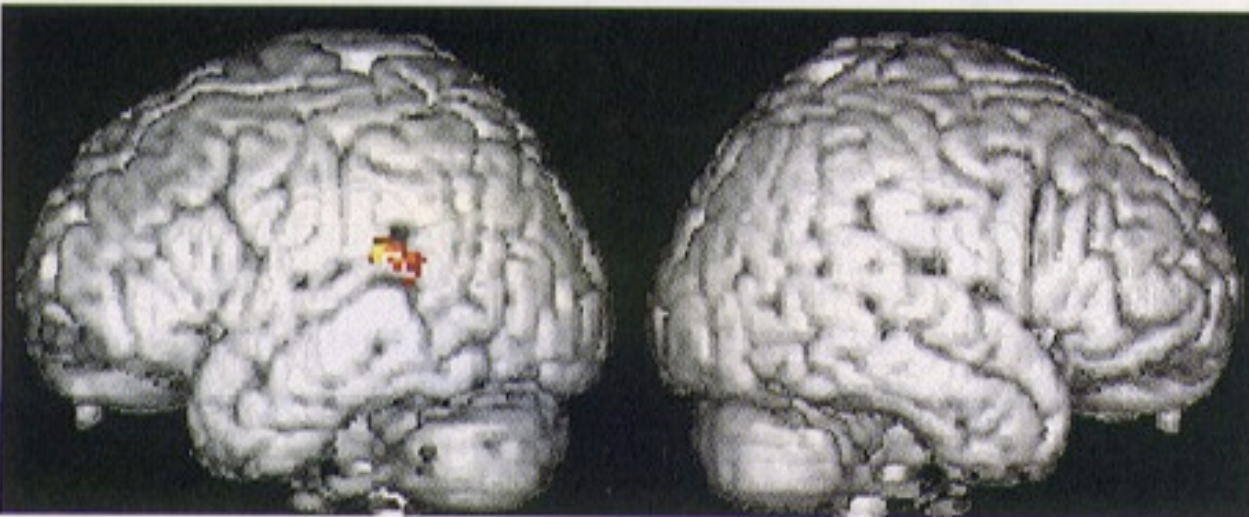




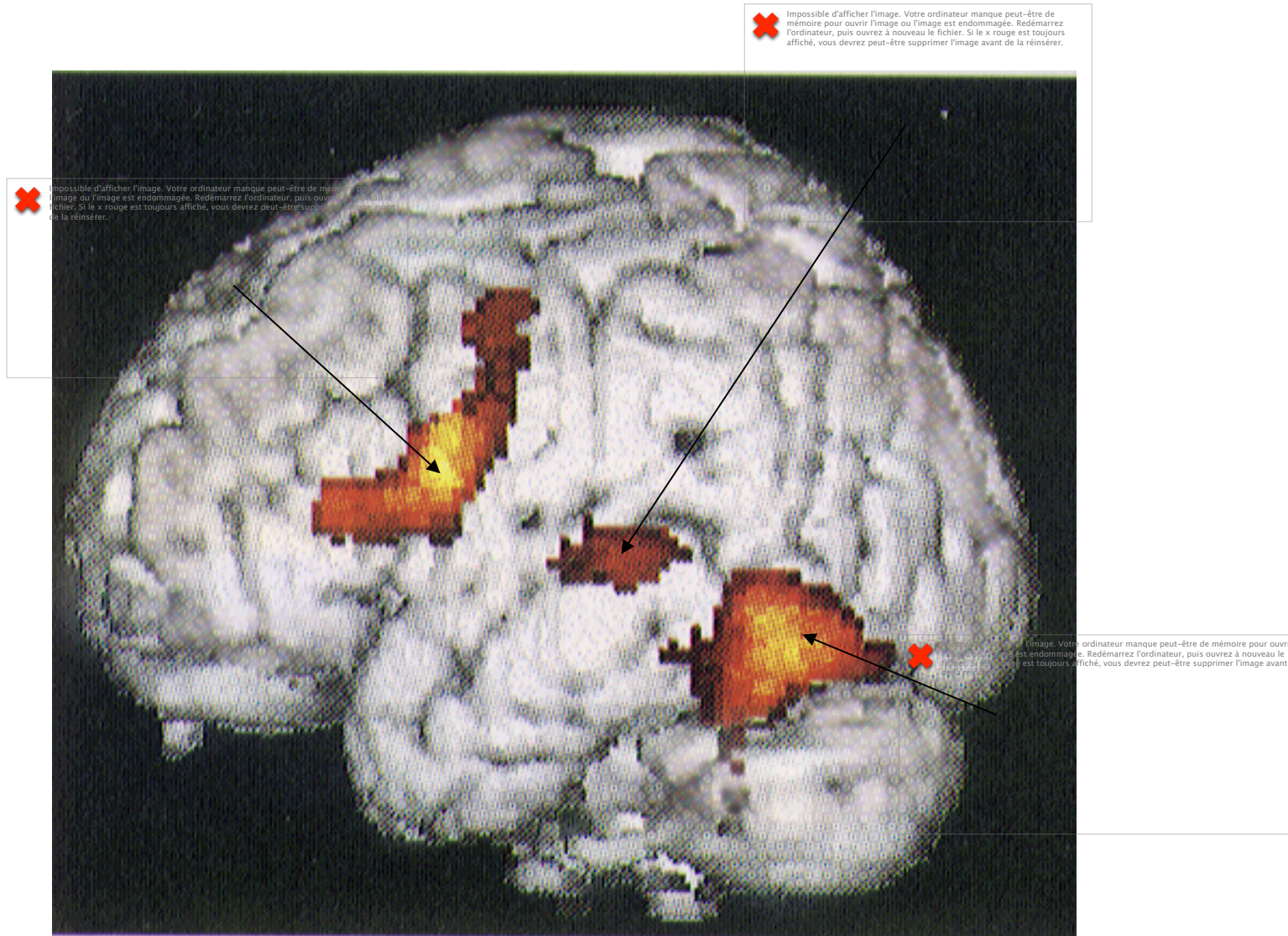
Paulesu et al. (2000)  
A cultural effect on brain function



English > Italians :  
(non-words)

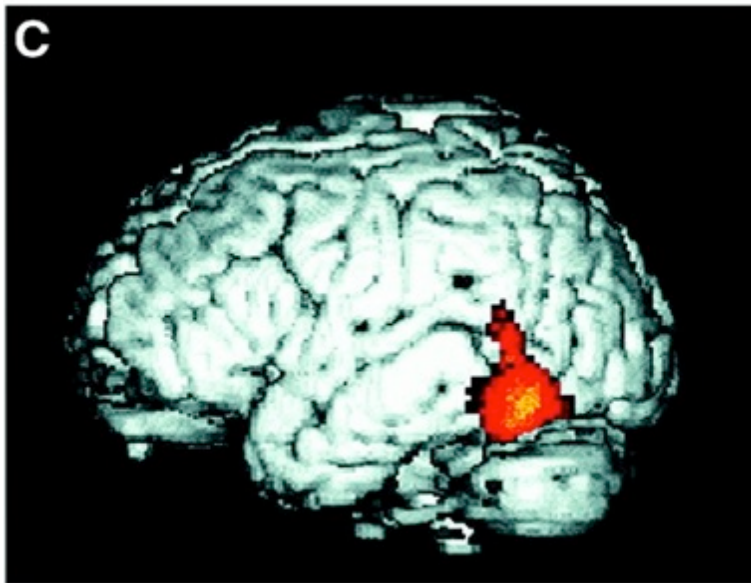


Italians > English  
(all word types)



Paulesu et al. (2000)  
A cultural effect on brain function





Controls - dyslexics

# Dyslexia: Cultural Diversity and Biological Unity

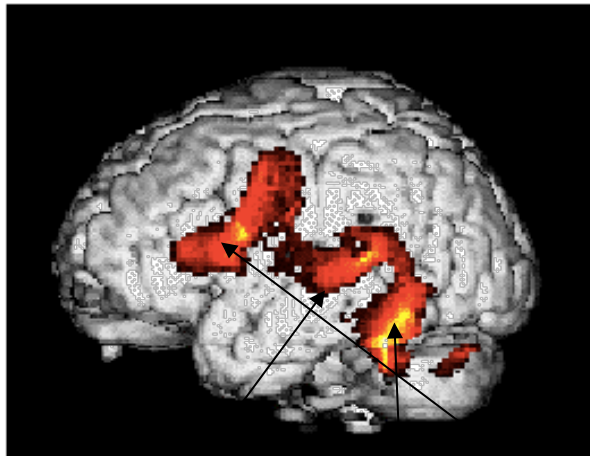
E. Paulesu,<sup>1,2\*</sup> J.-F. Démonet,<sup>3</sup> F. Fazio,<sup>2,4</sup> E. McCrory,<sup>5</sup>  
V. Chanoine,<sup>3</sup> N. Brunswick,<sup>6</sup> S. F. Cappa,<sup>7</sup> G. Cossu,<sup>8</sup> M. Habib,<sup>9</sup>  
C. D. Frith,<sup>6</sup> U. Frith<sup>5</sup>

The recognition of dyslexia as a neurodevelopmental disorder has been hampered by the belief that it is not a specific diagnostic entity because it has variable and culture-specific manifestations. In line with this belief, we found that Italian dyslexics, using a shallow orthography which facilitates reading, performed better on reading tasks than did English and French dyslexics. However, all dyslexics were equally impaired relative to their controls on reading and phonological tasks. Positron emission tomography scans during explicit and implicit reading showed the same reduced activity in a region of the left hemisphere in dyslexics from all three countries, with the maximum peak in the middle temporal gyrus and additional peaks in the inferior and superior temporal gyri and middle occipital gyrus. We conclude that there is a universal neurocognitive basis for dyslexia and that differences in reading performance among dyslexics of different countries are due to different orthographies.

<sup>1</sup>Psychology Department, University of Milan Bicocca, Milan, Italy. <sup>2</sup>INB-CNR, Scientific Institute H San Raffaele, Milan, Italy. <sup>3</sup>INSERM U455, Hôpital Purpan, Toulouse, France. <sup>4</sup>Neuroscience and Biomedical Technologies Department, University of Milan Bicocca, Milan, Italy. <sup>5</sup>Institute of Cognitive Neuroscience, University College London, London, UK. <sup>6</sup>Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK. <sup>7</sup>Psychology Department, University "Vita e Salute H San Raffaele", Milan, Italy. <sup>8</sup>Institute of Human Physiology, University of Parma, Parma, Italy. <sup>9</sup>Centre de Recherche Institut Universitaire de Gériatrie, Montréal, Québec, Canada.

\*To whom correspondence should be addressed at University of Milan Bicocca. E-mail: eraldo.paulesu@unimib.it

A

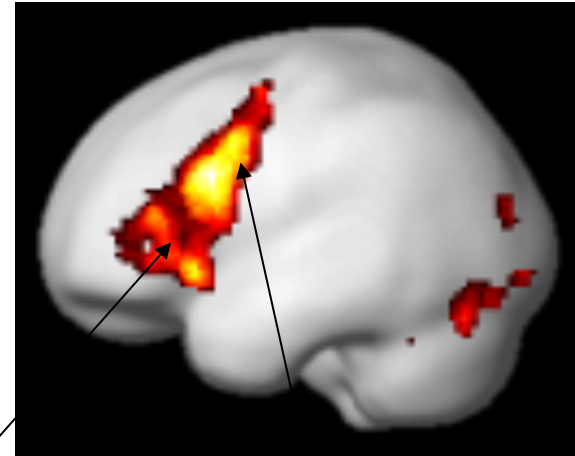


Wernicke's area

Posterior temporal lobe

Broca's area (BA45)

B



电  
+  
店

Middle frontal gyrus (BA9)

Ziegler & Habib (2005) TICS

# A structural–functional basis for dyslexia in the cortex of Chinese readers

Wai Ting Siok<sup>†‡</sup>, Zhendong Niu<sup>§</sup>, Zhen Jin<sup>¶</sup>, Charles A. Perfetti<sup>||</sup>, and Li Hai Tan<sup>††‡‡</sup>

In and Cognitive Sciences, University of Hong Kong, Pokfulam Road, Hong Kong;  
<sup>||</sup>Institute of Technology, Beijing 100081, China; <sup>¶</sup>Beijing 306 Hospital,  
<sup>||</sup>Department Center, University of Pittsburgh, Pittsburgh, PA 15260

of Technology, Cambridge, MA, February 25, 2008 (received for review January 1, 2008)

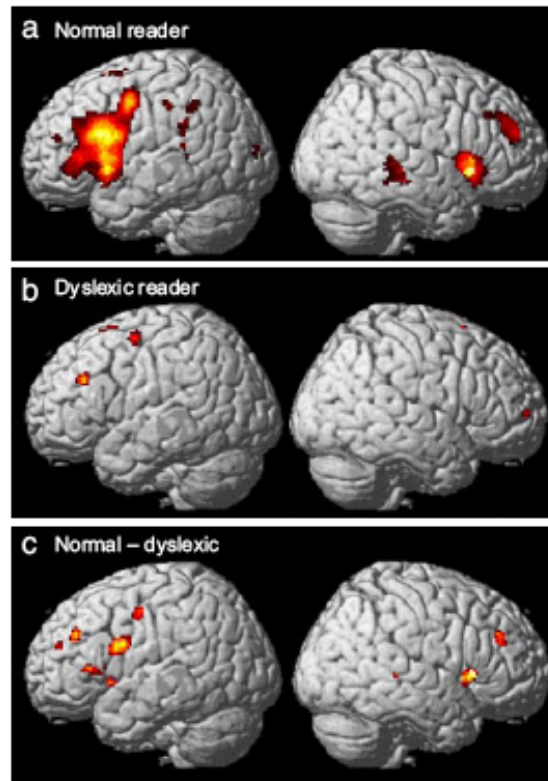


Fig. 2. Brain regions with significant activation during rhyme judgment. (a and b) Cortical activation associated with rhyme judgment contrasted with font-size decision in normal and dyslexic Chinese readers. (c) Brain regions showing group differences during rhyme judgment.

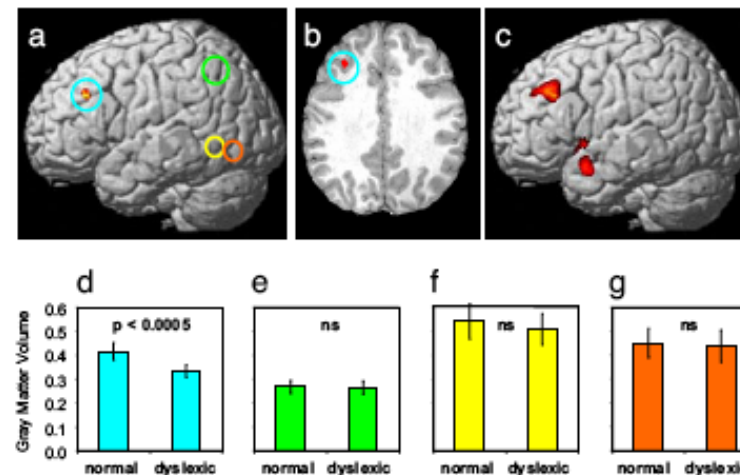


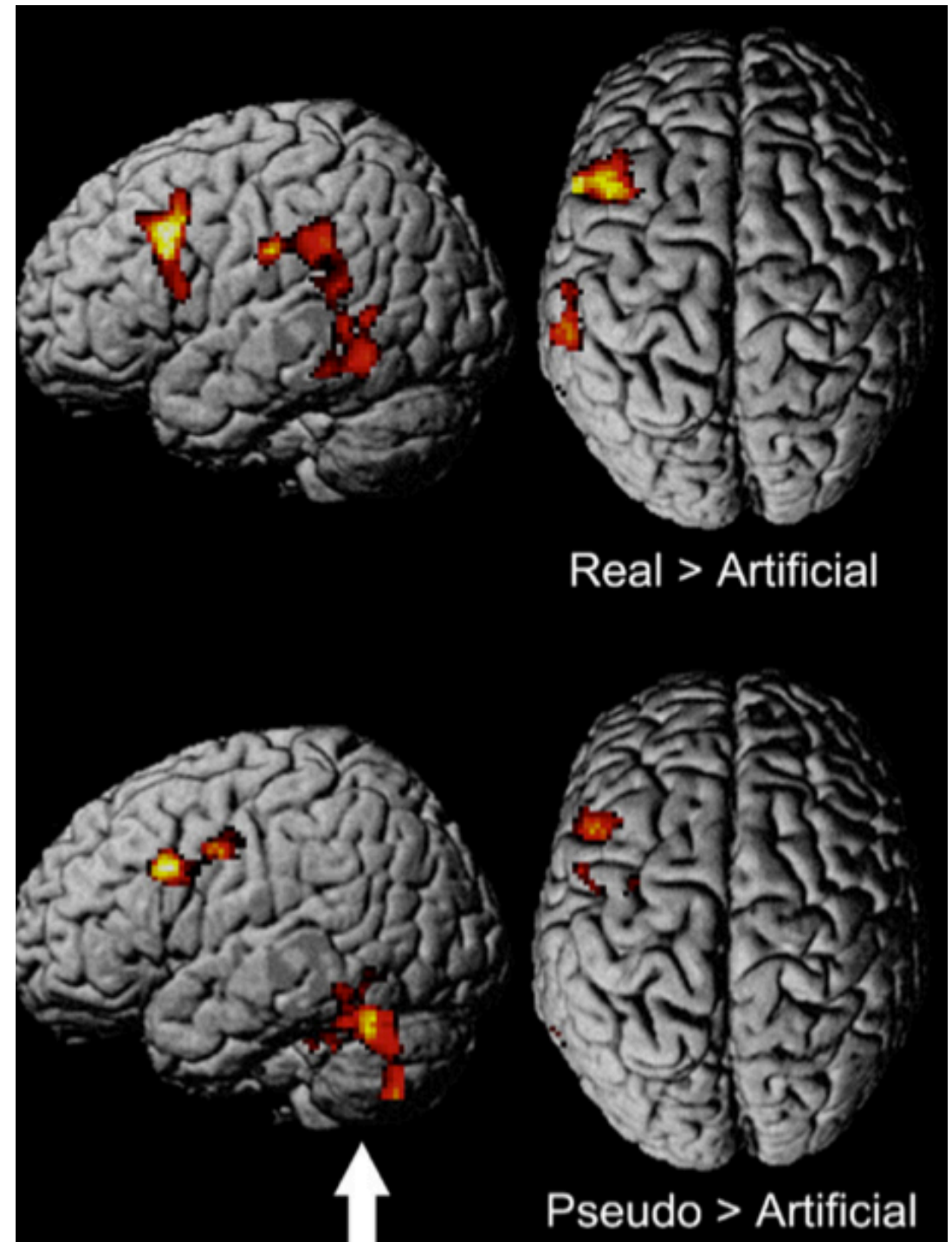
Fig. 1. Group differences in gray matter volume. (a, b, and d) A region in the left middle frontal gyrus (BA 9;  $x = -32$ ,  $y = 31$ ,  $z = 28$ ) exhibited reduced volume in the dyslexic group,  $P < 0.05$  corrected using the FWE correction for the whole brain. (c) At a less stringent uncorrected threshold of  $P < 0.001$ , reduced gray matter volume was seen in the left anterior temporal gyrus (BA 38/21) and the left Sylvian fissure, in addition to the left middle frontal gyrus. (e–g) ROI analysis of gray matter volume difference in the left posterior temporoparietal region (in green), the left middle temporal gyrus (in yellow), and the left inferior occipito-temporal cortex (in orange). No significant alteration was observed in these regions.

Parmi les aires sous-activées en IRMf, une région du GFMoy Gche présente une diminution significative du volume de substance grise

## The Visual Word Form Area: Evidence from an fMRI study of implicit processing of Chinese characters

Chao Liu,<sup>a,b</sup> Wu-Tian Zhang,<sup>a</sup> Yi-Yuan Tang,<sup>a,c</sup> Xiao-Qin Mai,<sup>a,b,d</sup> Hsuan-Chih Chen,<sup>c</sup> Twila Tardif,<sup>b,d</sup> and Yue-Jia Luo<sup>a,f,\*</sup>

<sup>a</sup>Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences, Beijing, 100101, China





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# Neural Systems for Compensation and Persistence: Young Adult Outcome of Childhood Reading Disability

Sally E. Shaywitz, Bennett A. Shaywitz, Robert K. Fulbright, Pawel Skudlarski,  
W. Einar Mencl, R. Todd Constable, Kenneth R. Pugh, John M. Holahan,  
Karen E. Marchione, Jack M. Fletcher, G. Reid Lyon, and John C. Gore

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BIOL PSYCHIATRY  
2003;54:25–33

3 groups :

NI (non-impaired)

AIR (compensated)

PPR (persistent poor)

2 tasks :

NWR = « do [LEAT] and [JETE]  
rhyme? »

CAT = « are [CORN] and [RICE]  
from the same category »

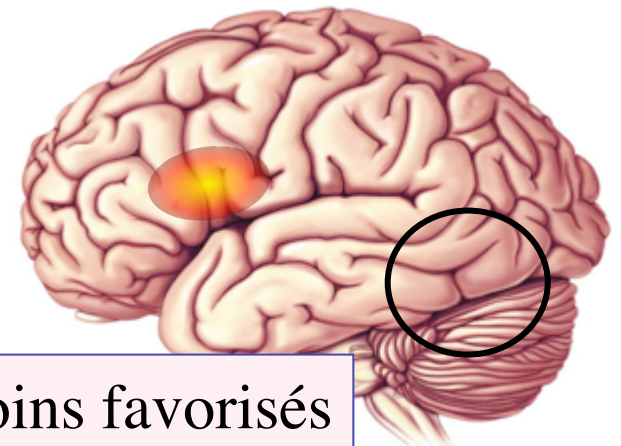
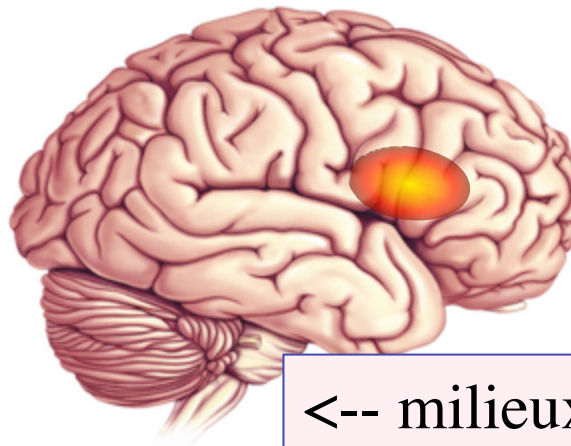
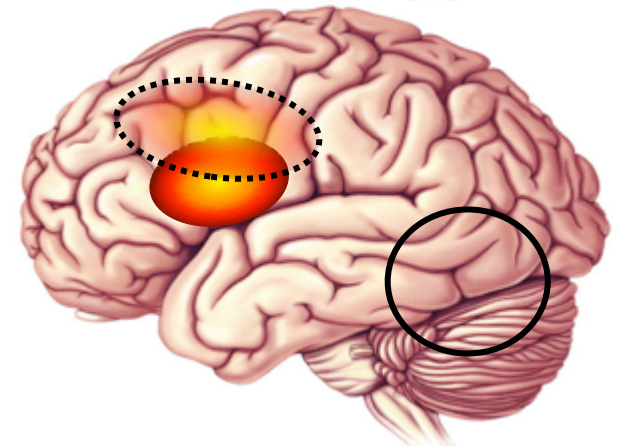
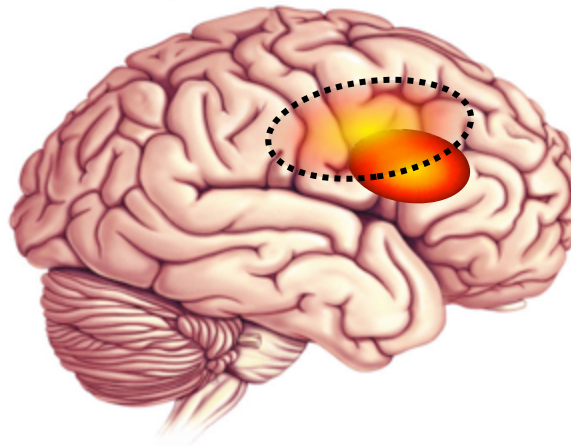
LEAT JETE

Témoins  
non dys

Riment?

Dyslexiques  
"compensés"

Dyslexiques  
"persistants"



<-- milieux moins favorisés

Table 1. Early Influences and Measures as Young Adults

|                                                                           | Group               |                      |                      |
|---------------------------------------------------------------------------|---------------------|----------------------|----------------------|
|                                                                           | NI ( <i>n</i> = 27) | AIR ( <i>n</i> = 19) | PPR ( <i>n</i> = 24) |
| Early Influences                                                          |                     |                      |                      |
| Family SES <sup>a,f</sup>                                                 |                     |                      |                      |
| High                                                                      | 18                  | 6                    | 8                    |
| Average                                                                   | 7                   | 6                    | 6                    |
| Low                                                                       | 2                   | 7                    | 10                   |
| % School Subsidized Meals <sup>b,g</sup>                                  | 11.2 (13.3)         | 15.5 (19.5)          | 28.4 (25.6)          |
| Child                                                                     |                     |                      |                      |
| WISC-R (Wechsler 1981) FSIQ—Grade 1 <sup>c</sup>                          | 116 (9.1)           | 108 (11.0)           | 97 (16.1)            |
| Woodcock Johnson Reading (Woodcock and Johnson 1977)—Grade 1 <sup>a</sup> | 117 (9.4)           | 94.0 (11.2)          | 87.9 (15.1)          |
| Measures as Young Adults                                                  |                     |                      |                      |
| Age (years)                                                               | 20.3 (1.0)          | 19.9 (.9)            | 19.9 (1.1)           |
| WAIS-R (Wechsler 1981) FSIQ <sup>d</sup>                                  | 110 (8.5)           | 100 (9.9)            | 91.2 (11.0)          |
| Woodcock-Johnson Revised (Woodcock and Johnson 1989)                      |                     |                      |                      |
| Letter-Word Identification <sup>d</sup>                                   | 123 (13.0)          | 109 (15.0)           | 95.8 (3.9)           |
| Word Attack <sup>d</sup>                                                  | 141 (11.4)          | 122 (16.6)           | 104 (11.4)           |
| Gray Oral Reading (Wiederholt and Bryant 1992)                            |                     |                      |                      |
| Accuracy <sup>d</sup>                                                     | 12.2 (3.3)          | 5.7 (3.2)            | 3.1 (2.3)            |
| Rate <sup>d</sup>                                                         | 14.1 (1.2)          | 9.2 (2.1)            | 6.7 (2.0)            |
| Passage <sup>d</sup>                                                      | 13.2 (2.1)          | 7.6 (2.2)            | 4.9 (2.0)            |
| Comprehension <sup>c</sup>                                                | 10.5 (3.4)          | 10.2 (2.8)           | 7.7 (3.4)            |
| Quotient <sup>d</sup>                                                     | 111 (12.4)          | 93.2 (12.9)          | 77.9 (13.7)          |
| Prose Literacy <sup>c,h</sup>                                             | 341 (28.2)          | 319 (27.1)           | 283 (36.8)           |

Numbers in parentheses are SD.

NI, nonimpaired readers; AIR, accuracy improved (compensated) readers; PPR, persistently poor readers; SES, socioeconomic status; WISC-R, Wechsler Intelligence Scale for Children-Revised; FSIQ, fullscale intelligence quotient; WAIS-R, Wechsler Adult Intelligence Scale-Revised.

<sup>a</sup>NI > AIR, AIR = PPR, NI > PPR

<sup>b</sup>NI = AIR, AIR = PPR, NI < PPR

<sup>c</sup>NI = AIR, AIR > PPR, NI > PPR

<sup>d</sup>NI > AIR, AIR > PPR, NI > PPR

<sup>e</sup>NI = AIR, AIR = PPR, NI > PPR

## Shaywitz et al., 2003 : Conclusion

- À égalité de sévérité initiale de la dyslexie
- Les deux groupes (compensé et persistant) diffèrent
  - outre l'évolution de la dyslexie
  - Par le QI de départ (compensé > persistant)
  - Par le niveau socio-culturel (non significativement différent au début)
  - Par le degré de compréhension écrite (pers. > comp.)

« PPR may represent a more environmentally influenced dyslexic reader »

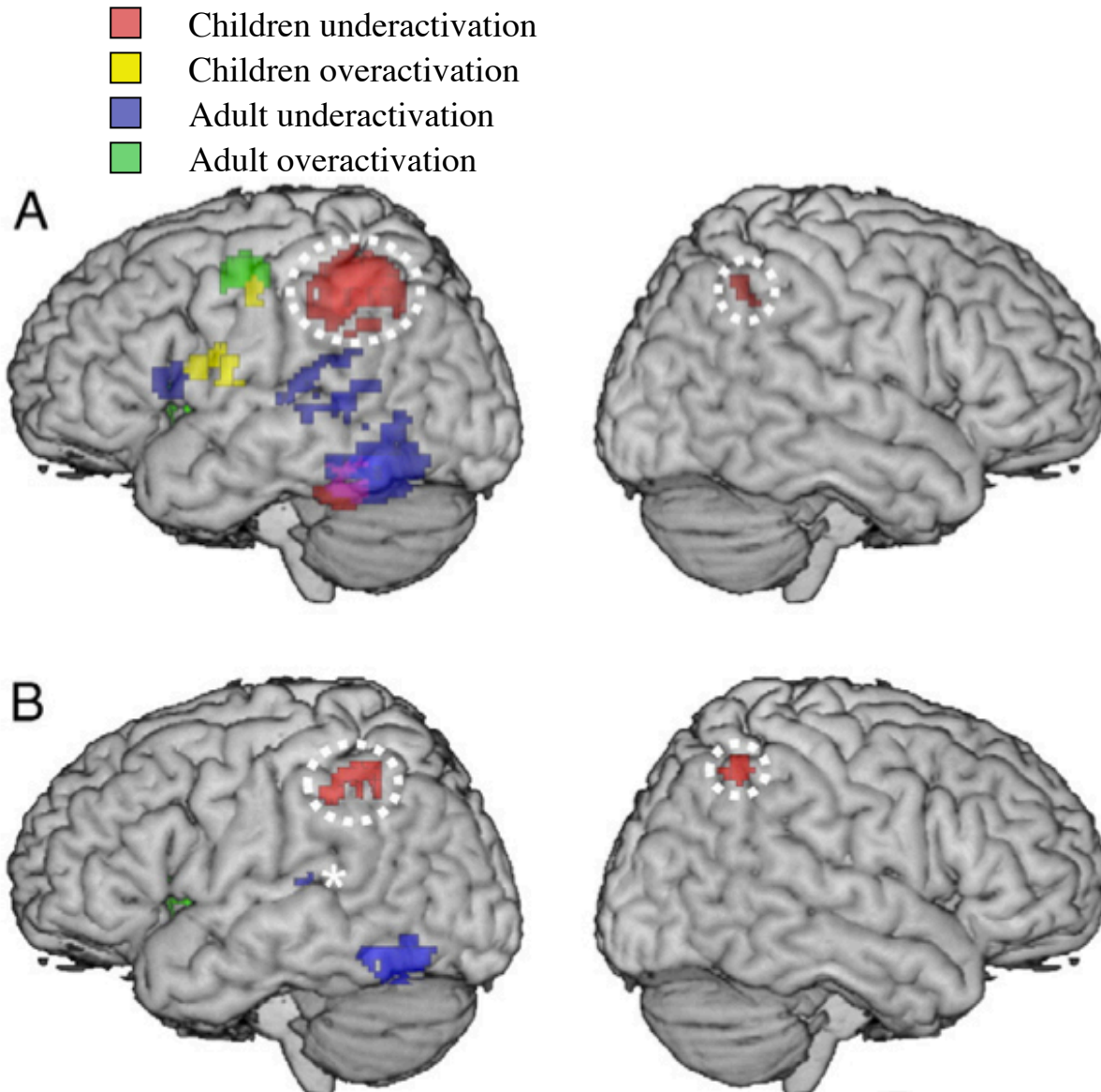


# Meta-analyzing brain dysfunctions in dyslexic children and adults

Fabio Richlan<sup>a,\*</sup>, Martin Kronbichler<sup>a,b</sup>, Heinz Wimmer<sup>a</sup>

<sup>a</sup> Department of Psychology and Center for Neurocognitive Research, University of Salzburg, Hellbrunnerstr. 34, 5020 Salzburg, Austria

<sup>b</sup> Neuroscience Institut and Department of Neurology, Christian Doppler Clinic, Paracelsus Private Medical University, Ignaz-Harrer-Str. 79, 5020 Salzburg, Austria



We examined the evidence from functional imaging studies for predominance of a phonological left temporo- parietal (TP) dysfunction in dyslexic children and predominance of a visual-orthographic left occipito-temporal (OT) dysfunction in dyslexic adults. Separate meta-analyses of **9 studies with children (age means: 9-11 years)** and of **9 studies with adults (age means: 18-30 years)** and statistical comparison of these meta-analytic maps did find support for a dysfunction of a left ventral OT region in both children and adults. The findings on a possible predominance of a left TP dysfunction in children were inconclusive. Contrary to expectation, underactivation in superior temporal regions was only found for adults, but not for children. For children, underactivation was found in bilateral inferior parietal regions, but this abnormality was no longer present when foci identified by higher dyslexic task-negative activation (i.e., deactivation in response to reading compared to baseline) were excluded. These meta-analytic results are consistent with recent findings speaking for an early engagement of left OT regions in reading development and for an early failure of such an engagement in dyslexia.

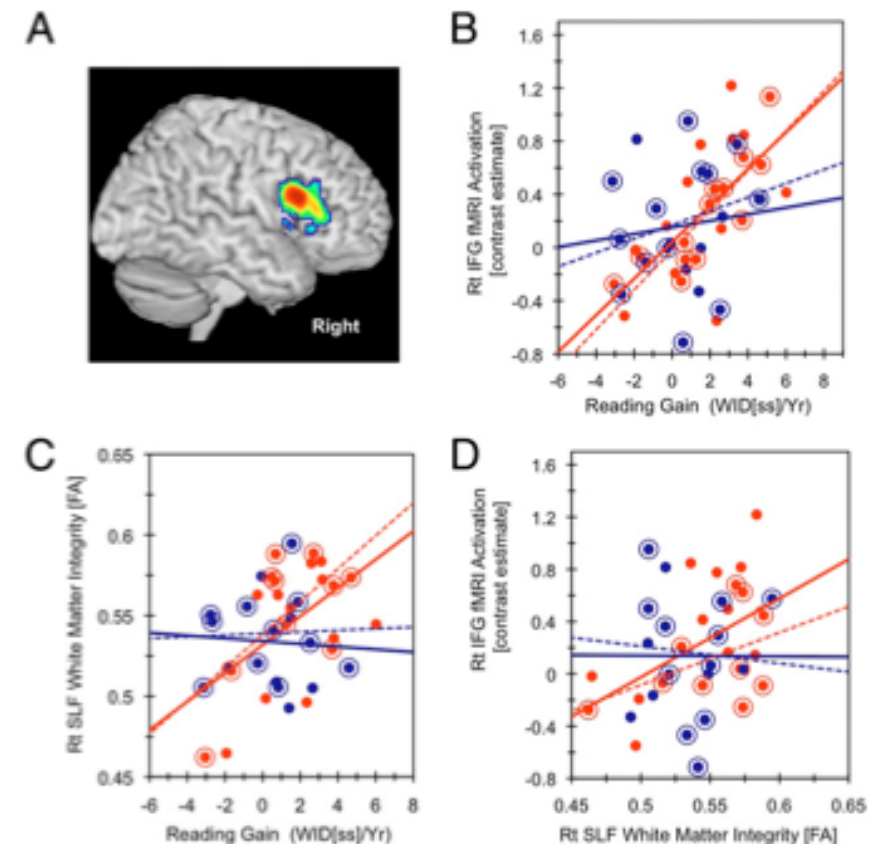
# Neural systems predicting long-term outcome in dyslexia

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

<sup>a</sup>Center for Interdisciplinary Brain Sciences Research, and <sup>b</sup>Department of Psychiatry and Behavioral Sciences, Stanford University School of Medicine, Stanford, CA 94129; <sup>c</sup>Department of Psychology and Human Development, Vanderbilt University, Nashville, TN 37203; <sup>d</sup>Graduate School of Social Work, Boston College, Chestnut Hill, MA 02467; <sup>e</sup>Department of Psychology, University of York, York YO10 5DD, United Kingdom; <sup>f</sup>Department of Psychology, University of Jyväskylä, 40351 Jyväskylä, Finland; <sup>g</sup>Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139; and <sup>h</sup>Department of Radiology, Stanford University School of Medicine, Stanford, CA 94305

Edited by Marcus E. Raichle, Washington University of St. Louis, St. Louis, MO, and approved November 2, 2010 (received for review June 24, 2010)

Utilisent une double méthodologie d'imagerie fonctionnelle et morphologique (DTI) pour prédire l'évolution à long terme du trouble de la lecture chez des pré-adolescents dyslexiques. Deux mesures particulières (activation du lobe frontal inférieur droit en IRMf et anisotropie du faisceau arqué droit en DTI) prédisent à elles seules 72% de la variance en termes d'évolution de la lecture sur 2,5 ans faisant suite au premier examen. Ces mesures sont des meilleurs prédicteurs de l'évolution que n'importe quelle combinaison de tests cognitifs réalisés sur la même période.



**Fig. 2.** fMRI and DTI predictors of reading gains in dyslexia. (A) Association between brain activation (rhyme > rest) and future reading improvement.



