RMN, Feb 2022

Functional brain correlates of writing acquisition / ECRITAPP

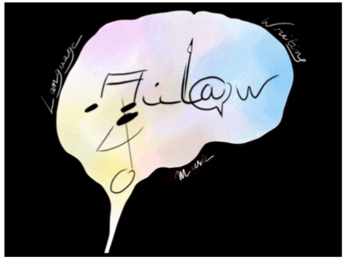
Marieke Longcamp, Sarah Palmis
Laboratoire de Neurosciences Cognitives

Project-ANR-14-CE30-0013 (S. Kandel, 2014-2019)

cnrs dépasser les frontières

Aix*Marseille université
Initiative d'excellence

ILCB
Institute of
Language, Communication
and the Brain



french word « *galop* » written by a child (left) and by an adult (right)

THE ECRITAPP PROJECT

77 participants included

3 groups: CE2 (N = 24), CM2 (N = 25) and Adults (N=28)

Inclusion: standardized graphomotor, spelling and reading tests

LOCALIZER RUN

Write Letters, words, or draw loops, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

335 volumes

4 DICTATION RUNS

Write regular and irregular words to dictation, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

440 volumes per run

T1 MRI
Voxel
size=
1mm3

T2 MRI
Voxel
size=
1mm3

THE ECRITAPP PROJECT

77 participants included

3 groups: CE2 (N = 24), CM2 (N = 25) and Adults (N=28)

Inclusion: standardized graphomotor, spelling and reading tests

LOCALIZER RUN

Write Letters, words, or draw loops, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

335 volumes

4 DICTATION RUNS

Write regular and irregular words to dictation, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

440 volumes per run

T1 MRI
Voxel
size=
1mm3

T2 MRI
Voxel
size=
1mm3

Palmis et al. Dev. Sci. 2021

THE ECRITAPP PROJECT

77 participants included

3 groups: CE2 (N = 24), CM2 (N = 25) and Adults (N=28)

Inclusion: standardized graphomotor, spelling and reading tests

LOCALIZER RUN

Write Letters, words, or draw loops, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

335 volumes

4 DICTATION RUNS

Write regular and irregular words to dictation, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

440 volumes per run

Developmental effects of spelling regularity: Palmis, Fabiani et al., in prep.

T1 MRI
Voxel
size=
1mm3

T2 MRI
Voxel
size=
1mm3

THE ECRITAPP PROJECT

77 participants included

3 groups: CE2 (N = 24), CM2 (N = 25) and Adults (N=28)

Inclusion: standardized graphomotor, spelling and reading tests

LOCALIZER RUN

Write Letters, words, or draw loops, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

335 volumes

4 DICTATION RUNS

Write regular and irregular words to dictation, tablet recordings

TR= 957 ms, voxel size= 2.5 mm3, multiband factor= 4, slices= 56

440 volumes per run

T1 MRI
Voxel
size=
1mm3

T2 MRI
Voxel
size=
1mm3

Morphometric analysis: Cachia, Dupont et al., in prep.

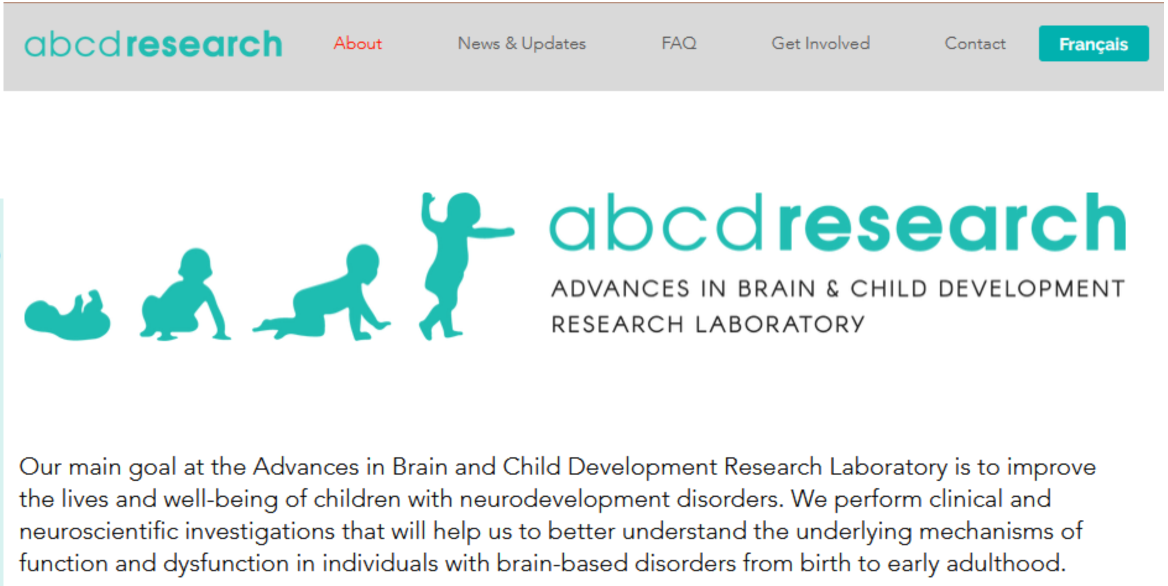
THE ECRIAPP PROJECT

Sarah Palmis's PhD

Postdoctoral researchers

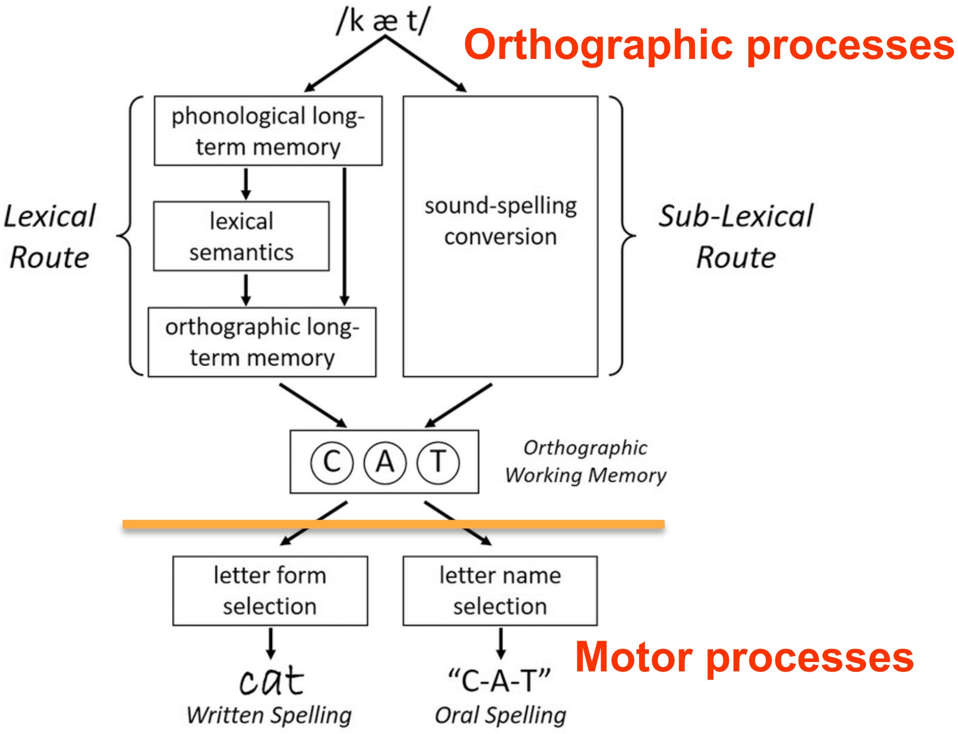
Sarah Palmis, PhD
Postdoctoral Fellow

Sarah joined the ABCD research laboratory as a Postdoctoral Fellow in February 2021. She completed a PhD in Neurosciences at Université de Aix-Marseille. During her PhD she developed an expertise in functional MRI technique as a proxy to study neural and motor development. During her postdoctoral training, Sarah is interested in using a variety of quantitative structural MRI techniques to characterize brain growth in a variety of clinical populations. In her free time, she enjoys doing sport in particular basketball, reading, listening to music, and cooking.



Our main goal at the Advances in Brain and Child Development Research Laboratory is to improve the lives and well-being of children with neurodevelopment disorders. We perform clinical and neuroscientific investigations that will help us to better understand the underlying mechanisms of function and dysfunction in individuals with brain-based disorders from birth to early adulthood.

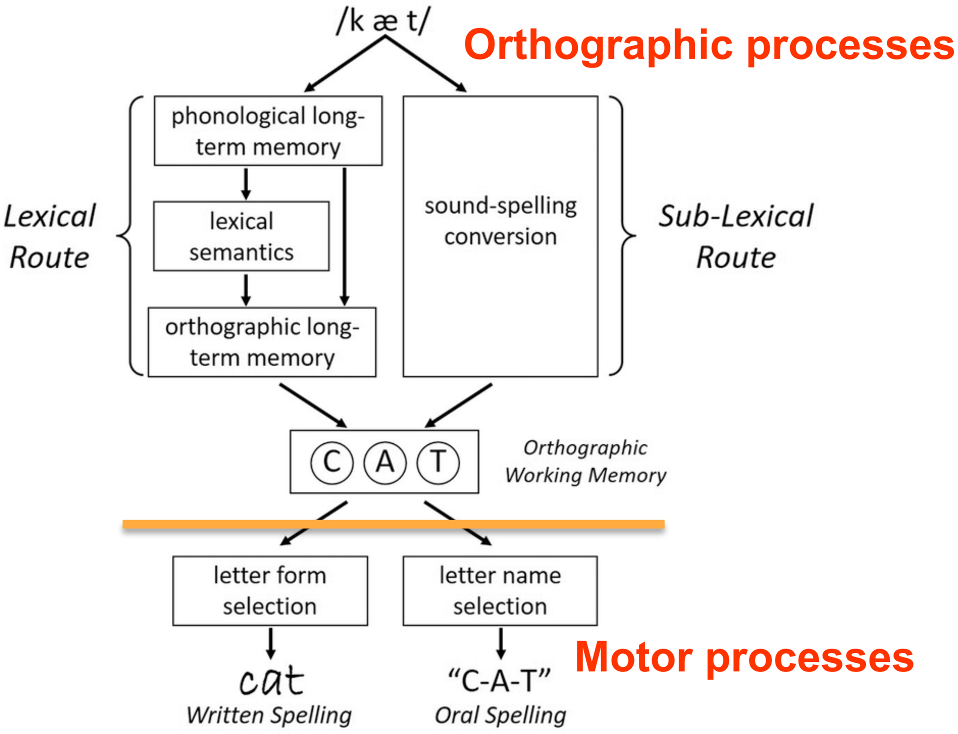
HANDWRITING PROCESSES



Rapp and McCloskey, 2017

Relationship between orthographic and motor processes during handwriting

HANDWRITING PROCESSES



Rapp and McCloskey, 2017

Serial vs parallel flow of processing?

Do orthographic processes affect motor processes?

How does this develop?

