Bridging the structural and functional correlates of infant brain development using MRI and EEG

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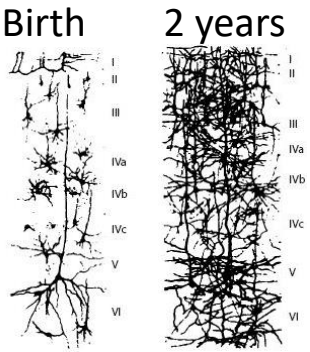
NeuroDiderot – INSERM U1141/Neurospin

Neobrain2-Reims 14 June 2021

From brain development to functional acquisitions

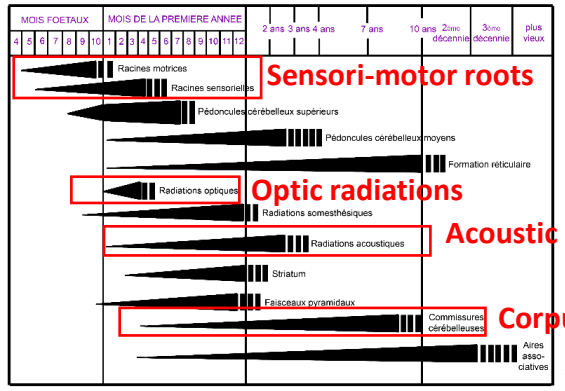
Gray matter maturation



White matter maturation

Flechsig, 1920

Myelination of pathways



Yakovlev and Lecours, 1967

Asynchronies in maturation

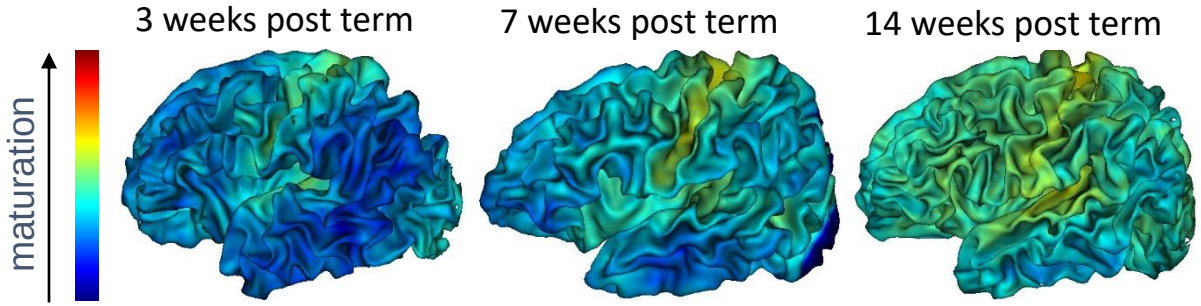
How neuroanatomical changes are translated into behavioral acquisitions ?

- Non-invasive neuroimaging of the developing brain *in vivo*

Brain development during infancy

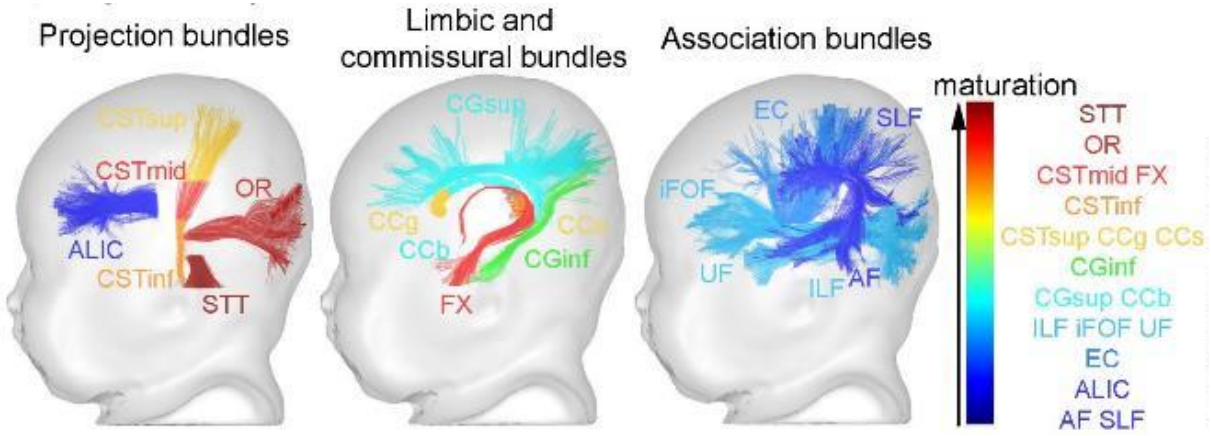
Structural maturation – MRI

Maturation of gray matter



Leroy *et al.*, J. Neuroscience 2011

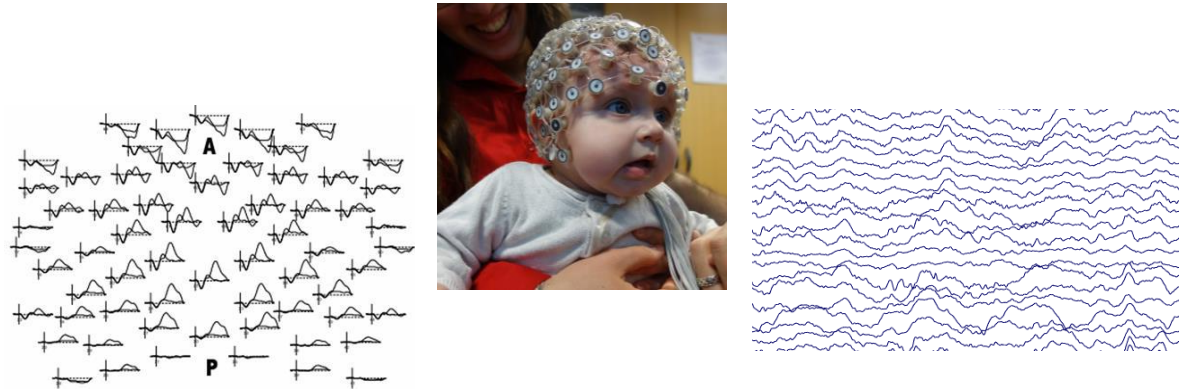
Maturation of white matter pathways – diffusion MRI