# Grey Matter Alterations Co-Localize with Functional Abnormalities in Developmental Dyslexia: An ALE Meta-Analysis

Janosch Linkersdörfer<sup>1,2\*</sup>, Jan Lonnemann<sup>2,3</sup>, Sven Lindberg<sup>1,2</sup>, Marcus Hasselhorn<sup>1,2,3</sup>,  
Christian J. Fiebach<sup>1,3,4</sup>

<sup>1</sup> Center for Individual Development and Adaptive Education of Children at Risk, Frankfurt, Germany, <sup>2</sup> German Institute for International Educational Research, Frankfurt, Germany, <sup>3</sup> Institute for Psychology, Goethe-University Frankfurt, Germany, <sup>4</sup> Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, The Netherlands

## Abstract

The neural correlates of developmental dyslexia have been investigated intensively over the last two decades and reliable evidence for a dysfunction of left-hemispheric reading systems in dyslexic readers has been found in functional neuroimaging studies. In addition, structural imaging studies using voxel-based morphometry (VBM) demonstrated grey matter reductions in dyslexics in several brain regions. To objectively assess the consistency of these findings, we performed activation likelihood estimation (ALE) meta-analysis on nine published VBM studies reporting 62 foci of grey matter reduction in dyslexic readers. We found six significant clusters of convergence in bilateral temporo-parietal and left occipito-temporal cortical regions and in the cerebellum bilaterally. To identify possible overlaps between structural and functional deviations in dyslexic readers, we conducted additional ALE meta-analyses of imaging studies reporting functional underactivations (125 foci from 24 studies) or overactivations (95 foci from 11 studies) in dyslexics. Subsequent conjunction analyses revealed overlaps between the results of the VBM meta-analysis and the meta-analysis of functional underactivations in the fusiform and supramarginal gyri of the left hemisphere. An overlap between VBM results and the meta-analysis of functional overactivations was found in the left cerebellum. The results of our study provide evidence for consistent grey matter variations bilaterally in the dyslexic brain and substantial overlap of these structural variations with functional abnormalities in left hemispheric regions.

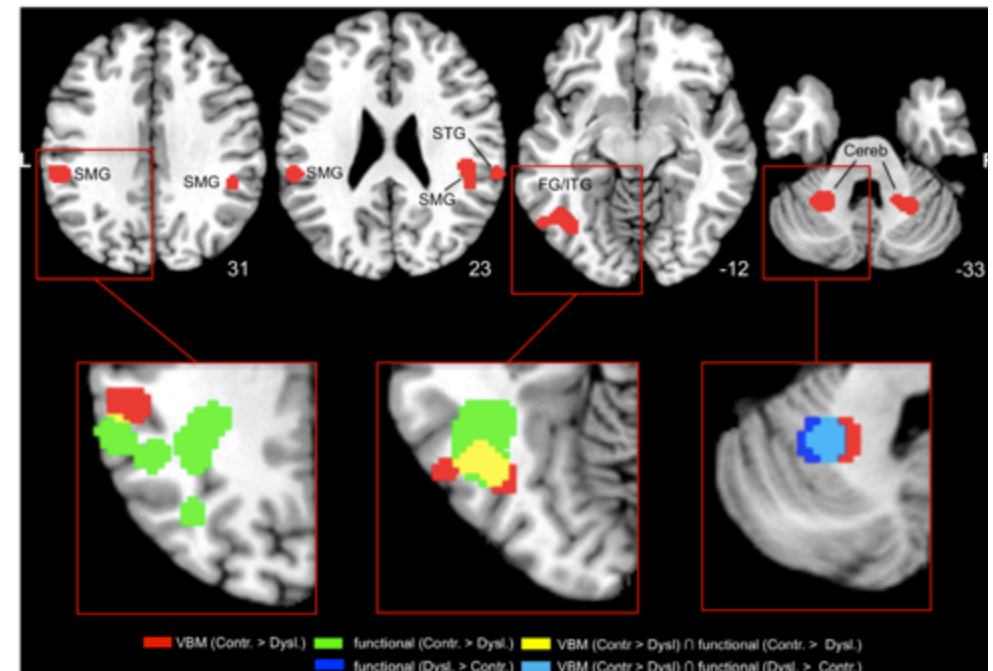
## Double méta-analyse :

- 9 études en VBM=62 foyers de réduction de SG chez dyslexiques
- 24 études en IRMf =125 foyers d'hypoactivation et 11 études=95 foyers de sur-activation

## Résultats:

- VBM : clusters de convergence dans G bilatéral, GTInf Gche et cervelet bilatéral
- superposition entre hypoactivation fonctionnelle et foyer de réduction VBM temporal inférieur gauche
- superposition entre hyperactivation et foyer de réduction VBM cervelet

Meta-Analysis Dyslexia – Structure & Function



**Figure 1. Results of the ALE meta-analysis of VBM studies and the conjunction analyses.** Upper row–2D axial slices depicting t thresholded and binarized ALE map for the VBM meta-analysis (red) projected onto the Colin T1-template in MNI space. Images are presented neurological convention (i.e., left = left) and MNI coordinates in the inferior-superior (Z) plane are provided with each slice. Lower row – cut-outs the axial slices display overlaps (yellow) of the VBM meta-analysis (red) with the thresholded and binarized ALE map for the meta-analysis functional underactivations (green) and overlaps (light blue) with the thresholded and binarized ALE map for the meta-analysis of functional overactivations (dark blue). SMG = supramarginal gyrus; STG = superior temporal gyrus; FG/ITG = fusiform gyrus/inferior temporal gyrus; Cereb = cerebellum.

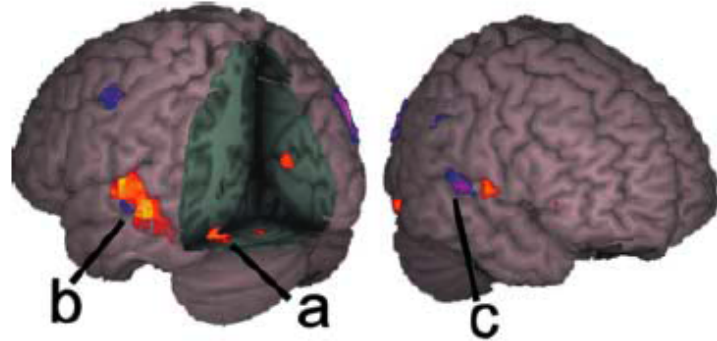
doi:10.1371/journal.pone.0043122.g001

## PAPER

### Brain–behavior relationships in reading acquisition are modulated by socioeconomic factors

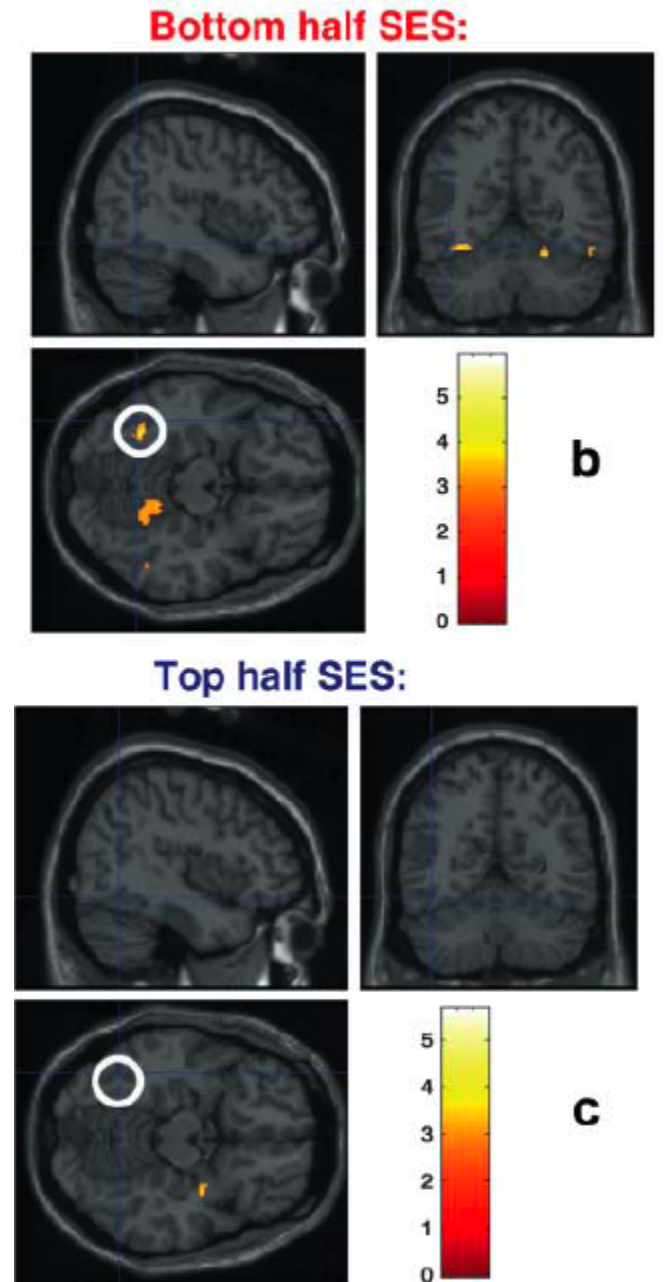
Kimberly G. Noble,<sup>1,2</sup> Michael E. Wolmetz,<sup>1</sup> Lisa G. Ochs,<sup>1</sup> Martha J. Farah<sup>2</sup> and Bruce D. McCandliss<sup>1</sup>

*1. Sackler Institute for Developmental Psychobiology, Weill Medical College of Cornell University, USA*

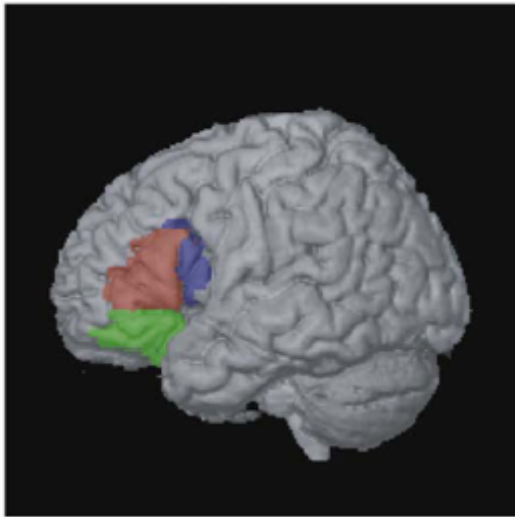


**Figure 2** Correlations of PA and activity in left fusiform and superior temporal gyrus regions, across a median split of SES. As in Figure 1, although all analyses were conducted using SES as a continuous variable, the continuum of SES has been schematically represented by dividing subjects by SES median split. Red-yellow represents correlations between PA and brain activity among children below the median SES, while blue-purple represents correlations between PA and activity among children above the median SES. Lower SES children show a positive correlation between PA and activity in (a) left fusiform (interaction cluster peak  $-34, -58, -16$ ). This correlation is not observed in higher SES children. While both lower SES and higher SES children show areas of positive correlation between PA and activity in (b) left perisylvian cortex (interaction cluster peak  $-54, -10, 10$ ) and (c) right perisylvian cortex (interaction cluster peak  $62, -26, 6$ ), the size of the regions exhibiting these correlations are qualitatively much larger in lower and higher SES children, respectively. Maps are depicted at  $p < .005$  uncorrected.

Pixels  
présentant une  
interaction entre  
PA (conscience  
phonologique)  
x SES (statut  
socio-  
économique)



a



## Socioeconomic status predicts hemispheric specialisation of the left inferior frontal gyrus in young children

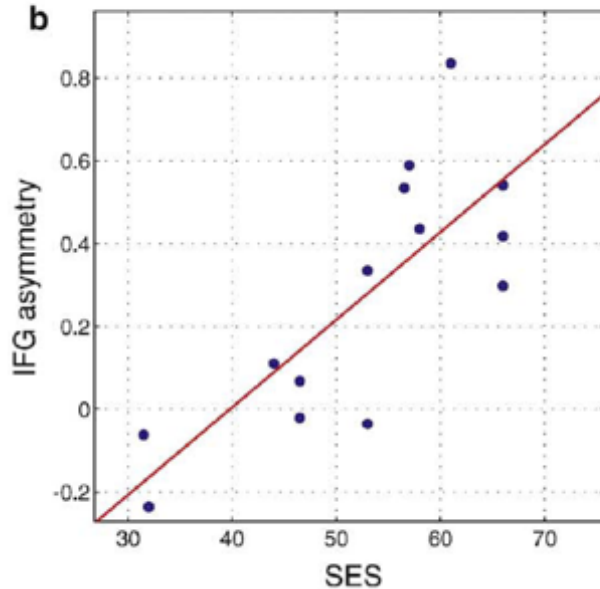
Rajeev D.S. Raizada,<sup>a,\*</sup> Todd L. Richards,<sup>b</sup> Andrew Meltzoff,<sup>a</sup> and Patricia K. Kuhl<sup>a</sup>

<sup>a</sup>Institute for Learning and Brain Sciences, University of Washington, Box 357988, Seattle, WA 98195, USA

<sup>b</sup>Department of Radiology, University of Washington Medical School, Seattle, WA 98195, USA

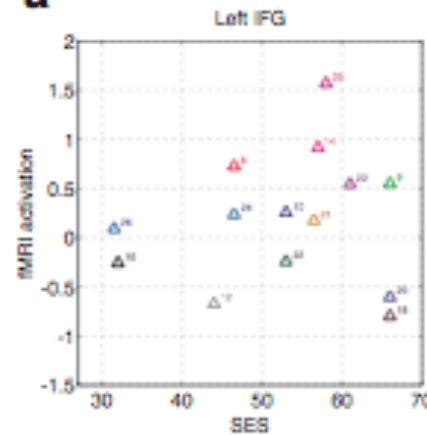
14 enfants de 5 ans, en "pre-school", de milieux socio-économiques moyen-faibles à aisés. fMRI sur tâche de rimes auditive + neuroanatomie en VBM (segmentation SG/SB).

b

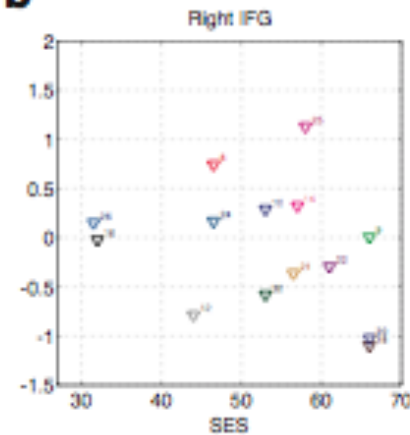


Corrélation entre le degré d'asymétrie de l'aire de Broca dans une tâche d'activation (dire si deux mots entendus riment) et le statut socio-économique

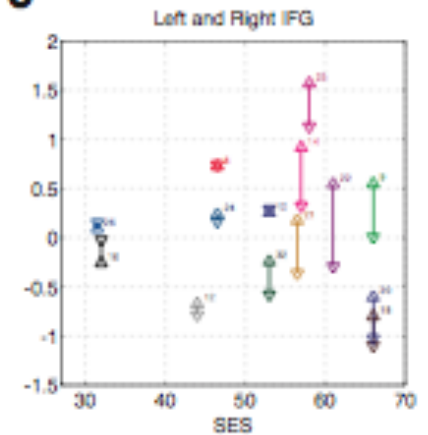
a



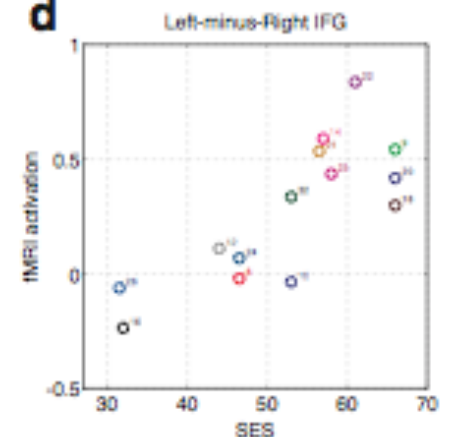
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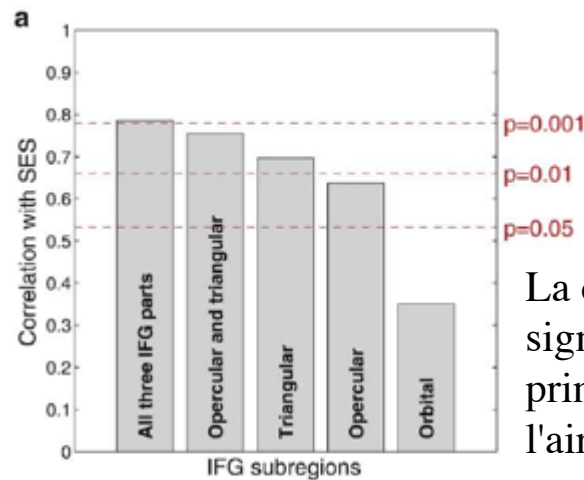
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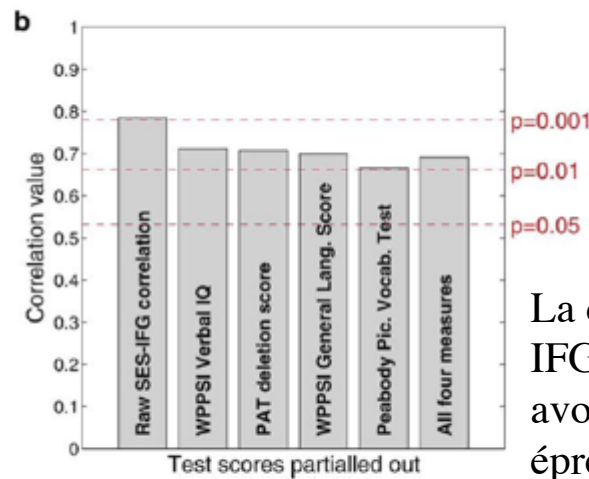
La corrélation concerne principalement l'asymétrie d'activation (et non chaque côté pris séparément)

Le statut socio-économique détermine donc le degré de latéralisation de la fonction étudiée





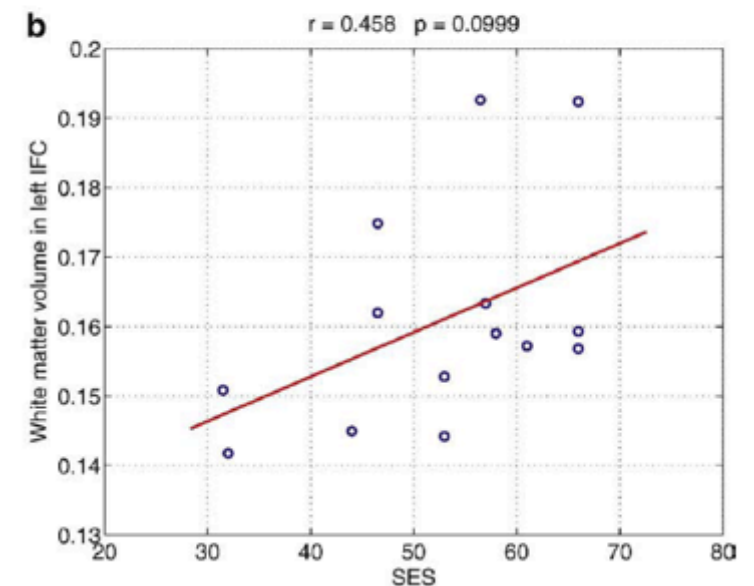
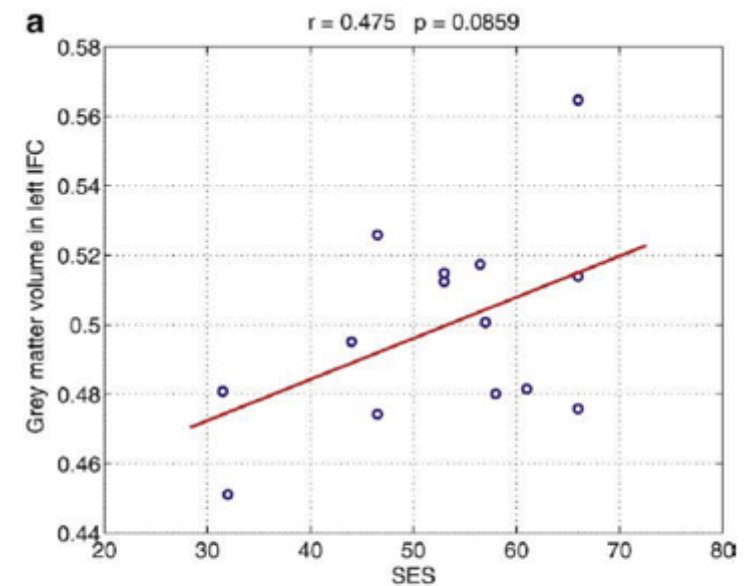
La corrélation est significative pour les deux principales régions de l'aire de Broca



La corrélation entre SES et IFG reste significative après avoir éliminé les scores aux épreuves verbales

Fig. 3. (a) The correlations of the different subparts of the IFG with socioeconomic status. (b) The partial correlations between SES and IFG asymmetry, after removing the effects of various standardised test scores. The test that was partialled out is marked on each bar, with the leftmost bar showing the correlation without any partialling and the rightmost bar showing the effect of partialling out the four test scores simultaneously.

Conclusion : le niveau socio-économique détermine en partie non seulement le degré de latéralisation de la fonction, mais la taille même des structures sous-jacentes.



Il existe également une corrélation du point de vue neuroanatomique entre les volumes de SG et de SB et le SES



## Structural brain alterations associated with dyslexia predate reading onset

Nora Maria Raschle, Maria Chang, Nadine Gaab\*

Children's Hospital Boston, Department of Medicine, Division of Developmental Medicine, Laboratories of Cognitive Neuroscience, 1 Autumn Street, Mailbox # 713, Boston, MA 02115, USA

Twenty healthy, native English speaking children with (FHD+/ n = 10) and without (FHD–/n = 10) a family-history of developmental dyslexia, (mean age 5 years and 11 months)

Voxel-based morphometry revealed significantly reduced gray matter volume indices for pre-reading children with, compared to children without, a family-history of developmental dyslexia in left occipitotemporal, bilateral parietotemporal regions, left fusiform gyrus and right lingual gyrus. Gray matter volume indices in left hemispheric occipitotemporal and parietotemporal regions of interest also correlated positively with rapid automatized naming.

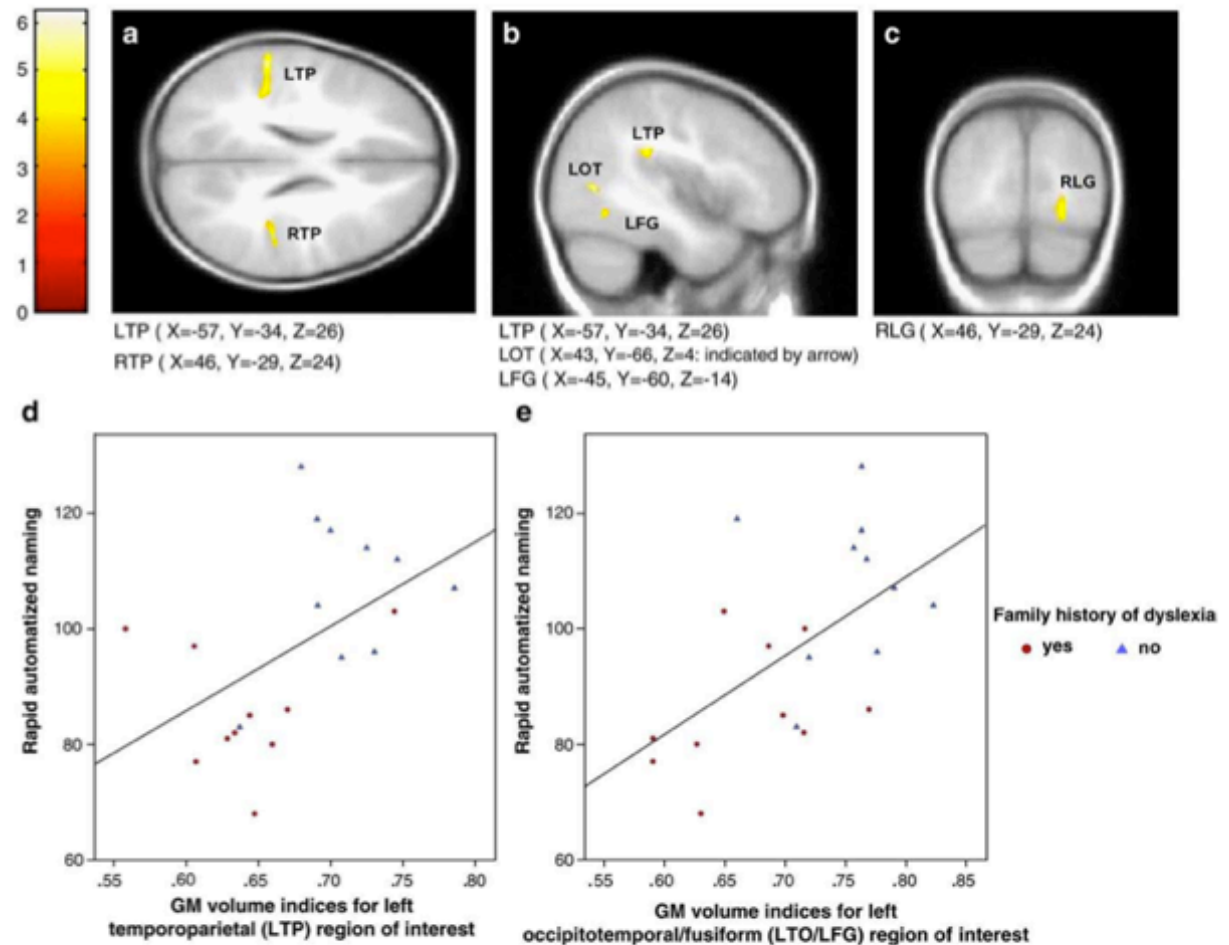


Fig. 1. [a–c] Statistical parametric maps showing brain areas with significant decreased gray matter volume indices in pre-reading FHD+ compared to FHD– children (a = axial, b = sagittal, c = coronal view). [d–e] Correlations between gray matter volume indices in the left parietotemporal (d) and left occipitotemporal/fusiform (LTO/LFG) region of interest (e) and rapid automatized naming.

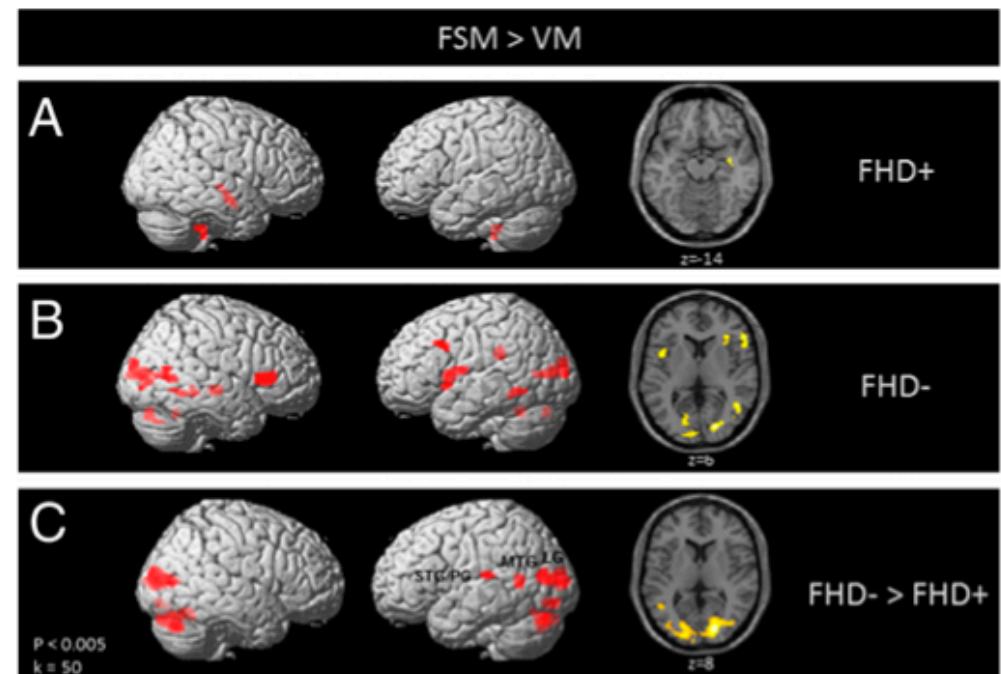


# Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset

Nora Maria Raschle<sup>a,b</sup>, Jennifer Zuk<sup>a</sup>, and Nadine Gaab<sup>a,b,c,1</sup>

<sup>a</sup>Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Department of Medicine, Children's Hospital Boston, and <sup>b</sup>Harvard Medical School, Boston, MA 02115; and <sup>c</sup>Harvard Graduate School of Education, Cambridge, MA 02138

Activation d'un réseau occipito-temporo-frontal chez des enfants pré-lecteurs (moyenne âge 5ans 8mois) avec (FHD+) ou sans (FHD-) une histoire familiale de dyslexie avérée, dans une tâche de décision de similitude du premier phonème de deux mots représentés sur des dessins



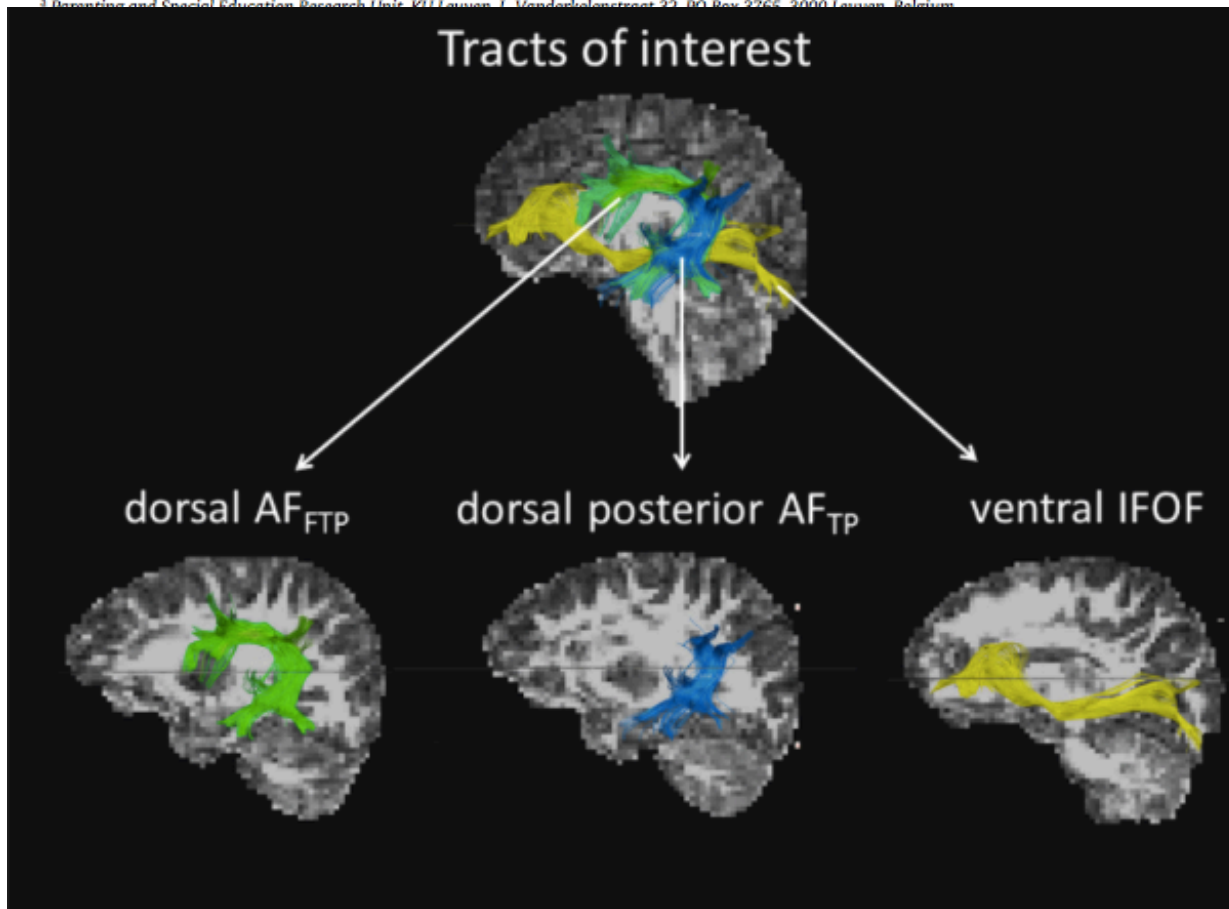
**Fig. 1.** Statistical parametric maps showing brain activation during phonological processing (FSM > VM) for children with (A) and without (B) a familial risk for DD, as well as group differences between children with compared to without (FHD<sup>-</sup> > FHD<sup>+</sup>) a familial risk for DD (C). FHD<sup>-</sup> show significantly greater activation compared to FHD<sup>+</sup> children in bilateral occipitotemporal and left temporoparietal brain regions, as well as left and right cerebellar regions.



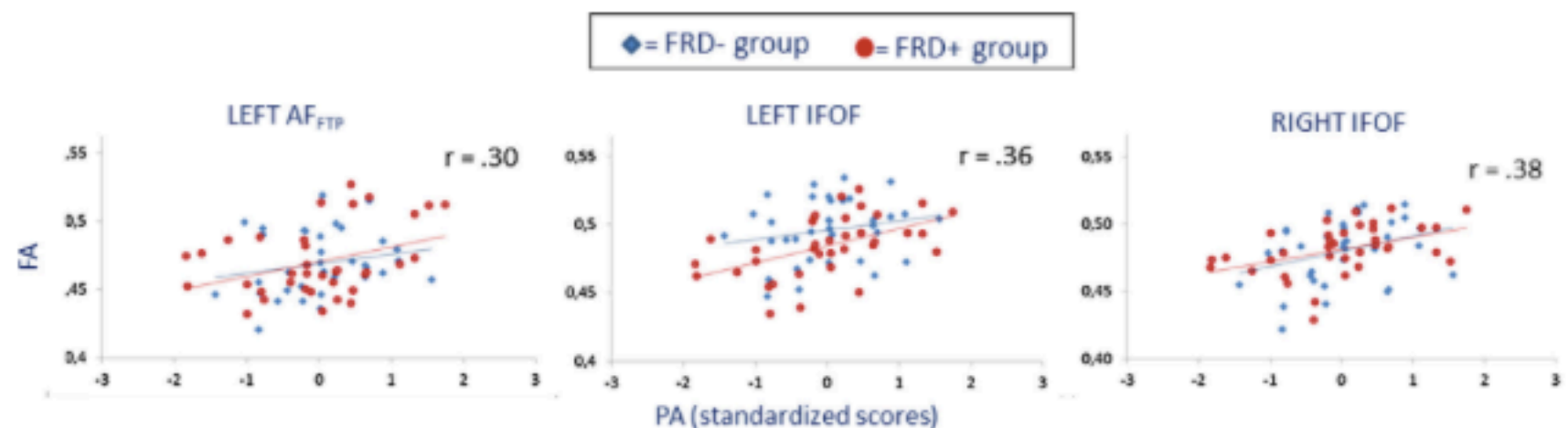
## A DTI tractography study in pre-readers at risk for dyslexia

Maaïke Vandermosten<sup>a,b,\*</sup>, Jolijn Vanderauwera<sup>a,b</sup>, Catherine Theys<sup>b</sup>, Astrid De Vos<sup>a,b</sup>, Sophie Vanvooren<sup>a,b</sup>, Stefan Sunaert<sup>c</sup>, Jan Wouters<sup>b</sup>, Pol Ghesquière<sup>a</sup>

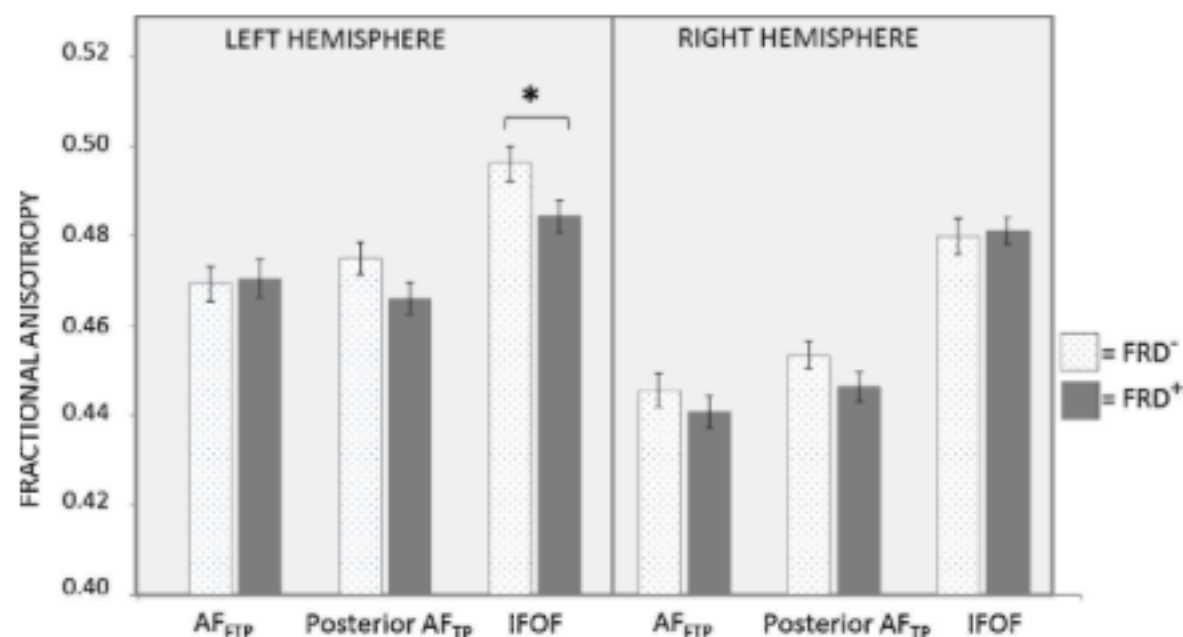
<sup>a</sup> Department of Special Education Research Unit, KU Leuven, J. Vanderkelenstraat 22, PO Box 2265, 2000 Leuven, Belgium



Using diffusion MRI in 36 pre-readers with a family risk for dyslexia (FRD+) and 35 well matched pre-readers without a family risk (FRD–), our results show that phonological predictors of reading are sustained bilaterally by both ventral and dorsal tracts. This suggests that a dorsal and left-hemispheric specialisation for phonological aspects of reading, as observed in adults, is presumably gradually formed throughout reading development



**Fig. 2.** depicts the significant correlations between phonological awareness (PA) and fractional anisotropy (FA) in left AF<sub>FTP</sub> and bilateral IFOF. Data of FRD<sup>-</sup> group are depicted in blue diamonds and data of FRD<sup>+</sup> group in red circles. The reported Pearson correlation values are calculated across the whole sample. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

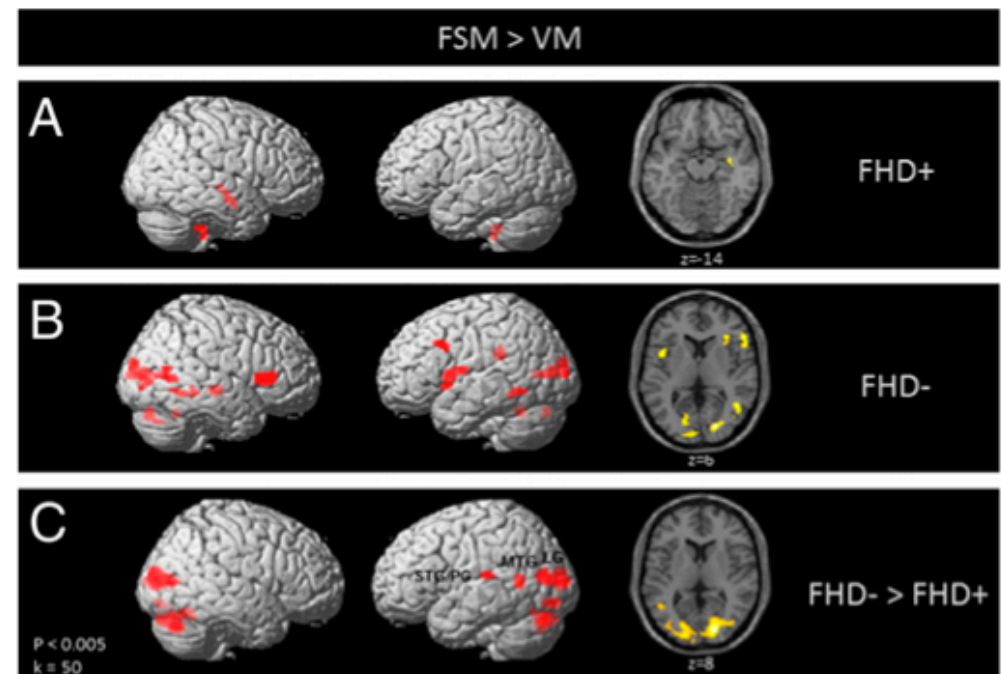


# Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset

Nora Maria Raschle<sup>a,b</sup>, Jennifer Zuk<sup>a</sup>, and Nadine Gaab<sup>a,b,c,1</sup>

<sup>a</sup>Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Department of Medicine, Children's Hospital Boston, and <sup>b</sup>Harvard Medical School, Boston, MA 02115; and <sup>c</sup>Harvard Graduate School of Education, Cambridge, MA 02138

Activation d'un réseau occipito-temporo-frontal chez des enfants pré-lecteurs (moyenne âge 5ans 8mois) avec (FHD+) ou sans (FHD-) une histoire familiale de dyslexie avérée, dans une tâche de décision de similitude du premier phonème de deux mots représentés sur des dessins



**Fig. 1.** Statistical parametric maps showing brain activation during phonological processing (FSM > VM) for children with (A) and without (B) a familial risk for DD, as well as group differences between children with compared to without (FHD- > FHD+) a familial risk for DD (C). FHD- show significantly greater activation compared to FHD+ children in bilateral occipitotemporal and left temporoparietal brain regions, as well as left and right cerebellar regions.