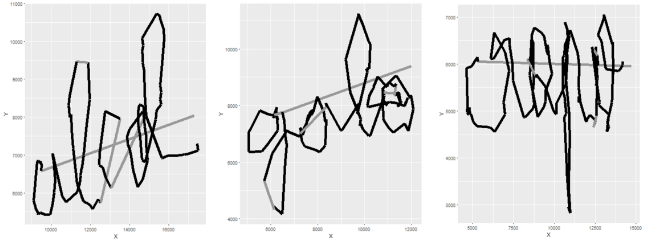
Assessment of the effect of psycholinguistic variables on parameters of motor execution during written word production

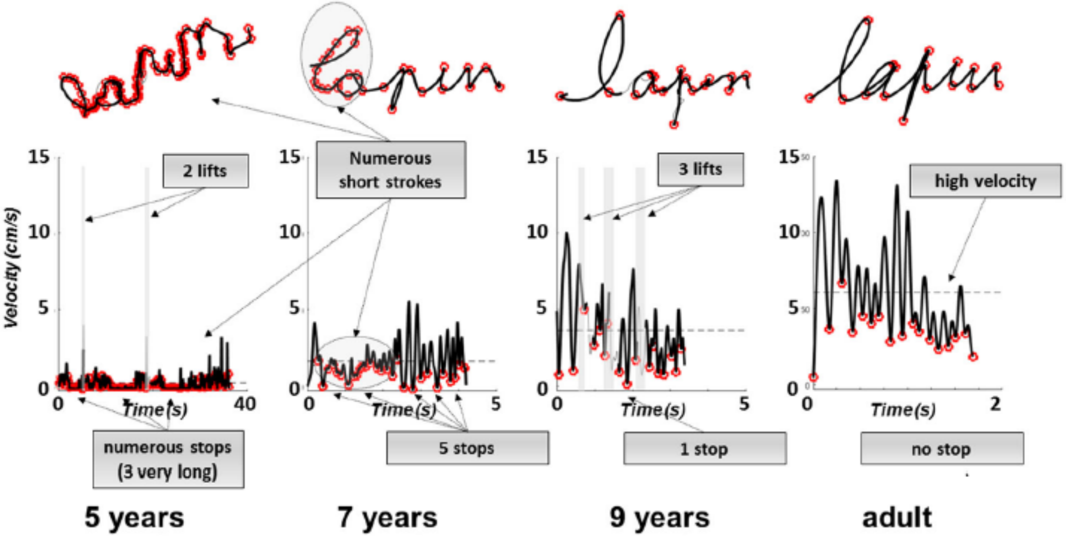
Delattre and Bonin, 2006; Kandel et al., 2006; Kandel and Perret, 2015; Damian and Freeman, 2008; Baus et al., 2013; Sausset et al., 2013; Planton et al., 2017b; Pinet et al., 2017; Roux et al., 2013; Scaltritti et al., 2016; 2017; etc…

HANDWRITING ACQUISITION

Orthographic processes

Motor processes


Treiman, 2017



Palmis et al, Cogn. Neuropsychol., 2017

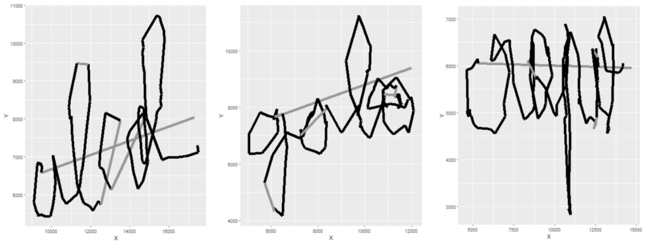
HANDWRITING ACQUISITION

Orthographic processes

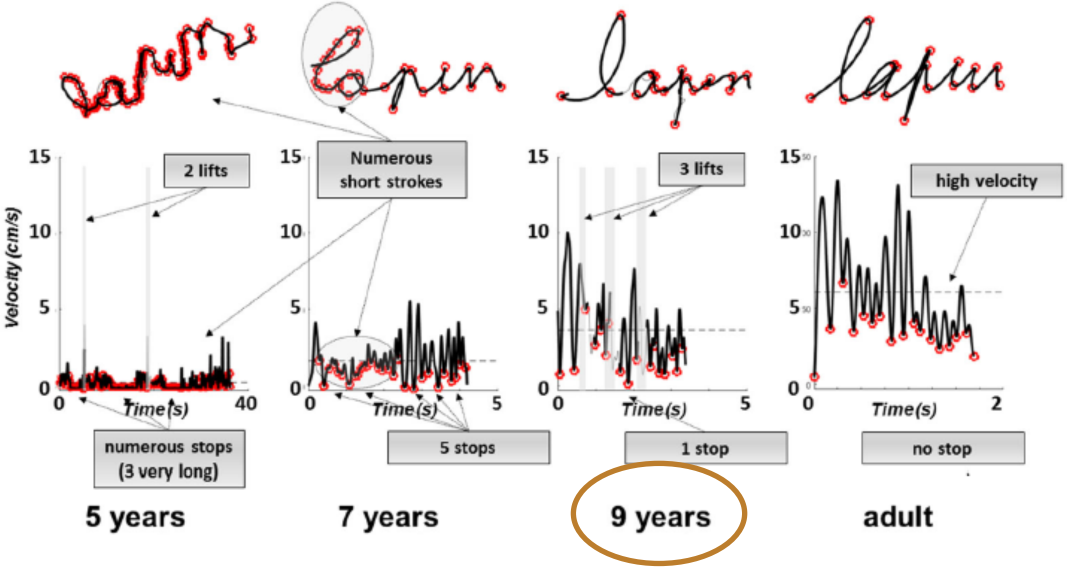
↓

Motor processes

“Developmental studies support the idea that at ages 9–10 word writing starts to be regulated by orthographic knowledge” (Kandel and Perret, 2015)



Treiman, 2017



Palmis et al, Cogn. Neuropsychol., 2017

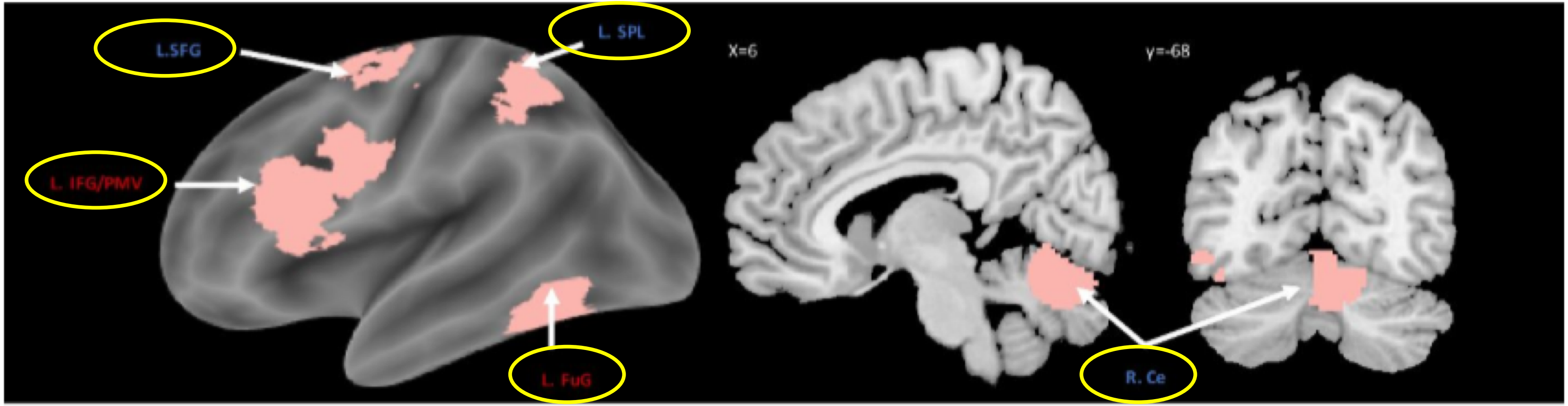
THE WRITING NETWORK

- Left inferior frontal gyrus
- Left fusiform gyrus

Regions coding orthographic information

- Left superior parietal lobule
- Left superior frontal gyrus
- Right Cerebellum

Regions coding motor aspects of writing



Purcell et al., 2011; Planton et al., 2013; Rapp et al., 2016, etc…

Outline of the talk:

1- Quick overview of previous studies

2- Developmental effects of spelling regularity on writing behavior and brain activation

→ The aim: show you the results and discuss questions raised by statistical analyses

3- If time: Morphometric analisys of OTS and ACC: early cerebral constraints on writing development

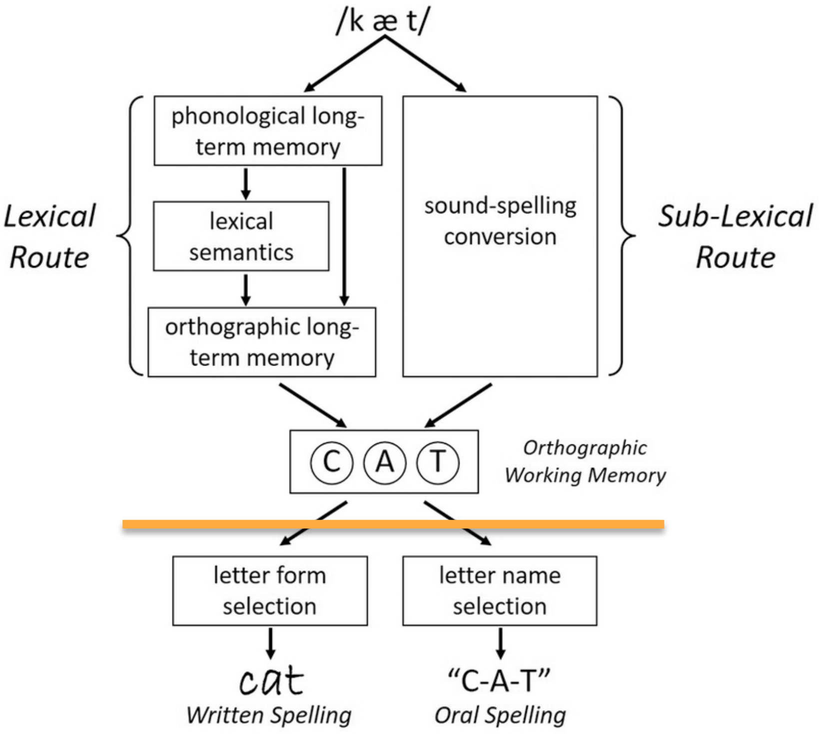
1- Quick overview of previous studies

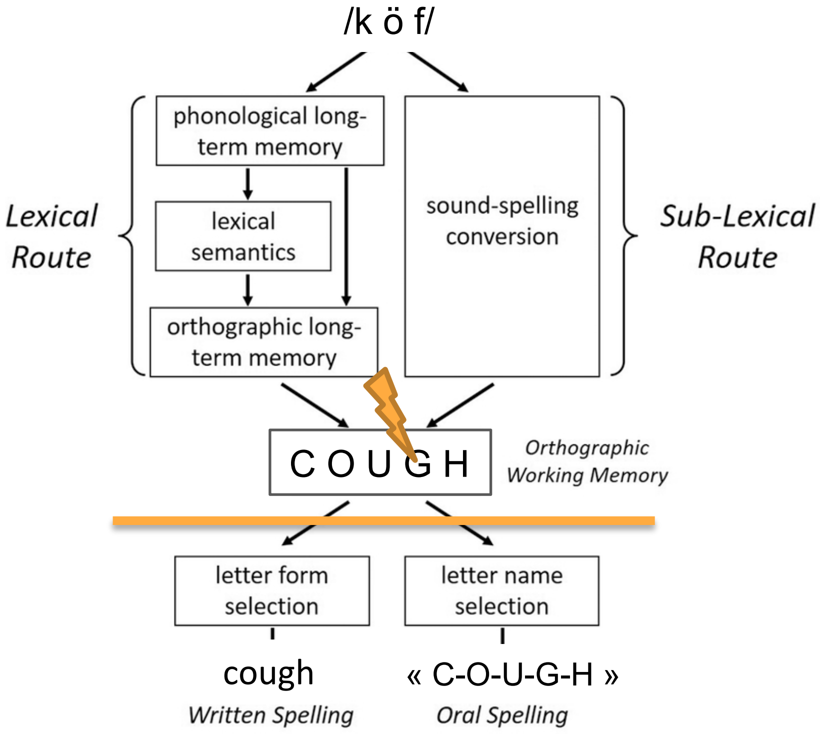
The impact of spelling regularity on handwriting: relationship between orthographic and motor processes in adults (study 1)