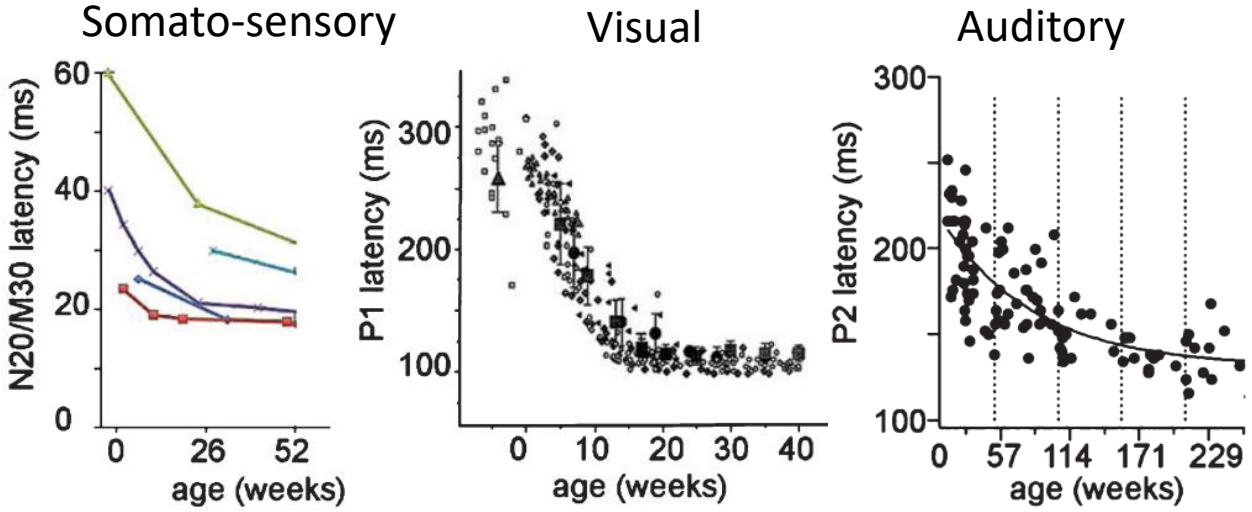
Dubois *et al.*, Brain mapping, 2015

Asynchronies in maturation

Functional maturation – EEG/MEG



Response latencies



Nevalainen et *al.*, Front Hum Neuroscience 2014
McCulloch et *al*, Vision Research 1999
Shafer et *al.*, Int J Psychophysiol. 2015

Aim

Structural development

diffusion MRI

Functional development

EEG

- Evaluating the maturation of brain responses with respect to structural maturation of white matter pathways and cortical gray matter :

  ❑ Regressing out the effect of age

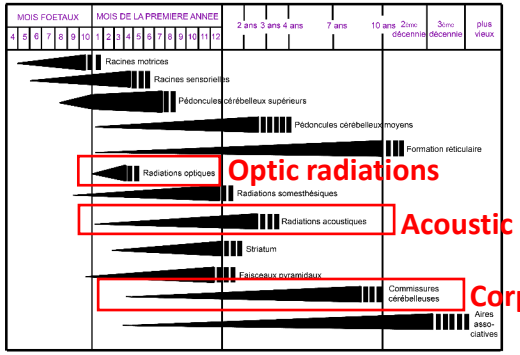
  ➢ **In white matter:** Myelination of neuronal fibers increases the speed of neural information that travel through the neurons

  ➢ **In gray matter:** Increase in synaptic density, myelination of intra-cortical fibers or the changes in intracellular organelle density could affect cortical responses.