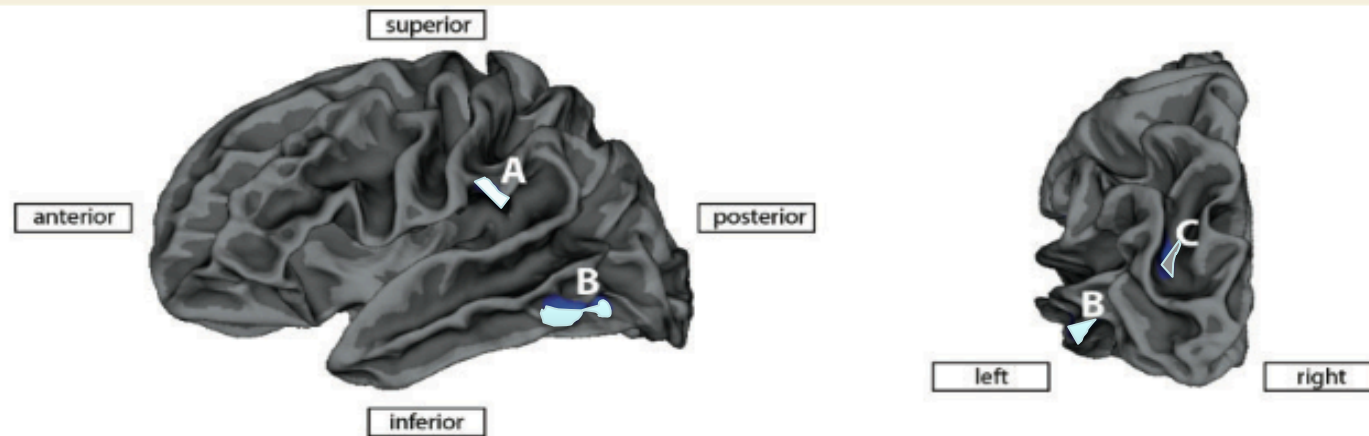
## LETTER TO THE EDITOR

### Cortical differences in preliterate children at familial risk of dyslexia are similar to those observed in dyslexic readers

Indra Kraft,<sup>1</sup> Riccardo Cafiero,<sup>1</sup> Gesa Schaadt,<sup>1,2</sup> Jens Brauer,<sup>1</sup> Nicole E. Neef,<sup>1</sup> Bent Müller,<sup>3</sup> Holger Kirsten,<sup>3</sup> Arndt Wilcke,<sup>3</sup> Johannes Boltze,<sup>3,4</sup> Angela D. Friederici<sup>1</sup> and Michael A. Skeide<sup>1</sup>

<sup>1</sup> Department of Neuropsychology, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

Crucially, Clark and colleagues had only 57% power in their sample at MRI time point 1 to detect the clusters in the left supramarginal gyrus and the left occipito-temporal cortex identified in our analyses (effect size = 0.93; effect size in Clark et al. = 0.53; effect size is defined as the mean difference divided by common standard deviation). Despite the significant value of the longitudinal study by Clark and colleagues for the field, larger and statistically more powerful studies may be required to reveal ultimately which of the contrary hypotheses best approximates reality.



**Figure 1** Cortical thickness differences between 5-year-old preliterate children at familial risk of developmental dyslexia and non-risk controls. Compared to children without a family history of developmental dyslexia, individuals with a family history of developmental dyslexia showed a significantly reduced cortical thickness ( $P < 0.05$ , false discovery rate corrected) in the left supramarginal gyrus (A), the left inferior temporal gyrus (B), and the left superior and transversal occipital sulci (C), but not in right-hemispheric regions. The opposite contrast (non-risk children versus at-risk children) did not reveal any significant results. Depicted are z-transformed cortical thickness values on the white matter surface of the group-averaged left hemisphere.



# En résumé,

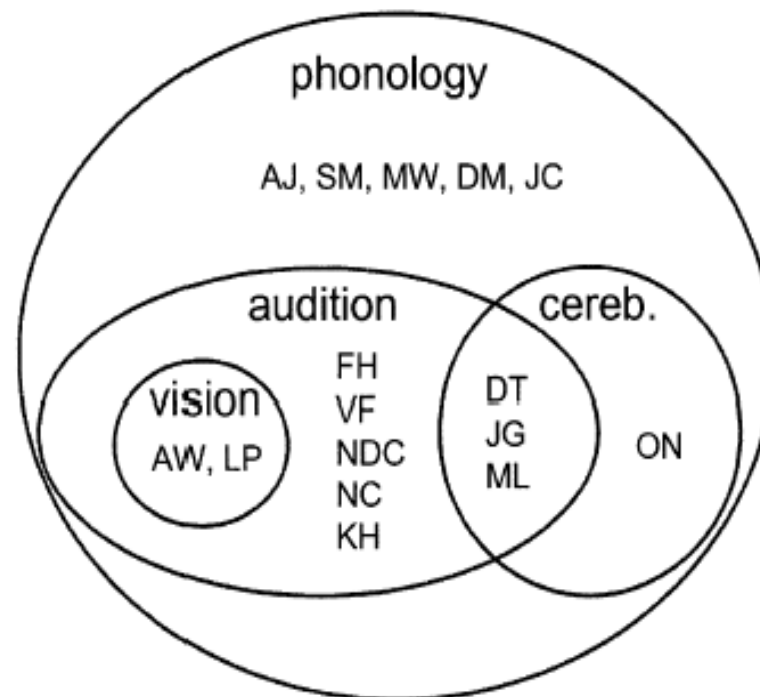
- Le cerveau du dyslexique présente des anomalies tant morphologiques que fonctionnelles des régions principalement hémisphériques gauches impliquées dans la lecture : aire temporo-occipitale de la forme visuelle des mots, aire de Broca frontale inférieure, aire pariétale d'intégration multisensorielle...
- Ces anomalies sont certainement en relation avec une prédisposition génétique actuellement vue plutôt comme trait génétique complexe (multiples allèles interagissant et chacun augmentant le risque)...
- ...et aussi interagissant toujours avec des facteurs environnementaux :
  - autres facteurs biologiques extrinsèques,
  - environnement langagier,
  - orthographe de la langue,
  - méthodes d'enseignement de la lecture,
  - rééducations et traitements.

# Dyslexie : du cerveau à la dysfonction

- Approche centrée sur l'explication du trouble de la lecture
  - Causes proximales : phonologique et visuelle
  - Causes distales : multiples
- Approche prenant en compte les co-occurrences
  - Trouble du traitement temporel
  - Trouble cérébelleux
  - Trouble du transcodage intermodalitaire

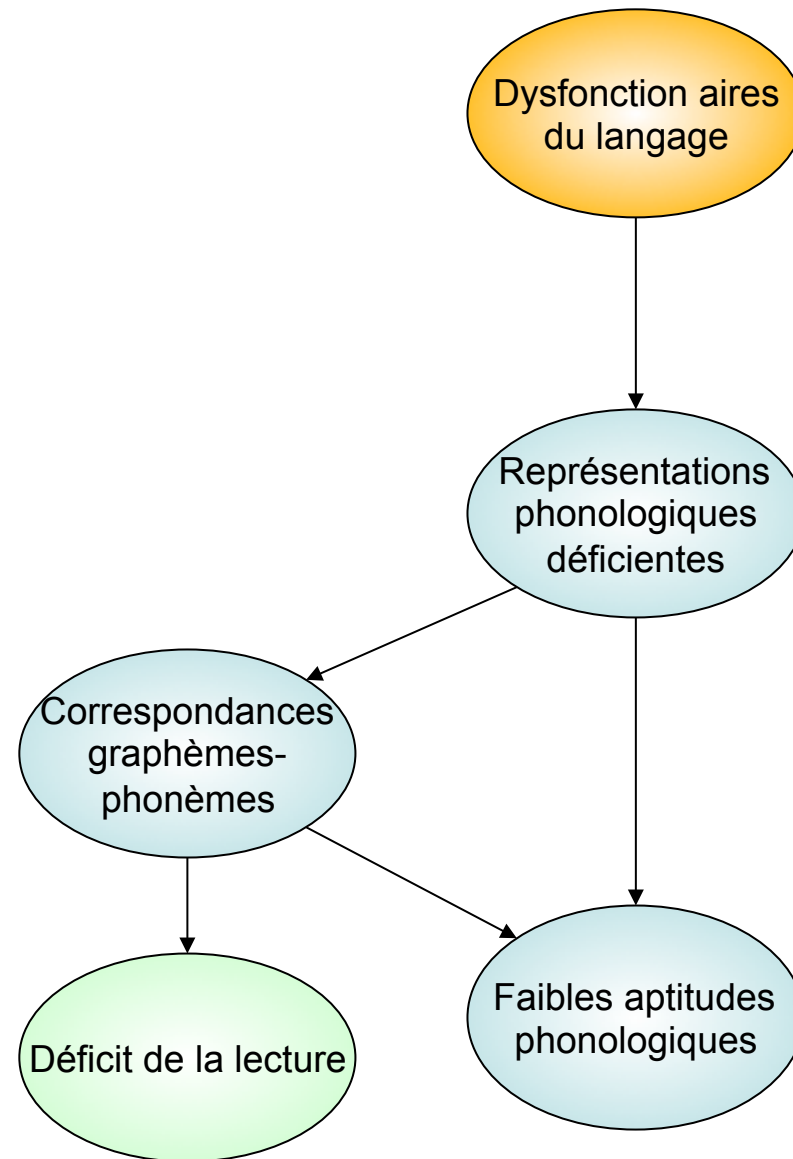
# Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults

Franck Ramus,<sup>1,5</sup> Stuart Rosen,<sup>2</sup> Steven C. Dakin,<sup>3</sup> Brian L. Day,<sup>4</sup> Juan M. Castellote,<sup>4,6</sup> Sarah White<sup>1</sup> and Uta Frith<sup>1</sup>

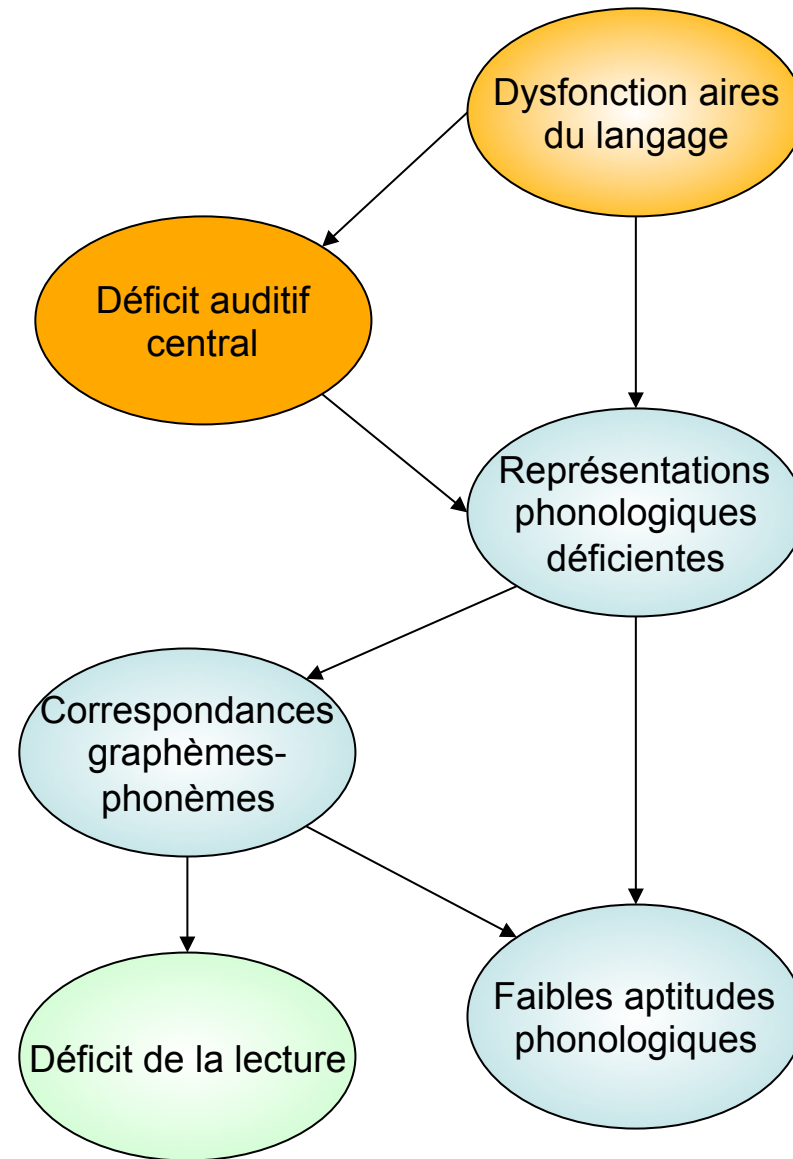


- Principaux résultats :
  - 16/16 déficit phonologique
  - 10/16 déficit traitement auditif [speech, nonspeech, slow and rapid]
  - 4/16 déficit moteur
  - 2/16 déficit visuel

**Fig. 4** Distribution of phonological, auditory, visual and cerebellar disorders in the sample of 16 dyslexic adults. Initials refer to individual dyslexic subjects.

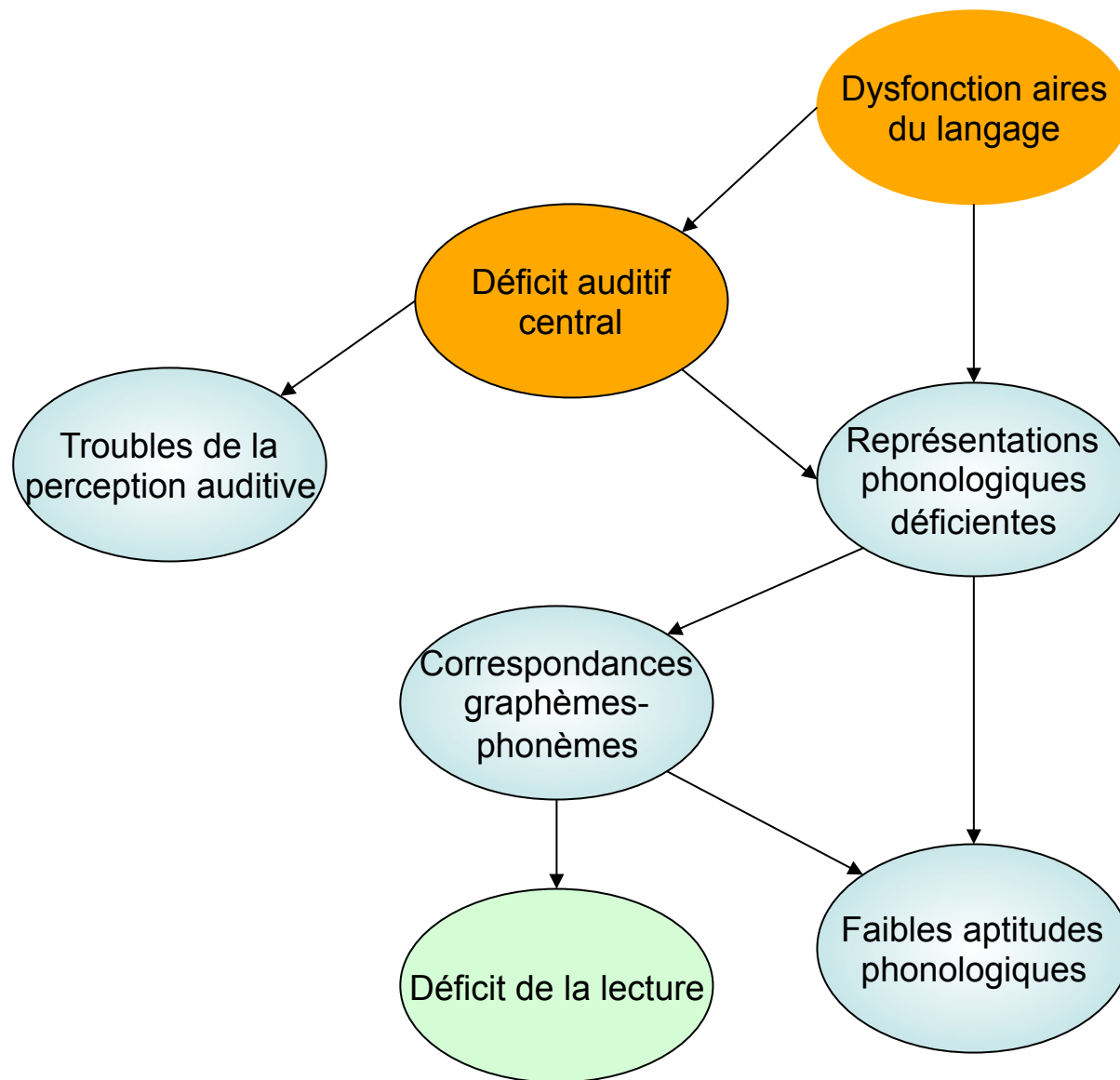


théorie dominante : la théorie du  
déficit phonologique



déficit auditivo-perceptif





déficit auditivo-perceptif

---

# Perceptual Discrimination of Speech Sounds in Developmental Dyslexia

**Willy Serniclaes**

Laboratoire de Statistique  
Médicale  
Ecole de Santé Publique  
Université Libre de Bruxelles  
Brussels, Belgium

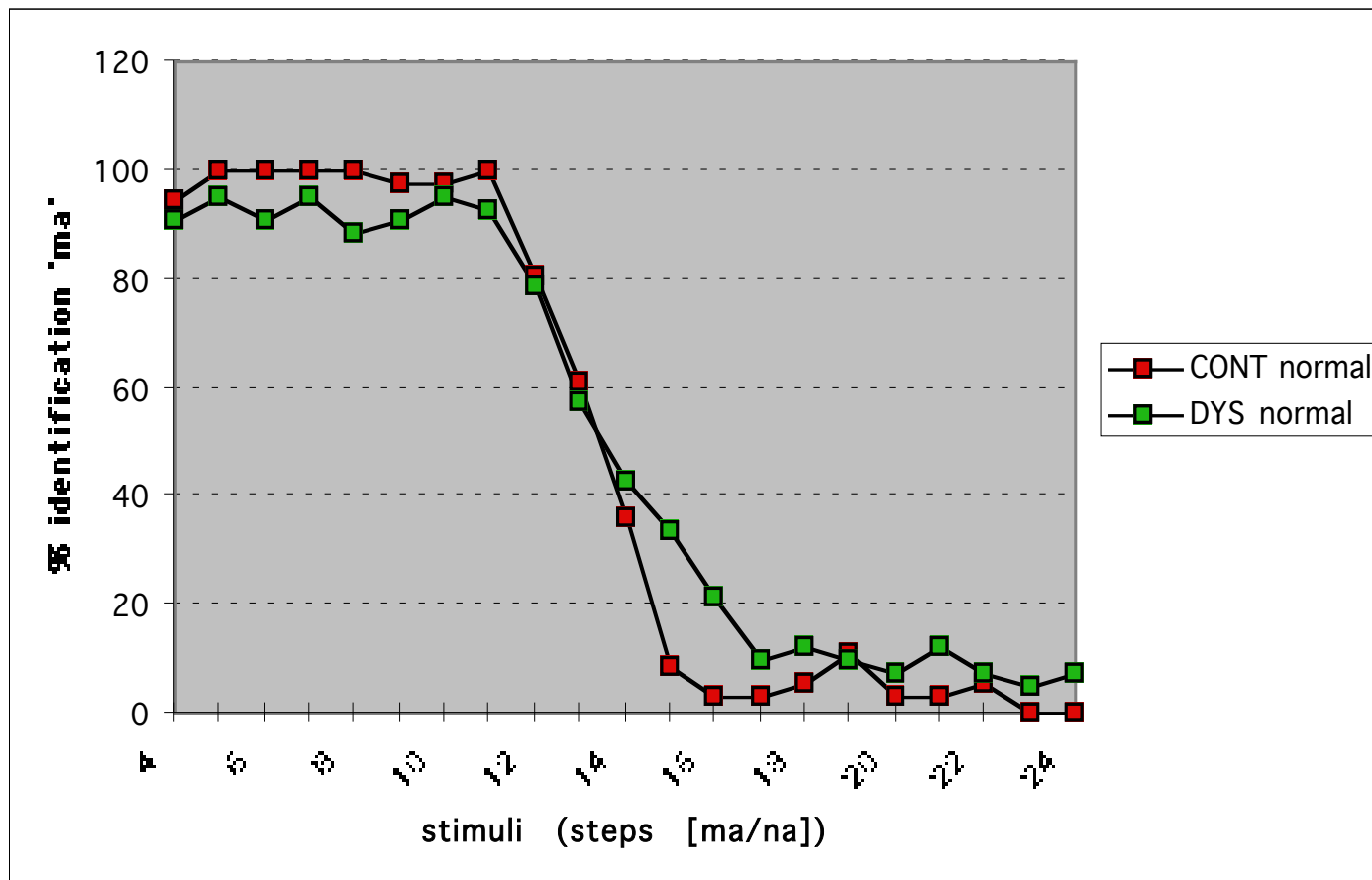
**Liliane Sprenger-Charolles**

CNRS - LEAPL  
and  
Université René Descartes  
Paris, France

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Experiments previously reported in the literature suggest that people with dyslexia have a deficit in categorical perception. However, it is still unclear whether the deficit is specific to the perception of speech sounds or whether it more generally affects auditory function. In order to investigate the relationship between categorical perception and dyslexia, as well as the nature of this categorization deficit, speech specific or not, the discrimination responses of children who have dyslexia and those of average readers to sinewave analogues of speech sounds were compared. These analogues were presented in two different conditions, either as nonspeech whistles or as speech sounds. Results showed that children with dyslexia are less categorical than average readers in the speech condition, mainly because they are *better* at discriminating acoustic differences between stimuli

# Sujets témoins et dyslexiques: continuum [ma/na]



Allophonic perception (Serniclaes et al., 2001; 2004)

categorical perception in dyslexics is underdeveloped

by contrast: dyslexics are better at detecting the differences between allophones

*allophonic perception mode*

In other words: dyslexics suffer from a "developmental arrest": they perceive speech just as babies younger than 8 months do.

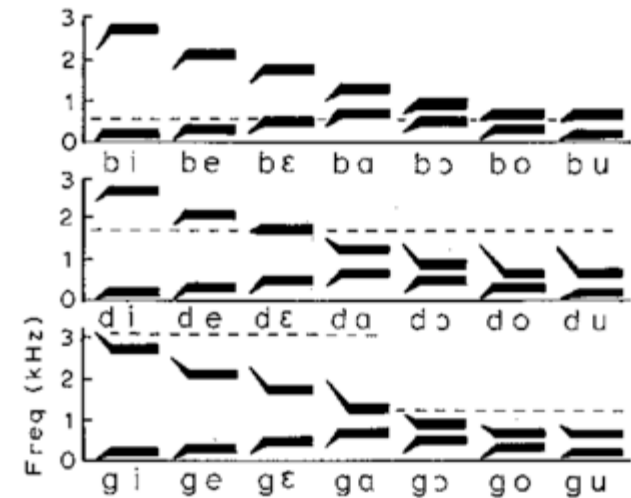
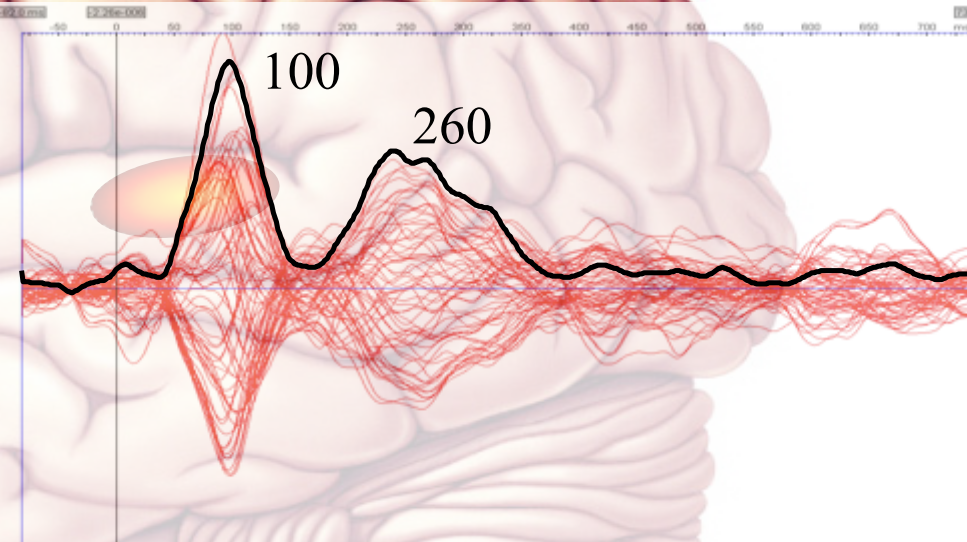
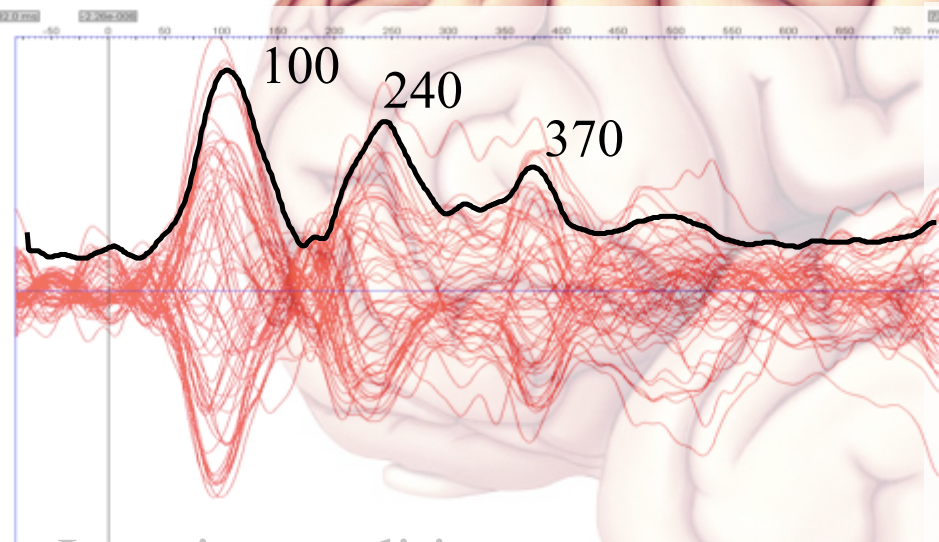
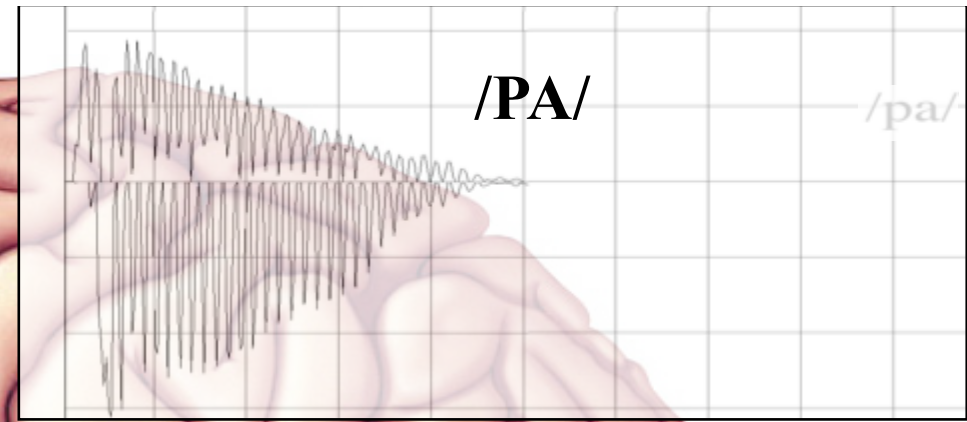
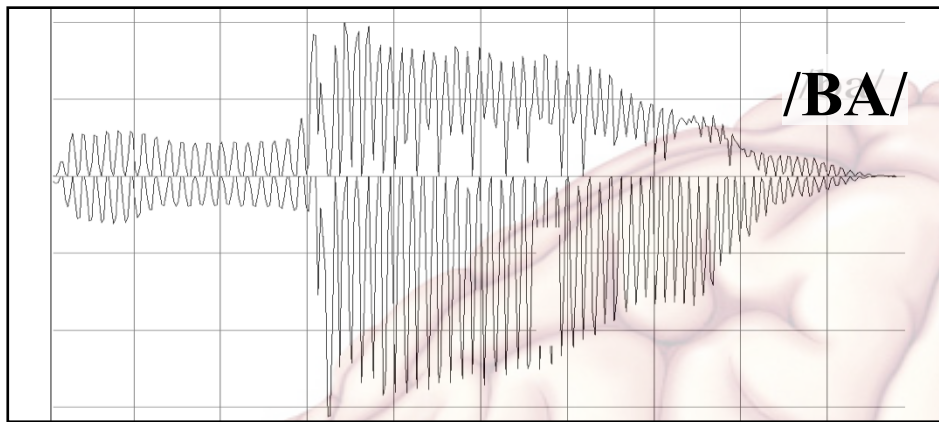


Figure 4 Dans la coarticulation, la réalisation des sons affecte celles des sons voisins. Ici, les consonnes occlusives voisées bilabiales (/b/), alvéodentales (/d/), et vélaires (/g/) commencent à des fréquences différentes selon la voyelle suivante et ont des effets différents sur la positionnement des formants caractérisant chaque voyelle. Le déroulement des « transitions formantiques » contenant toute l'information critique à l'identification de ces sons se déroule dans une fenêtre temporelle de seulement quelques dizaines de millisecondes (d'après Delattre et al., 1955).

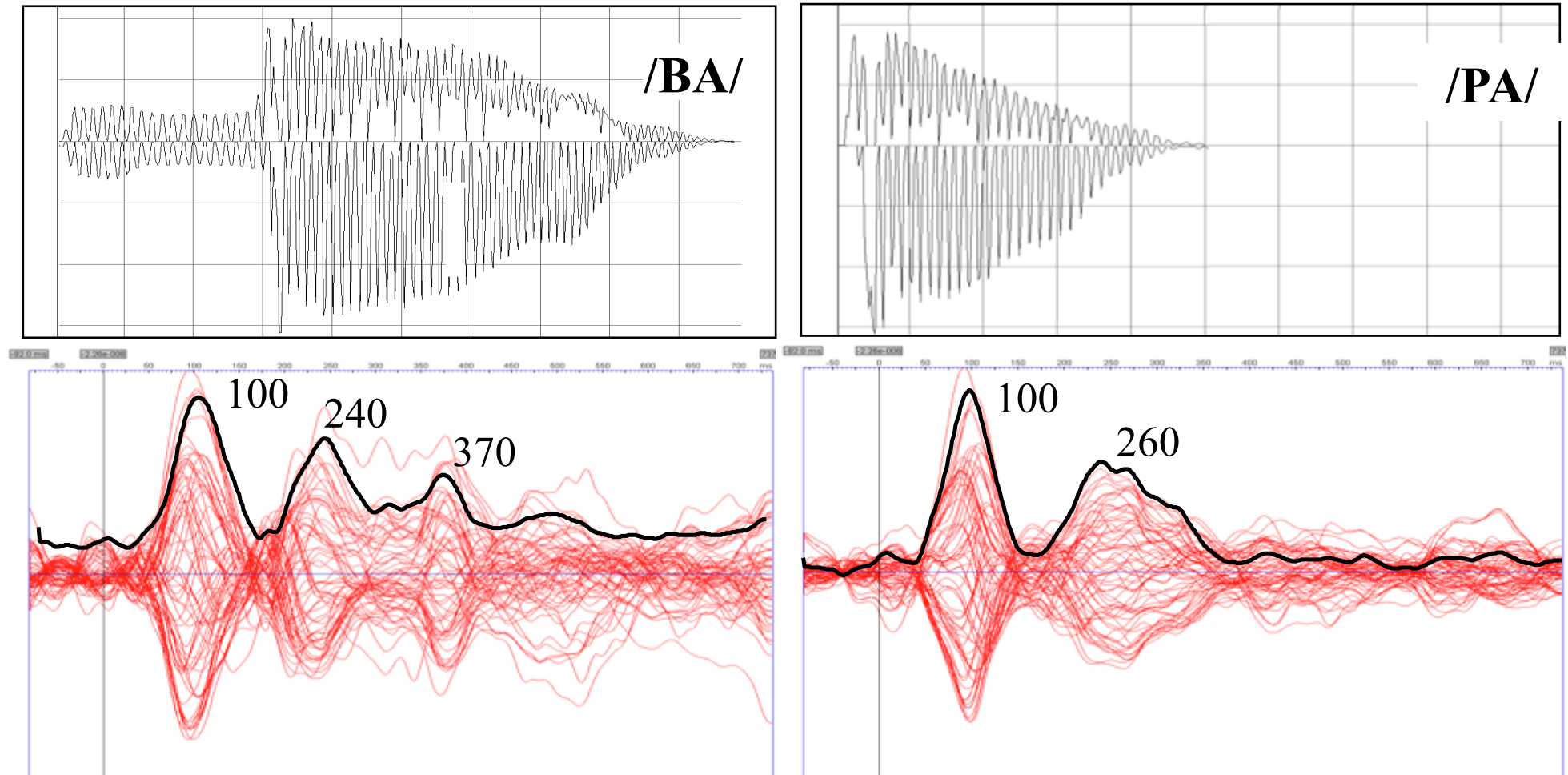


Les aires auditives ne sont pas capables de recruter des groupes de neurones de façon synchrone à la succession d'éléments acoustiques caractérisant les phonèmes



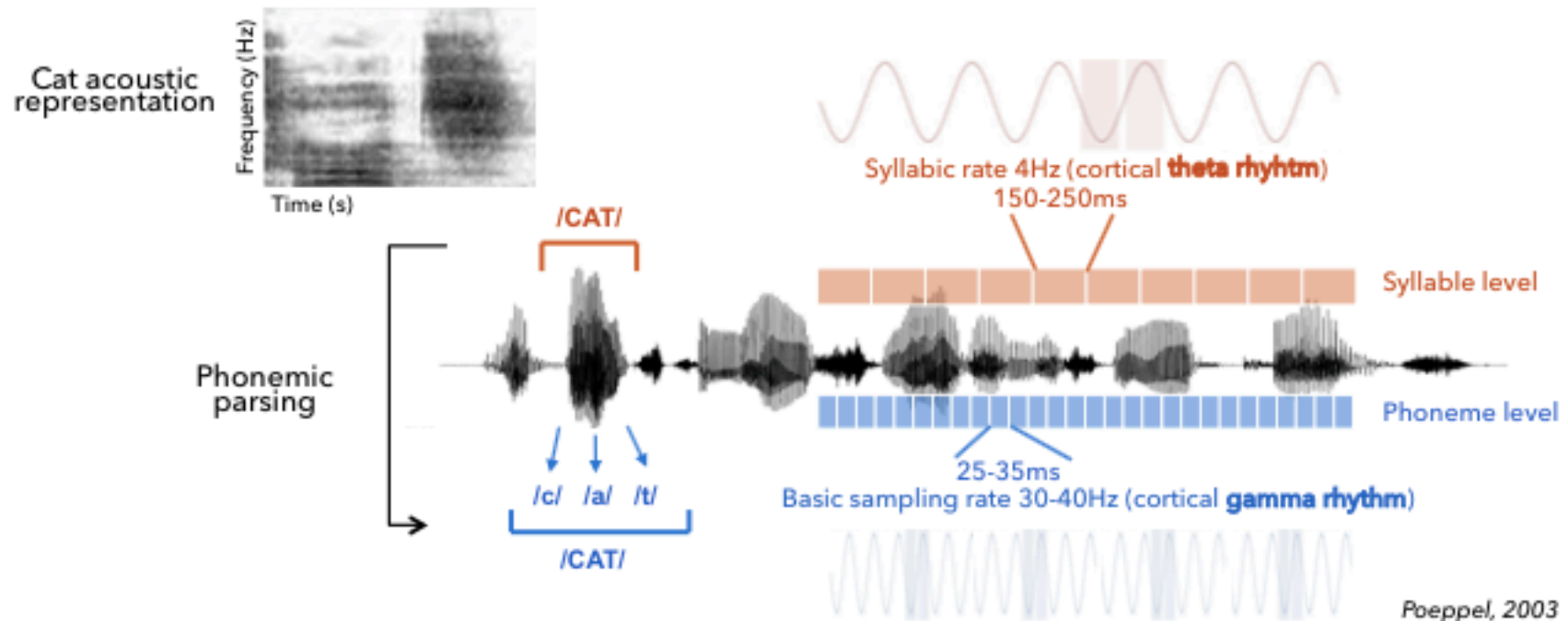
# Corrélat électrophysiologiques du déficit de discrimination dans la dyslexie

K. Giraud et al., 2005



Giraud K, Trébuchon A, Demonet JF, Habib M, Liégeois-Chauvel C. Asymmetry of voice onset time (VOT) processing in adult developmental dyslexics. *Cerebral Cortex* October 2005;15:1524—1534

## Segmenter la parole continue



La structure syllabique de la parole apparaît sous formes de fortes modulations de l'énergie du signal, dont la fréquence est à peu près 4-6 Hz (4-6 syllabes/s).  
Le structure phonémique n'apparaît pas clairement dans le signal acoustique de parole.