Palmis, Velay, Fabiani, Nazarian, Anton, Habib, Kandel, Longcamp,
Cortex, 2019

STUDY 1: BACKGROUND

Spelling inconsistent words: a conflict between the output of the two routes



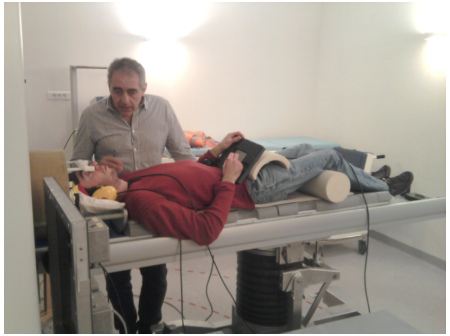


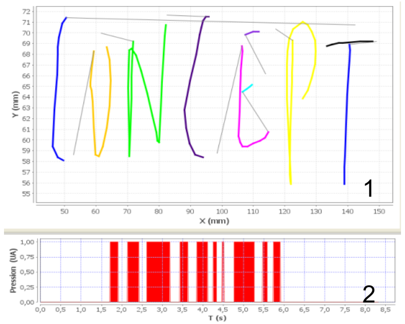
Rapp and McCloskey, 2017

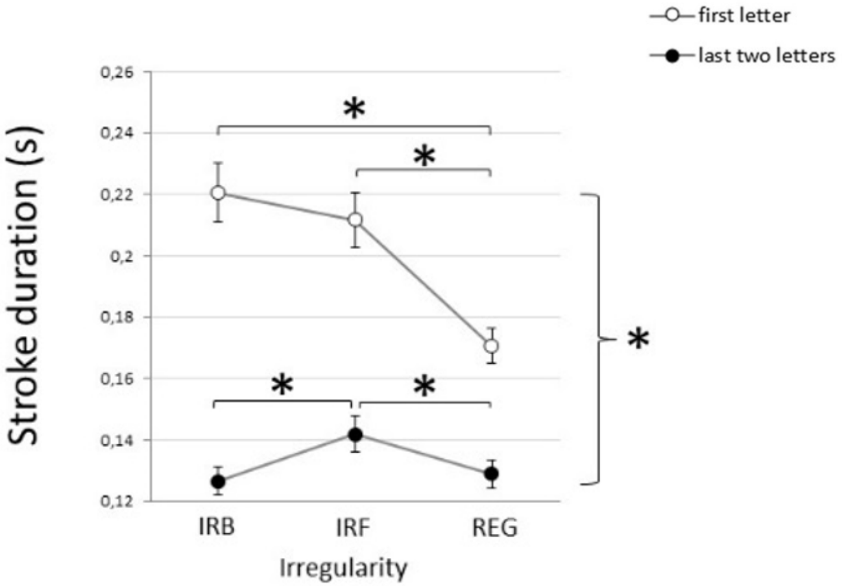
STUDY 1: DESIGN and BEHAVIORAL RESULTS

Effects of the presence of an irregularity and its position (Roux et al., 2013)

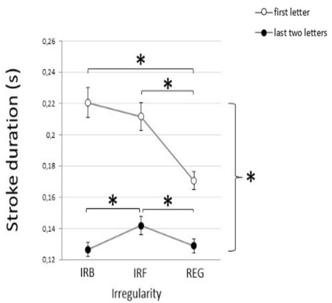
NATURE PHARAON CAFARD

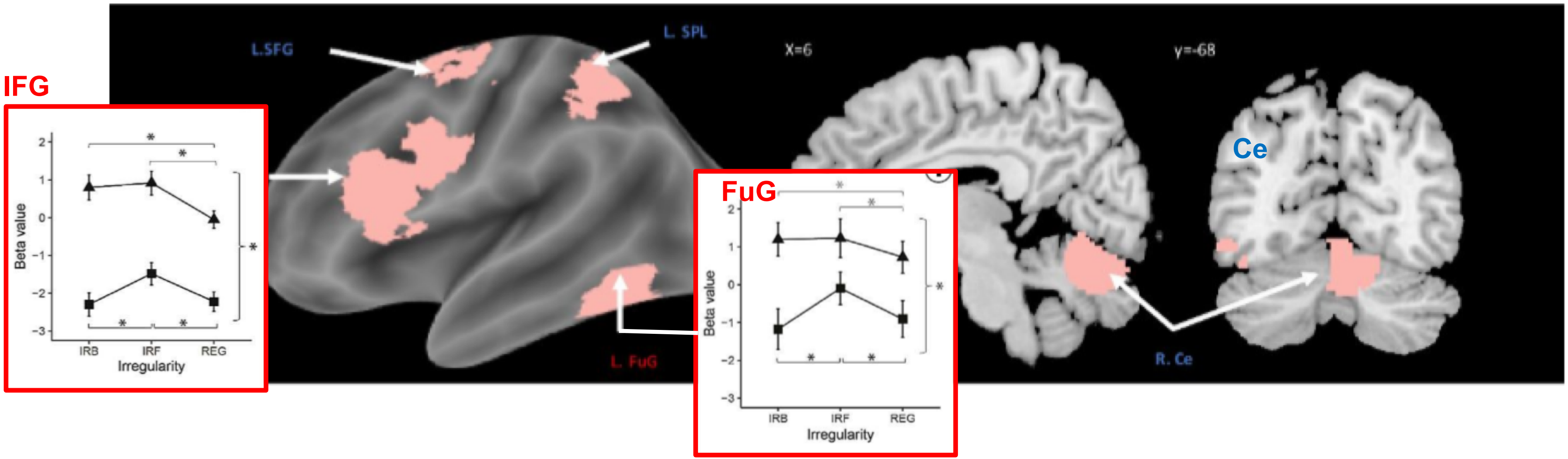






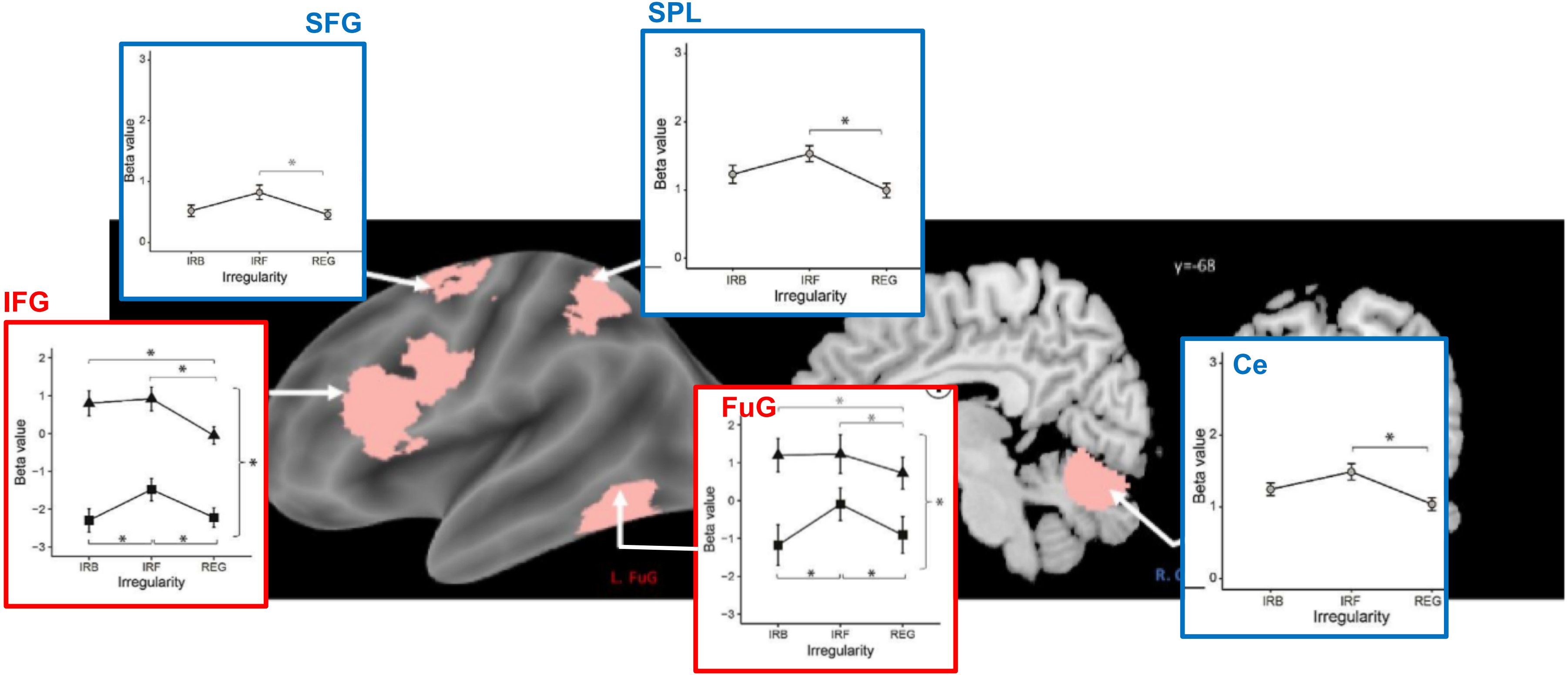
STUDY 1 : RESULTS





Orthographic processes are still active during motor execution

PREVIOUS STUDY IN ADULTS



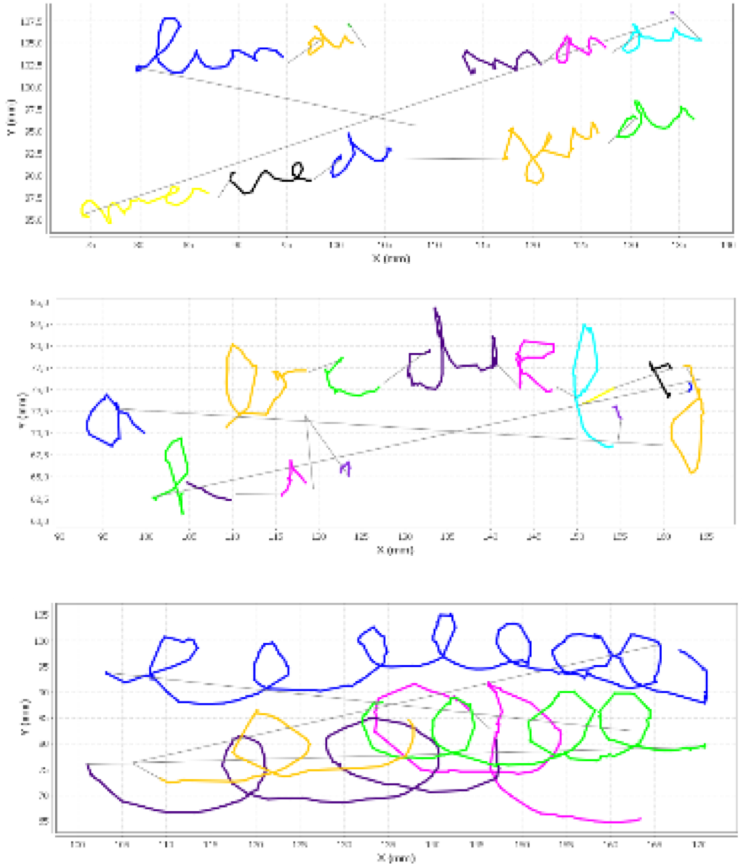
Orthographic processes are still active during motor execution

Orthographic processes influence motor processes

Study 2: Comparing the writing network of adults and children (study 2)