- Visual and auditory networks

  1. Early responses

  2. Inter-hemispheric transfer of the responses



Yakovlev and Lecours, 1967

Functional relevance of structural changes

MRI

Maturation of white matter

diffusion MRI

Myelination

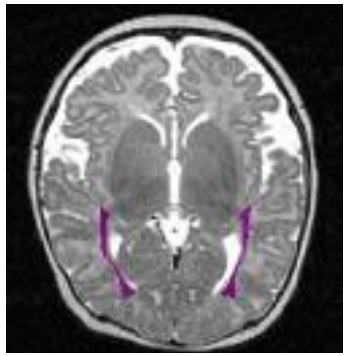
Maturation of brain responses

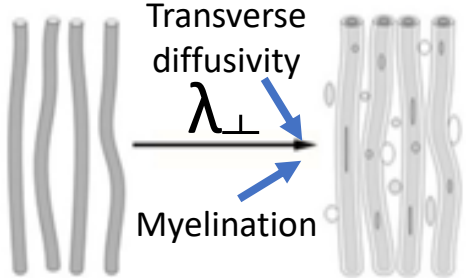
EEG

Neural conduction speed

EEG

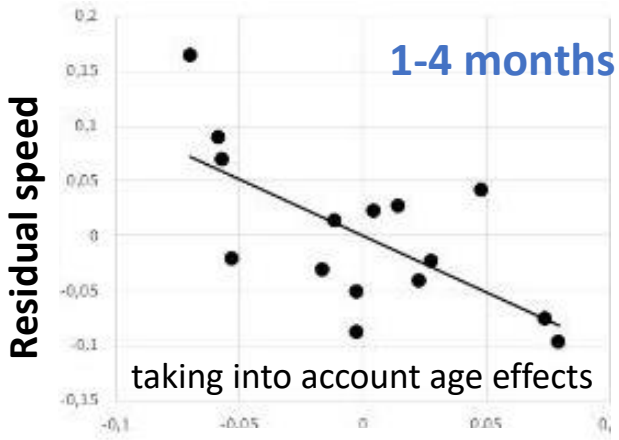
DTI in the optic radiations



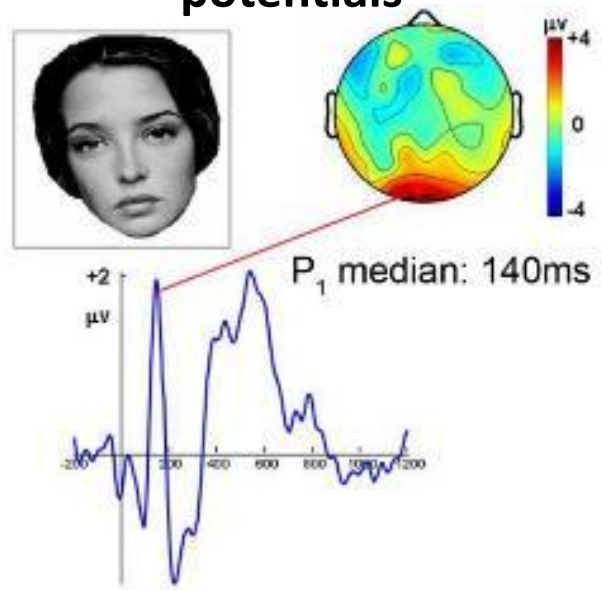


Correlations between functional and structural development

Latency — Anatomical Distances → Conduction Speed



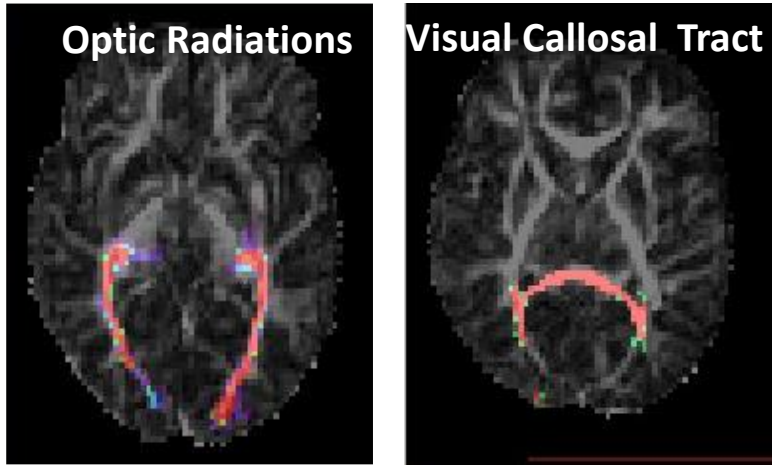
EEG – Visual evoked potentials



Dubois *et al.*, J Neuroscience, 2008

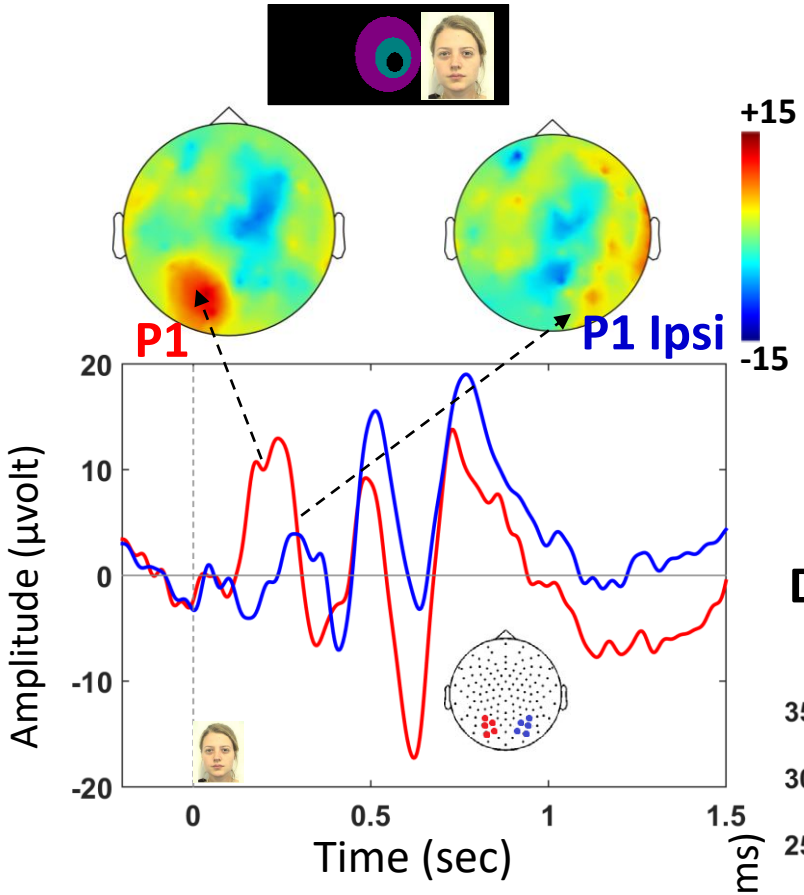
MRI and EEG correlates of visual development