Les oscillations neurales permettent de repérer les syllabes.

- Elles suivent le **rythme syllabique**,
- Elles permettent de reconstruire les **unités phonémiques**.

# Altered Low-Gamma Sampling in Auditory Cortex Accounts for the Three Main Facets of Dyslexia

Katia Lehongre,<sup>1</sup> Franck Ramus,<sup>2</sup> Nadège Villiermet,<sup>2</sup> Denis Schwartz,<sup>3</sup> and Anne-Lise Giraud<sup>1,\*</sup>

<sup>1</sup>Inserm U960 - Ecole Normale Supérieure, 75005 Paris, France

Using magnetoencephalography and behavioral tests, we show in dyslexic subjects a reduced left- hemisphere bias for phonemic processing, reflected in less entrainment to z30 Hz acoustic modulations in left auditory cortex. This deficit correlates with measures of phonological processing and rapid naming. We further observed enhanced cortical entrainment at rates beyond 40 Hz in dyslexics and show that this particularity is associated with a verbal memory deficit.

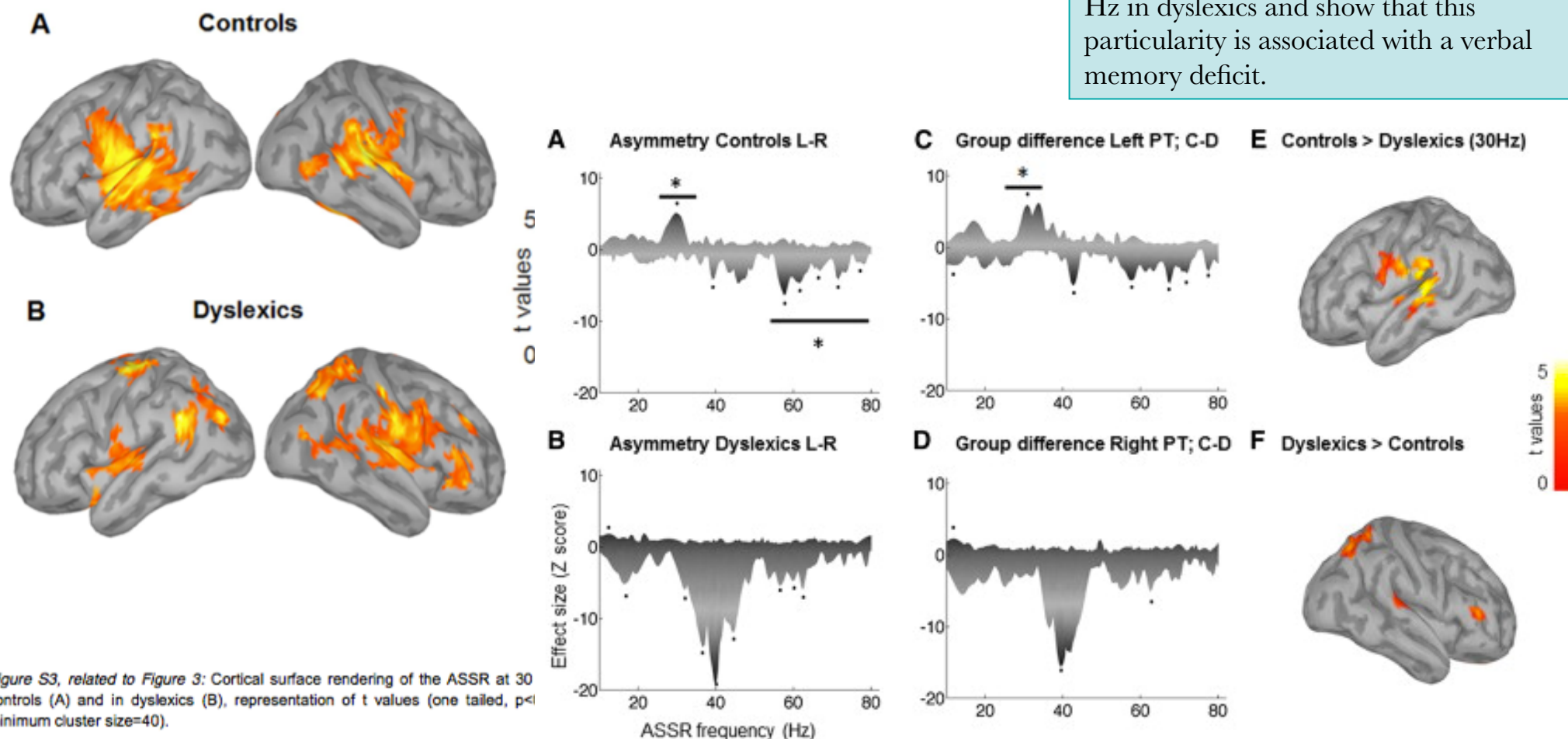


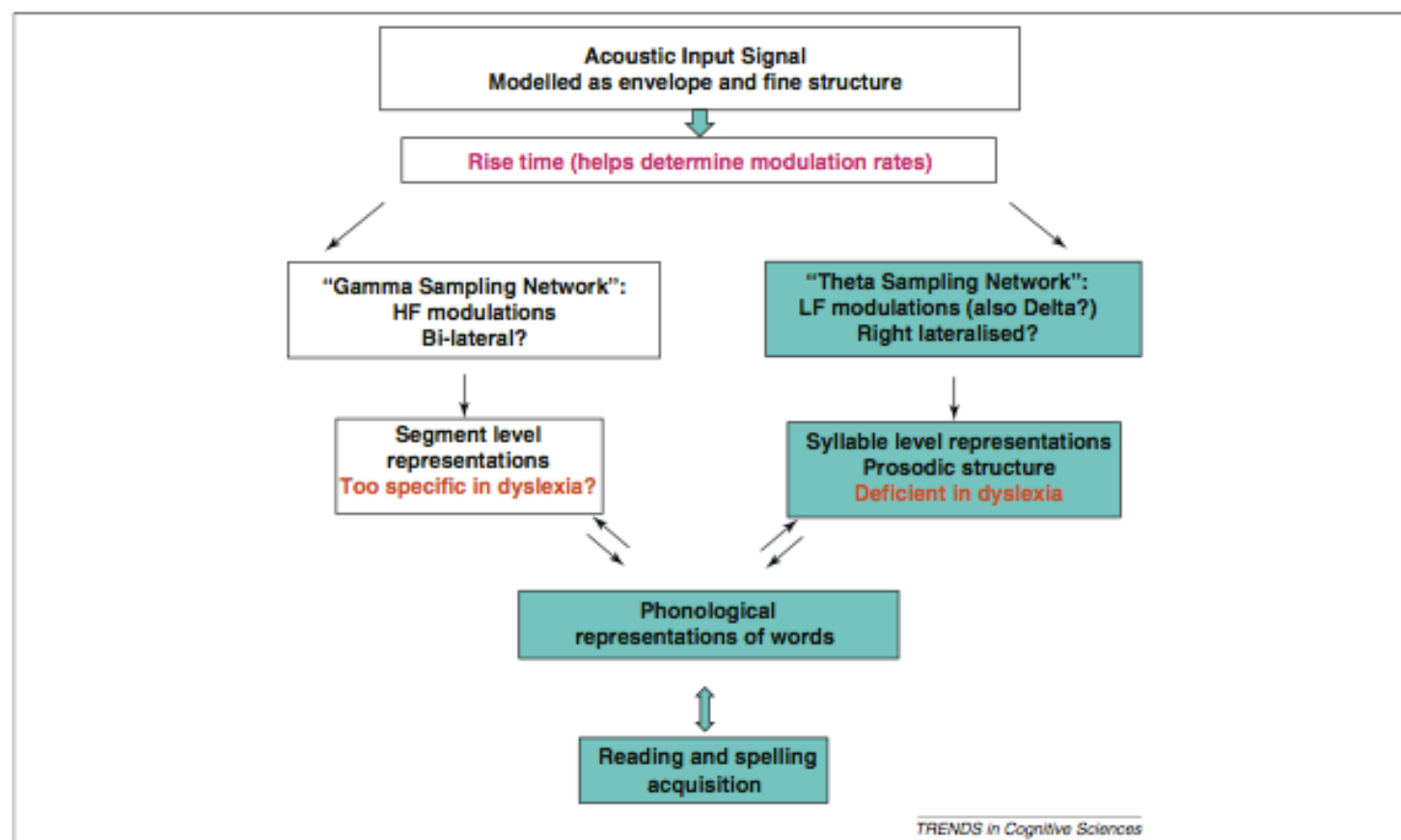
Figure S3, related to Figure 3: Cortical surface rendering of the ASSR at 30 controls (A) and in dyslexics (B), representation of t values (one tailed,  $p < \text{minimum cluster size} = 40$ ).

# Lehongre et al. 2011

- Chez les adultes dyslexiques, les oscillations gamma ont une fréquence plus haute que chez les contrôles: ils contruisent des représentations phonémiques de plus petit format.
- Ils traitent donc plus d'unités phonémiques par unité de temps, ce qui sature plus vite les capacités de mémoire verbale. A nombre de mots égal, le nombre d'unités phonémiques à manipuler mentalement est plus grand.
- Les réponses oscillatoires auditives gamma dominant à droite chez les adultes dyslexiques, ce qui engendre une moins bonne extraction phonémique par le cerveau gauche et des difficultés à intégrer les représentations dans le plan d'action (difficulté de dénomination d'objets). Différents profils de dyslexie peuvent être liés à des niveaux variables de compensation par l'hémisphère droit. Compensation à droite = moins de déficit de perception, mais un plus grand déficit de dénomination.

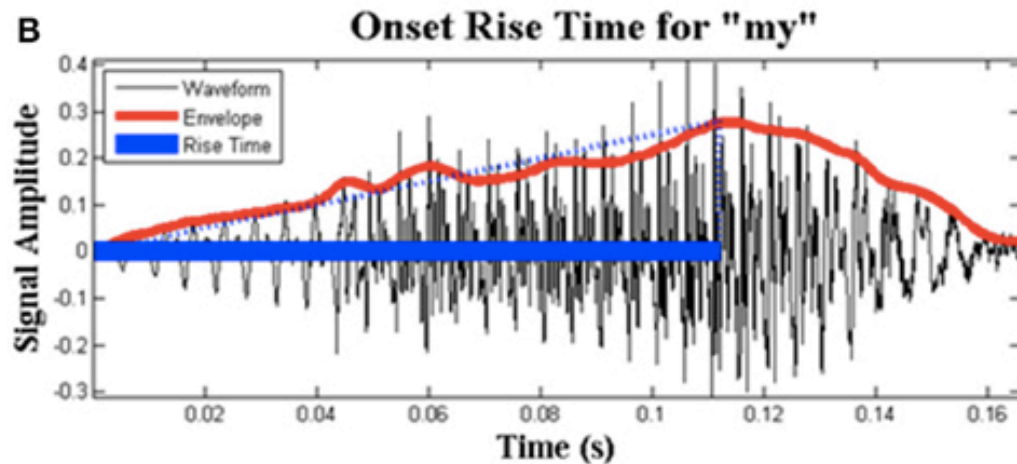
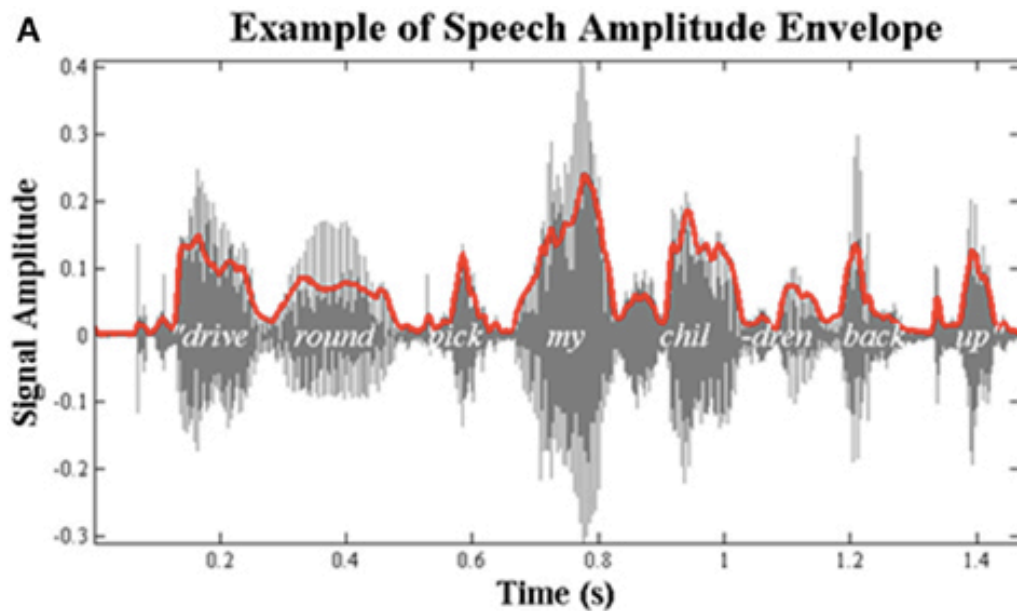
# A temporal sampling framework for developmental dyslexia

Usha Goswami



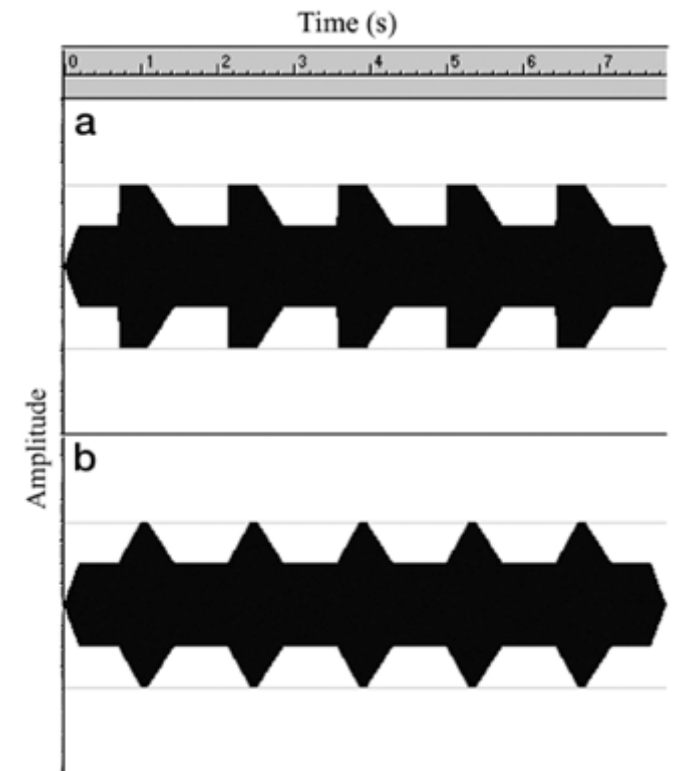
**Figure 1.** The temporal sampling framework. The TSF assumes a specific dyslexic difficulty with slower temporal modulations, as rise-time perception difficulties in dyslexia involve more extended rise times. As slower modulations are preferentially processed by the right hemisphere, the TSF assumes a right-lateralised impairment in Theta and Delta oscillators. The proposed range of low-frequency modulations processed by the Theta oscillators varies across published studies, but is proposed by Poeppel *et al.* [6] to yield a temporal integration window of ~100–300 ms (approximating the syllable rate). The proposed range for high-frequency modulations also varies across studies, but in [6] yields a temporal integration window of 20–50 ms, approximating the phonetic rate. According to the TSF, the proposed temporal integration window for syllabic parsing in the right hemisphere might function atypically in dyslexia, yielding the auditory basis of the associated phonological and language deficits (deficits indicated by blue shading).

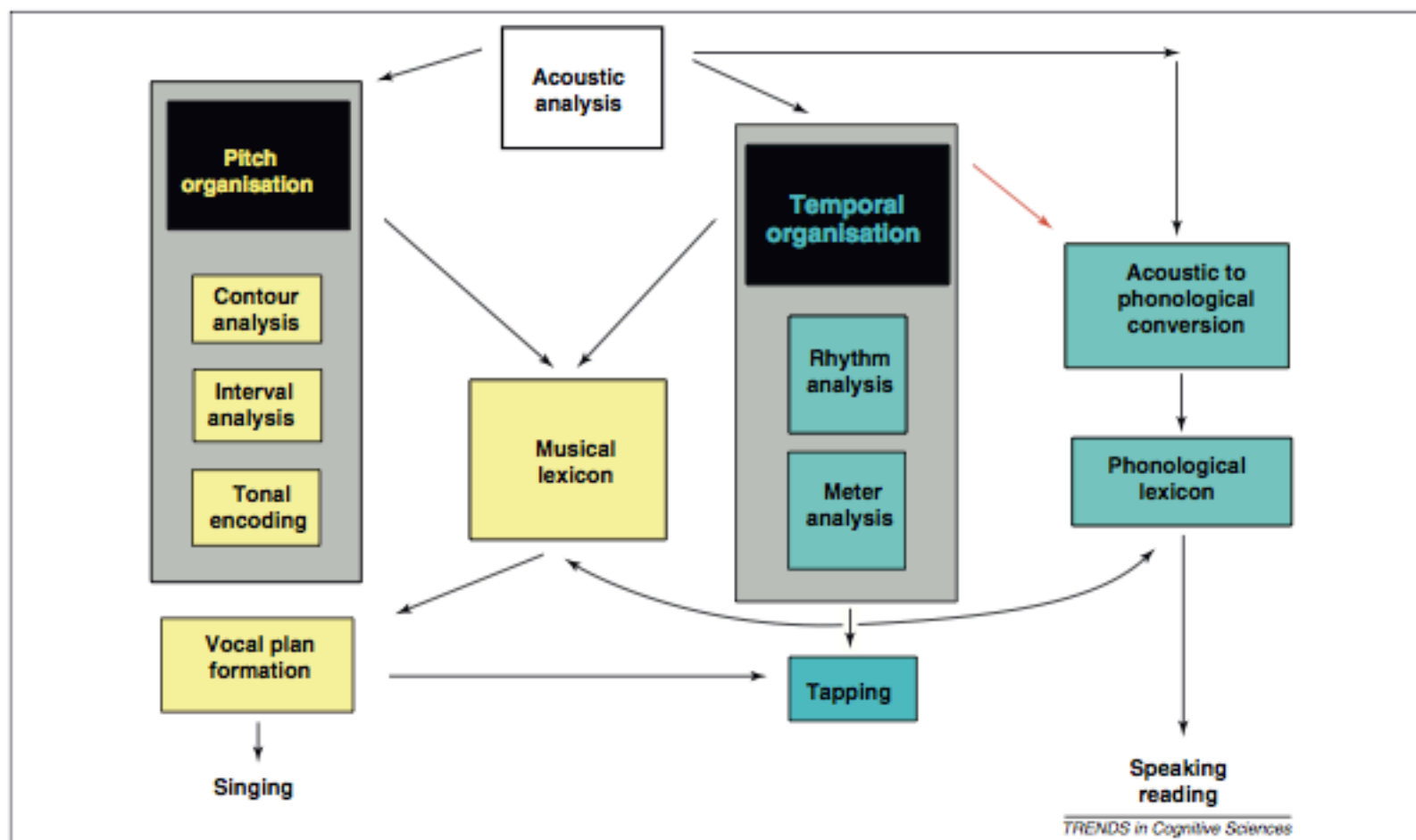




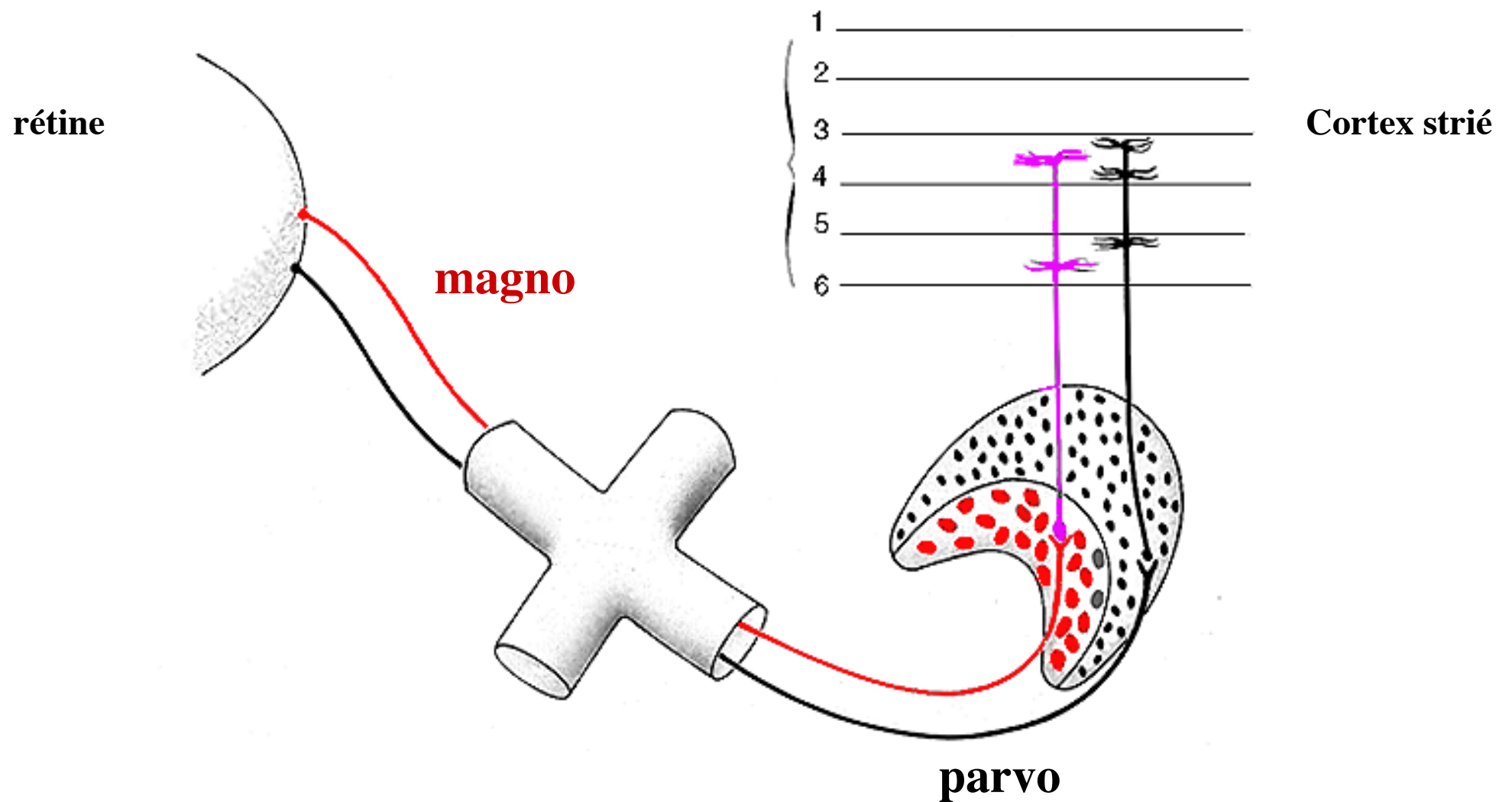
**The amplitude envelope of speech, syllable rise times and the modulation spectrum.** Schematic depiction of (A) the amplitude envelope (AE) for the phrase “..drive round, pick my children back up..,” the AE is in red and the original signal is in gray; (B) the rise time for the syllable “my,” shown as blue filled and dotted lines; the *rise time* is the time taken for the envelope to reach its highest amplitude;

Examples of the stimulus wave form for rise times of 15 (a) and 300 (b) ms



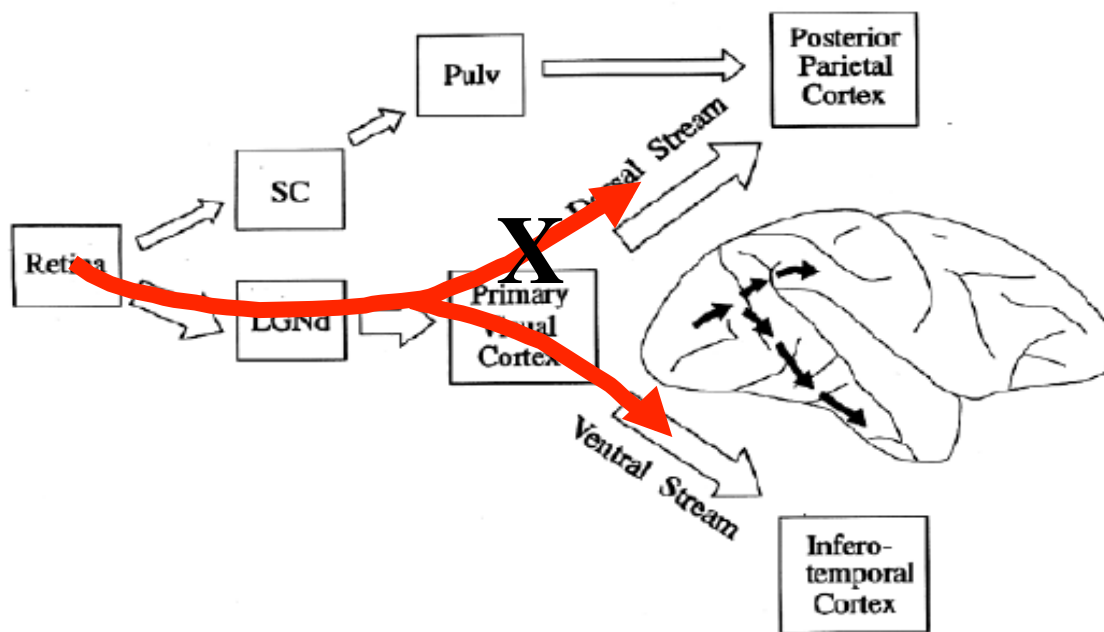


**Figure 2.** Components of music and language processing. A model of how acoustic analysis of pitch versus rhythm might contribute to language versus musical processing, based on the modular framework of Peretz and Coltheart [69]. The skills preserved in amusia yet impaired in dyslexia are shown in blue. The skills impaired in amusia are shown in yellow. Although developmental disorders of learning are not modular, the framework is useful for supporting the view that musical remediation of dyslexia via training in rhythm and meter might improve phonological development and processing of low-frequency modulations.

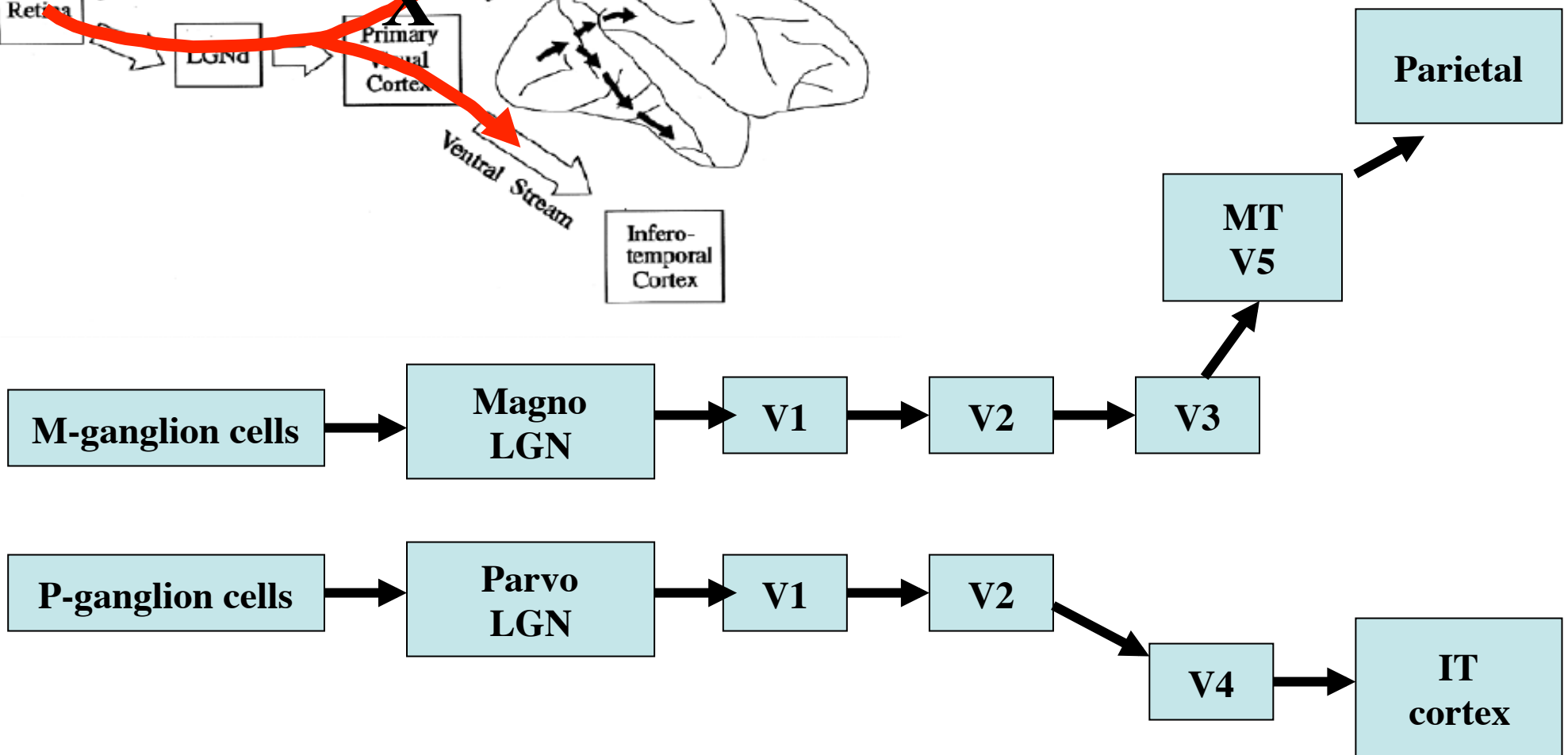


Défaut du système magno-cellulaire :

- sensibilité aux contrastes
- persistance visuelle excessive



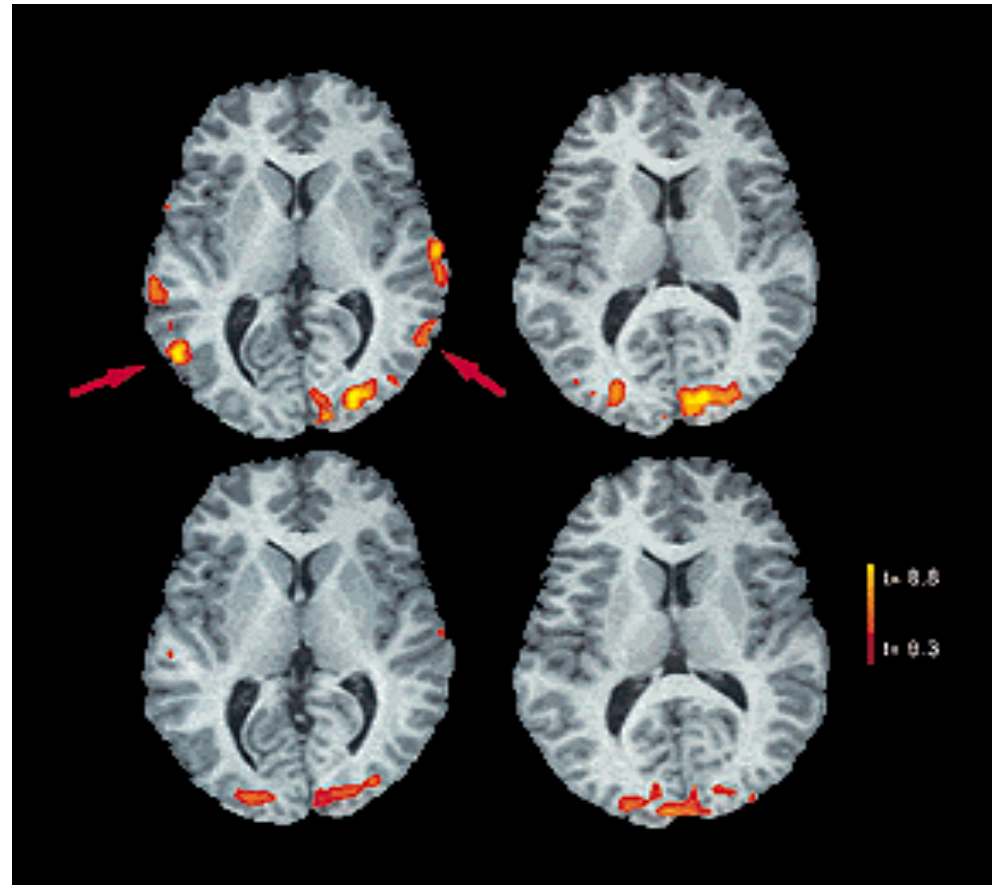
**Where/How**



**What**

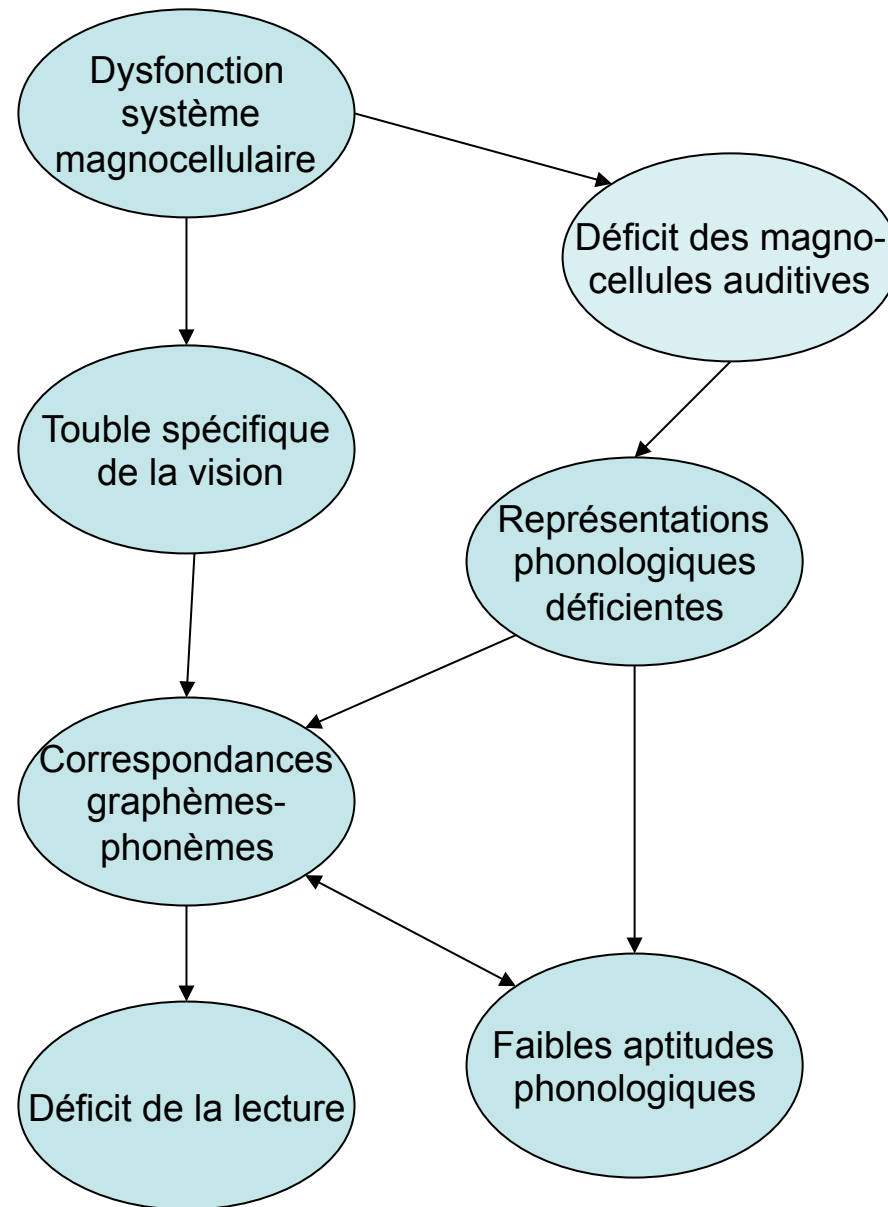
controls

dyslexics



Dyslexics : failure to activate V5/MT « motion area »  
(Eden et al., 1996)





dysfonction système magnocellulaire (J. Stein)

# Les théories "attentionnelles"

- Mini-héminégligence gauche (Hari et Renvall, 2001) : : difficultés liées à l'orientation dans le champ visuel gauche
- « viscosité du déplacement attentionnel » (SAS="sluggish attentional shifting", Hari & Renvall, 2001) : difficultés que rencontrent les dyslexiques pour se désengager d'un stimulus lorsqu'il doivent traiter une série de stimuli en succession rapide.
- trouble de l'ajustement de la fenêtre attentionnelle (Valdois et al., 2004) : les dyslexiques seraient limités dans le nombre d'éléments visuels qu'ils peuvent traiter simultanément, en parallèle.