Palmis et al. Dev. Sci. 2021

STUDY 2 : DESIGN

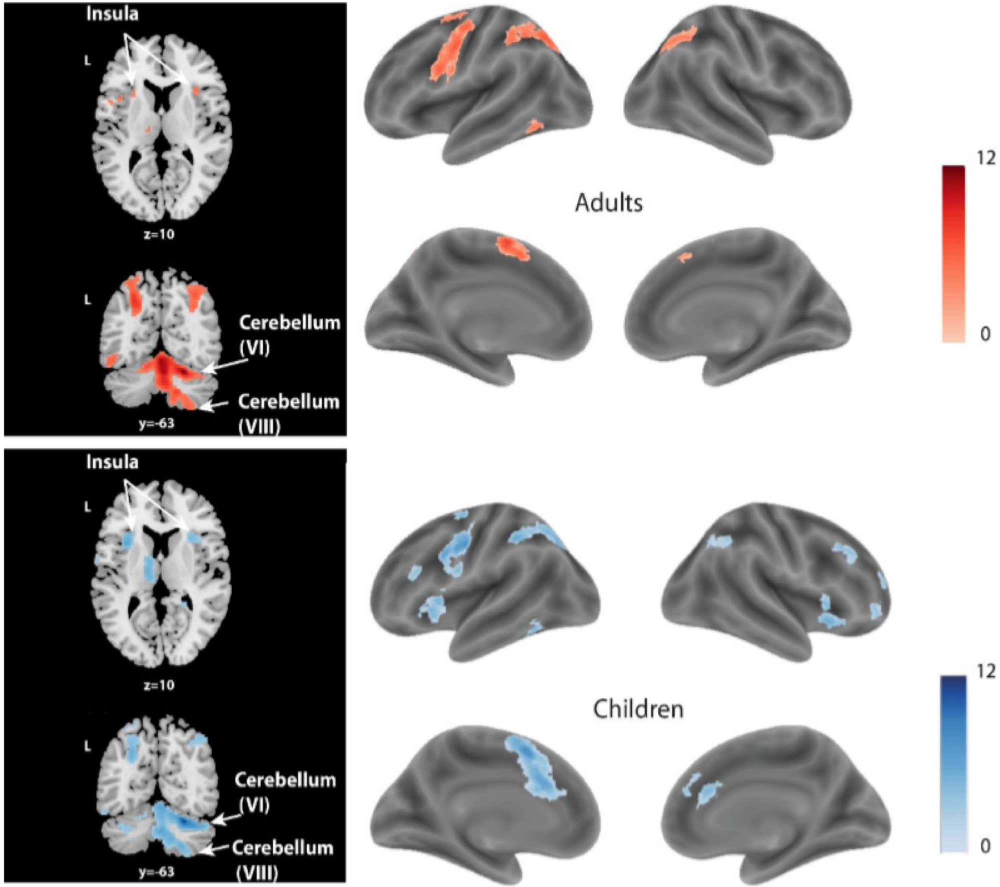


Block design: write series of letters, words and draw loops

Subsample of 23 adults (aged 19 to 40, mean 24.91) and 42 children (aged 8 to 11, mean 8.88)

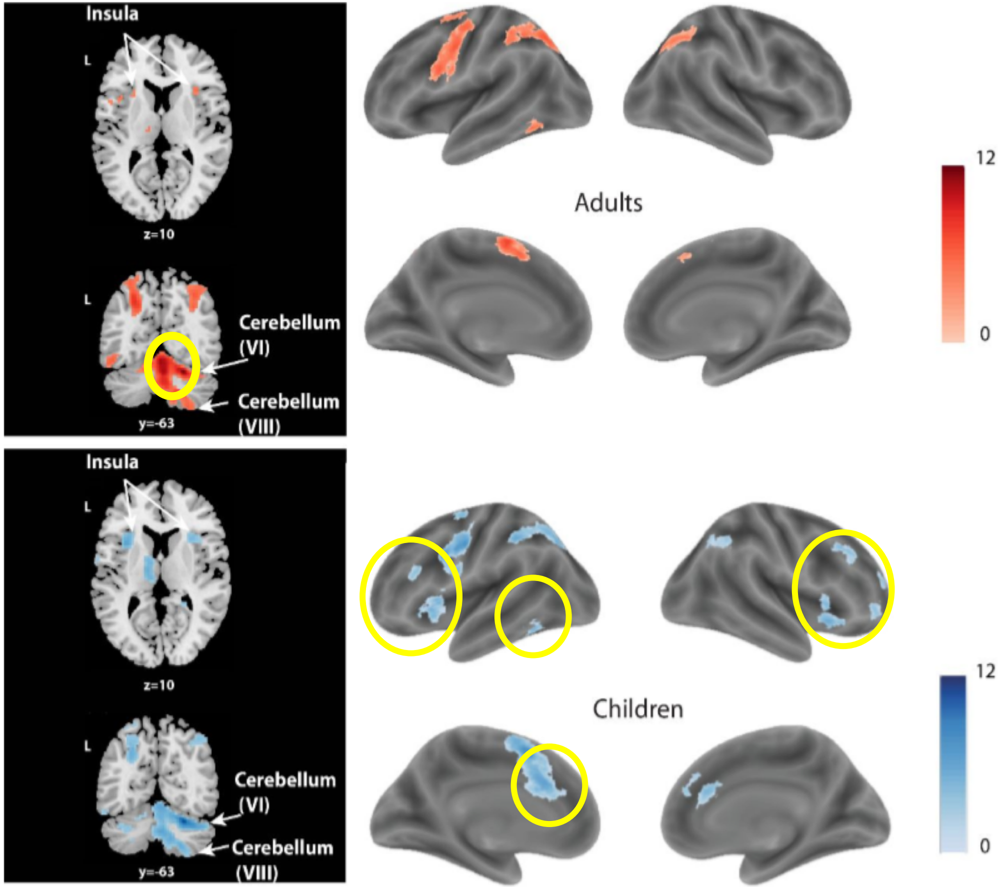
We pooled CE2 and CM2 in a single children group

STUDY 2 : RESULTS



- Writing network also activated in children
- More activation clusters in children
- Activation in **anterior/frontal** regions

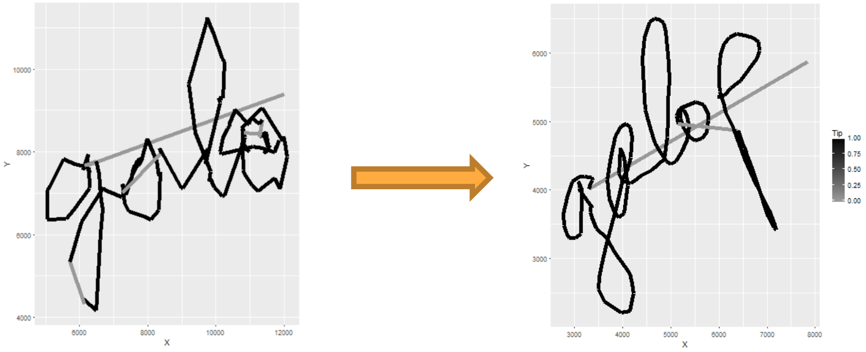
STUDY 2 : RESULTS



- Writing network also activated in children
- More activation clusters in children
- Activation in **anterior/frontal** regions
- Group differences:

Frontal regions (ant insulas, ACC); Left Fusiform Gyrus ; Cerebellum (right anterior lobe) ;

Study 3: Developmental effects of spelling regularity on writing behavior and brain activation



Palmis, Fabiani et al, in prep.

How does the relationship between orthographic and motor processes of handwriting evolve between middle childhood and adulthood ?

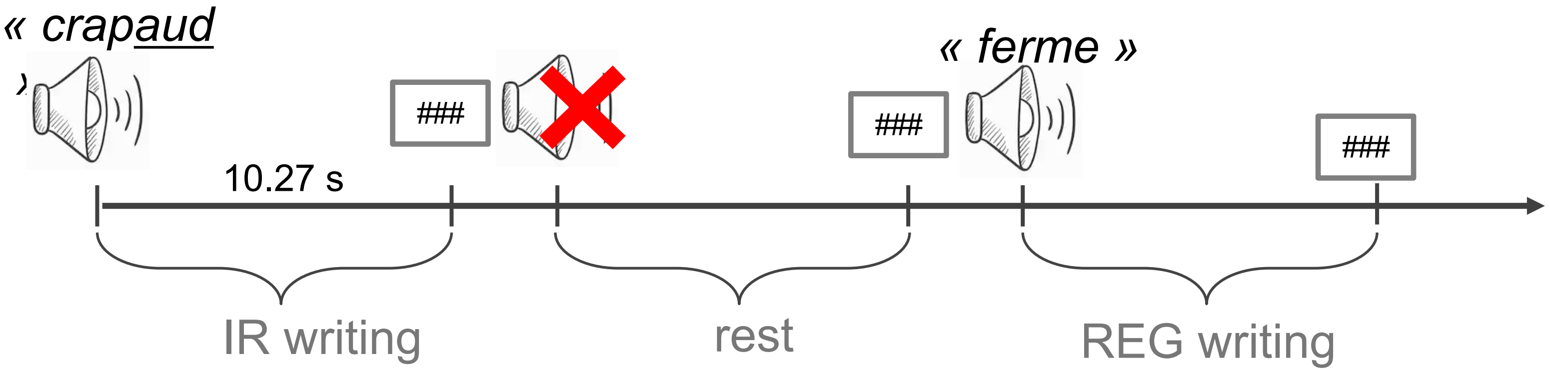
Children writing is less automated than adults writing: Age 9 is critical because it is the period in which grapho-motor skills start being automatic (Halsband & Lange, 2006; Mojet, 1991)

In adults, orthographic and motor processes occur in parallel during handwriting

H1 = In children, orthographic and motor processes should be more independent and sequential (Olive, 2014; Kandel and Perret, 2015)

H2 = Lexical processes strongly impact graphomotor processes during writing acquisition but this influence diminishes at some point in development (Afonso et al., 2018)

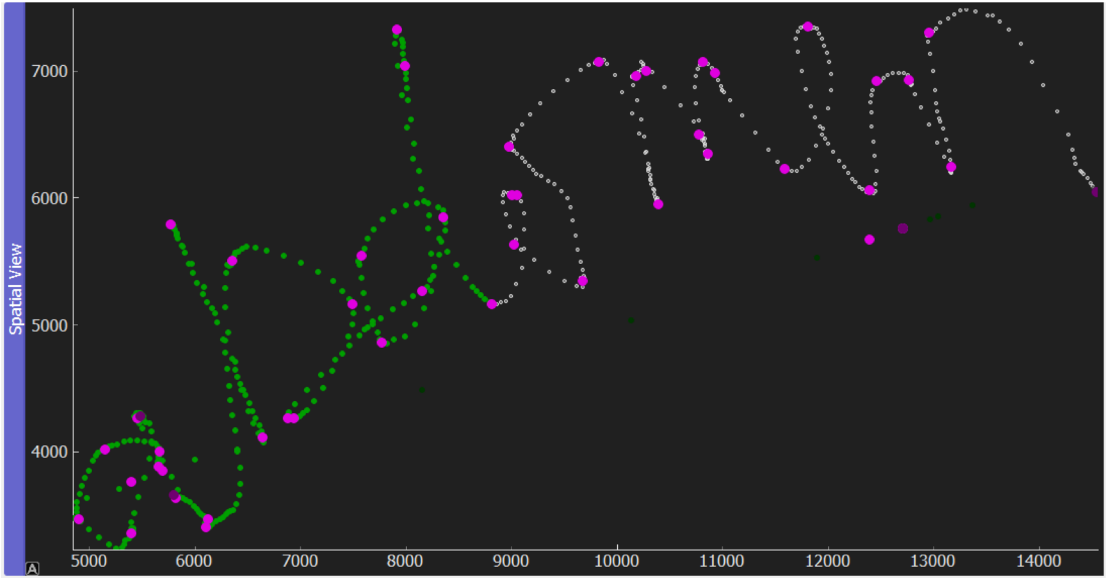
STUDY 3: DESIGN



- Writing-to-dictation task on a MRI-compatible tablet
- 2 conditions : regular words (REG) and words irregular at the end (IR)
- 100 words : 50 REG (autruche, avoine, banane, etc)