Pathways reconstruction: Tractography



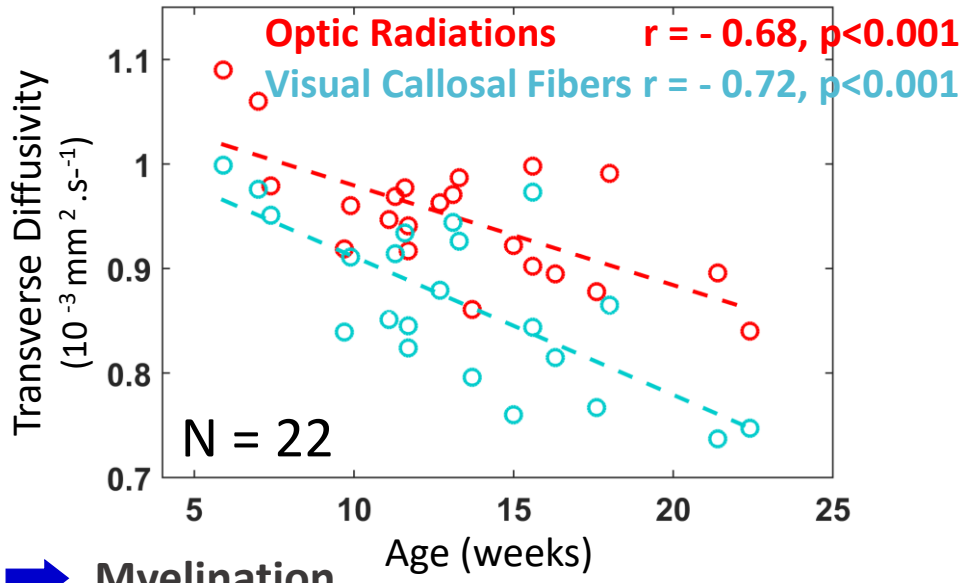
Visual evoked responses

- 40 infants : 1-6 months old



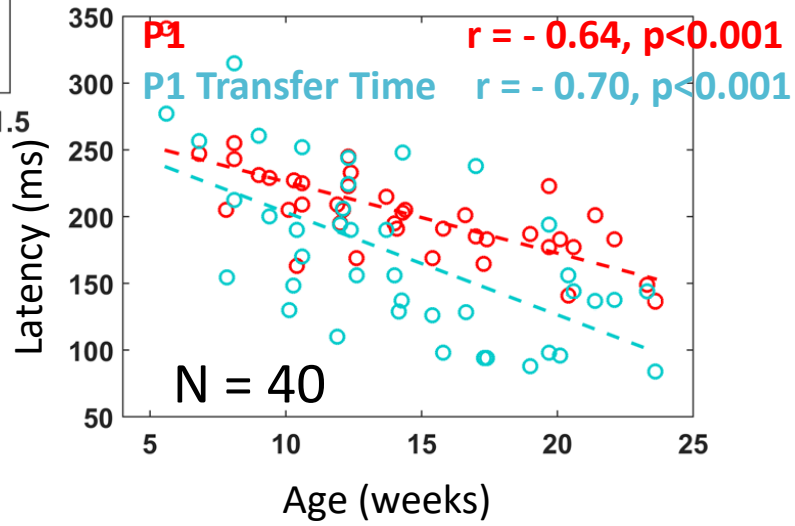
P1 transfer time:
P1 Ipsi – P1 contra

Decrease in transverse diffusivity across development



➡ **Myelination**

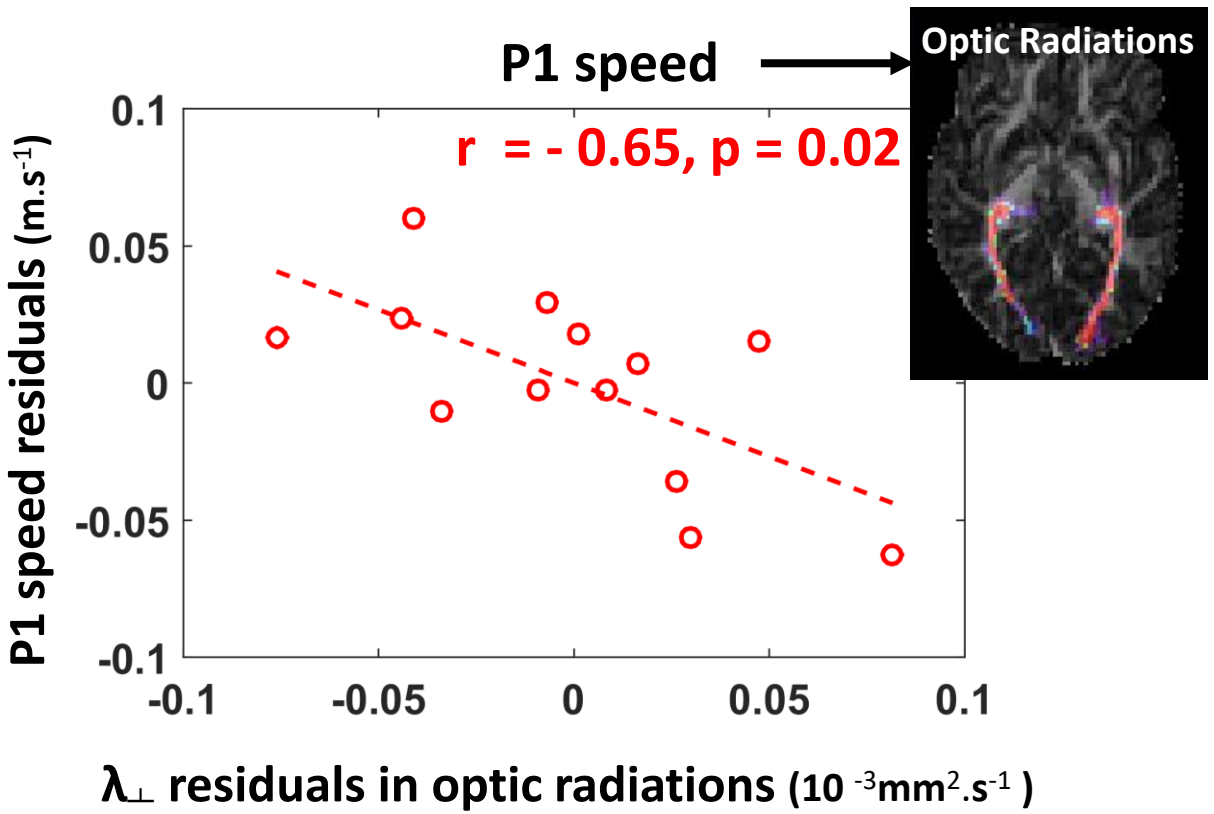
Decrease in response latencies across development