Dysfonction des systèmes attentionnels  
pariétaux

# Superior parietal lobule dysfunction in a homogeneous group of dyslexic children with a visual attention span disorder

C. Peyrin<sup>a</sup>, J.F. Démonet<sup>b</sup>, M.A. N'Guyen-Morel<sup>c</sup>, J.F. Le Bas<sup>d</sup>, S. Valdois<sup>a,\*</sup>

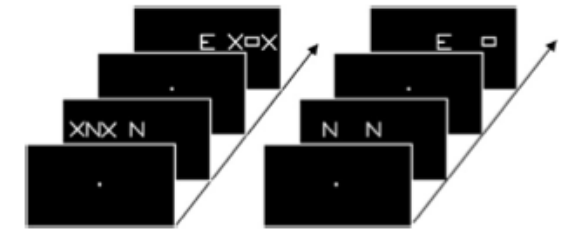
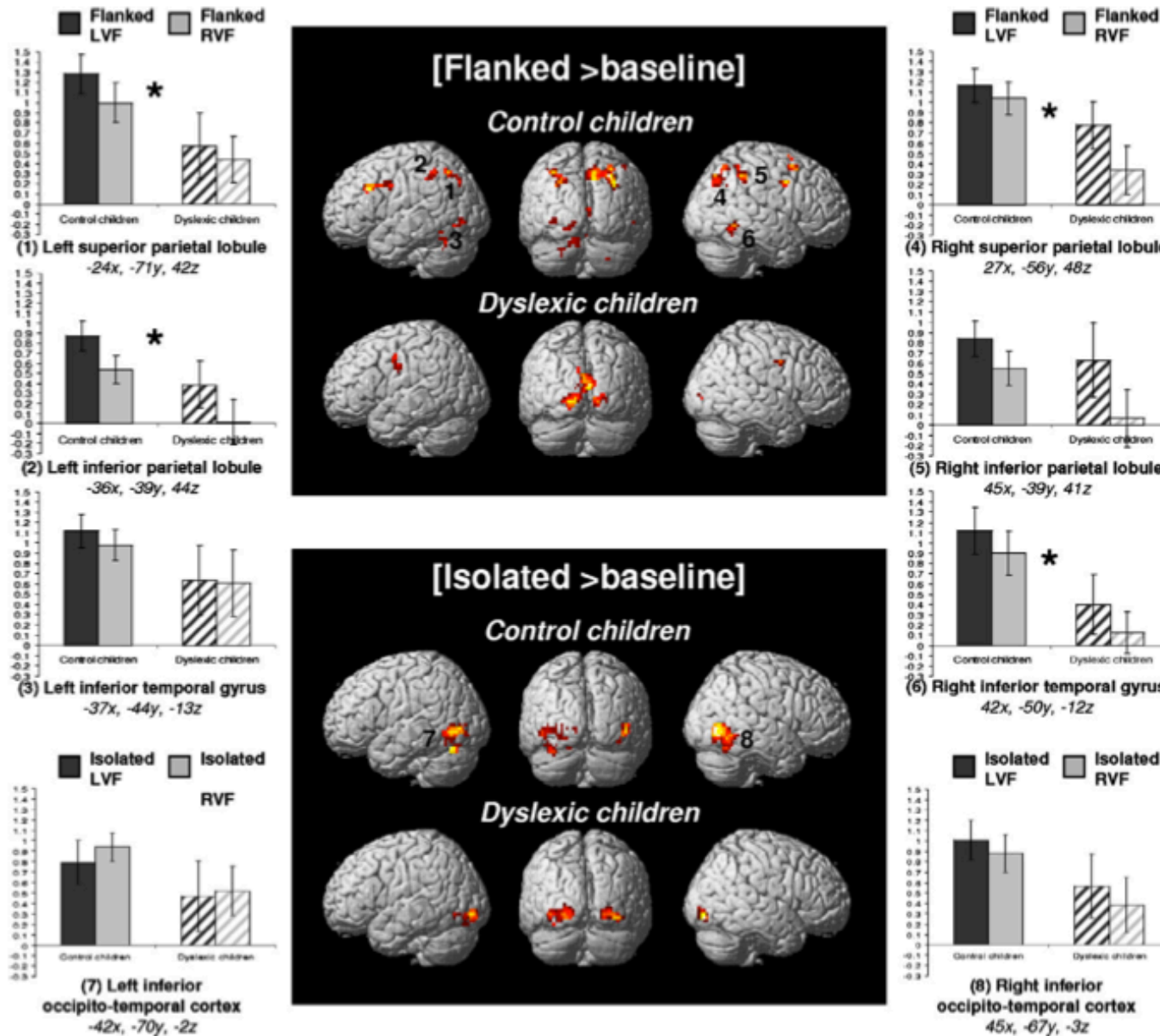


Fig. 1. Example of stimuli used in the categorisation task. Participants have to decide whether the stimuli of a pair were identical or not. Parafoveal stimuli were lateralized in either the right or left visual field, masked by two X in the flanked condition (left side of the figure) and displayed alone in the isolated condition (right side).

With respect to controls, the dyslexic children showed significantly reduced activation within bilateral parietal and temporal areas during flanked processing, but no difference during the isolated condition.

## Neural dissociation of phonological and visual attention span disorders in developmental dyslexia: fMRI evidence from two case reports

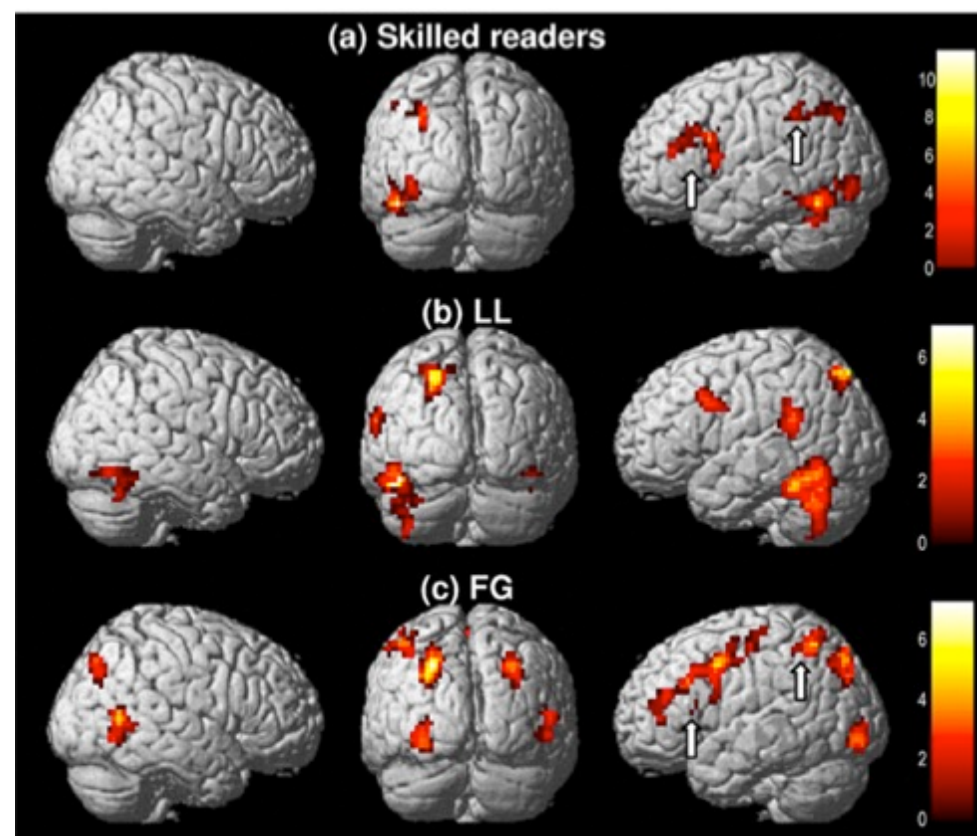
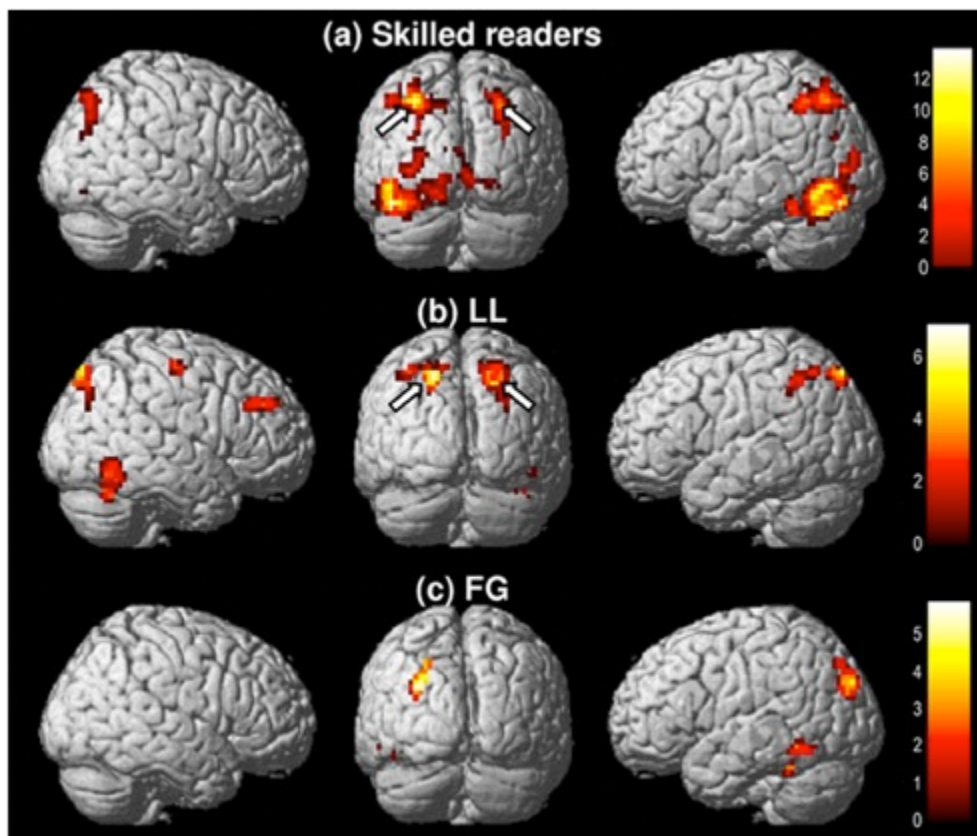
C. Peyrin<sup>a,b,\*</sup>, M. Lallier<sup>b,c</sup>, J.F. Démonet<sup>d</sup>, C. Pernet<sup>e</sup>, M. Baciú<sup>a,f</sup>, J.F. Le Bas<sup>g</sup>, S. Valdois<sup>a,b</sup>

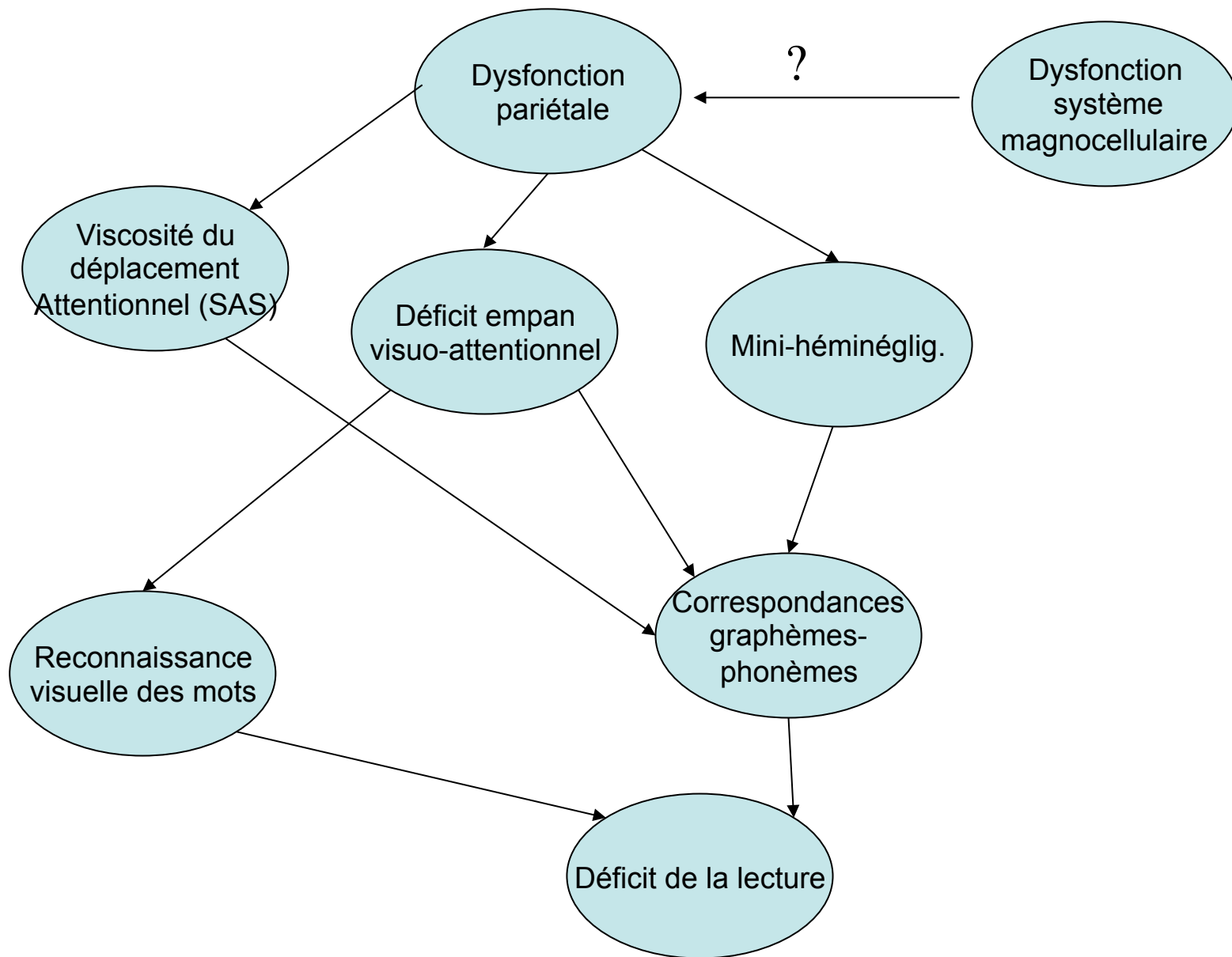
Performance of the two dyslexic young adults, LL and FG, in reading and spelling, and in phonological and visual attention tasks as compared to 20 chronological age controls.

|                                     | LL          |                    | FG          |                    | Controls (N = 20) |
|-------------------------------------|-------------|--------------------|-------------|--------------------|-------------------|
|                                     | Performance | t(19) <sup>a</sup> | Performance | t(19) <sup>a</sup> | Mean (SD)         |
| <b>Reading</b>                      |             |                    |             |                    |                   |
| Irregular words (/40)               |             |                    |             |                    |                   |
| Accuracy                            | 38          | +0.60              | 33          | -1.90*             | 36.80 (1.94)      |
| Rate                                | 32          | -1.30              | 49          | -3.97***           | 23.75 (6.20)      |
| Pseudo-words (/40)                  |             |                    |             |                    |                   |
| Accuracy                            | 38          | +0.06              | 25          | -7.77***           | 37.90 (1.62)      |
| Rate                                | 56          | -2.33*             | 61          | -2.97**            | 37.75 (7.64)      |
| Regularisations                     | 1/2 (50%)   |                    | 6/7 (86%)   |                    |                   |
| Visual errors                       | 0/2 (0%)    |                    | 9/15 (60%)  |                    |                   |
| GPC knowledge (/51)                 | 51          | +1.14              | 48          | -0.23              | 48.50 (2.13)      |
| <b>Spelling</b>                     |             |                    |             |                    |                   |
| Consistent words (/40)              | 37          | +0.33              | 33          | -1.72*             | 36.35 (1.90)      |
| Irregular words (/40)               | 22          | -1.43              | 12          | -3.09**            | 29.55 (5.53)      |
| Pseudo-word (/40)                   | 33          | -2.42*             | 35          | -1.33              | 37.45 (1.80)      |
| PPEs                                | 18/21 (90%) |                    | 34/35 (97%) |                    | 86% (2.4)         |
| <b>Phonological processing</b>      |             |                    |             |                    |                   |
| Pseudo-word repetition (/92)        | 83          | -3.13**            | 89          | -0.23              | 89.45 (2.01)      |
| Phoneme segmentation (/28)          | 14          | -1.62              | 20          | -0.39              | 21.90 (4.74)      |
| Spoonerisms (/10)                   | 1           | -5.22***           | 8           | -0.35              | 8.50 (1.40)       |
| <b>Visual attention span</b>        |             |                    |             |                    |                   |
| Global report - five-letters (/100) | 58          | -0.02              | 11          | -3.97***           | 73.10 (16.01)     |
| Global report - six-letters (/144)  | 115         | -0.30              | 74          | -2.88**            | 119.75 (15.49)    |
| Partial report - six-letters (/72)  | 48          | -0.84              | 44          | -1.38              | 54.20 (7.17)      |

Catégorisation formes (lettres/non-lettres)

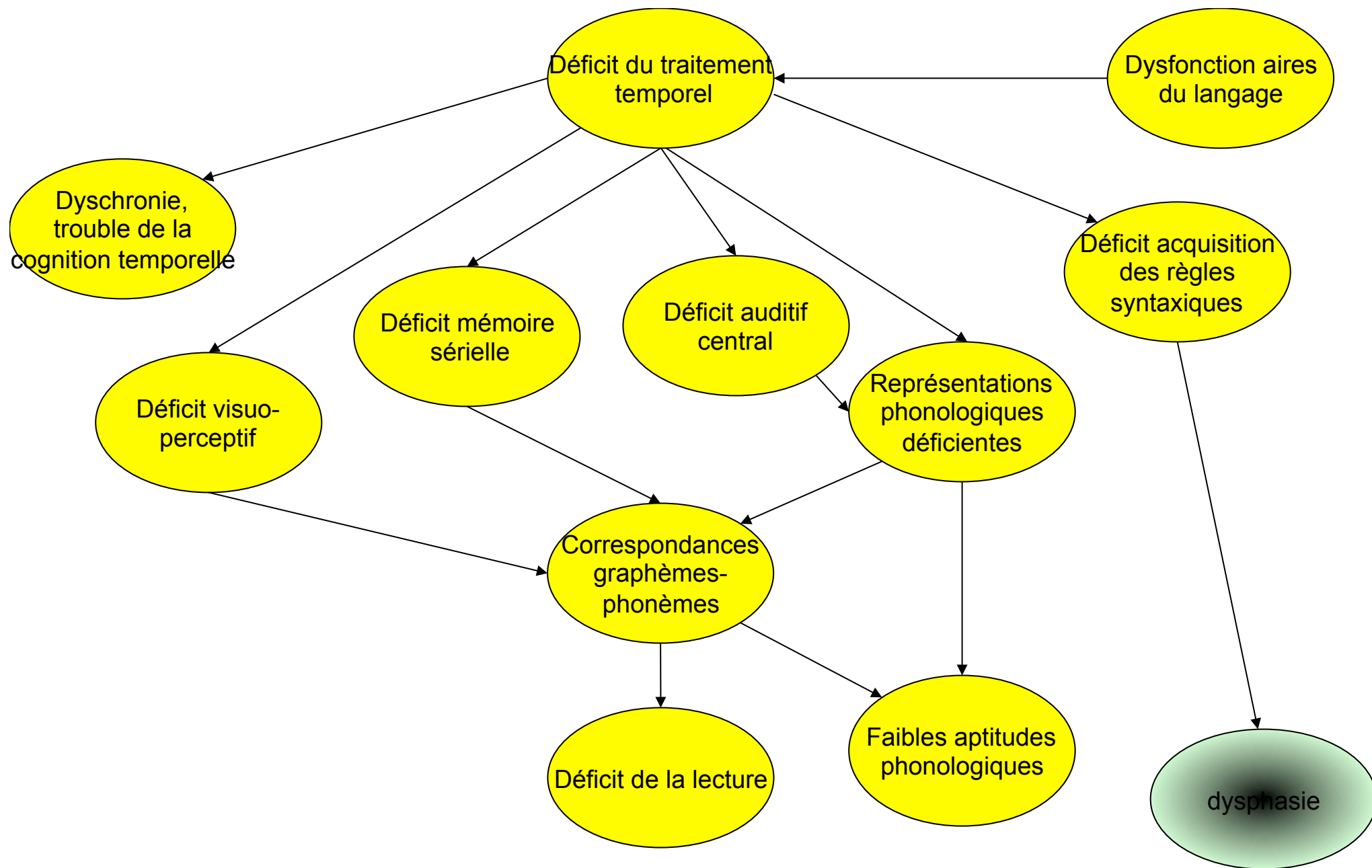
Détection de rimes (lettre écrite rime avec 'b')



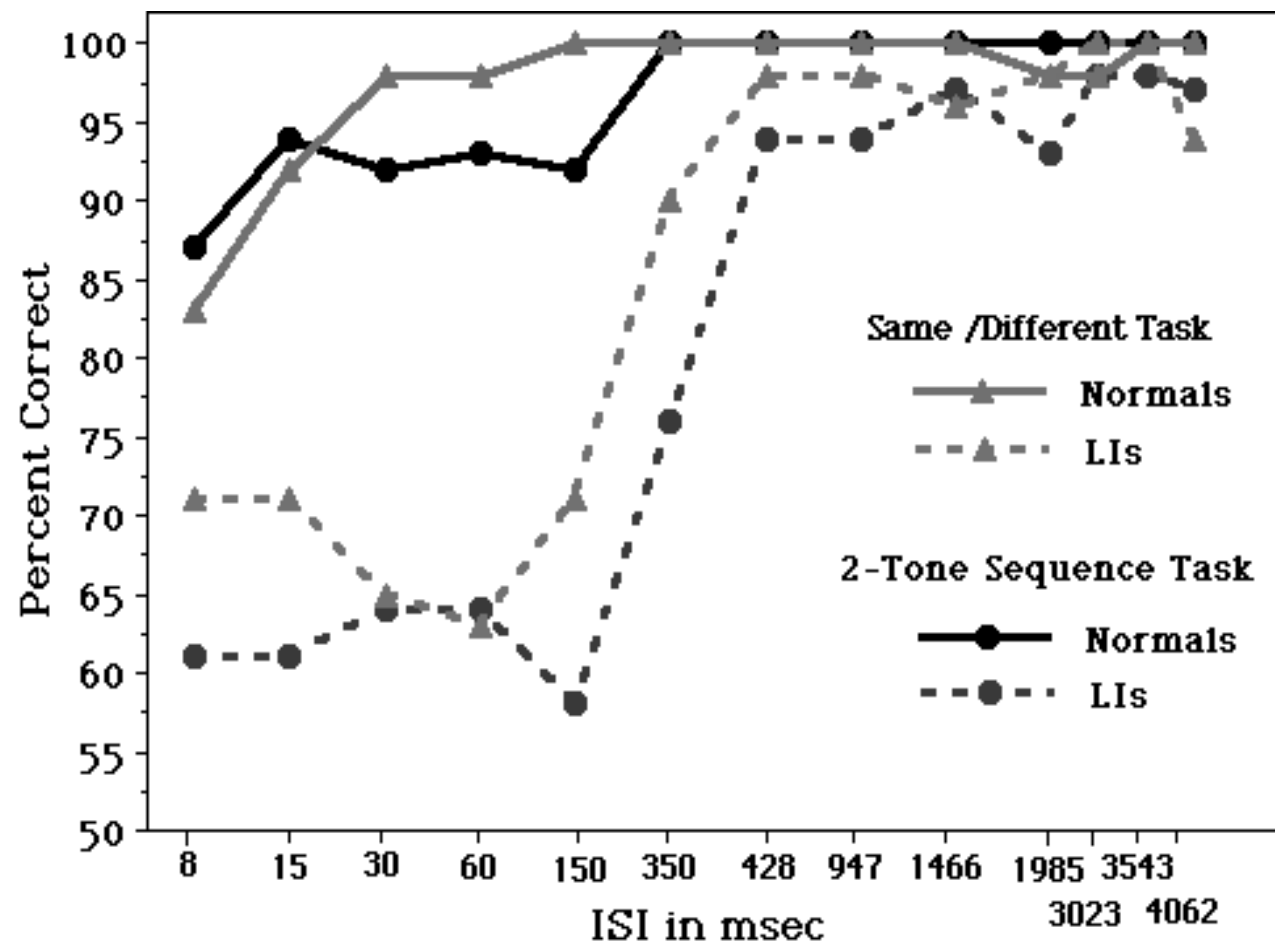


Les trois théories "attentionnelles"





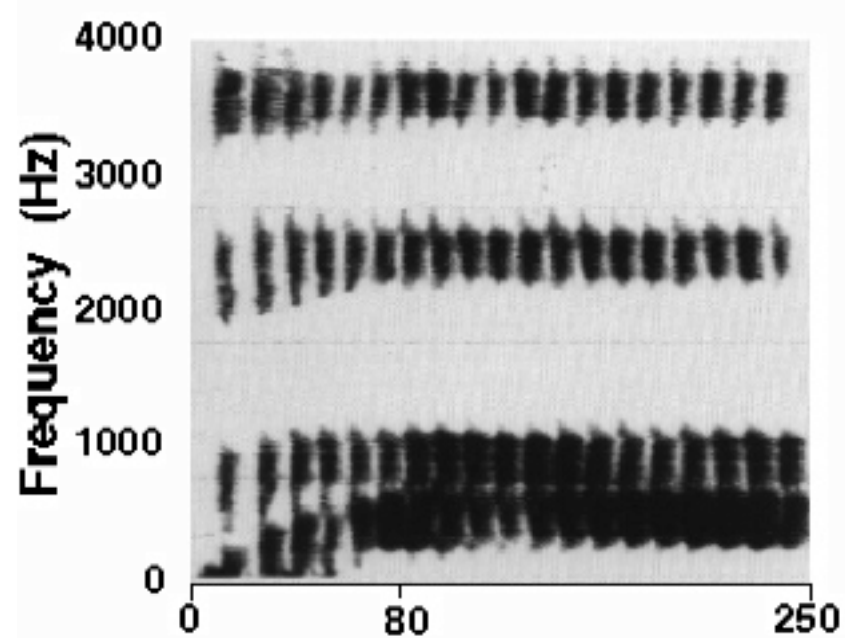
déficit du traitement temporel (Tallal)



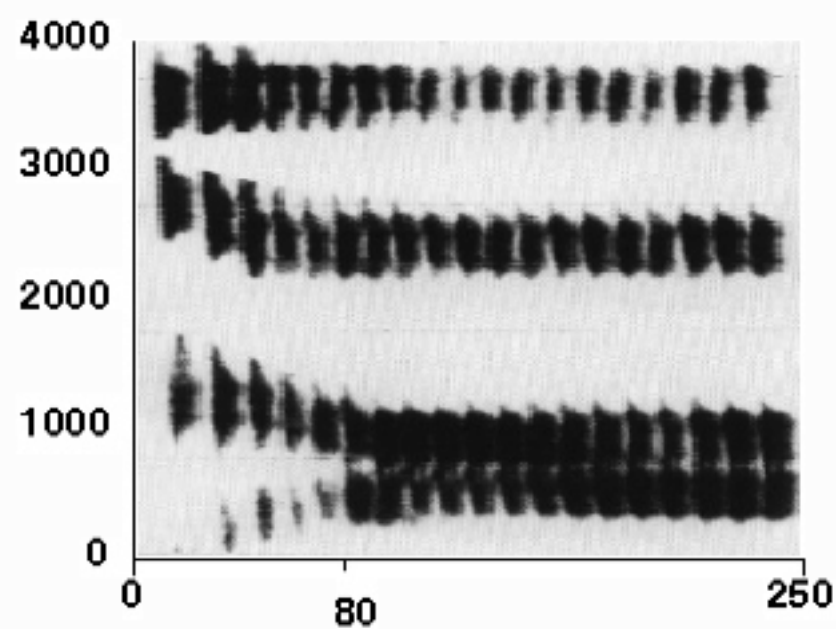
Tallal et al., 1973-76

## CONSONANTS

*/ba/*



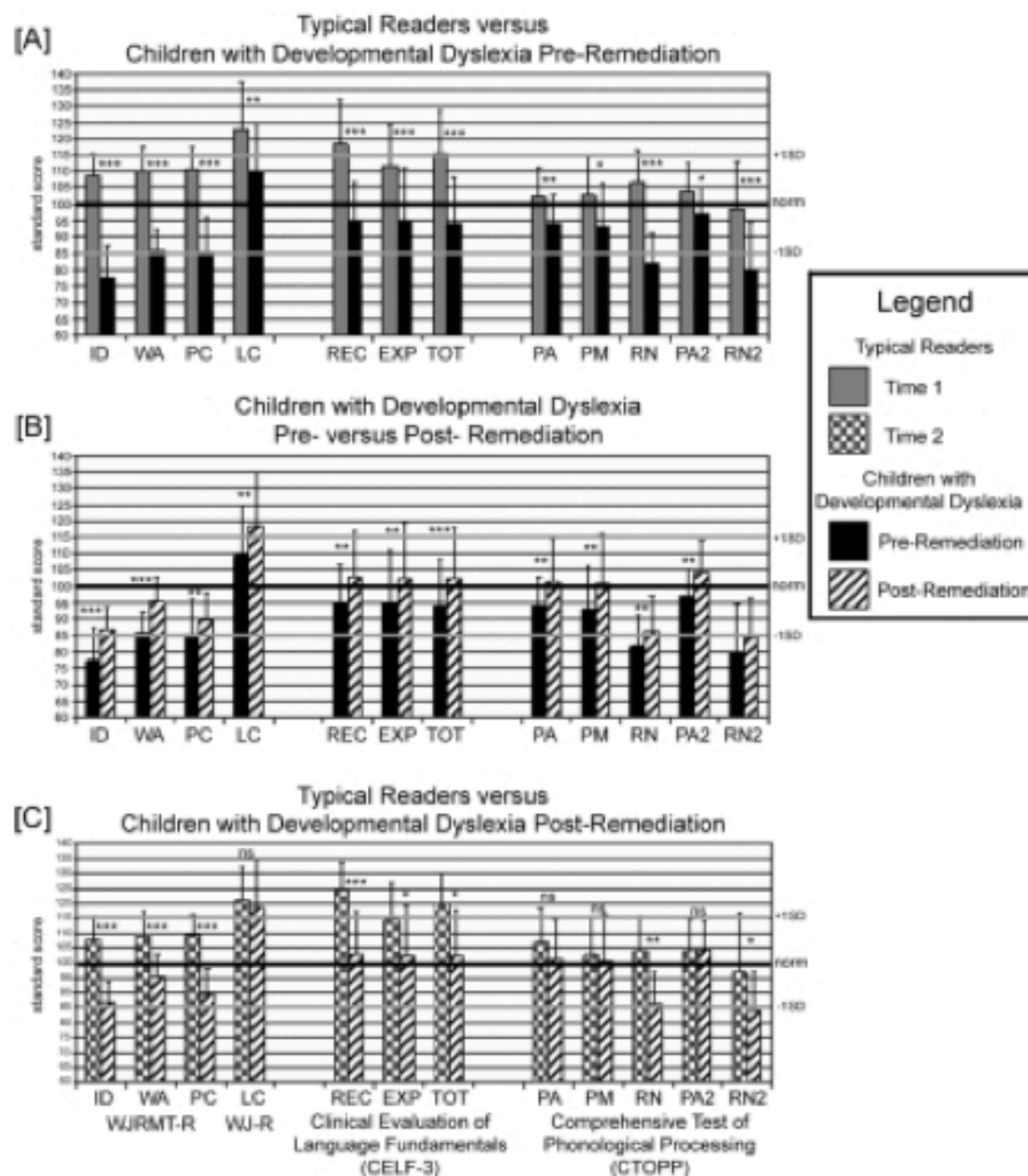
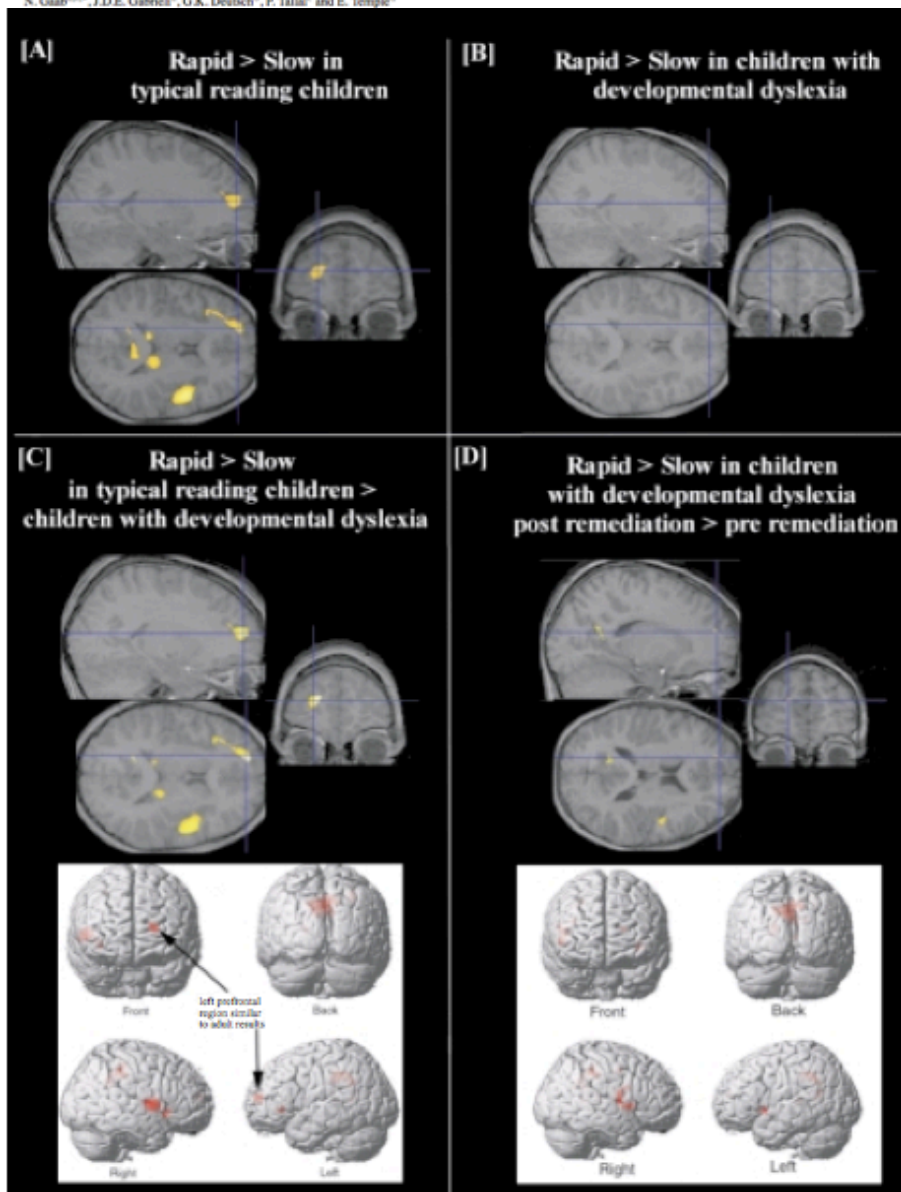
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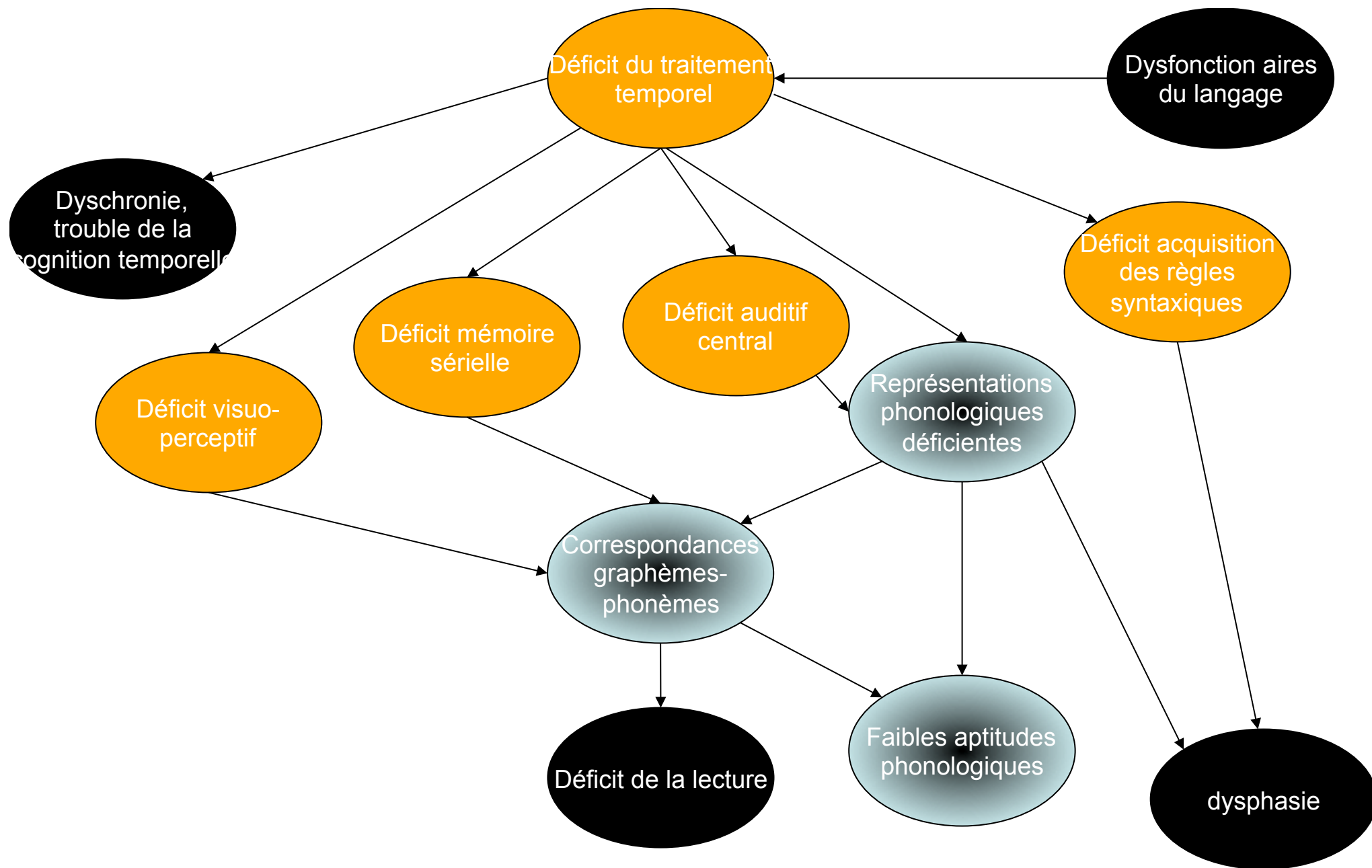