  50 IR (automne, avocat, bandit, etc)
- Recording **behavioural** and **fMRI** data

STUDY 3: BEHAVIOURAL DATA



Writing Latency

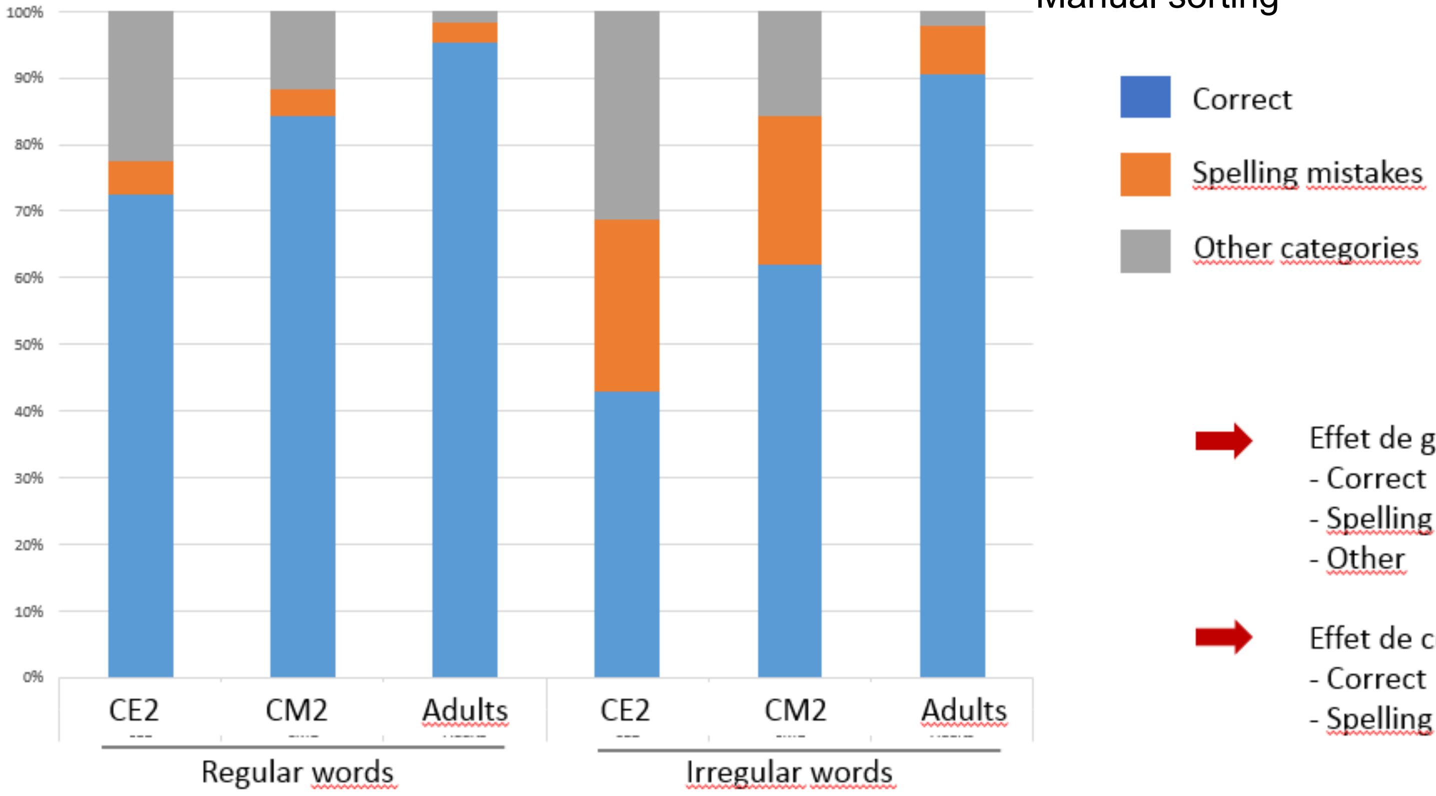
Total duration

Duration of the first 3 letters

STUDY 3: BEHAVIOURAL DATA

Behavioural data classification

67 participants: 17 3rd Grade, 24 5th Grade, 26 adults (**4777 correct trials**)
Manual sorting

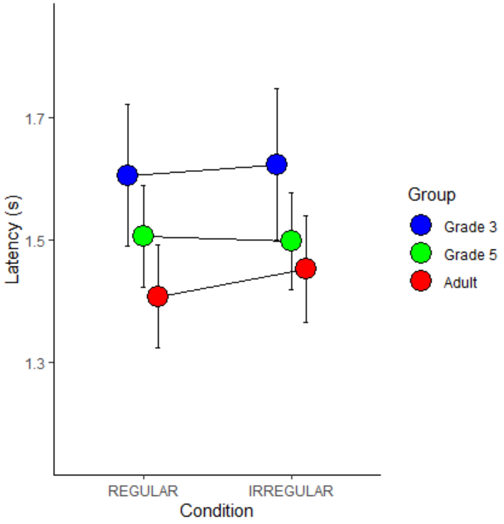


➡ Effet de groupe :
- Correct
- Spelling mistakes
- Other

➡ Effet de condition :
- Correct
- Spelling mistakes

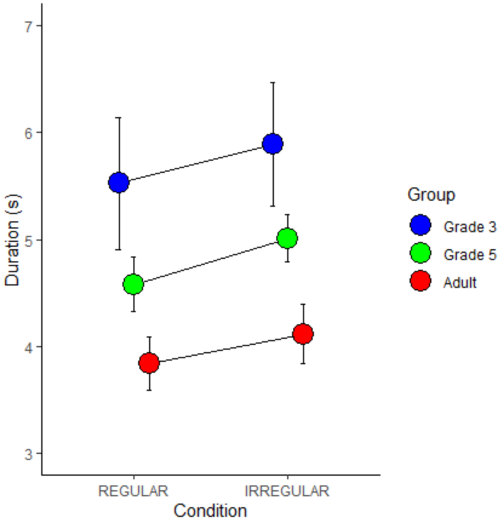
STUDY 3: BEHAVIORAL RESULTS

Latency



No ME
No interaction
(rather a good point for the fMRI statistical models)

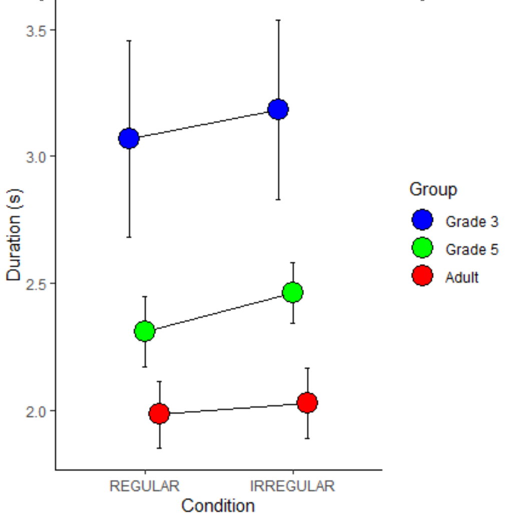
Writing duration



ME Condition
ME Group
Interaction (5th gr vs adults)

Duration first 3 letters

(autruche vs automne)



ME Condition
ME Group
Interaction (5th gr vs adults)

+ Similar effects on writing size

fMRI data preprocessing: fMRIprep

- Calculation of the IQMs with MRIqc and descriptive stats (Julien)
- Exclusion of the sessions where more than 25% of the data points have FD values > 0.9 mm (27 sessions, including 2 participants (children))
- Systematic exploration of the IQMs before and after preprocessing (fMRIprep)

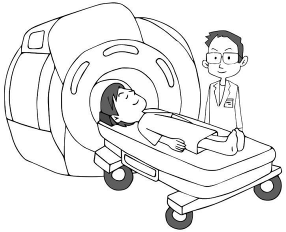
- fMRIprep: *fMRIPrep* 20.0.6 (Esteban, Markiewicz, et al. (2018); Esteban, Blair, et al. (2018); RRID:SCR_016216)

tpl-MNI152NLin2009cAsym_space-MNI_res-01_T1w

spatially smoothed (FWHM 5 mm) with FSL

Confounds: 24 motion regressors + 26 nuisance regressors (22+1 WM, 22+1 CSF) + motion censoring (Frames that exceeded a threshold of 0.5 mm FD or 1.5 standardised DVARS were annotated as motion outliers)

STUDY 3: fMRI DATA



fMRI data modeling – Main model

5 regressors of interest :

- Regular words writing
- Irregular words writing
- Rest
- Auditory stimulus
- Empty trials

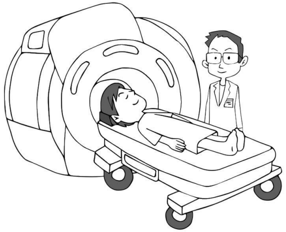
All categories (except empty trials)

CONDITION	DURATION	ONSET
REG	Effective total writing duration Or mean writing duration	Onset of stim + latency Or mean latency
IR	Effective total writing duration Or mean writing duration	Onset of stim + latency Or mean latency
Rest	10.27s	Onset of stim
Stim	0	Onset of stim
Empty	0	Onset of stim

!! Participant excluded if nb sessions < 3 out of 4

17/24/26 → 10/20/26 participants per group

fMRI data modeling – Other models



Auditory Stimulus

5 regressors of interest :

- Regular words Auditory stim
- Irregular words Auditory stim
- Rest
- Auditory stimulus
- Empty trials

All categories (except empty trials)

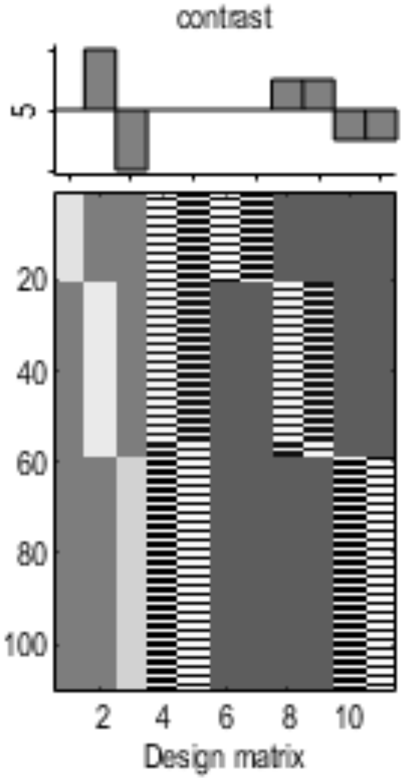
For all 3 models: The number of sessions was matched between groups

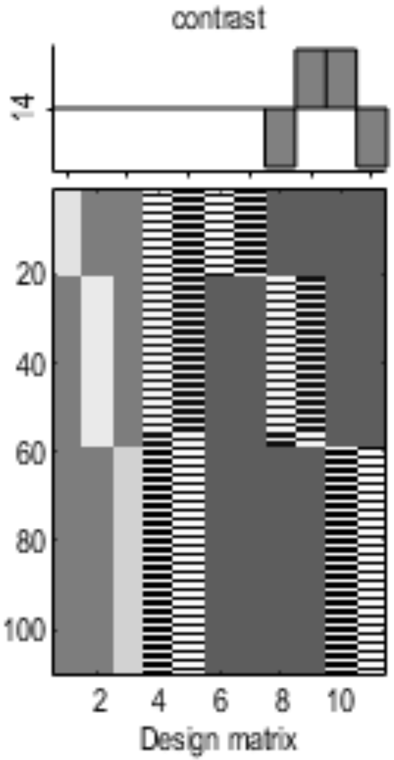
Writing: correct trials

8 regressors of interest :

- Correct Regular words
- Correct Irregular words
- Misspelled Regular words
- Misspelled Irregular words
- Rest
- Auditory stimulus
- Empty trials
- Other trials