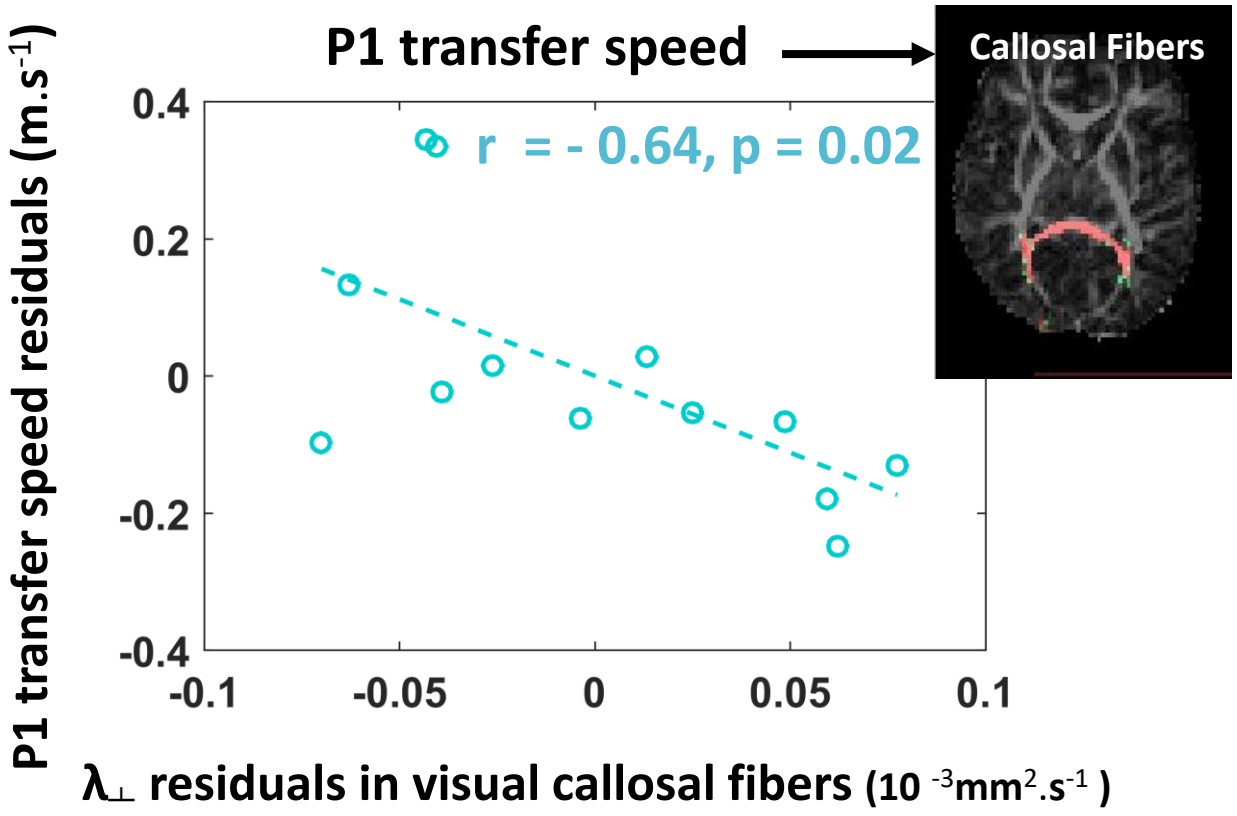


Adibpour *et al.*, Nature Human Behavior, 2018

Correlations between structural and functional maturation

- 13 infants completed both EEG & MRI experiments





Controlling for age effects

➢ Variability in the response speeds relates to the maturation of corresponding pathways