Time (msec)

# Neural correlates of rapid auditory processing are disrupted in children with developmental dyslexia and ameliorated with training: An fMRI study

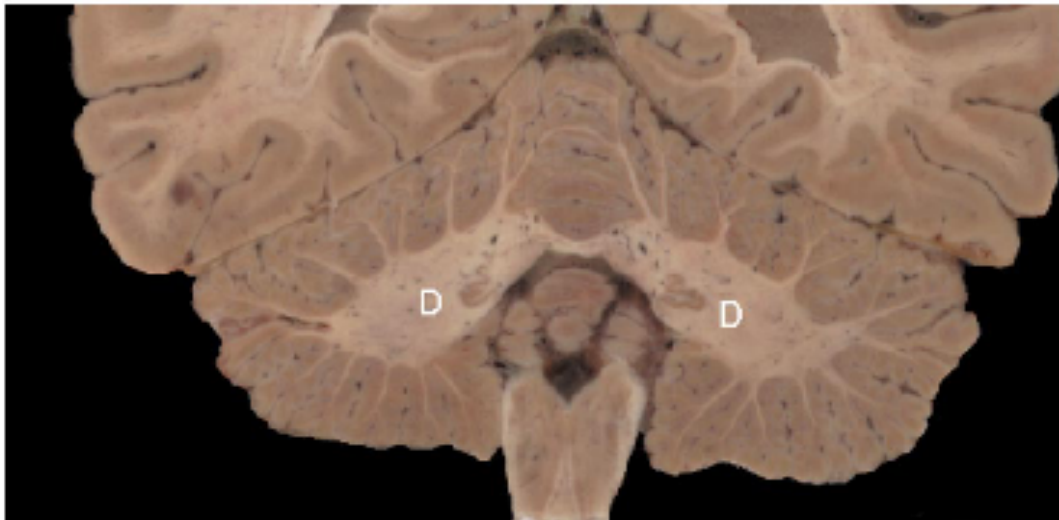
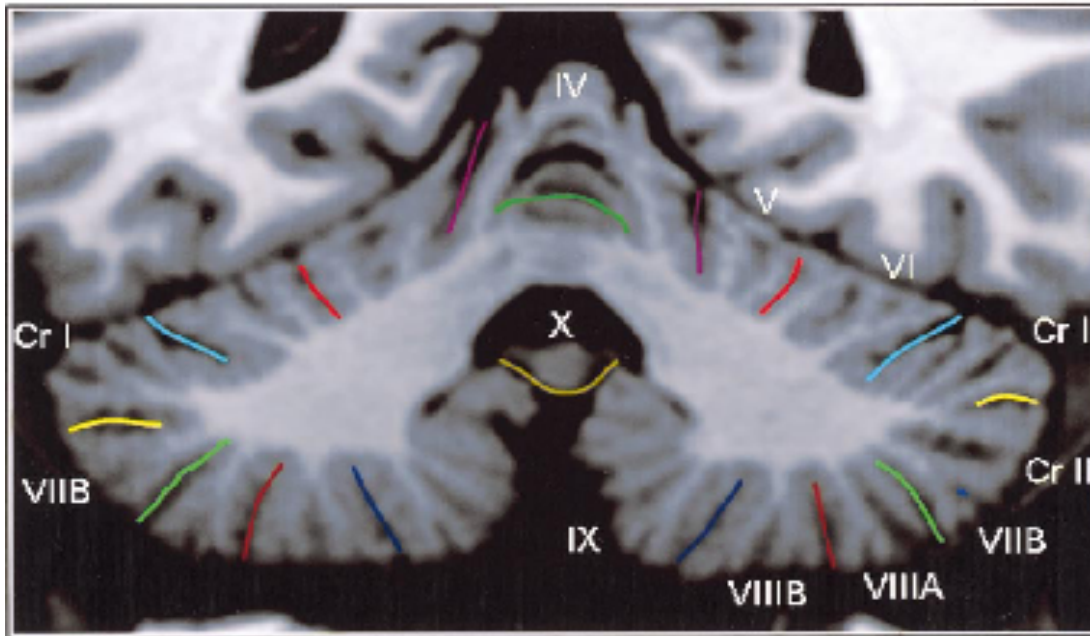
N. Gosh<sup>1,2,3,4</sup>, J.D.E. Gabriels<sup>5</sup>, G.K. Deutsch<sup>6</sup>, P. Tallal<sup>7</sup> and E. Temple<sup>1</sup>





déficit du traitement temporel (Tallal)





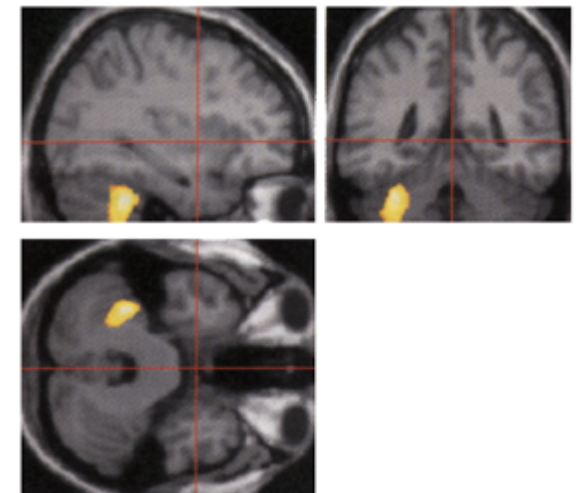
## Le cervelet : un organe aux fonctions multiples et émergentes

- motricité, coordination, posture
- Modulateur des apprentissages procéduraux et des automatismes (sensori-moteurs et cognitifs)
- Pace-maker des structures sus-jacentes?

# Developmental dyslexia: the cerebellar deficit hypothesis

Roderick I. Nicolson, Angela J. Fawcett and Paul Dean

Surprisingly, the problems faced by many dyslexic children are by no means confined to reading and spelling. There appears to be a general impairment in the ability to perform skills automatically, an ability thought to be dependent upon the cerebellum. Specific behavioural and neuroimaging tests reviewed here indicate that dyslexia is indeed associated with cerebellar impairment in about 80% of cases. We propose that disorders of cerebellar development can in fact cause the impairments in reading and writing characteristic of dyslexia, a view consistent with the recently appreciated role of the cerebellum in language-related skills. This proposal has implications for early remedial treatment.

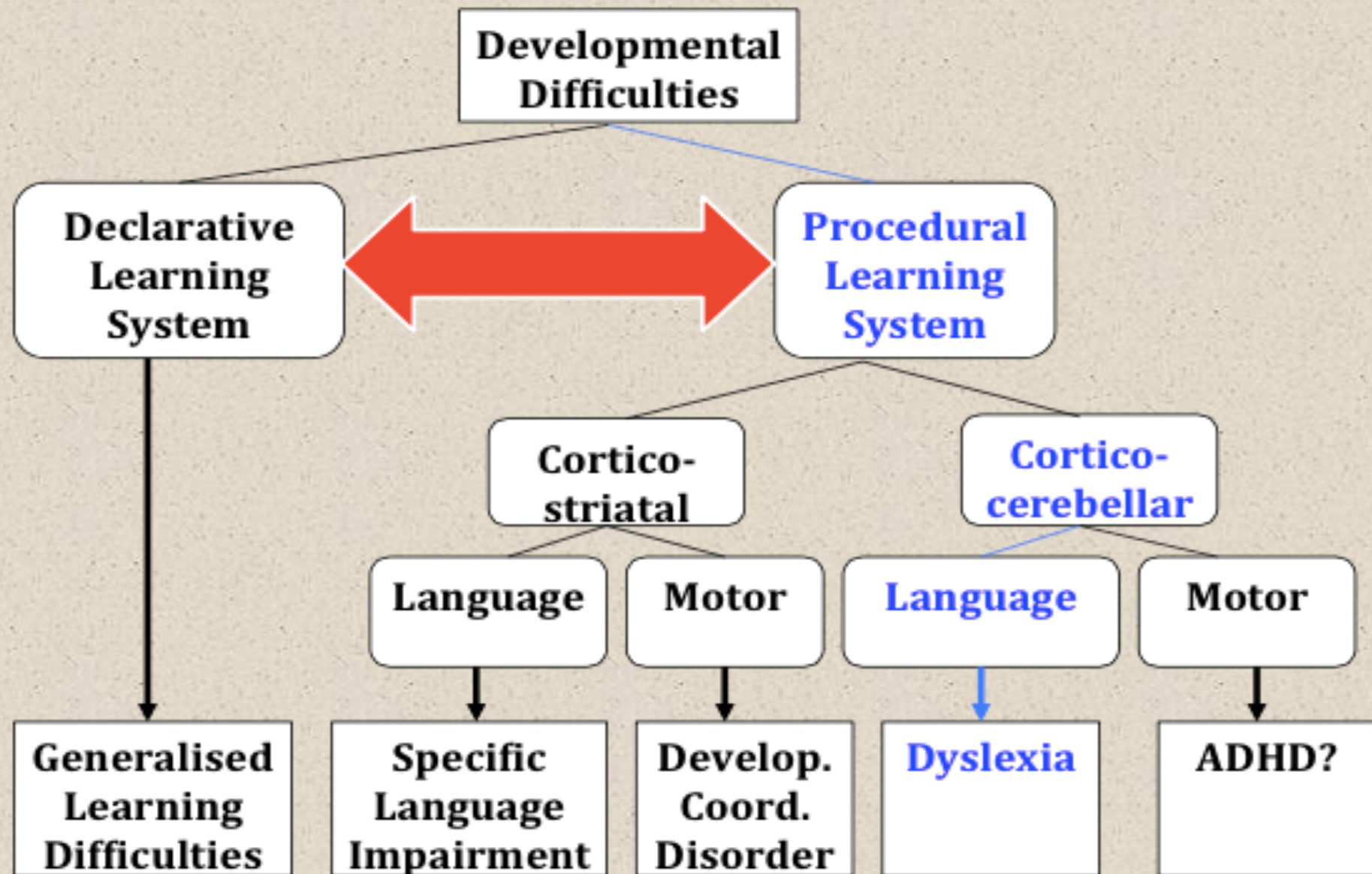


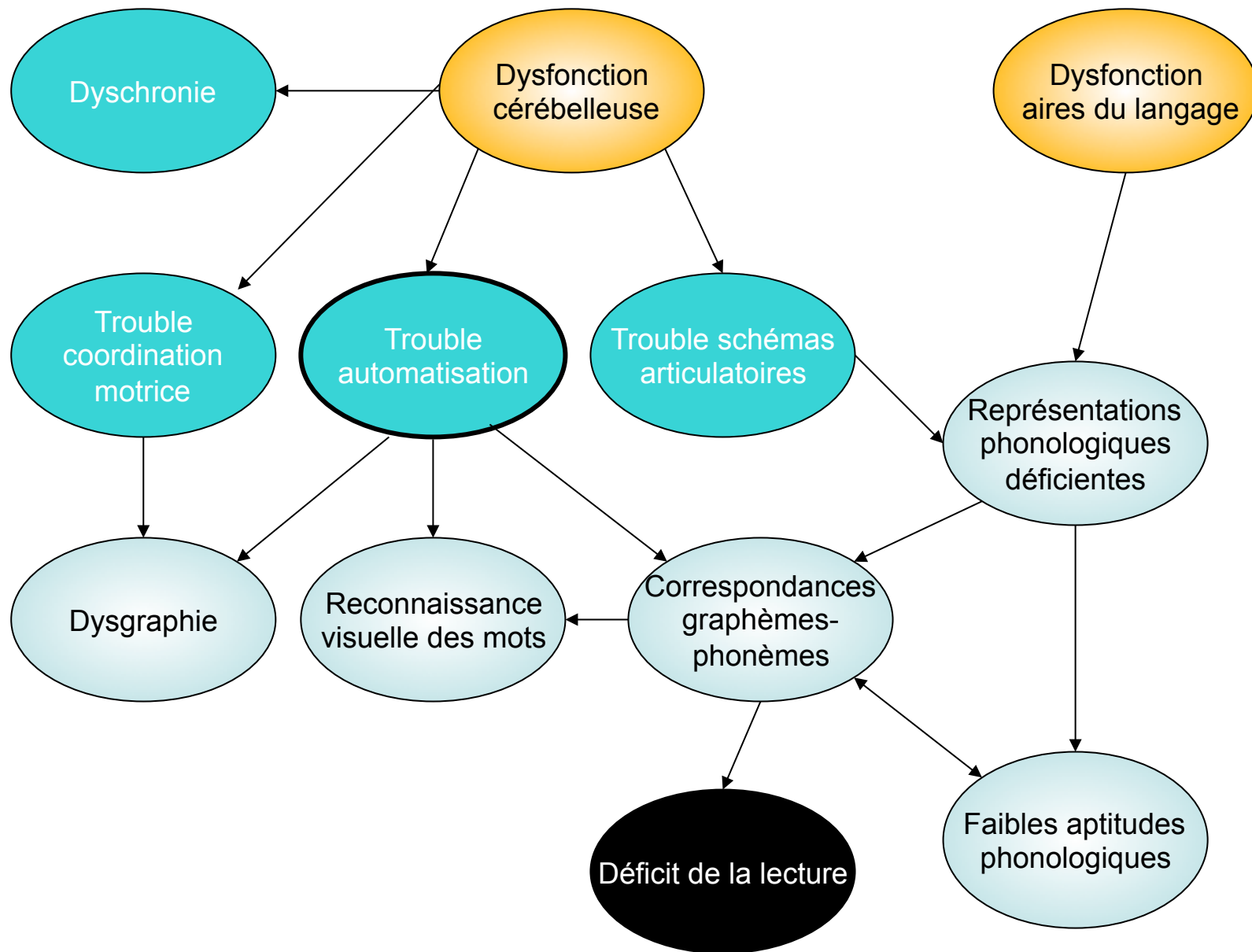
Nicolson et al., 1999

Nicolson et al., T.I.N.S., 2001

# Declarative vs Procedural Circuits

Nicolson & Fawcett, TINS, 2007





dysfonction cérébelleuse (Nicolson)





Métronomes couplés vs non couplés : synchronisation par transmission d'énergie





## Timing precision and rhythm in developmental dyslexia

PETER H. WOLFF

Children's Hospital and Harvard Medical School, Boston MA 02115, USA

dyslexic students anticipated the signal of an isochronic pacing metronome by intervals that were two or three times as long as those of age matched normal readers or normal adults. These group differences were significant when participants tapped with the preferred index finger alone or with both fingers in unison. Dyslexic students also took significantly longer than normal readers did to recalibrate their tapping responses when the metronome rate was experimentally changed in the middle of a trial. In addition, dyslexic students, by contrast to normal readers, had inordinate difficulty reproducing simple motor rhythms by finger tapping, and similar difficulty reproducing the appropriate speech rhythm of linguistically neutral nonsense syllables. These difficulties were exaggerated when participants had to synchronize their performance to an external pacing metronome.

Table 2. (A) Anticipation of isochronic intervals (finger tapping) and (B) Recalibration of anticipation mode (mean tracking responses before switch)

| Outcome measure                                                   | Dyslexic students<br>Mean (SD) | Normal readers<br>Mean (SD) |
|-------------------------------------------------------------------|--------------------------------|-----------------------------|
| <b>A. Absolute difference (ms) tap onset and metronome signal</b> |                                |                             |
| Stable rate – 2 Hz                                                |                                |                             |
| Right finger                                                      | 130 (53)                       | 41 (10)**                   |
| Both finger                                                       | 86 (41)                        | 28 (14)**                   |
| <b>B. Rate change: 1.5 to 2 Hz to 2.5 Hz</b>                      |                                |                             |
| Right finger                                                      | 6.1 (1.1)                      | 1.3 (14)**                  |

\*\* $p < 0.01$  Mann-Whitney U-Test.

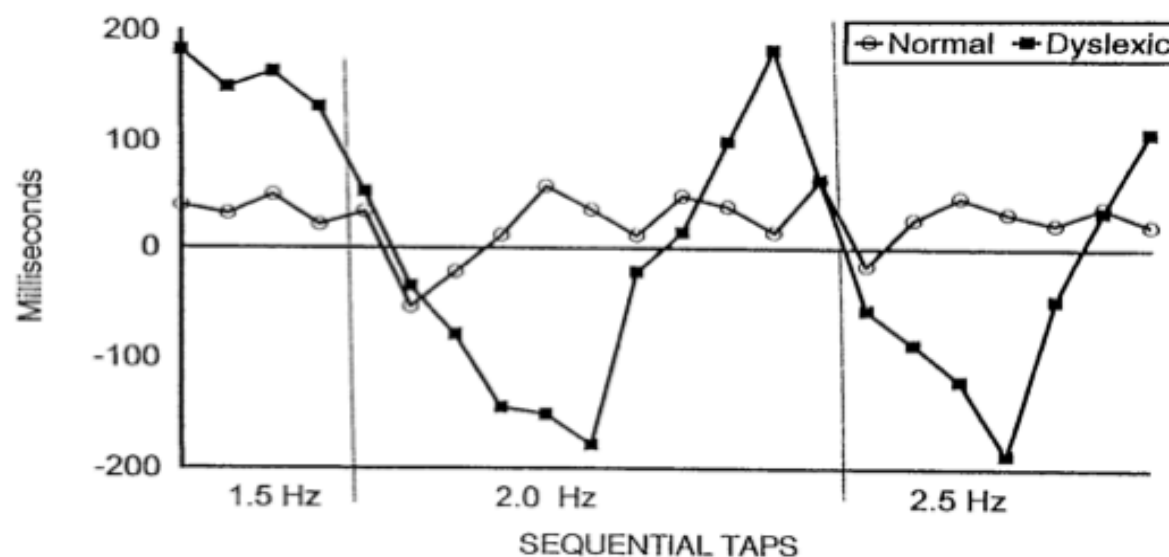
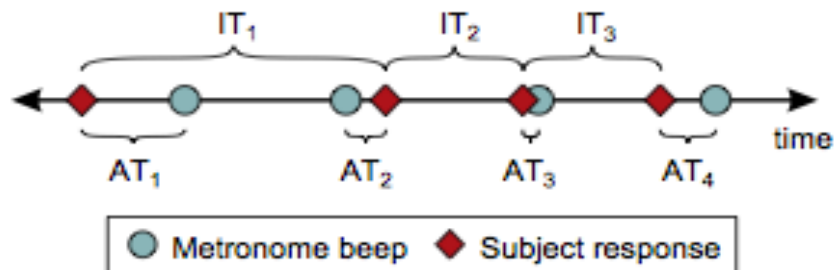


Figure 1. Mean intervals between tapping onset and metronome signal, before and after changes in metronome rate (dotted vertical lines). Points above the 0 line represent anticipation; those below the line represent tracking responses.



## Rhythmic processing in children with developmental dyslexia: Auditory and motor rhythms link to reading and spelling

Jennifer M. Thomson<sup>1</sup>, Usha Goswami<sup>\*</sup>



**Fig. 1 – Schematic depiction of ITI and AT calculation.**

We measure rhythmic finger tapping (paced by a metronome beat versus unpaced) and motor dexterity, phonological and auditory processing in 10-year old children, some of whom had a diagnosis of developmental dyslexia. We report links between paced motor tapping, auditory rhythmic processing and written language development. Motor dexterity does not explain these relationships. In regression analyses, paced finger tapping explained unique variance in reading and spelling.

CORTEX 45 (2009) 119–130

**Special issue: Research report**

### Rhythmic motor entrainment in children with speech and language impairments: Tapping to the beat

Kathleen H. Corriveau<sup>a,b</sup> and Usha Goswami<sup>a,\*</sup>

<sup>a</sup>Centre for Neuroscience in Education, University of Cambridge, Cambridge CB2 8PQ, UK

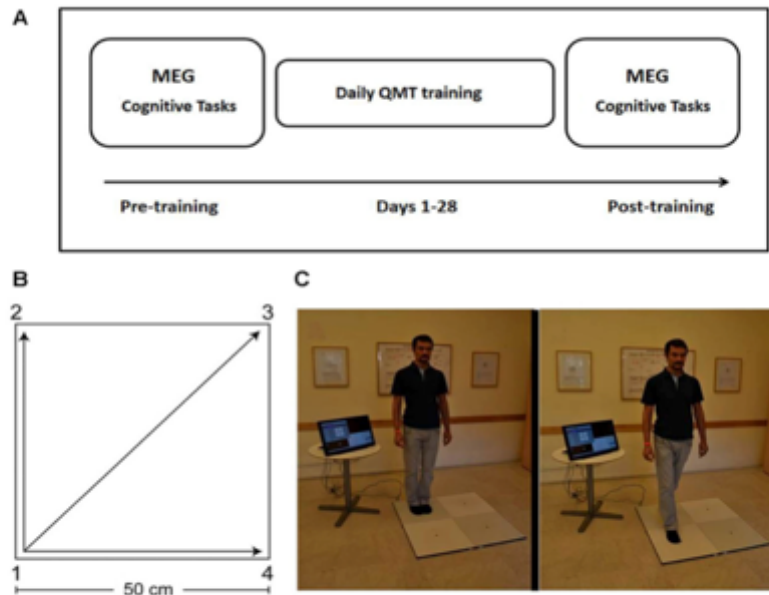
<sup>b</sup>Harvard University Graduate School of Education, Cambridge, MA, USA

Children with SLI were indeed found to be impaired in a range of measures of paced rhythmic tapping, but were not equally impaired in tapping in an unpaced control condition requiring an internally-generated rhythm. The severity of impairment in paced tapping was linked to language and literacy outcomes.



## Changes in cerebellar activity and inter-hemispheric coherence accompany improved reading performance following Quadrato Motor Training

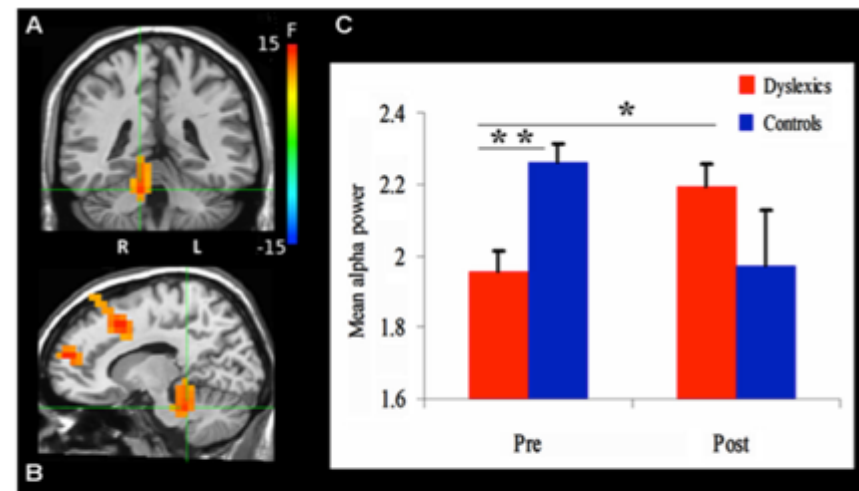
Tal Dotan Ben-Soussan<sup>1,2\*</sup>, Keren Avirame<sup>1,3†</sup>, Joseph Glicksohn<sup>1,4</sup>, Abraham Goldstein<sup>1,5</sup>, Yuval Harpaz<sup>1</sup>



**FIGURE 1 | Study design and Quadrato Motor Training.** (A) Experimental protocol. MEG and behavioral measurements were conducted before and after 4 weeks of QMT training (see text for details). Two different versions of the cognitive tests were presented pre- and post-training in a

counterbalanced order. (B) The spatial layout of the training: Practice setup. The trainee listens to recorded instructions a towards the target point. Figure adapted from Ben-Soussan. Quadrato Motor Training = QMT; Magnetoencephalography =

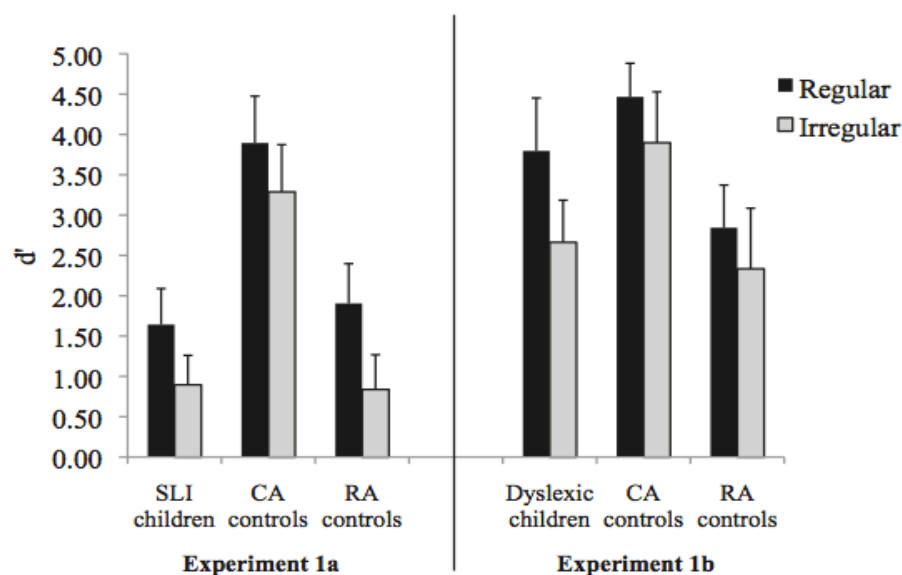
Twenty-two adult Hebrew readers (12 dyslexics and 10 controls) were recruited for the study. Using Magnetoencephalography (MEG), we measured changes in alpha power and coherence following QMT in a within-subject design. Reading performance was assessed pre- and post-training using a comprehensive battery of behavioral tests. Our results demonstrate improved performance on a speeded reading task following one month of intensive QMT in both the dyslexic and control groups. Dyslexic participants, but not controls, showed significant increase in cerebellar oscillatory alpha power following training.



**FIGURE 3 | Changes in alpha power.** (A) and (B) demonstrate the significant clusters resulting from the Group (dyslexics, controls) by Training (pre-training, post-training) interaction. Voxels are colored by the  $F$  statistics, overlaid on coronal (A) and sagittal (B) views. The statistical map is thresholded at  $p <$

0.0025 in addition to a cluster size threshold of 20 voxels. The focus point (green cross) is positioned in the right culmen (Talairach coordinate: 12, -37, -22). (C) The bar graph shows alpha power as a function of Group and Training (mean + SEM). \*  $p = 0.01$ ; \*\*  $p = 0.001$ .

## Rhythmic Auditory Stimulation Influences Syntactic Processing in Children With Developmental Language Disorders



*Figure 2.*  $d'$  data pattern of Experiments 1A and 1B averaged over participants, presented as a function of the musical prime (regular, irregular) and the participant groups: specific language impairment (SLI) children in Experiment 1A, dyslexic children in Experiment 1B, with their respective control groups matched for chronological age (CA) and reading age (RA). Error bars indicate between-participants standard errors.



Regular  
prime



Irregular  
prime

Children listened to either regular or irregular musical prime sequences followed by blocks of grammatically correct and incorrect sentences. They were required to perform grammaticality judgments for each auditorily presented sentence (grammatical vs agrammatical).

# Music Training Increases Phonological Awareness and Reading Skills in Developmental Dyslexia: A Randomized Control Trial

Elena Flaugnacco<sup>1,2</sup>, Luisa Lopez<sup>3</sup>, Chiara Terribili<sup>3</sup>, Marcella Montico<sup>4</sup>, Stefania Zoia<sup>1</sup>, Daniele Schön<sup>5,6\*</sup>

**Music training.** focus on rhythm and temporal processing (e.g. use of percussive instruments, use of rhythm syllables [ta, ti-ti, . . .], rhythmic body movements accompanying music, sensorimotor synchronization games). **Painting training.** This program emphasized visual-spatial and hand skills as well as creativity.

Training sessions involved groups of 5–6 children, one hour, twice a week, for 30 weeks (excluding holidays)

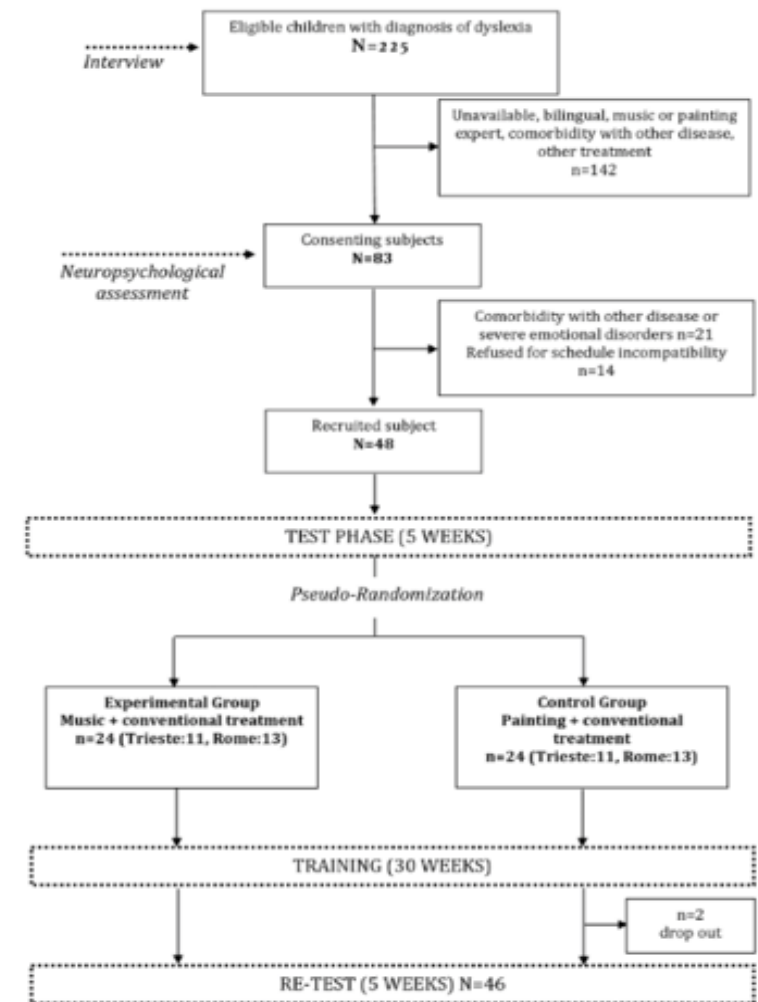


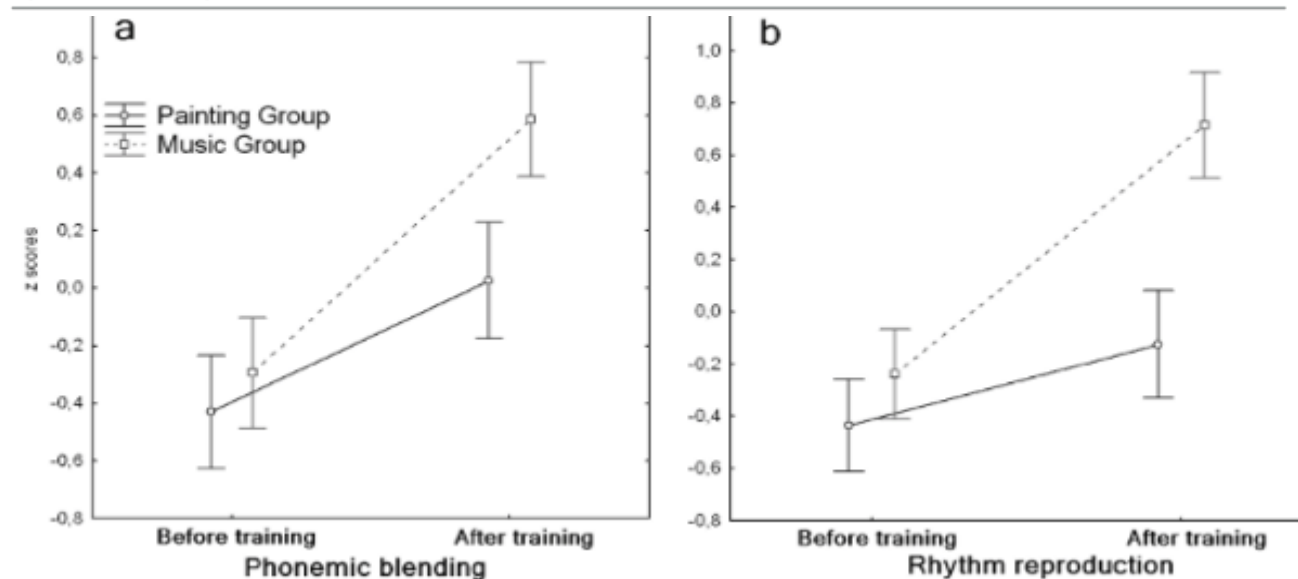
Fig 1. Flow chart illustrating participants' recruitment and experimental design.



Table 2. Summary of reading and phonological awareness results before and after training.

| Test                                    | Outcomes Variables         | Measure                               | Before training          |                       | After training           |                       | Larger effect of music training | Effect size |
|-----------------------------------------|----------------------------|---------------------------------------|--------------------------|-----------------------|--------------------------|-----------------------|---------------------------------|-------------|
|                                         |                            |                                       | Painting Group<br>n = 24 | Music Group<br>n = 22 | Painting Group<br>n = 24 | Music Group<br>n = 22 |                                 |             |
| DDE-2 Pseudo word reading test          | Accuracy (Primary Outcome) | N of severely impaired children (<5)  | 15                       | 17                    | 12                       | 5                     | 0.016                           | OR = 3.7    |
|                                         | Time                       | Mean of z score of seconds            | 4.1 (3.0)                | 3.6 (2.6)             | 2.89 (2.6)               | 2.42 (2.2)            | 0.57 (***)                      |             |
| MT Text reading                         | Accuracy                   | N of severely impaired children (<15) | 21                       | 20                    | 15                       | 8                     | 0.038                           | OR = 1.9    |
|                                         | Speed                      | Mean of z score syll/s                | -2.15 (0.84)             | -1.83 (0.62)          | -1.88 (0.81)             | -1.68 (0.61)          | 0.51 (**)                       |             |
| DDE-2 Word reading test                 | Accuracy                   | N of severely impaired children (<5)  | 18                       | 15                    | 8                        | 7                     | 0.76                            |             |
|                                         | Time                       | Mean of z score of seconds            | 6.2 (5.5)                | 5.6 (4.4)             | 4.18 (4.7)               | 3.38 (2.9)            | 0.67 (***)                      |             |
| Pseudo-word reproduction Promea Battery | Accuracy (40 items)        | Mean of correct Pseudo-words          | 32.45 (4.95)             | 31.33 (3.71)          | 33.77 (4.3)              | 34.87 (2.6)           | 0.03                            | 0.3         |
| Phonemic segmentation task              | Accuracy (38 items)        | Mean of correct words                 | 13.5 (9.48)              | 17.1 (9.50)           | 20.36 (8.78)             | 23.52 (7.72)          | 0.7 (***)                       |             |
|                                         | Speed                      | Mean of seconds                       | 437 (186)                | 429 (132)             | 401 (123)                | 397 (94)              | 0.17                            |             |
| Phonemic blending                       | Accuracy (38 items)        | Mean of correct words                 | 9.4 (9.45)               | 11 (10.96)            | 14.05 (9.38)             | 19.83 (9.54)          | 0.004                           | 0.4         |
|                                         | Speed                      | Mean of seconds                       | 614 (153)                | 630 (153)             | 620 (207)                | 557 (148)             | 0.10                            |             |

The column "Larger effect of music training" reports whether or not there is a larger improvement in the music training group compared to the painting group (p value<0.05). When this is not the case (ns, p>0.05), significant main effects of session are reported (\* = p<0.05; \*\* = p<0.01; \*\*\* = p<0.001), pointing to an equal improvement of both groups. The standard deviation from the mean is reported in parenthesis. The effect size is reported for significant effects (categorical data: Odd Ratio; interval data:  $z/\sqrt{N}$ ).