Second level models: flexible factorial designs





STUDY 3: fMRI RESULTS

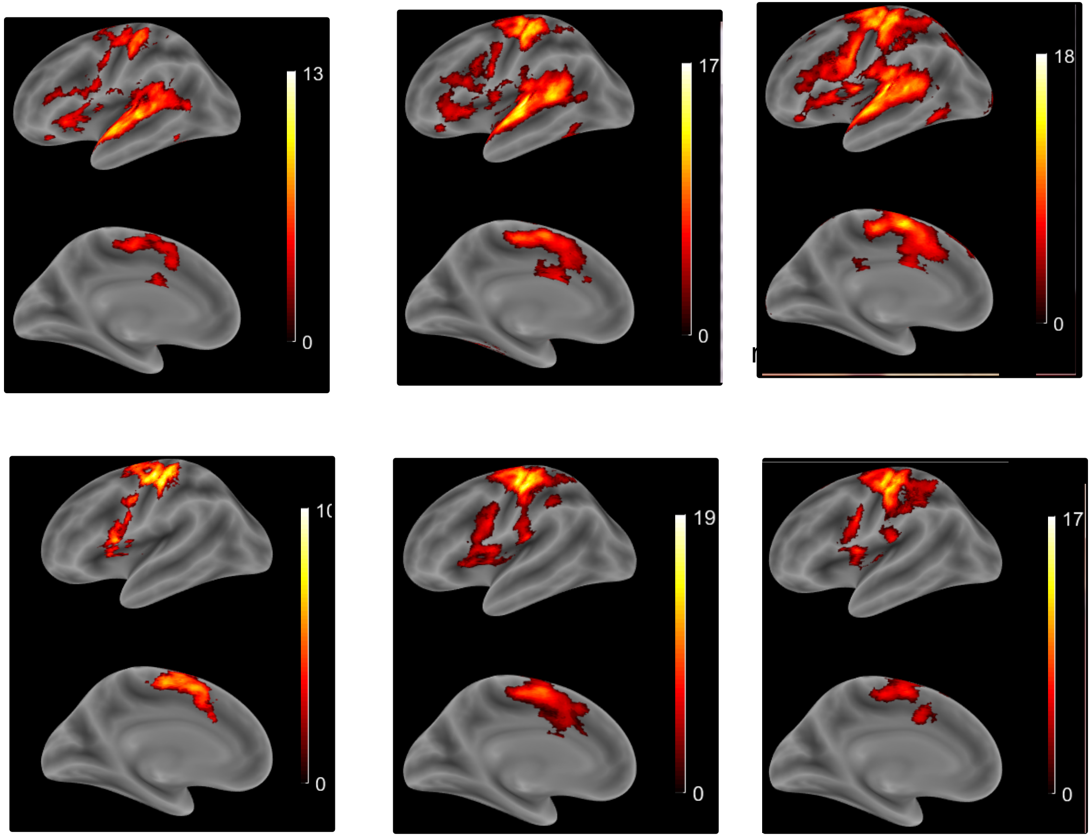
3rd grade
N = 10

5th grade
N = 20

Adults
N = 26

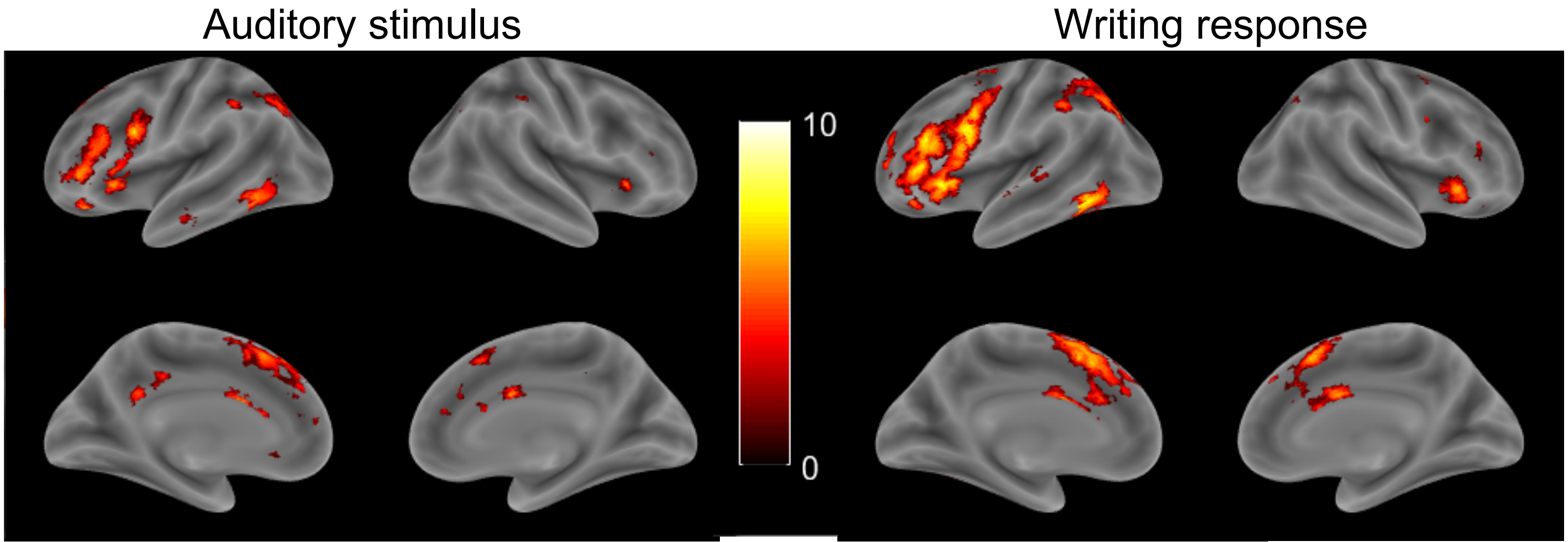
Auditory stimulus

Writing response

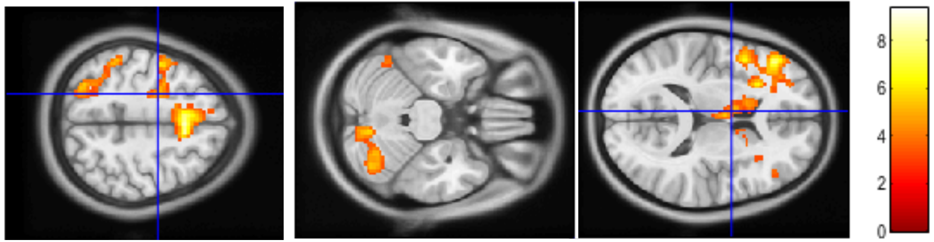


STUDY 3: RESULTS

Massive main effect of regularity <u>during</u> writing (Palmis et al., 2019)

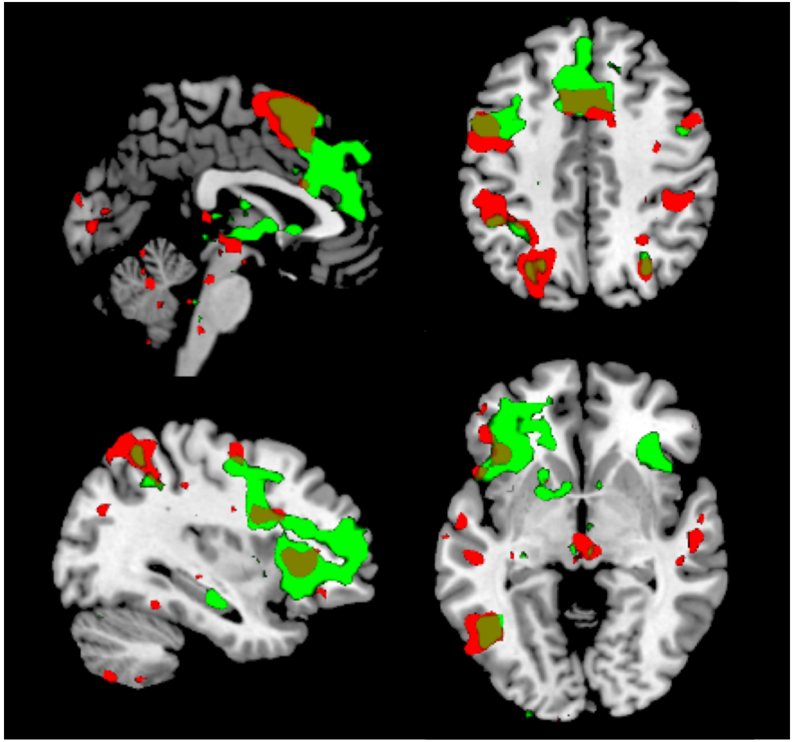

Auditory stimulus

Writing response



STUDY 3: RESULTS

Distribution of irregularity processing in adults (red) and 5th Graders (Green) during writing



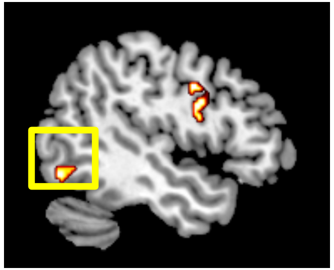
Irregularity is processed moslty in the writing network of adults

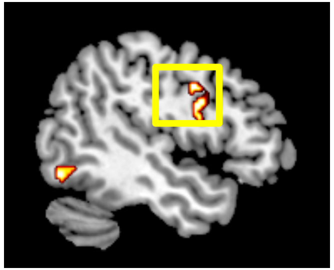
More prefrontal distribution in 5th graders

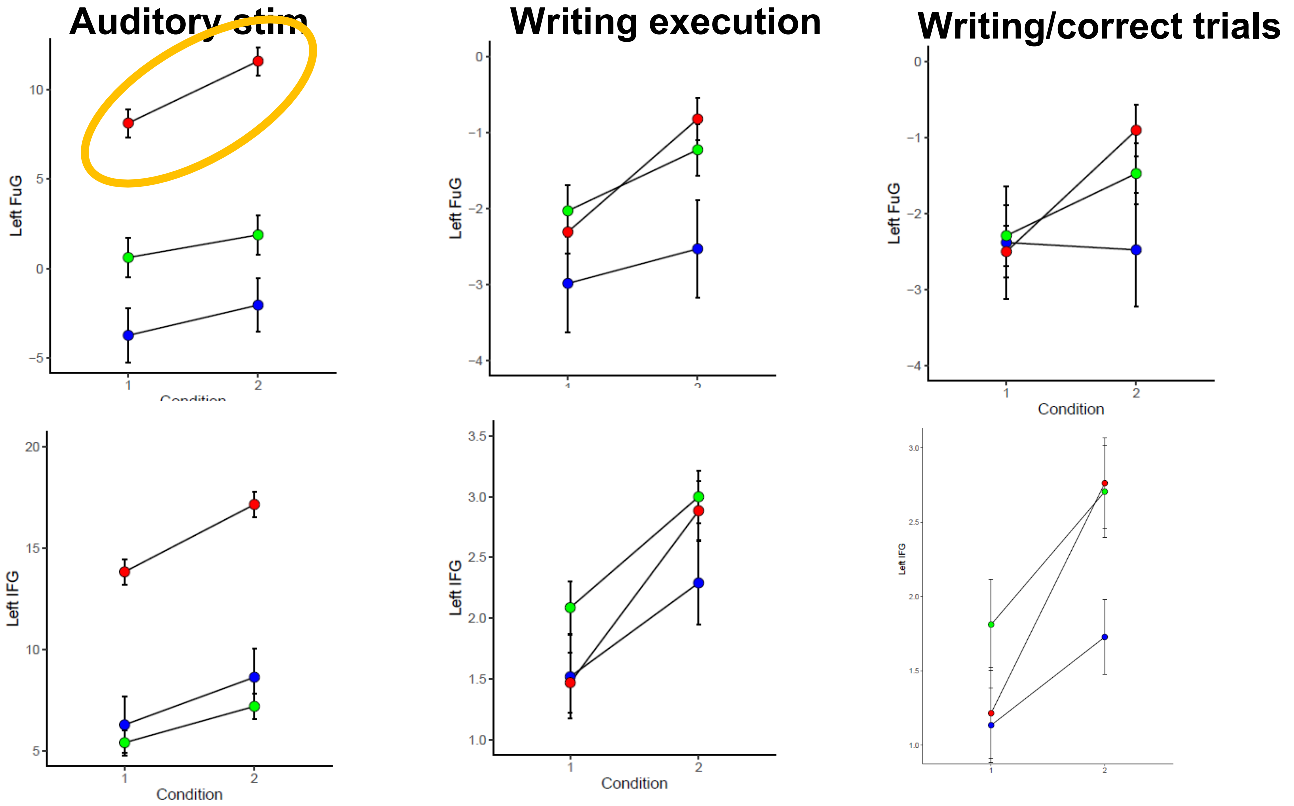
p < .005 unc.