Adibpour *et al.*, Nature Human Behavior, 2018

Structure-function relationship across multiple brain networks

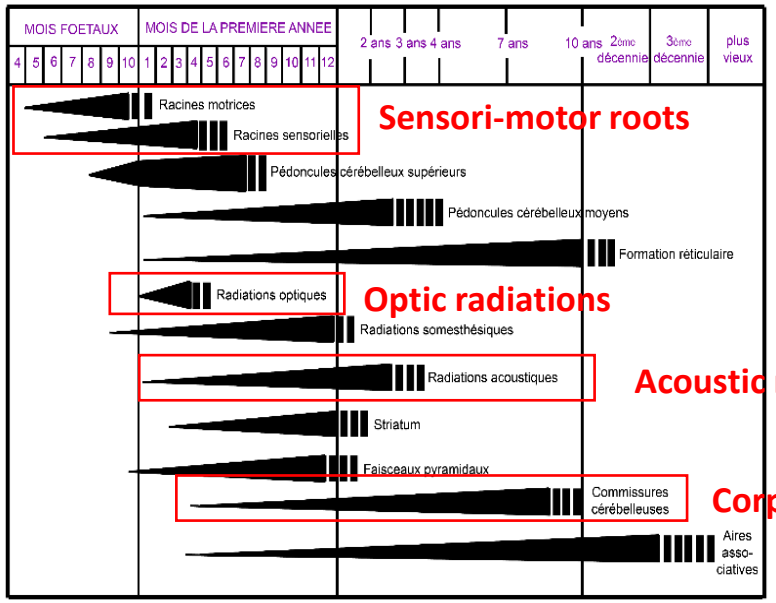
Maturation of white matter

diffusion MRI

Maturation of brain responses

EEG

Myelination of pathways



Yakovlev and Lecours, 1967

Visual network

Auditory network

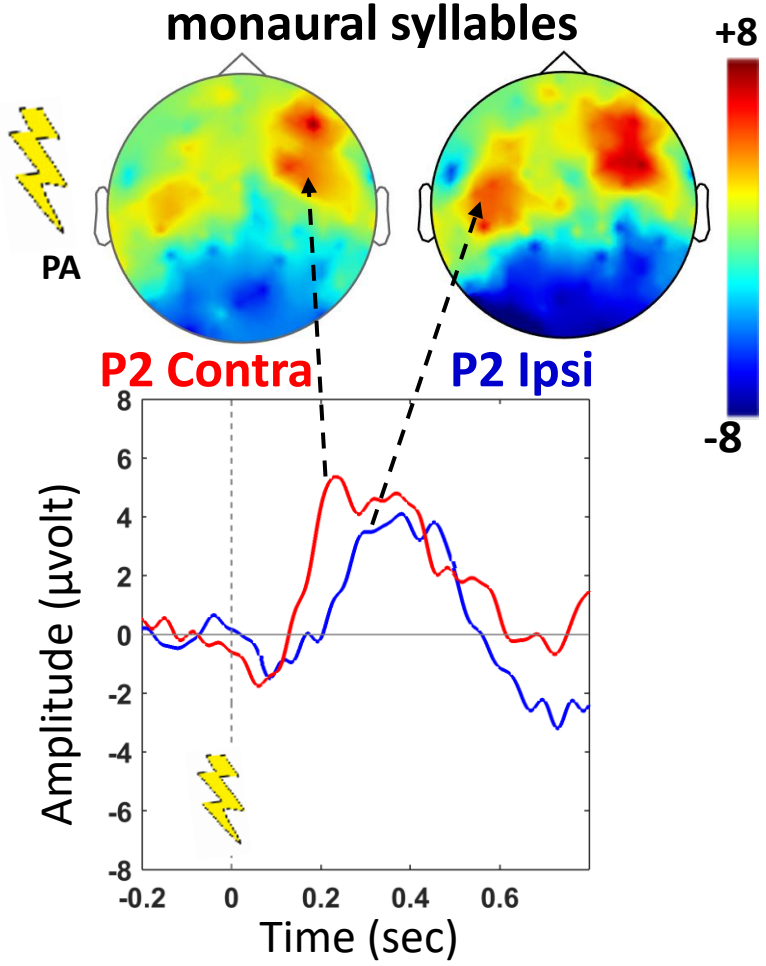
Different Maturational calendars

Different *in utero/ex utero* inputs

MRI and EEG correlates of auditory development

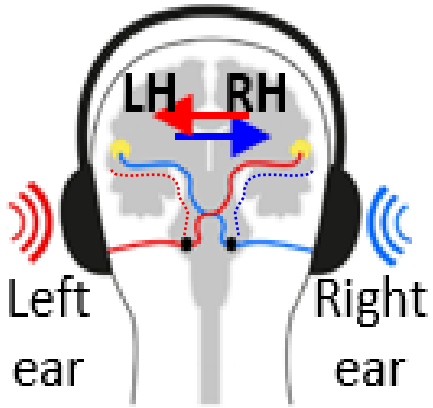
- 19 infants (1-6 months)

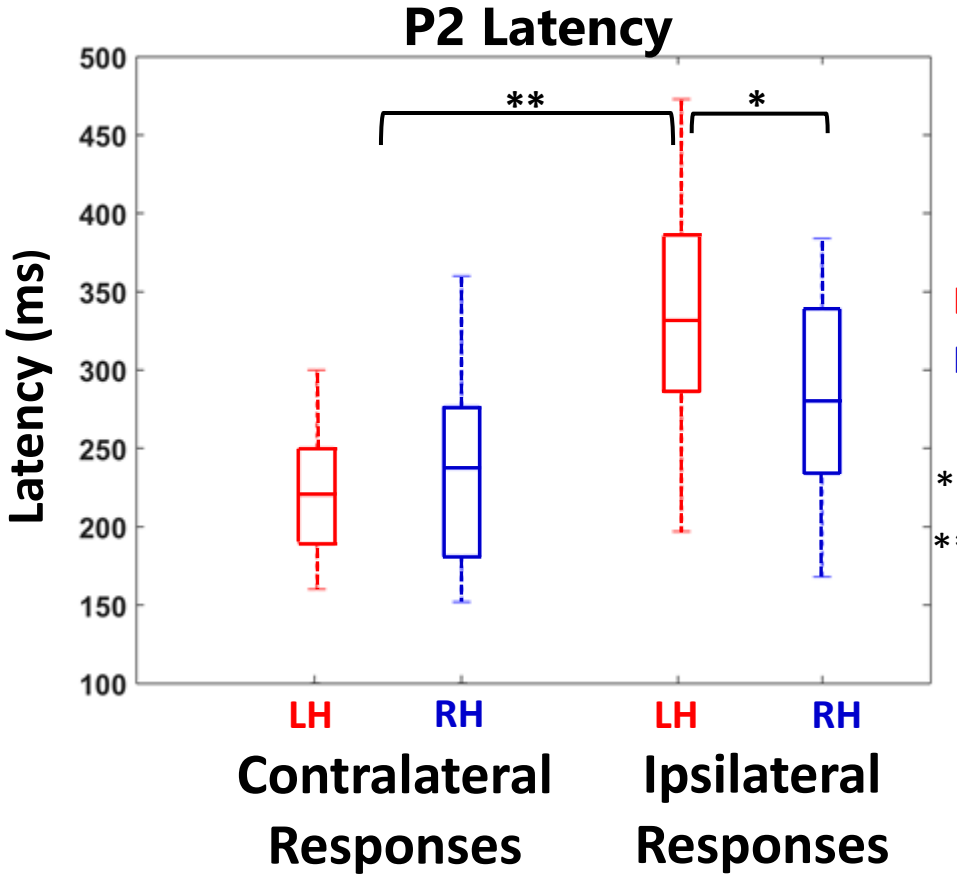
Auditory evoked responses to monaural syllables