A larger effect of music training was also found when testing **auditory attention** and in several perception and production abilities as tested by psychoacoustic and musical tasks (Table 3). This was particularly evident for tasks requiring precise temporal processing, such as the temporal anisochrony detection task (a psychophysical measure of temporal regularity perception) and **the rhythm reproduction task** (Fig 2b), wherein children had to tap a previously heard rhythmic sequence. The outcome in the rhythm production task turned out to be **the best predictor of phonological awareness** as measured by the phonemic blending and phonemic segmentation tasks



McGurk effect : an auditory /ba/ presented with a visual /ga/ is typically “heard” as /da/ (the reverse, i.e., auditory /ga/ and visual /ba/, tends to yield /bga/).

## Integration of heard and seen speech: a factor in learning disabilities in children

Erin A. Hayes<sup>a,\*</sup>, Kaisa Tiippana<sup>b</sup>, Trent G. Nicol<sup>a</sup>, Mikko Sams<sup>b</sup>, Nina Kraus<sup>a,c,d</sup>

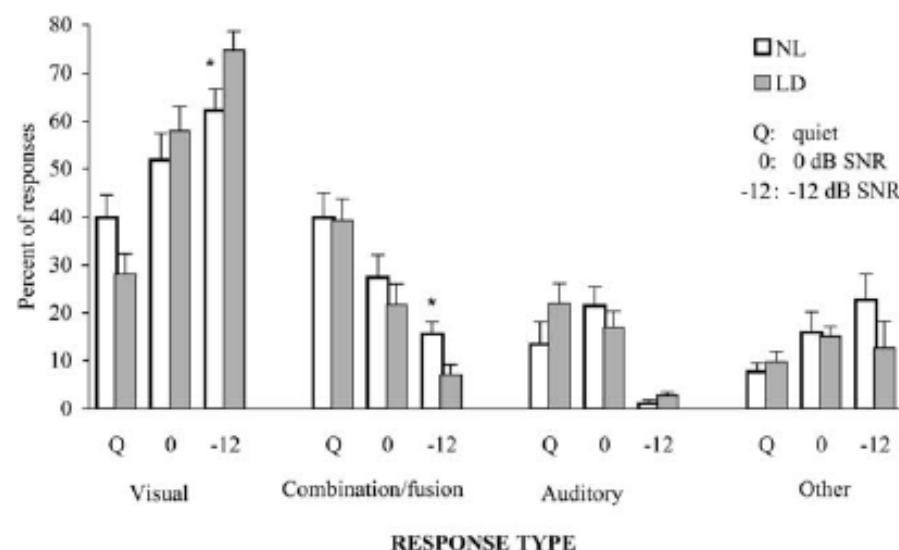


Fig. 1. Response types averaged across the four incongruent stimulus pairs. Presented here are the adjusted means for the response type, calculated with audio-alone and visual-alone scores as covariates; error bars represent one standard error of the mean. At  $-12$  dB SNR, LD children reported a higher proportion of visual responses to incongruent stimuli. Conversely, combinations/fusions were more likely to be reported by NL children. A similar pattern of results can be seen at 0 dB SNR, but the differences were not statistically significant. In addition, there was an interaction between noise level and diagnostic group such that LDs exhibited a greater increase in perception of the visual component of incongruent stimuli with increased noise level. Auditory and other responses did not differ between groups at any noise level.

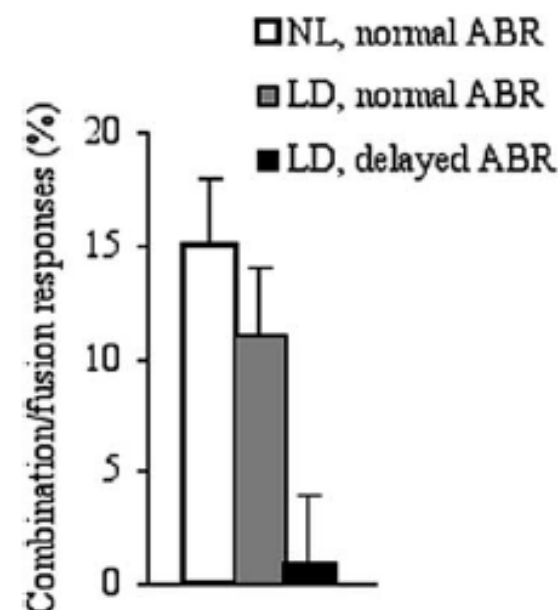


Fig. 2. Combination and fusion responses to incongruent stimuli at  $-12$  dB SNR for children grouped according to brainstem latency elicited by /da/. Presented here are the adjusted means calculated with audio-alone and visual-alone scores as covariates; error bars represent one standard error of the mean. LD children with delayed latencies reported fewer combination and fusion responses to incongruent audiovisual stimuli than NL children with a normal latency. The frequency of combination/fusion responses in LD children with a latency within normal limits was intermediate between the other two groups.

# Effet McGurk chez des adultes dyslexiques et normo-lecteurs

- 9 adultes gardant des séquelles de dyslexie (4 M, 5 F; Age moyen : 38, range: 34-52) et 10 adultes normo-lecteurs (5 M, 5 F; Age moyen 30, range: 20-40)
- 81 présentations séparées par intervalles de 10 sec.
- 3 stimuli auditifs (/aba/, /ada/, ou /aga/) associés à des séquences vidéo, sous 2 conditions : congruente vs incongruente.
- Validation préalable du matériel : /aba/-/aga/, --> /ada/; /ada/-/aba/, --> /abda/; /aga/-/aba/, --> /abga/ (Cathiard et al., 2001).

# Effet McGurk chez des adultes dyslexiques et normo-lecteurs

|              |  | COHERENT AUDIO-VISUAL : ABA |     |     |      |      |      |      |      |        |
|--------------|--|-----------------------------|-----|-----|------|------|------|------|------|--------|
|              |  | ABA                         | ADA | AGA | ABDA | ABGA | ADBA | ADGA | AGBA | Autres |
| Non-dyslexic |  | 93                          | 1   | 0   | 3    | 0    | 2    | 0    | 0    | 0      |
| Dyslexic     |  | 100                         | 0   | 0   | 0    | 0    | 0    | 0    | 0    | 0      |

|              |  | COHERENT AUDIO-VISUAL : ADA |     |     |      |      |      |      |      |        |
|--------------|--|-----------------------------|-----|-----|------|------|------|------|------|--------|
|              |  | ABA                         | ADA | AGA | ABDA | ABGA | ADBA | ADGA | AGBA | Autres |
| Non-dyslexic |  | 0                           | 80  | 0   | 9    | 0    | 0    | 1    | 0    | 10     |
| Dyslexic     |  | 0                           | 77  | 0   | 20   | 0    | 0    | 1    | 0    | 2      |

|              |  | COHERENT AUDIO-VISUAL : AGA |     |     |      |      |      |      |      |        |
|--------------|--|-----------------------------|-----|-----|------|------|------|------|------|--------|
|              |  | ABA                         | ADA | AGA | ABDA | ABGA | ADBA | ADGA | AGBA | Autres |
| Non-dyslexic |  | 0                           | 0   | 94  | 0    | 0    | 0    | 6    | 0    | 0      |
| Dyslexic     |  | 0                           | 1   | 91  | 0    | 4    | 0    | 4    | 0    | 0      |

Les trois conditions cohérentes



# Effet McGurk chez des adultes dyslexiques et normo-lecteurs

Audio ADA / Visual ABA

|               | AUDIO     | VISUAL | FUSION | COMB*     | OTHER   |
|---------------|-----------|--------|--------|-----------|---------|
| Non-dyslexics | 17 (19.1) | 0      | 0      | 83 (19.1) | 0       |
| Dyslexics     | 38 (41.5) | 0      | 0      | 57 (38.2) | 6 (8.4) |

Audio AGA / Visual ABA

|               | AUDIO     | VISUAL | FUSION | COMB      | OTHER   |
|---------------|-----------|--------|--------|-----------|---------|
| Non-dyslexics | 14 (21.0) | 0      | 0      | 84 (23.0) | 1 (3.5) |
| Dyslexics     | 31 (35.5) | 0      | 0      | 65 (34.3) | 4 (8.3) |

Audio ABA / Visual AGA

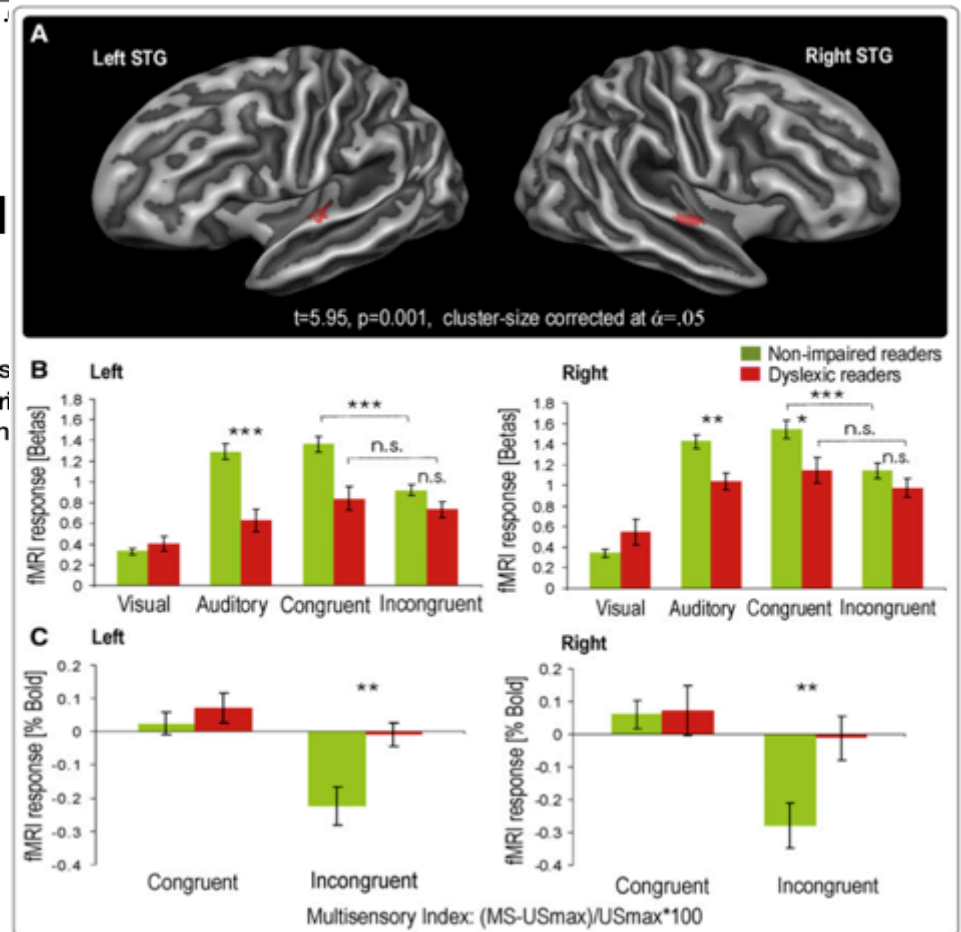
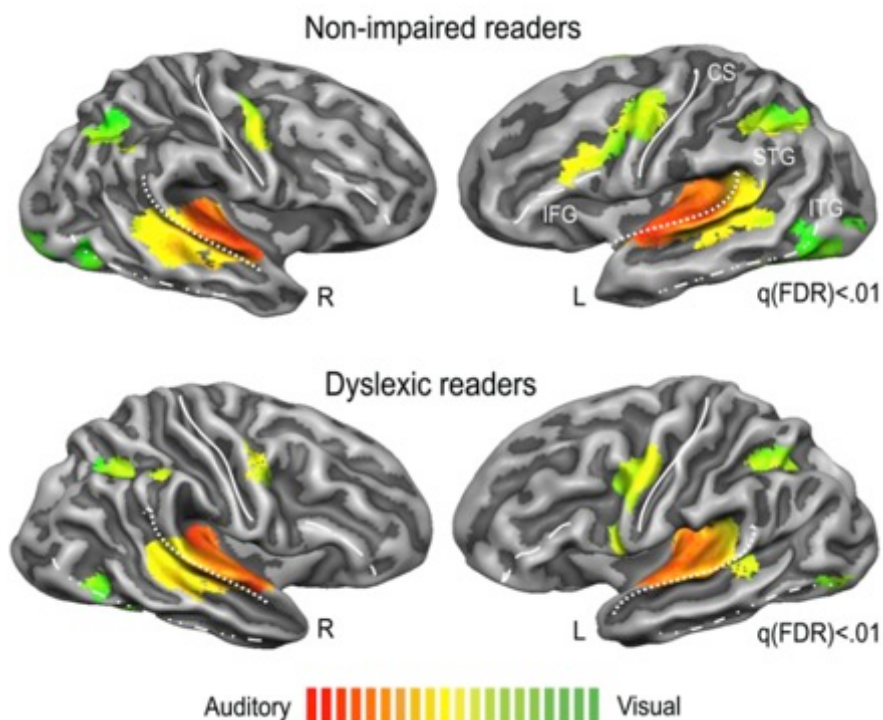
|               | AUDIO     | VISUAL  | FUSION    | COMB    | OTHER   |
|---------------|-----------|---------|-----------|---------|---------|
| Non-dyslexics | 44 (46.3) | 3 (7.5) | 50 (43.0) | 0       | 2 (4.7) |
| Dyslexics     | 67 (34.6) | 3 (5.1) | 25 (31.3) | 3 (5.1) | 3 (5.1) |

- Conditions incongruentes : moins de combinaisons ou de fusions chez les dyslexiques <-- déficit d'intégration intermodale
- préférence générale pour stimuli auditifs

# Reduced Neural Integration of Letters and Speech Sounds Links Phonological and Reading Deficits in Adult Dyslexia

Vera Blau,<sup>1,2,\*</sup> Nienke van Atteveldt,<sup>1,2</sup> Michel Ekkebus,<sup>3</sup>  
Rainer Goebel,<sup>1,2</sup> and Leo Blomert<sup>1,2</sup>  
<sup>1</sup>University of Maastricht

for letters and speech s  
dyslexia have been pri  
adequately representin



Zones activées par des stimuli unimodaux  
(parole=rouge, lettres=vert, commun=jaune)

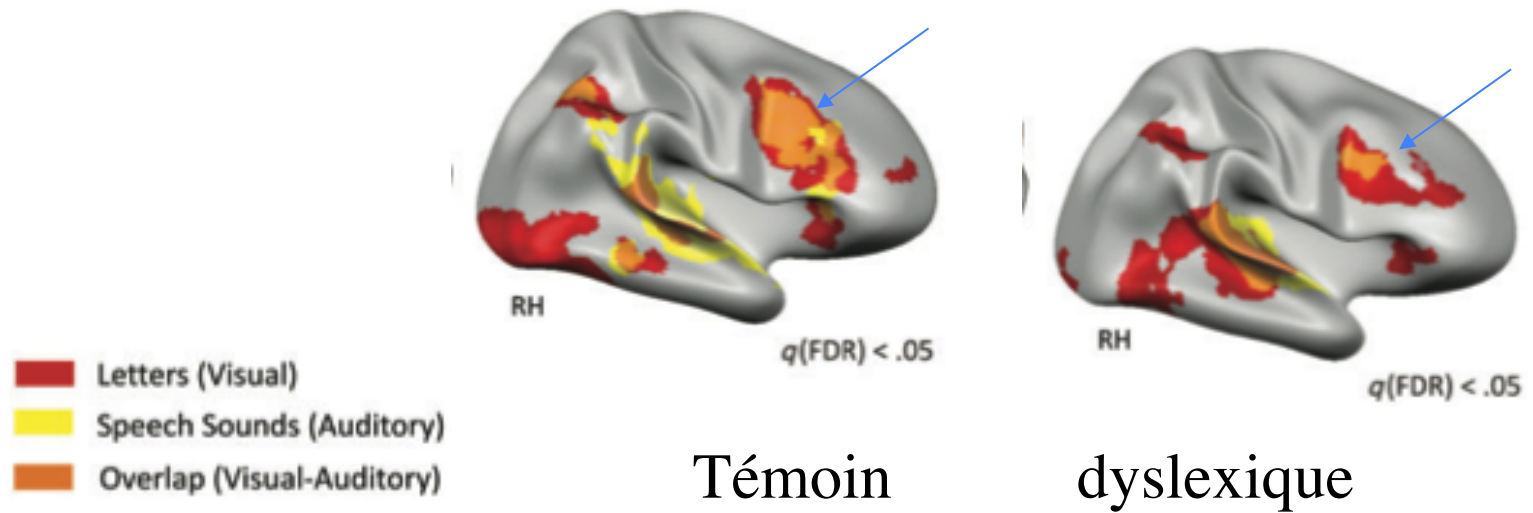
4 conditions : unimodal visuel, unimodal auditif, multimodal congruent et multimodal incongruent

A/ l'interaction groupe condition est significative dans les deux régions auditives moyennes

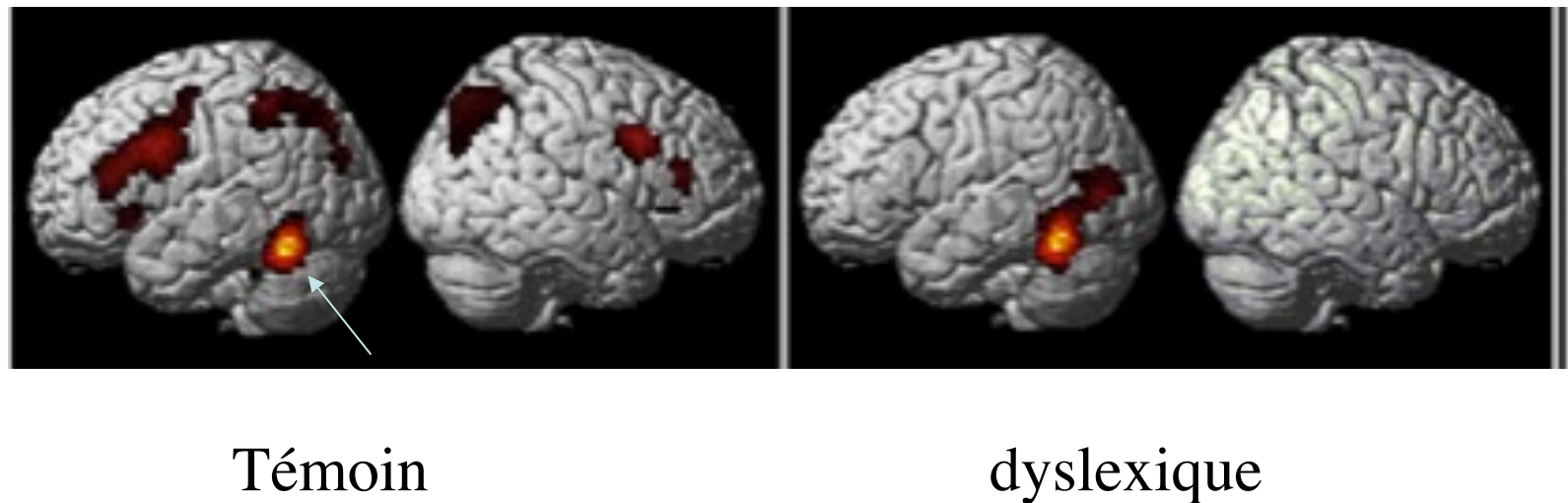
B/ dyslexiques activent moins en unimodal et en multimodal

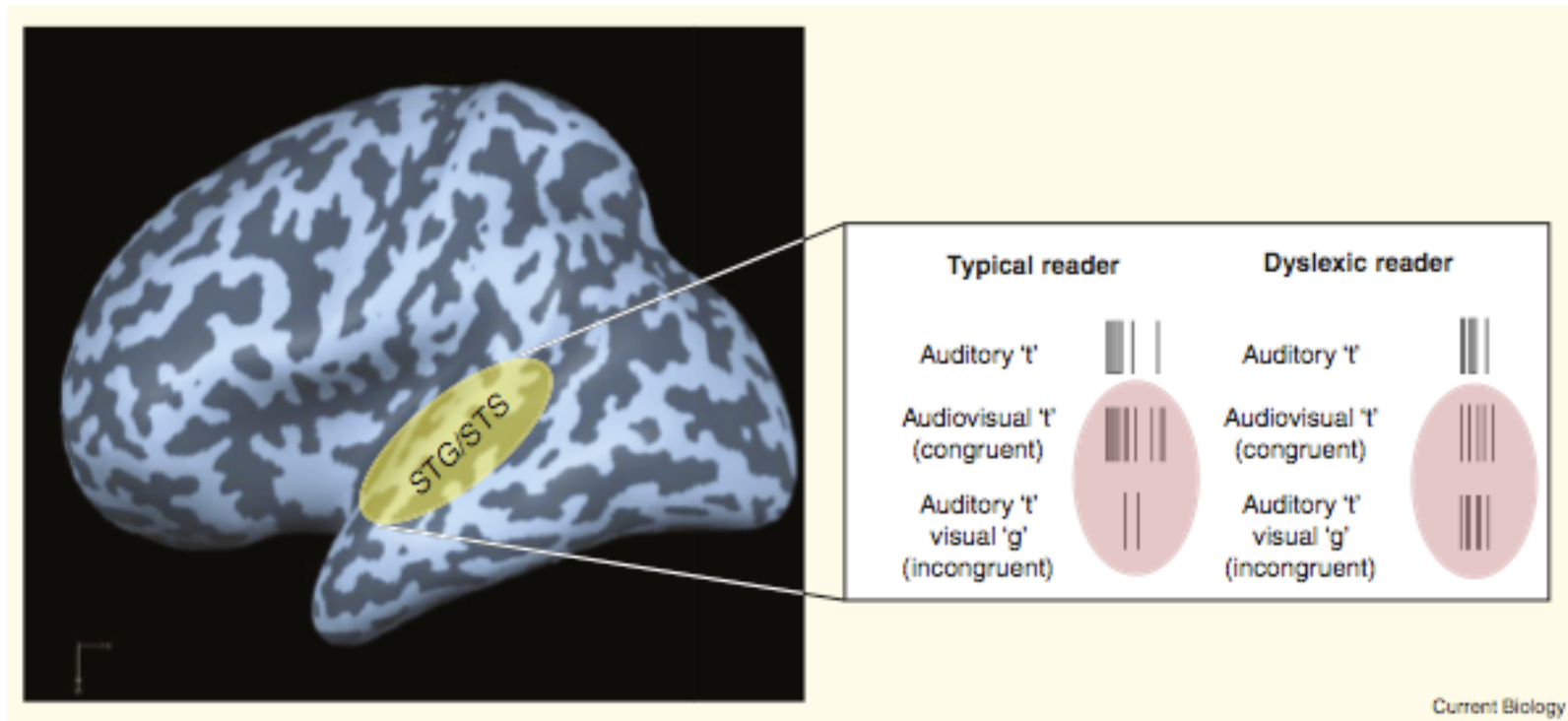
C/ témoins ont une moins forte activation pour les paires incongruentes, pas les dyslexiques

Blau et al.,  
Brain, 2010



Van den  
Mark,  
Neuroimage,  
2011





lorsque le stimulus est congruent (le sujet entend 't' et voit la lettre T), la décharge neuronale est moins bien organisée que chez le témoin; en outre, celle-ci est beaucoup plus importante qu'elle ne devrait l'être pour un stimulus incongruent (le sujet entend 't' et voit la lettre G).

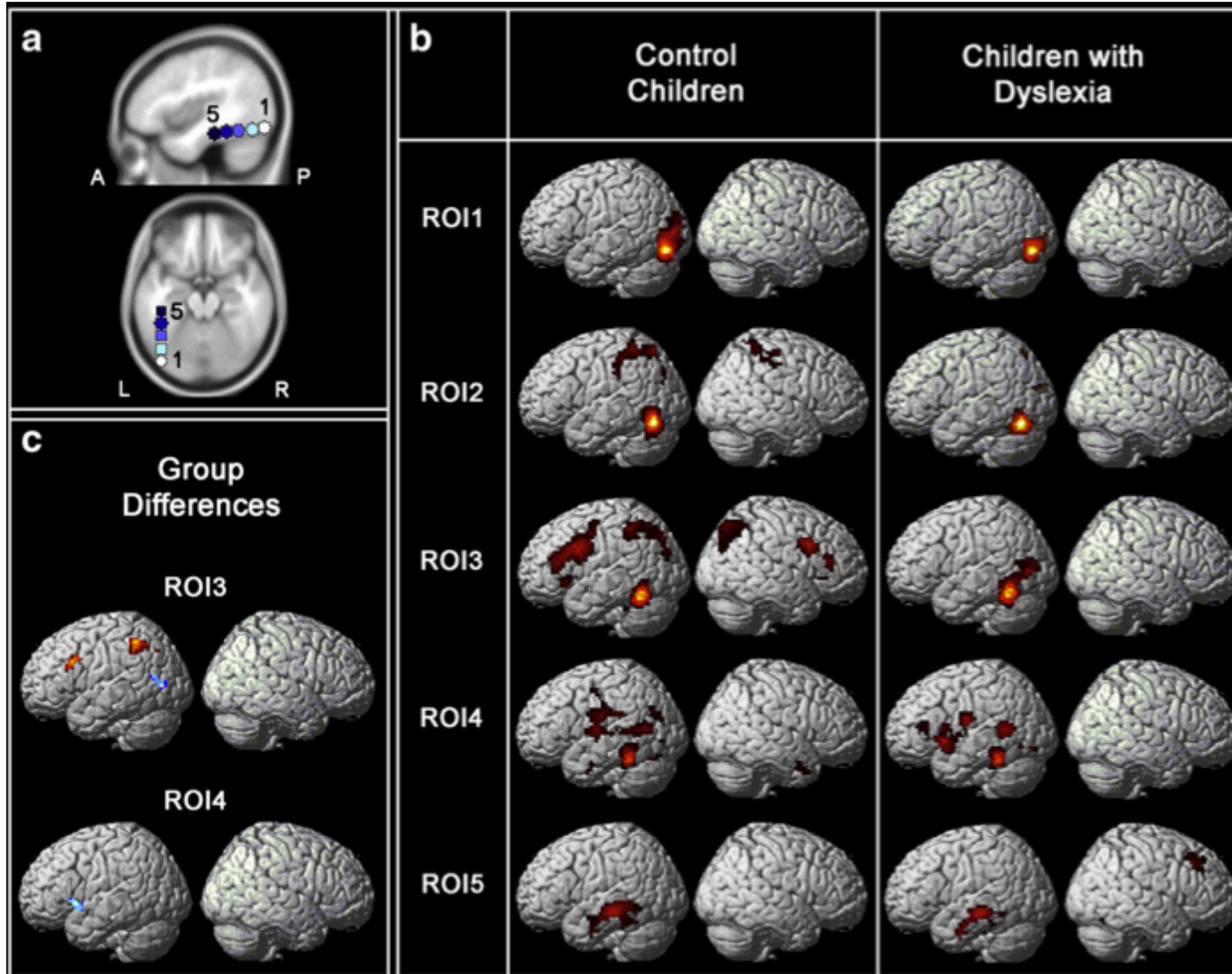
--> pb d'intégration intermodale





# The left occipitotemporal system in reading: Disruption of focal fMRI connectivity to left inferior frontal and inferior parietal language areas in children with dyslexia

Sanne van der Mark<sup>a,1</sup>, Peter Klaver<sup>a,b,c,1</sup>, Kerstin Bucher<sup>a</sup>, Urs Maurer<sup>d,e</sup>, Enrico Schulz<sup>d,f</sup>, Silvia Brem<sup>d,g</sup>, Ernst Martin<sup>a,c</sup>, Daniel Brandeis<sup>c,d,h,\*</sup>



MRI was used to assess connectivity of the VWF-System in 18 children with dyslexia and 24 age-matched controls (age 9.7–12.5 years) using five neighboring left occipitotemporal regions of interest (ROIs) during a continuous reading task requiring phonological and orthographic processing.

First, the results revealed a focal origin of connectivity from the VWF-system, in that mainly the VWFA was functionally connected with typical left frontal and parietal language areas in control children. Adjacent posterior and anterior VWF-System ROIs did not show such connectivity, confirming the special role that the VWFA plays in word processing.

Second, we detected a significant disruption of functional connectivity between the VWFA and left inferior frontal and left inferior parietal language areas in the children with dyslexia.



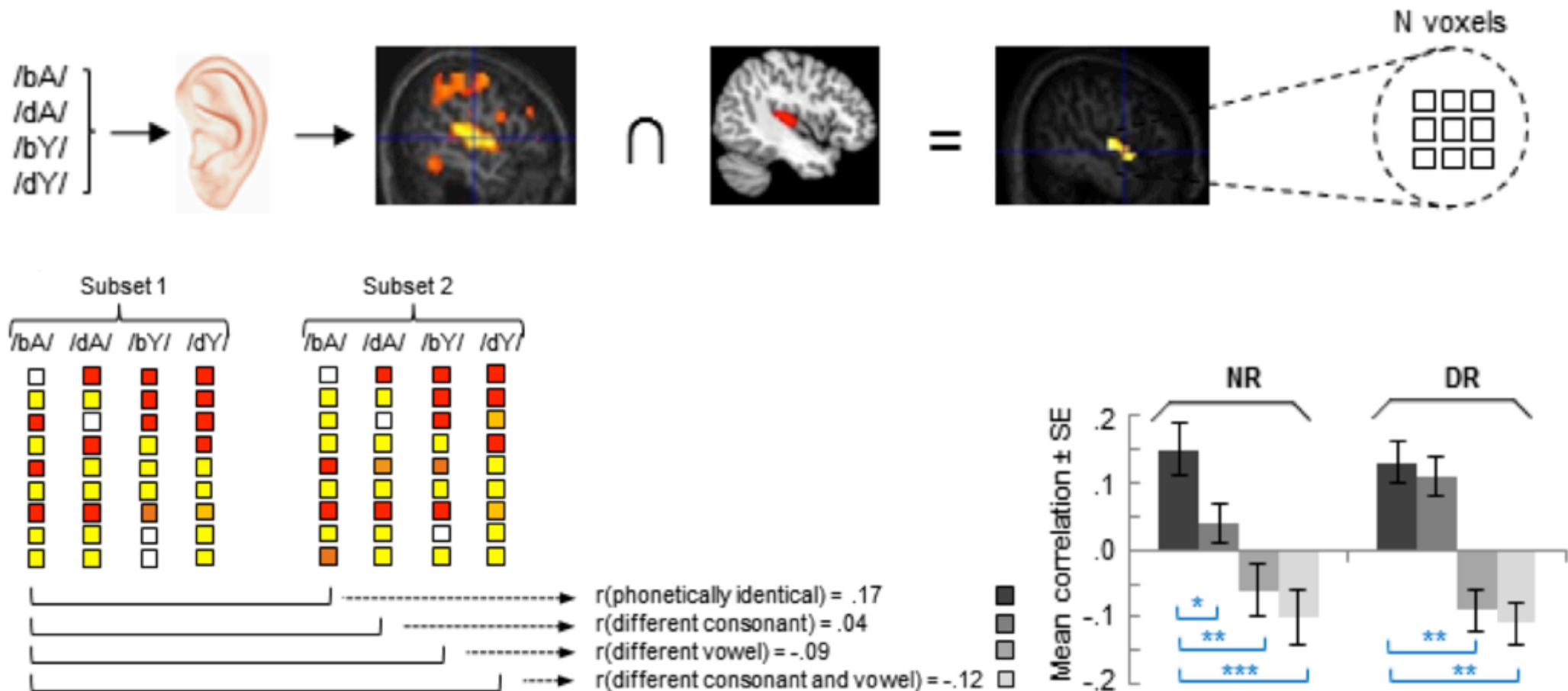


# Intact But Less Accessible Phonetic Representations in Adults with Dyslexia

Bart Boets *et al.*

*Science* **342**, 1251 (2013);

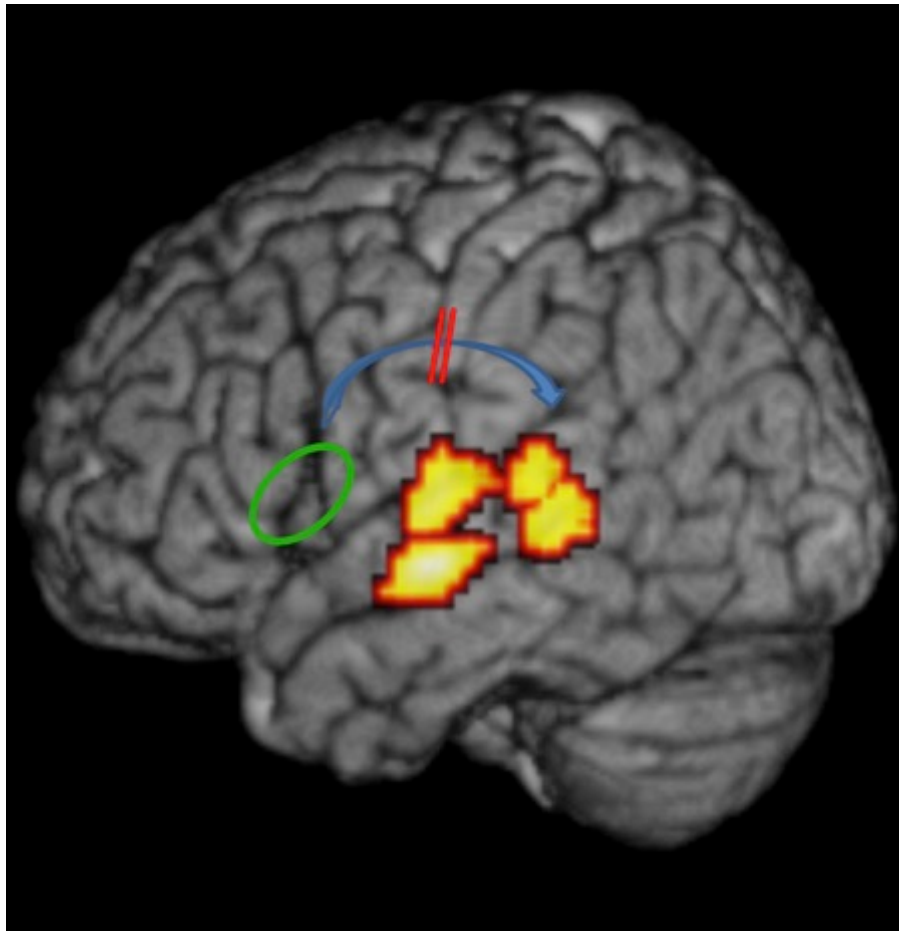
DOI: 10.1126/science.1244333



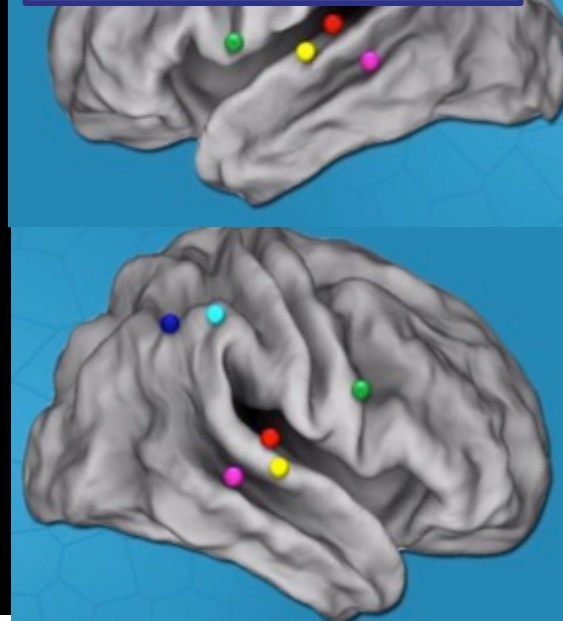
## Boets et al. : conclusions

- les corrélations sont plus fortes au sein d'une catégorie qu'entre les catégories : signe la robustesse des représentations
- les représentations sont aussi robustes chez les DYS que chez les NL : représentations ne sont pas altérées/dégradées chez les DYS

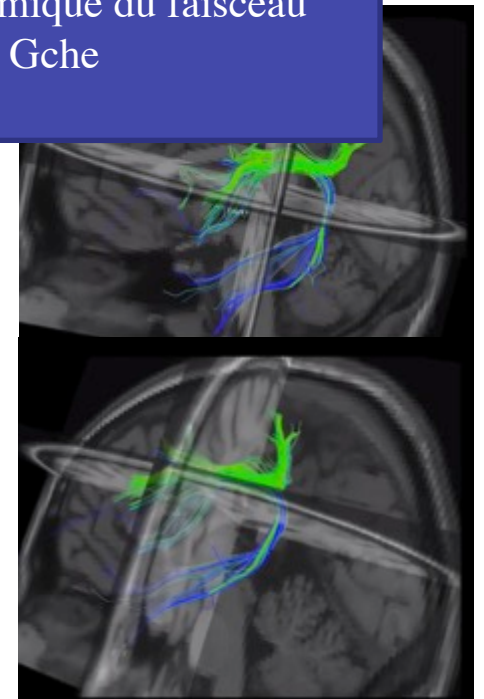
→ Les DYS auraient un problème **d'accès à des représentations intactes**