STUDY 3: RESULTS

« Orthographic regions »: L FuG and L IFG







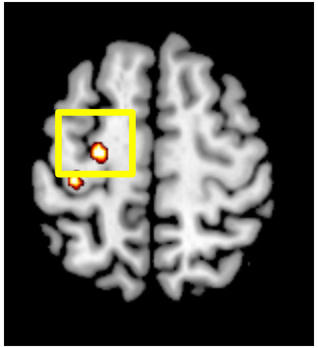
Auditory stim

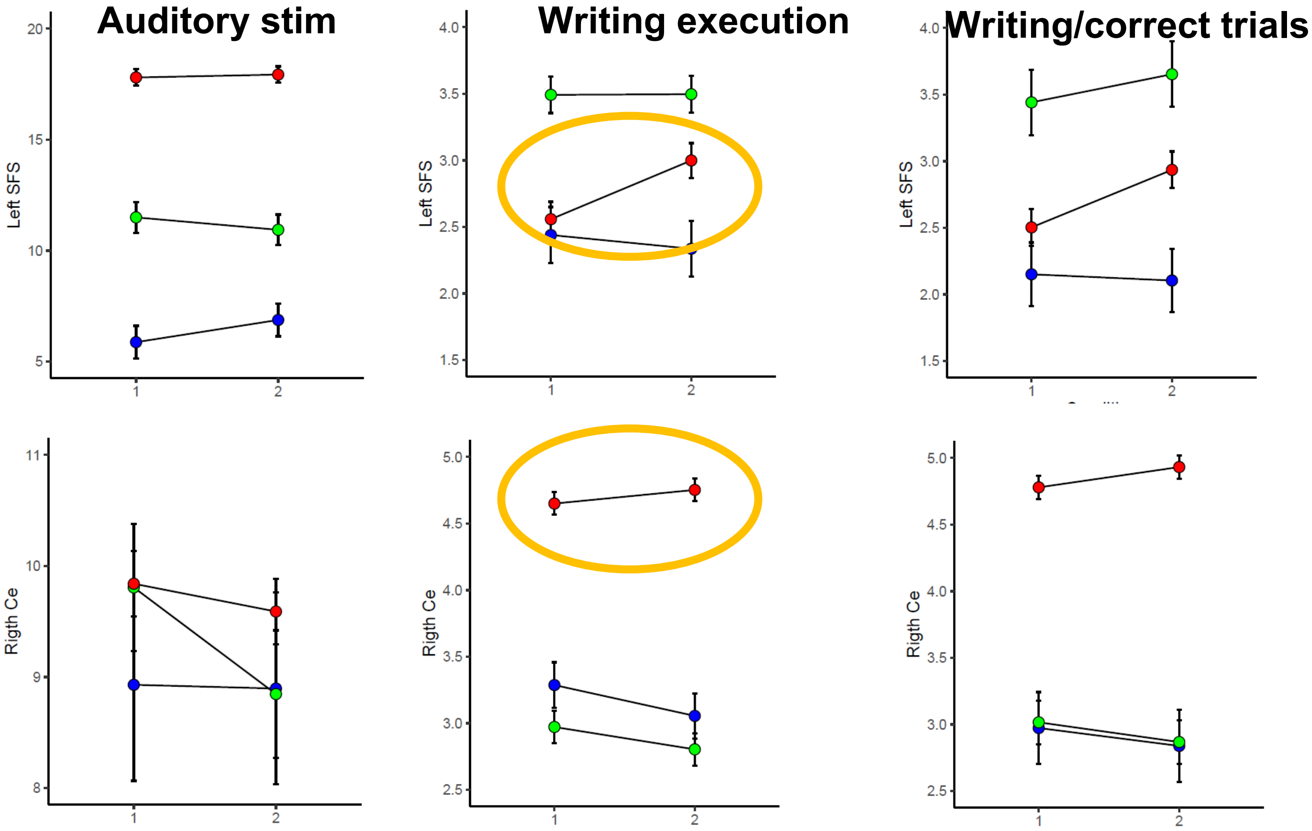
Writing execution

Writing/correct trials

STUDY 3: RESULTS

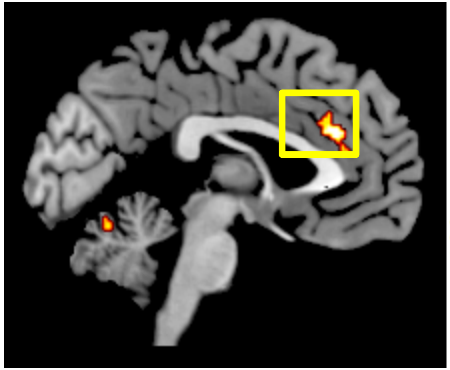
« Motor regions »: R Cb and L dPM

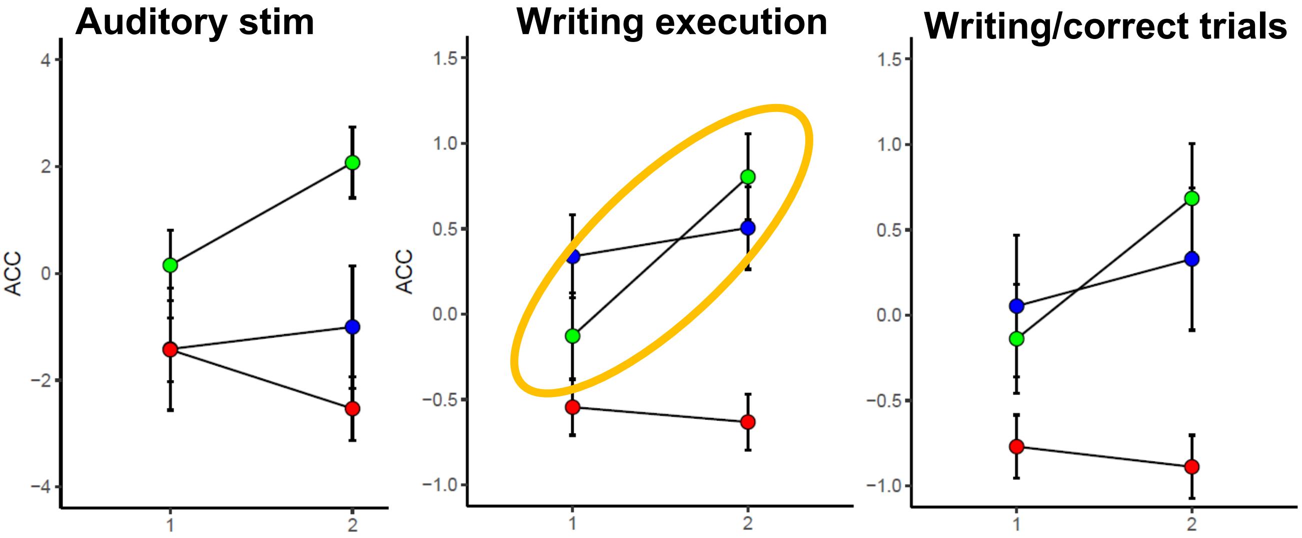




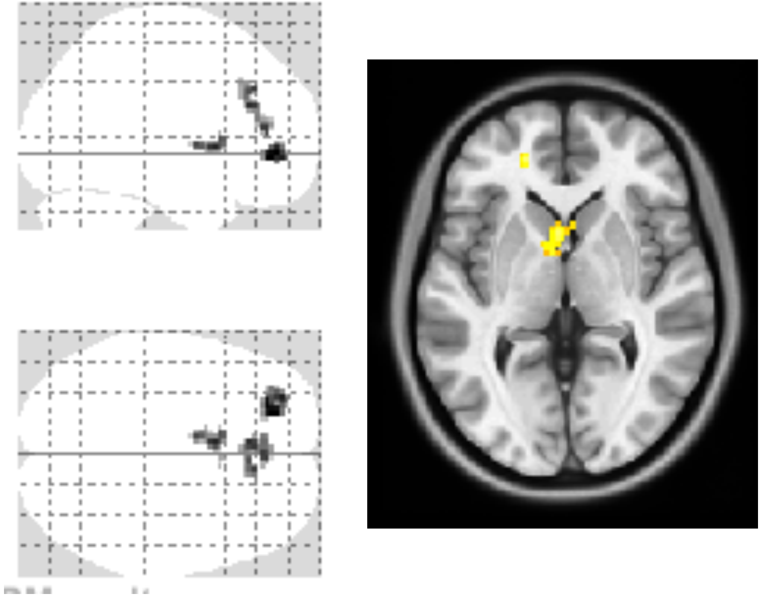
STUDY 3: RESULTS

ACC : interaction between group and regularity during writing → selective effect in 5th graders

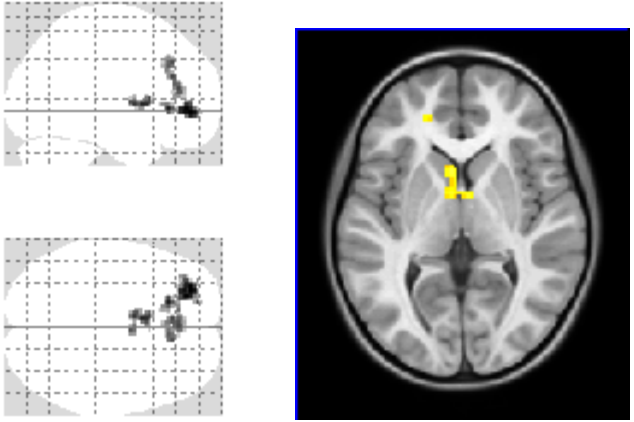




Interaction group X condition: whole brain



ACC + Caudate Nucleus + dorsolateral PFC: conflict monitoring network



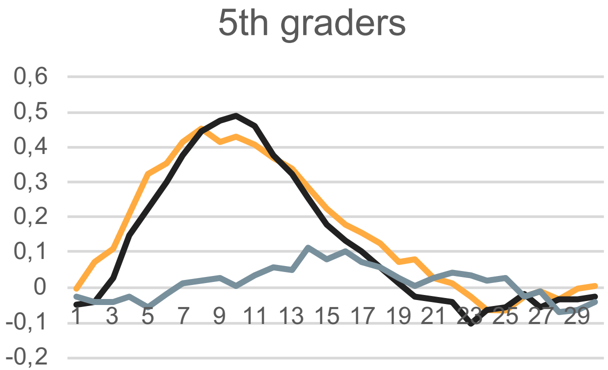
MNI Pediatric template

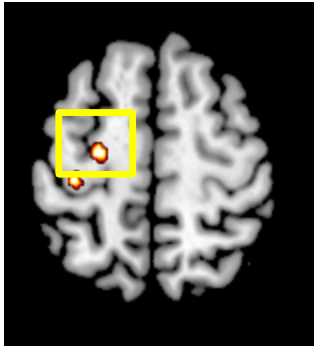
Spatial Normalization: choice of template

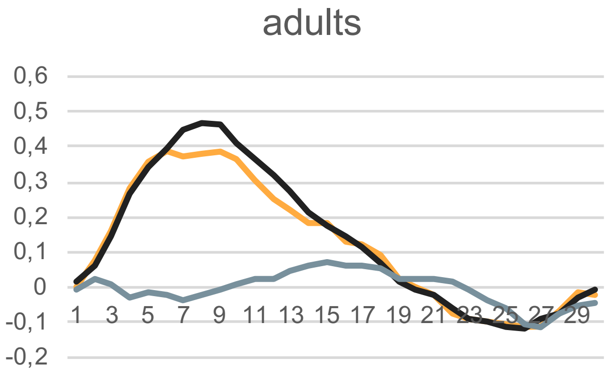
Weng et al., 2015
the norm index of the affine transformation matrix, i.e., the SFN, characterizes the difference between a template and a native image and differs significantly across subjects

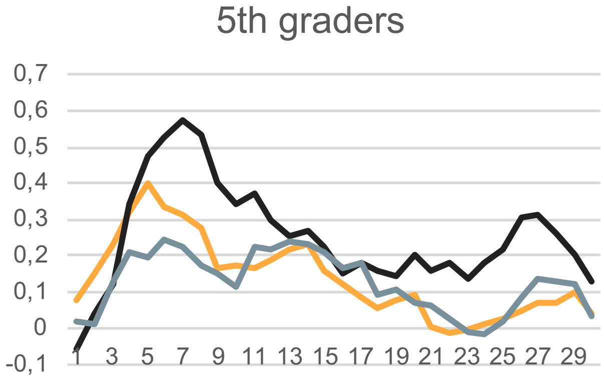
→ include the SFN as a covariate in group-wise statistics?