Auditory pathways:

- Contralateral and ipsilateral pathways
- Responses from the ipsilateral pathways superpose to the transfer of responses



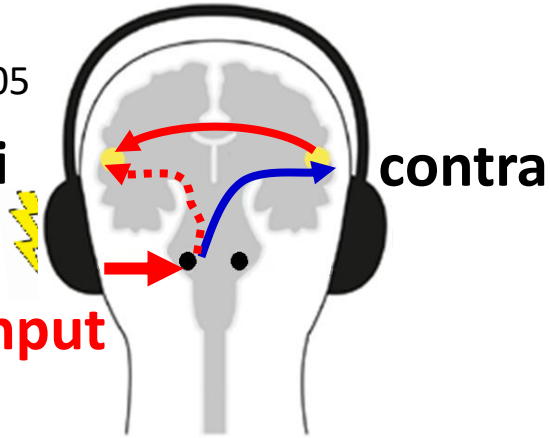


Left hemisphere (LH)

Right hemisphere (RH)

* p < 0.05

** p < 0.005



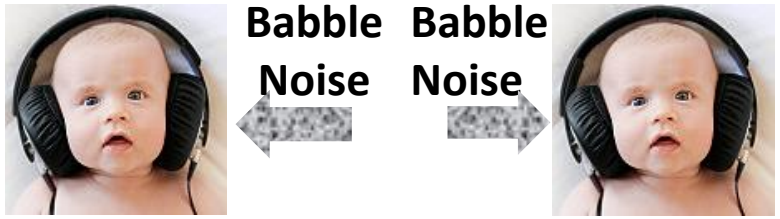
Adibpour *et al.*, Developmental Cognitive Neuroscience, 2020

Response latency differences between typical and AgCC infants

13 infants with **Agenesis of corpus callosum AgCC**

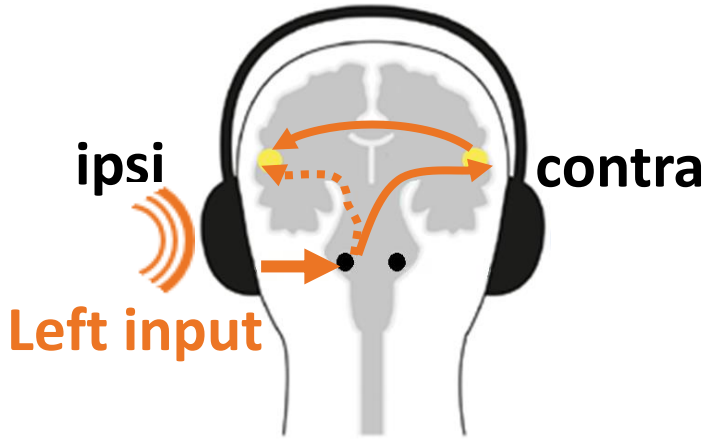
18 **Typical** infants 3-4 months

Auditory evoked responses to monaural noise

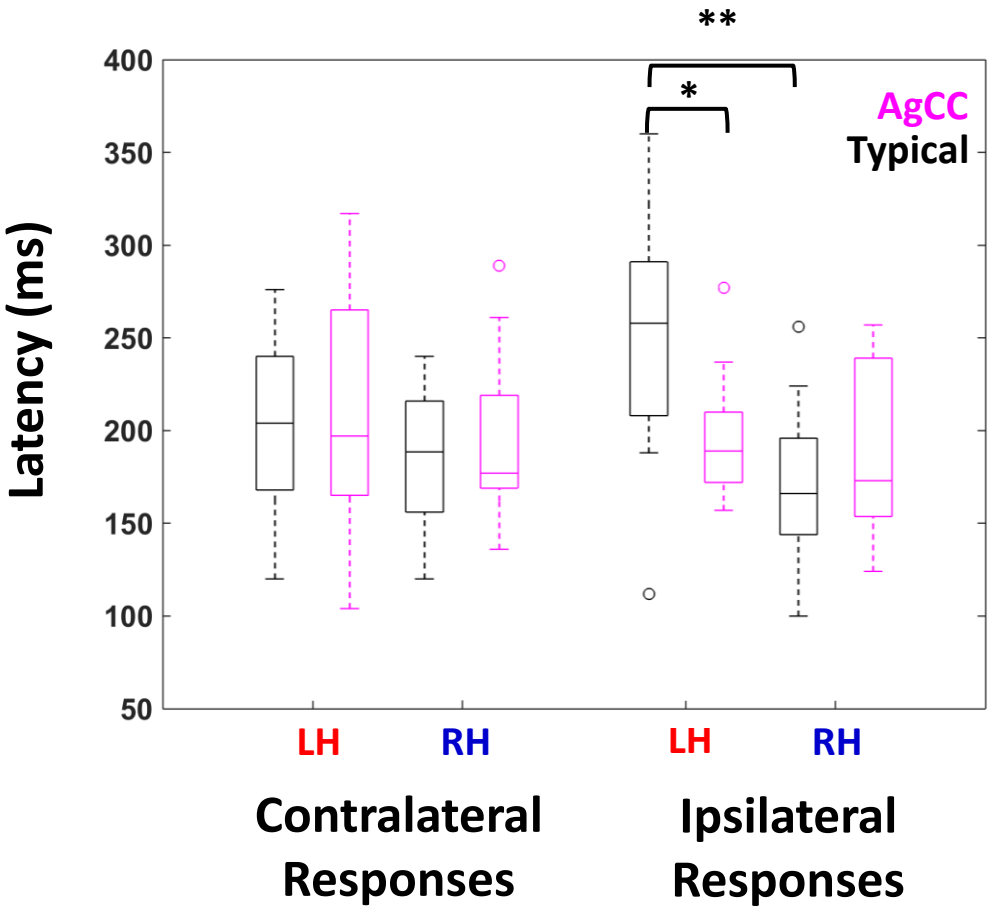


- **Delayed ipsilateral** responses in the **left** (but not right) hemisphere in typical but not AgCC infants.