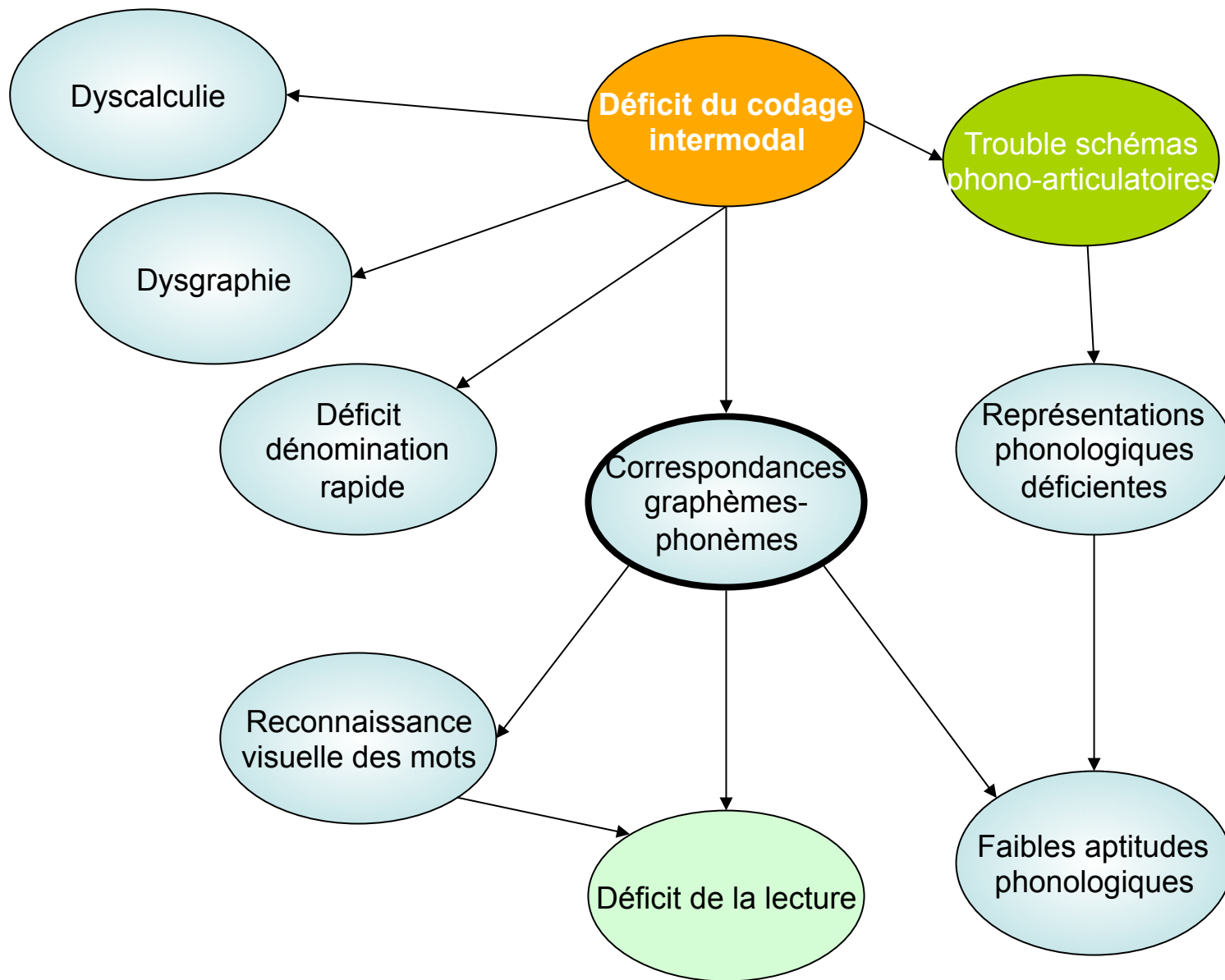


Défaut de connectivité  
fonctionnelle entre Broca  
et aires auditives D/G



Réduction de l'intégrité  
anatomique du faisceau  
arqué Gche





déficit transcodage intermodal



# Mapping symbols to sounds: electrophysiological correlates of the impaired reading process in dyslexia

Andreas Widmann<sup>1\*</sup>, Erich Schröger<sup>1</sup>, Mari Tervaniemi<sup>2,3</sup>, Satu Pakarinen<sup>2</sup> and Teija Kujala<sup>2,4</sup>

<sup>1</sup> Institute of Psychology, University of Leipzig, Leipzig, Germany

<sup>2</sup> Cognitive Brain Research Unit, Cognitive Science, Institute of Behavioural Sciences, University of Helsinki, Helsinki, Finland

<sup>3</sup> Center of Excellence in Interdisciplinary Music Research, University of Jyväskylä, Jyväskylä, Finland

<sup>4</sup> Cicero Learning, University of Helsinki, Helsinki, Finland

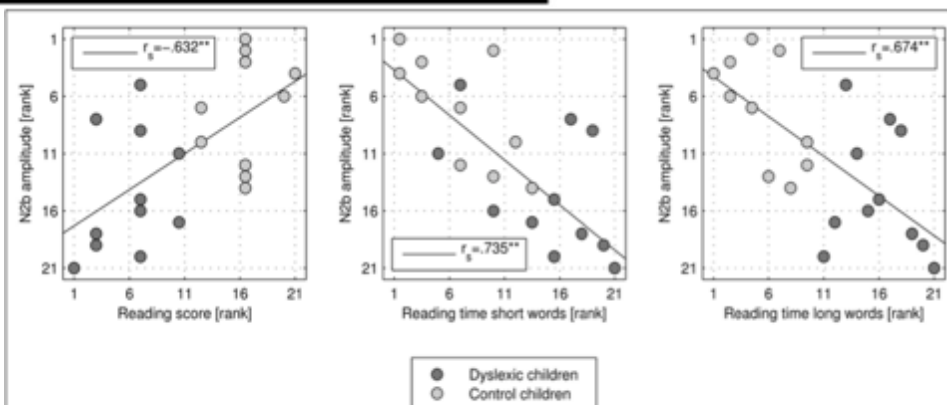
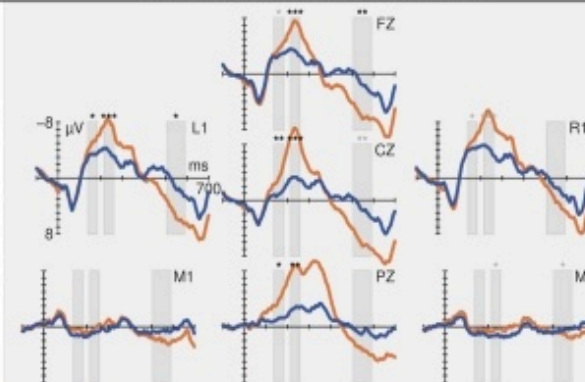


FIGURE 3 | Scatter plot and correlation of N2b amplitude rank (negative up) at electrode location Cz and rank of reading score, and reading time of short and long words, respectively.

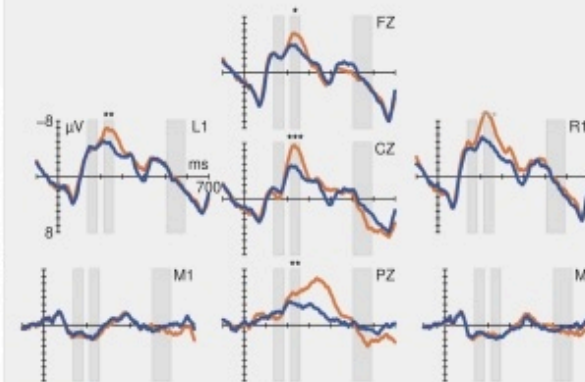
## A Symbol-to-Sound-Matching Task

ERPs Control Children



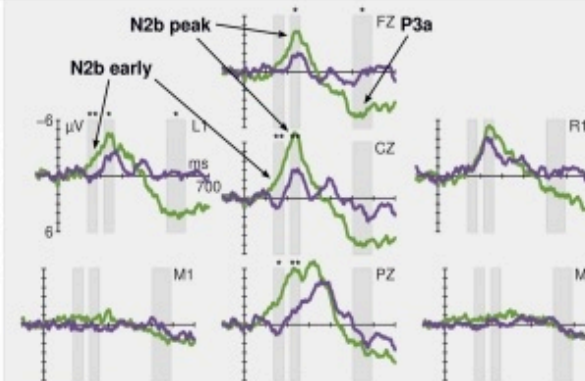
— Incongruent sounds  
— Congruent sounds

ERPs Dyslexic Children



— Incongruent sounds  
— Congruent sounds

Difference Waves



— Control children: Incongruent minus congruent sounds  
— Dyslexic children: Incongruent minus congruent sounds





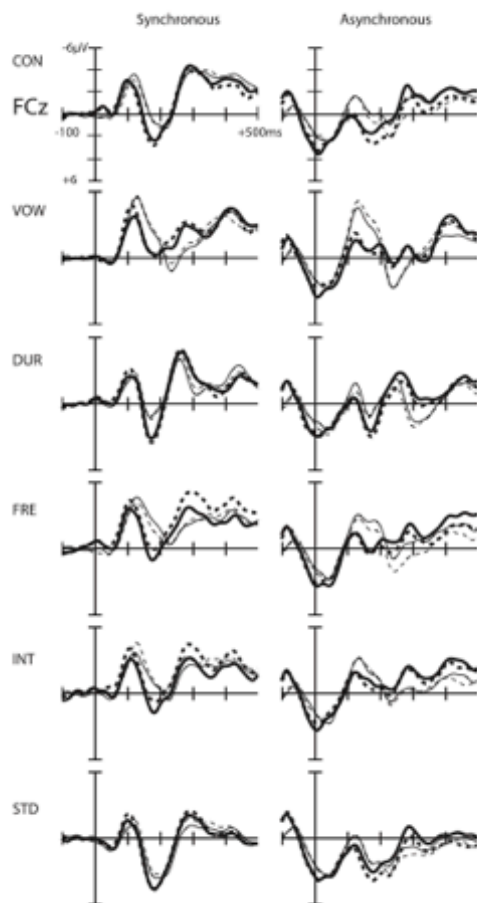
## The neurophysiological basis of the integration of written and heard syllables in dyslexic adults

Maria Mittag<sup>a,\*</sup>, Paula Thesleff<sup>a</sup>, Marja Laasonen<sup>b,c</sup>, Teija Kujala<sup>a,d</sup>

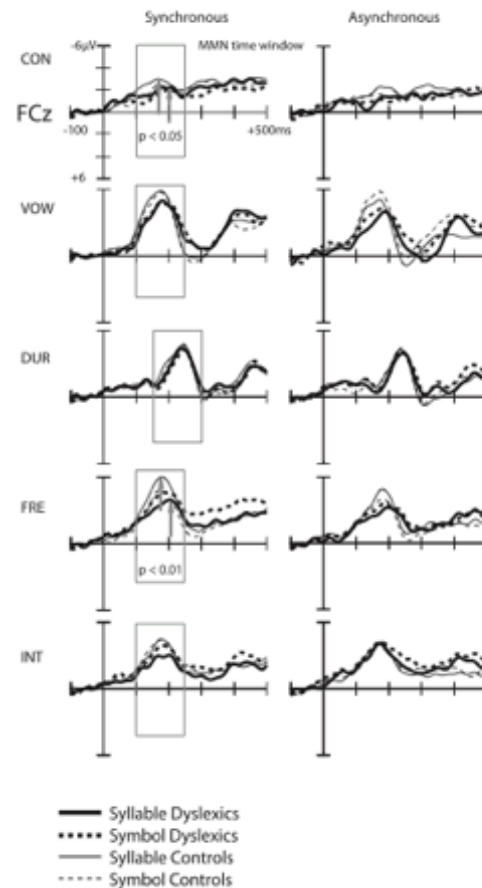
The main aim of our study was to investigate whether dyslexic readers are impaired in integrating speech sounds with written syllables as reflected by the MMN. To test this, syllable sounds were presented together with either written syllables or symbols.

MMNs were larger for written syllables than for symbols in fluent readers indicating a generally greater effect of printed text than nonsense visual material on early auditory speech discrimination. However, no such MMN differences were found between the conditions in dyslexic readers.

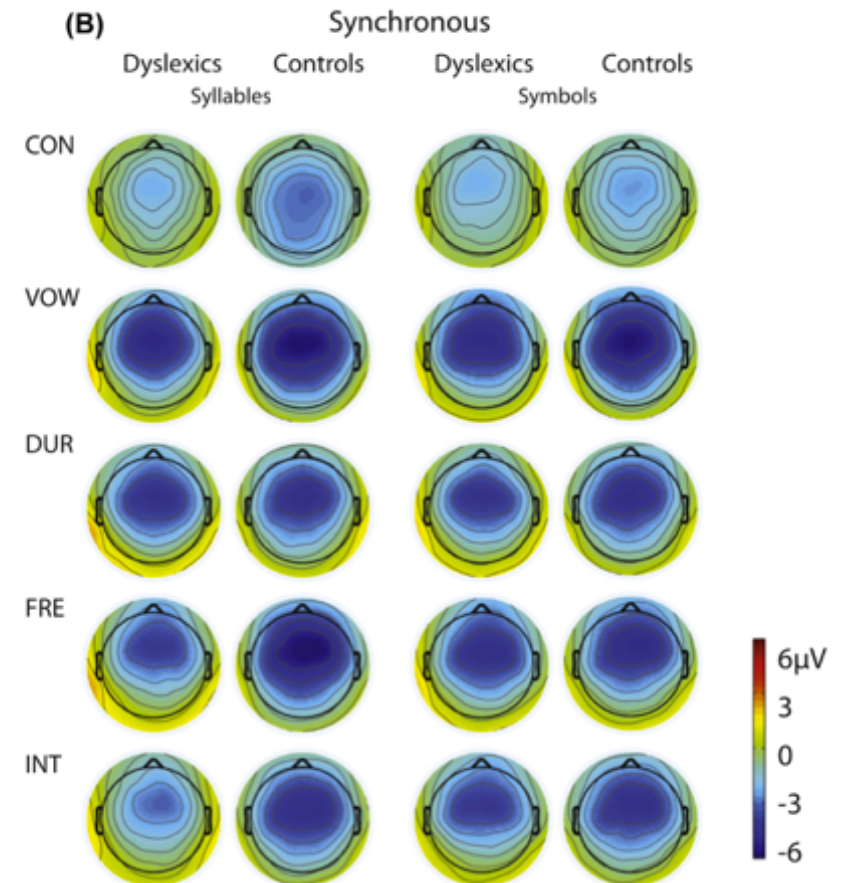
### Grandaverage waveforms



### Difference waveforms



(B)

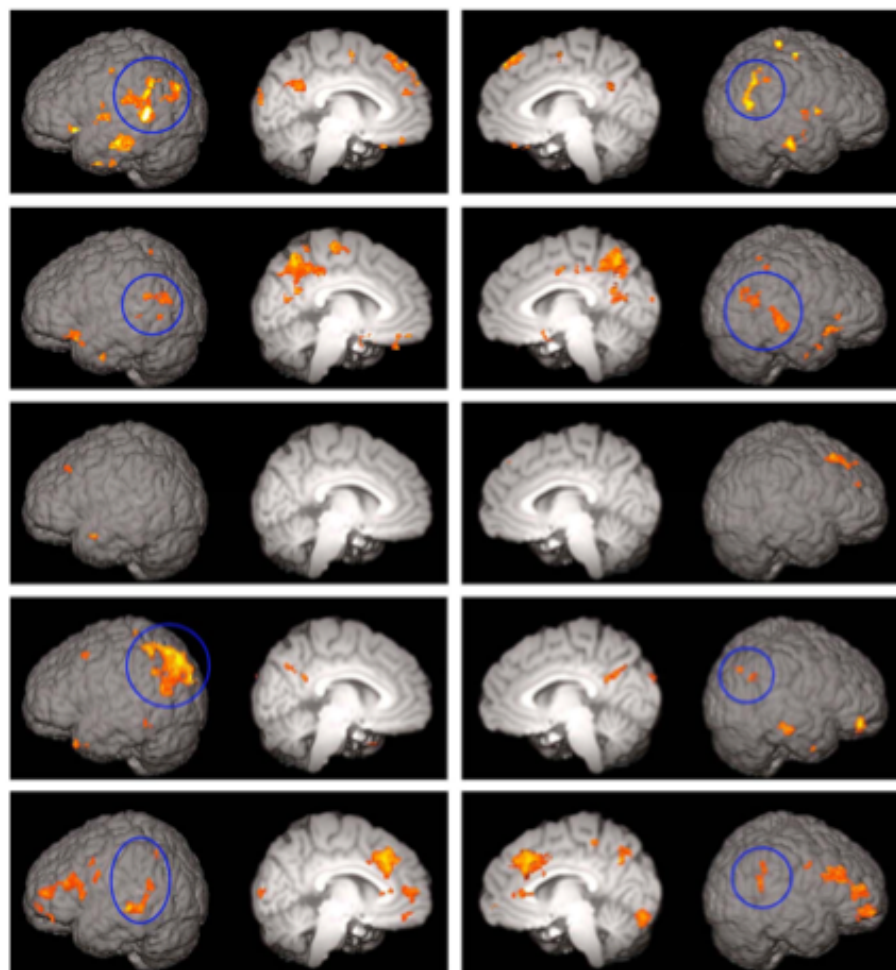




## Emergence of the neural network for reading in five-year old beginning readers of different levels of pre-literacy abilities: an fMRI study

Yoshiko Yamada<sup>1</sup>, Courtney Stevens<sup>2,1</sup>, Mark Dow<sup>1</sup>, Beth Harn<sup>3</sup>, David J. Chard<sup>4,3</sup>, and Helen J. Neville<sup>1</sup>

<sup>1</sup>Brain Development Laboratory, Department of Psychology, 1227 University of Oregon, Eugene, Oregon 97403, USA



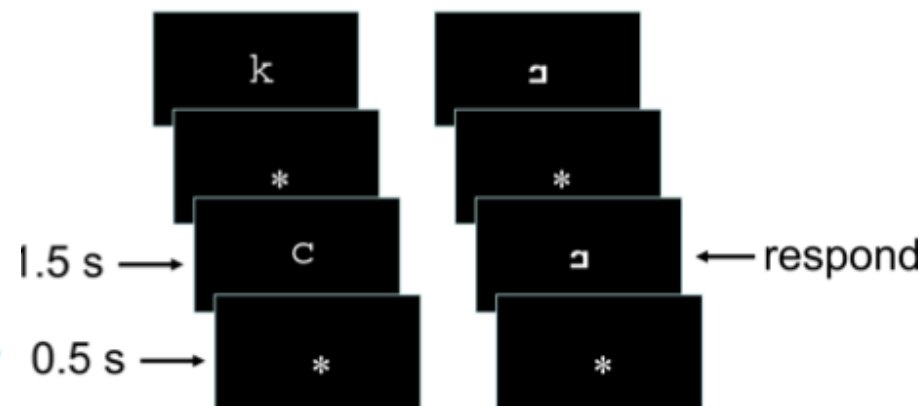
adultes

Norm dev  
(sess1)

À risque  
(sess1)

Norm dev  
(sess2)

À risque  
(sess2)



**Figure 1.** In-scanner one-back task. Letters (LT) and false fonts (FF) were presented separately in six alternating blocks, interleaved by asterisk fixation blocks (\*). Each block lasted for 20 s. Within each task block, ten letter or false font stimuli were presented one at a time. False font stimuli were created by rearranging the parts of corresponding lower-case letter. Each stimulus appeared for 1.5 s, separated by a 0.5 s presentation of a fixation asterisk. Participants were asked to respond by pressing a button with the thumb when the same stimulus was repeated twice in a row.

14 children, seven were considered to be on track for reading development (OT) and seven were considered to be at (some) risk for later reading difficulties (AR)

Following 3 months of kindergarten and, for AR children, supplemental reading instruction, OT children showed left-lateralized activation in the temporo-parietal region, whereas AR children showed bilateral activation and recruitment of frontal regions including the anterior cingulate cortex. These data suggest that typical reading development is associated with initial recruitment and subsequent disengagement of right hemisphere homologous regions while atypical reading development may be associated with compensatory recruitment of frontal regions.

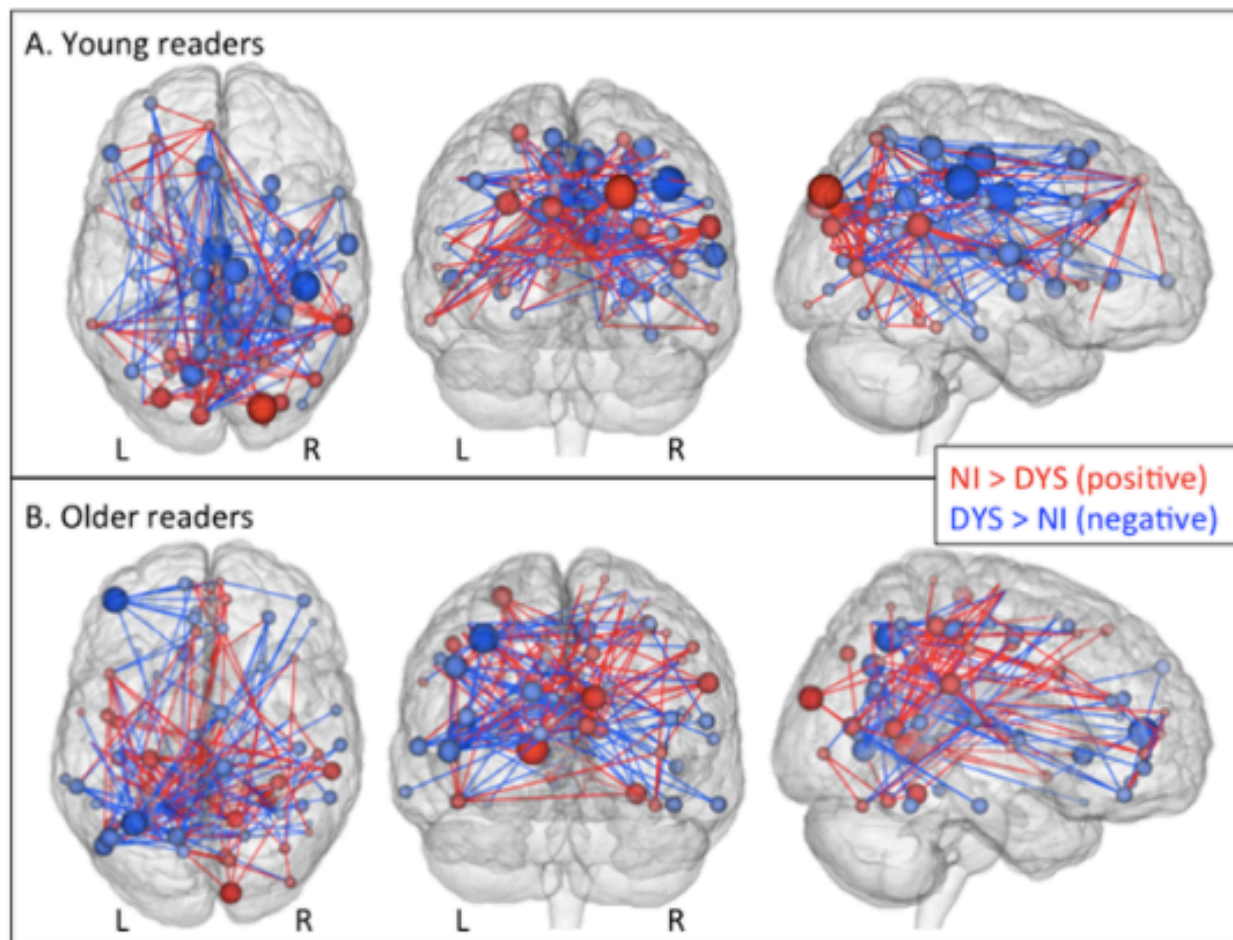
# En conclusion

- Une approche **modulaire** des troubles des apprentissages et de la dyslexie reste plus que jamais pertinente tant pour la description des faits cliniques que pour la compréhension des mécanismes sous-jacents
- L'hypothèse d'un trouble constitutionnel du traitement auditif des phonèmes reste la plus plausible et la mieux explorée, en particulier par les méthodes électrophysiologiques (PE chez le nourrisson, l'enfant et l'adulte, et EEG chez l'enfant et l'adulte)
- La notion de co-occurrence ou de **comorbidité** est un puissant outil de réflexion non seulement pour le clinicien mais également pour le chercheur qui peut y puiser des pistes pertinentes et des modèles potentiellement utiles
- Parmi ces modèles, les plus plausibles — ceux aptes à rendre compte du plus grand nombre de faits cliniques et expérimentaux — sont sans doute ceux faisant appel à la notion de **connectivité intermodale**.

## Disruption of Functional Networks in Dyslexia: A Whole-Brain, Data-Driven Analysis of Connectivity

Emily S. Finn, Xilin Shen, John M. Holahan, Dustin Scheinost, Cheryl Lacadie,  
Xenophon Papademetris, Sally E. Shaywitz, Bennett A. Shaywitz, and R. Todd Constable

400 BIOL PSYCHIATRY 2014;76:397–404



Compared to NI readers, DYS readers showed **divergent connectivity within the visual pathway** and between visual association areas and prefrontal attention areas; **increased right-hemisphere connectivity**; **reduced connectivity in the visual word-form area** (part of the left fusiform gyrus specialized for printed words); and **persistent connectivity to anterior language regions** around the inferior frontal gyrus.



## Topological properties of large-scale structural brain networks in children with familial risk for reading difficulties

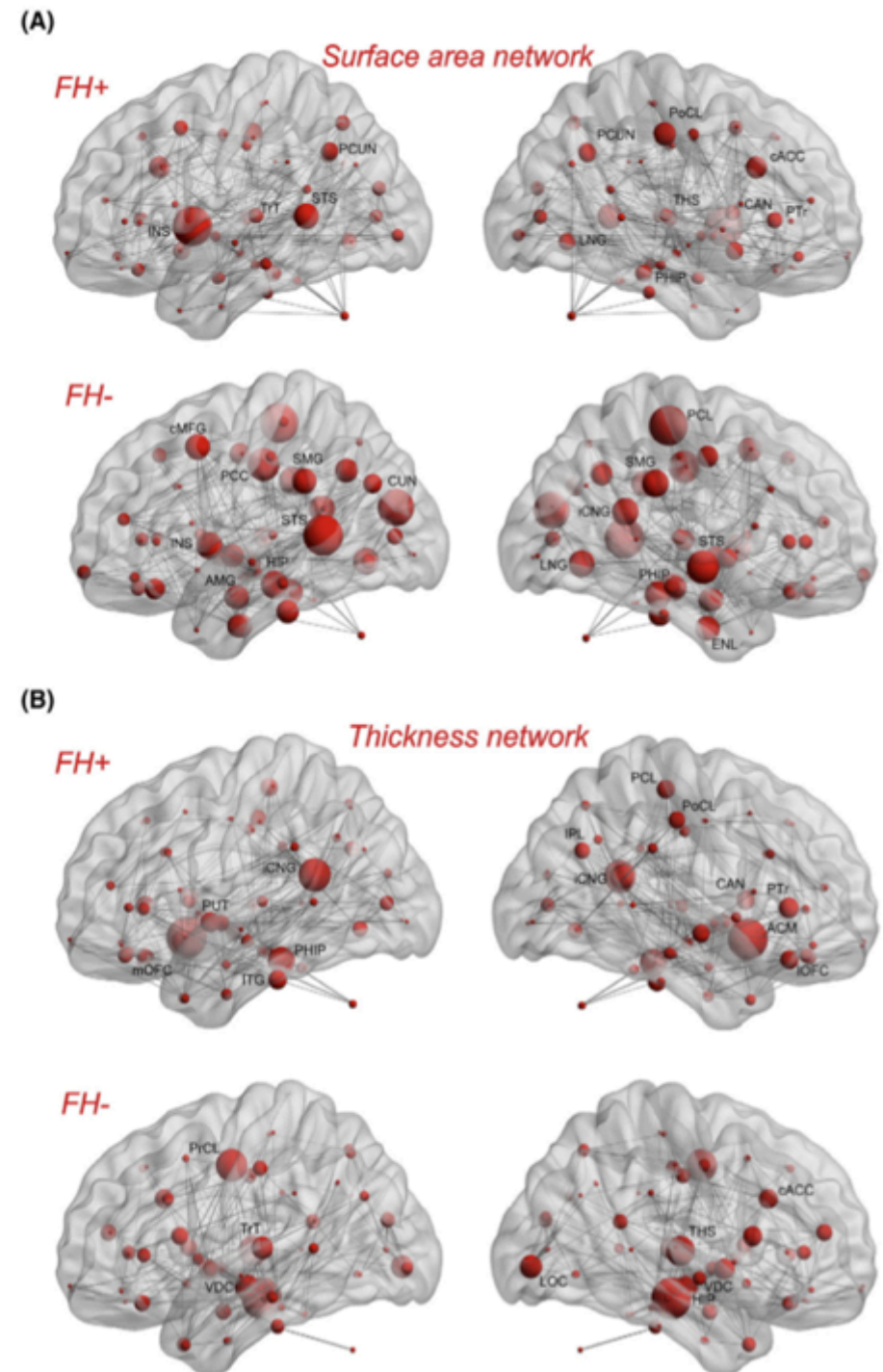
S.M. Hadi Hosseini<sup>a,\*</sup>, Jessica M. Black<sup>a,c</sup>, Teresa Soriano<sup>a</sup>, Nicolle Bugescu<sup>a,b</sup>, Rociel Martinez<sup>a,b</sup>, Mira M. Raman<sup>a</sup>, Shelli R. Kesler<sup>a</sup>, and Fumiko Hoefft<sup>a,d</sup>

<sup>a</sup>Department of Psychiatry and Behavioral Sciences, Stanford University School of Medicine, 401 Quarry Rd., Stanford, CA 94305-5795, USA

42 enfants de 5-6 ans, non lecteurs, présence d'antécédents familiaux (FH+ = 22) ou absence (FH-=20) déterminée par un questionnaire standardisé destiné aux parents. Mesure en IRM de la connectivité de deux variables :

- surface
- épaisseur

Résultat : « *altered topological properties of structural correlation networks in*



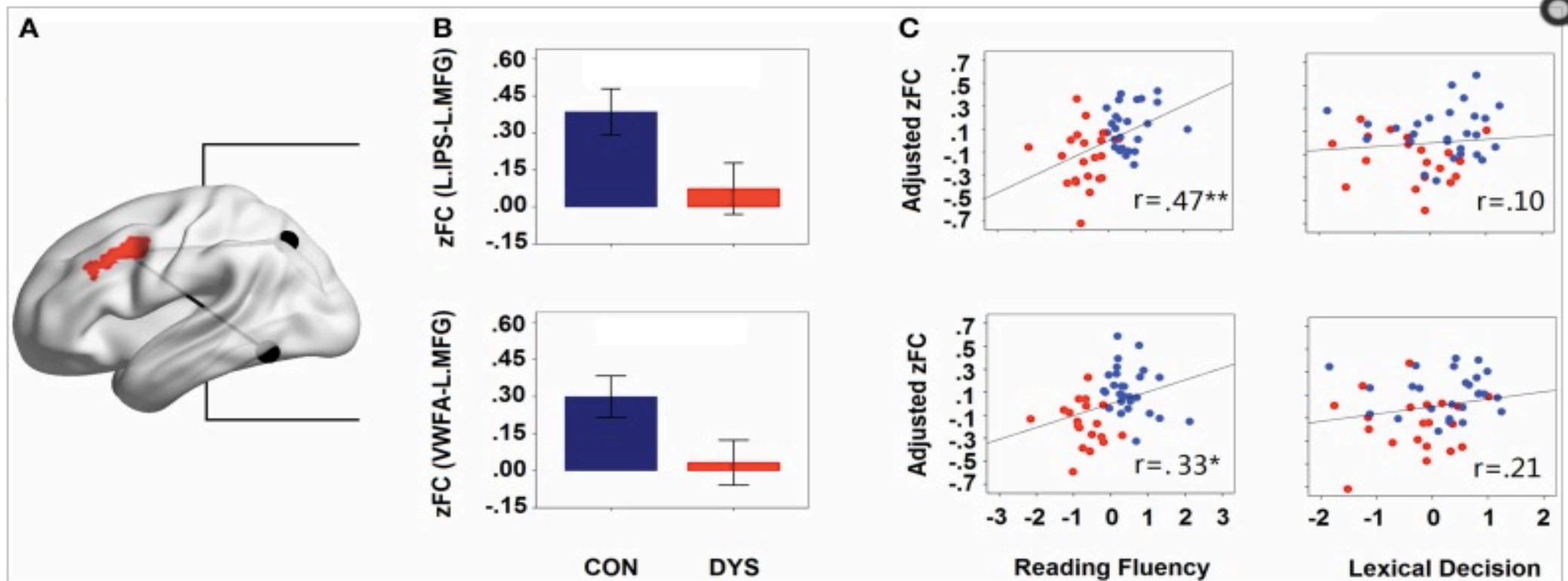


# Altered connectivity of the dorsal and ventral visual regions in dyslexic children: a resting-state fMRI study

Wei Zhou<sup>1,2,3</sup>, Zhichao Xia<sup>1,2</sup>, Yanchao Bi<sup>1,2</sup> and Hua Shu<sup>1,2\*</sup>

<sup>1</sup>State Key Laboratory of Cognitive Neuroscience and Learning and IDG/McGovern Institute for Brain Research, Beijing Normal University, Beijing, China

Étude de connectivité au repos (resting state) :  
moindre connectivité chez DYS entre 1- VWFA et 2-L-sillon intra-pariétal (IPS) et Gyrus frontal moyen (MFG)  
Corrélé à fluence en lecture et non à décision lexicale

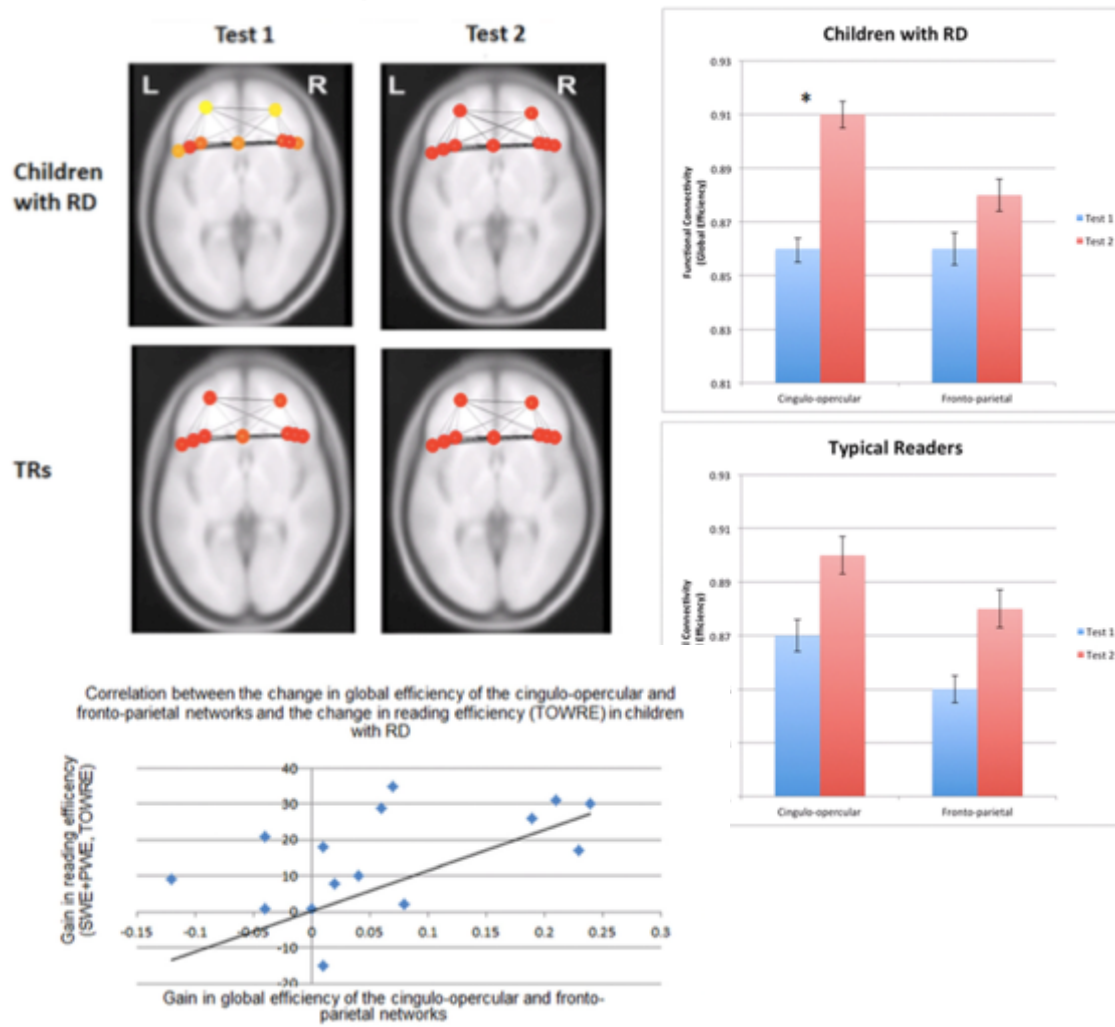




RESEARCH ARTICLE

# Increased Resting-State Functional Connectivity in the Cingulo-Opercular Cognitive-Control Network after Intervention in Children with Reading Difficulties

Tzipi Horowitz-Kraus<sup>1,2\*</sup>, Claudio Toro-Serev<sup>2</sup>, Mark DiFrancesco<sup>1</sup>



compared to typical readers, children with reading difficulty had significantly greater functional connectivity in the cingulo-opercular network after training, which may demonstrate the importance of cognitive control during reading in this population. These results support previous findings of increased error-monitoring activation after reading training in children with dyslexia and confirm greater gains with training in this group.

the current study provides evidence for the effect of the RAP training, an EF-based reading intervention, on functional connectivity of cognitive-control networks during rest in children with reading difficulties.