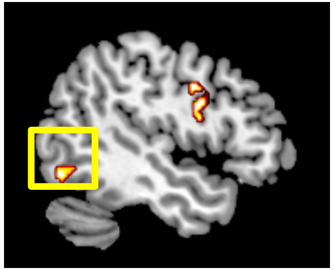
Extra models: FIR

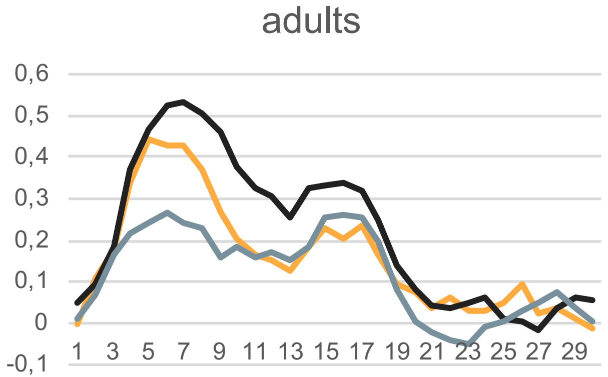

5th graders




adults


5th graders




adults

STUDY 3: CONCLUSIONS

Summary of the findings

- Coupled behavioral and brain evidence that orthographic aspects of handwriting are still active during writing, and cascade over the motor components in both expert adults and children

- Writing acquisition is mediated by massive behavioral changes, and by differential involvement of several parts of the writing network in adults and children

- **Similar behavioral effects but different neural underpinning in 5th graders vs adults**

- Possible confounds: writing in the MRI scanner and absence of visual feedback, data quality differences between groups, amount of data, precision of behavioral data, and choice of template for spatial norm.

STUDY 4: MORPHOMETRIC ANALYSIS:

Relationship between folding patterns in ACC and OTS and writing skills: Early cerebral constraints on writing acquisition

(Arnaud Cachia, LaPsyDE, Paris with Olivier and Guillaume)

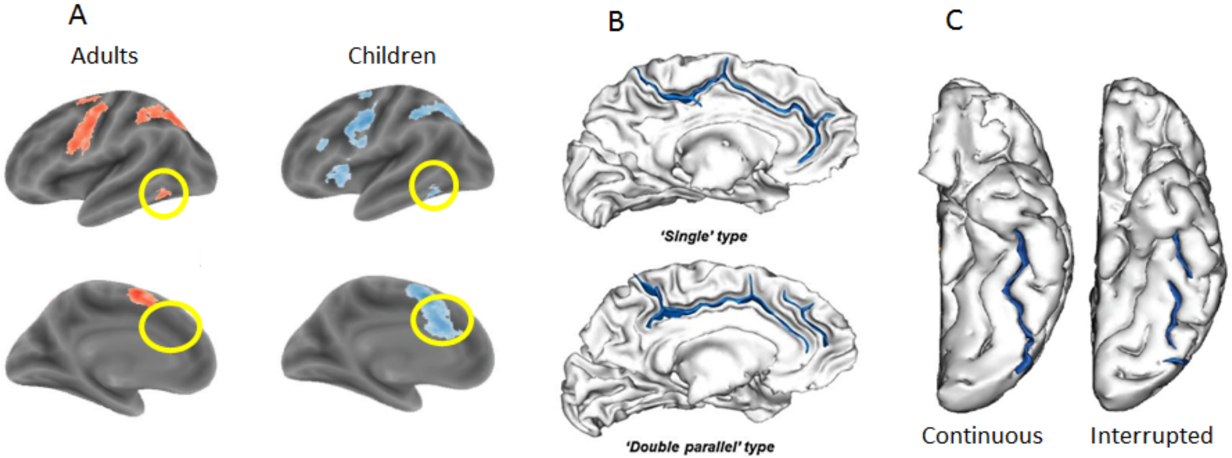
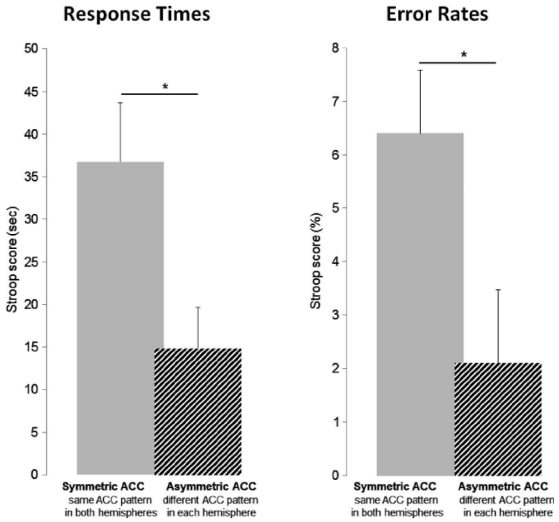


Figure 1. A-Brain activations during writing in a group of adults and children (8-11 y.o., Palmis et al., 2021). The ACC and fusiform Gyri are circled. B- Sulcal variability in the ACC (Borst et al., 2014). C- Sulcal Variability in the OTS (Borst et al., 2016)

Cortex cingulaire antérieur (ACC)

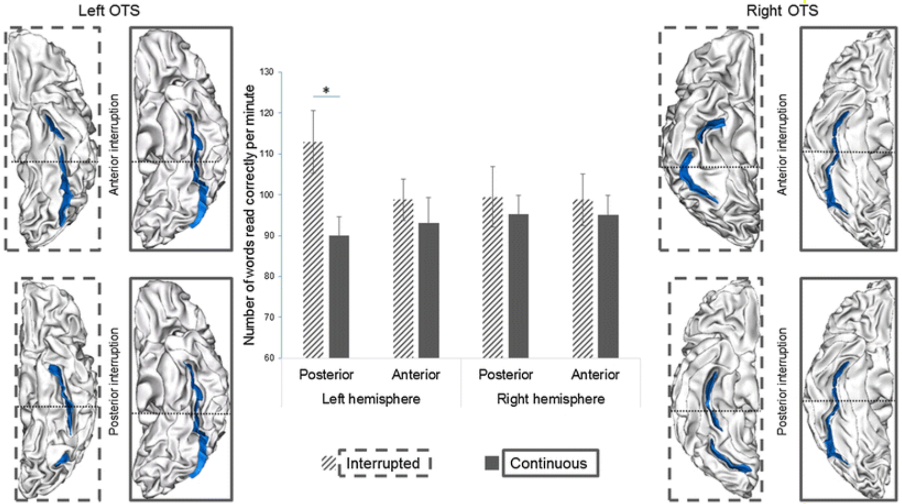
Patterns du CCA et contrôle cognitif : plus efficient lorsque les motifs des sillons sont asymétriques (Cachia *et al.,* 2014; Borst et al. 2014; Tissier et al. 2018)



L'effet de l'asymétrie du CCA sur l'efficience du contrôle cognitif chez des enfants (Cachia et al., 2014)

Sillon occipito-temporal (OTS)

Patterns de l'OTS et lecture : plus performante lorsque les motifs des sillons sont discontinus en postL (Borst et al., 2016 ; Cachia et al., 2018)

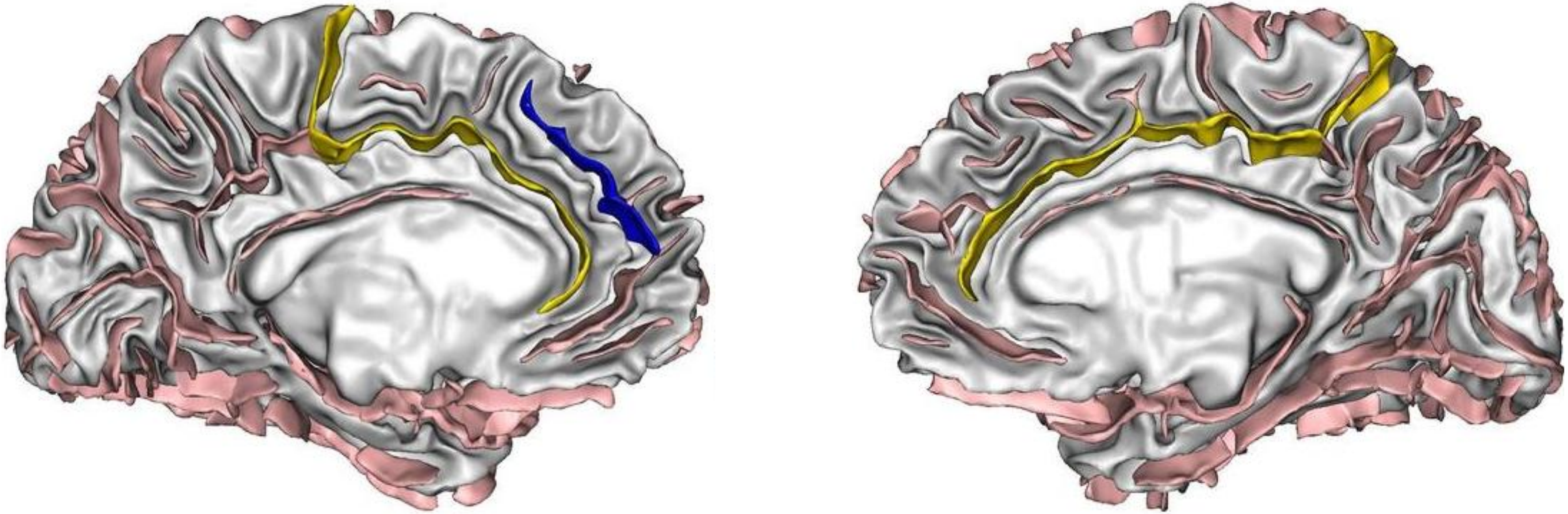


L'effet de la morphologie de l'OTS sur la compétence de lecture chez des lettrés et des illettrés (Cachia et al.,2018)

Structural MRI data processing

- A partir des images anatomiques T1 et T2→ reconstitution de l'interface matière grise – matière blanche en un maillage constitué d'environ 60 000 sommets (freesurfer)
- Ces images tridimensionnelles ont ensuite été importées dans le logiciel BrainVISA.
- Les motifs des sillons ont été déterminés visuellement « en aveugle » et labélisés manuellement par 2 des co-auteurs à partir de la reconstruction 3D des plis corticaux (Cachia et al., 2014).
- CCA : « simple » ou « double parallèle » basé sur la présence ou l'absence d'un sillon paracingulaire (PCS)
- OTS: continuous or interrupted we identified whether OTS interruption was located in the posterior part of the sulcus hosting the VWFA or anterior

Analyse IRM : Identification des motifs sulcaux CCA



Double parallele

Asymétrie

Simple

Visualisation de deux hémisphères (gauche et droit) – En jaune : sillon cingulaire ;
en bleu : sillon paracingulaire

Preliminary results

- R Package Lavaan : SEM to test the influence of sulcal patterns of OTS and ACC on graphomotor, orthographic and reading scores, without latent variable

→ Replication of the results of Cachia et al., 2018, with significant effect of left posterior interruption on reading scores (nb words read per minute for adults, and reading accuracy for children)

→ Finding of a combined effect of ACC asymetry and right OTS interruption on graphomotor performance (writing speed and quality, larger effects for children)

→ No effect of sulcal patterns on orthographic scores

Elie Fabiani, Gaelle Alhaddad, Anne Mathieu (Master BIM, Bordeaux), Charlotte Dupont (Master Clinical Neuroscience, Toulouse), Mihaela Nicolescu (Master Neuroschool), Jean Luc Velay, Jeremy Danna, Sonia Kandel (Grenoble University), Michel Habib, Bruno Nazarian, Julien Sein, Jean Luc Anton (fMRI Center, INT-CERIMED, Marseille), Arnaud Cachia (Paris University), Olivier Coulon and Guillaume Auzias