Involvement of callosal pathways



P2 Latency in AgCC vs. typical infants



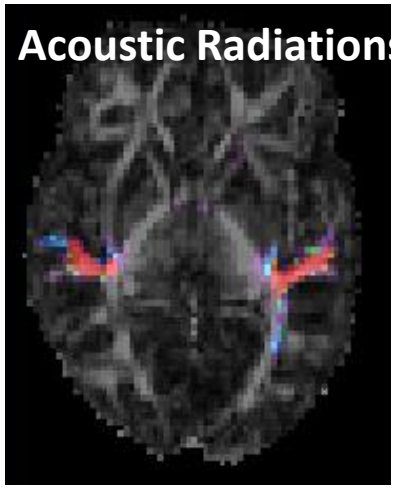
* $p < 0.05$
** $p < 0.005$

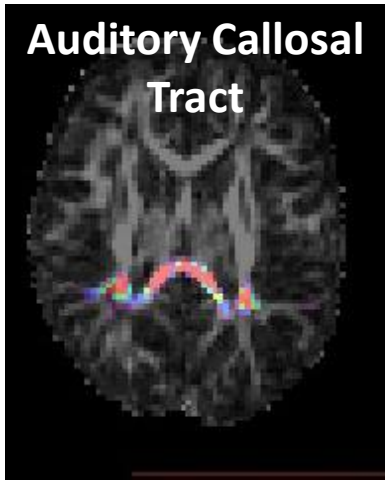
Left hemisphere (LH)
Right hemisphere (RH)

Adibpour *et al,* Brain Structure and Function, 2018

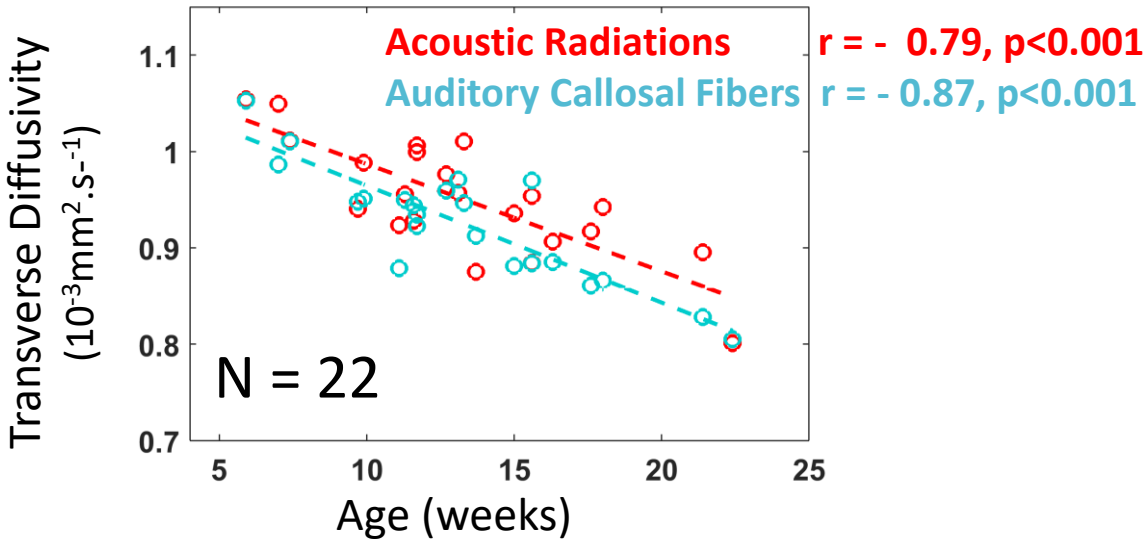
Correlations between structural and functional maturation

Maturation of auditory white-matter pathways



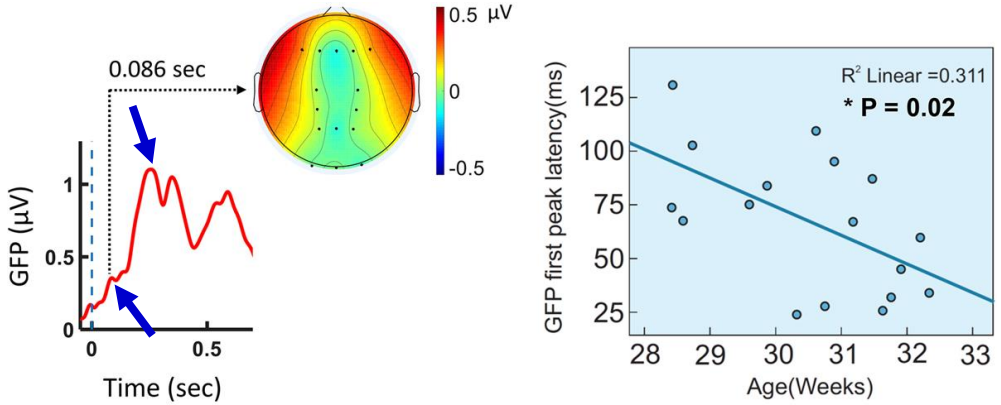


Age-related changes



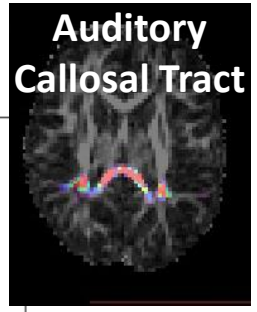
Adibpour *et al*., Developmental Cognitive Neuroscience, 2020

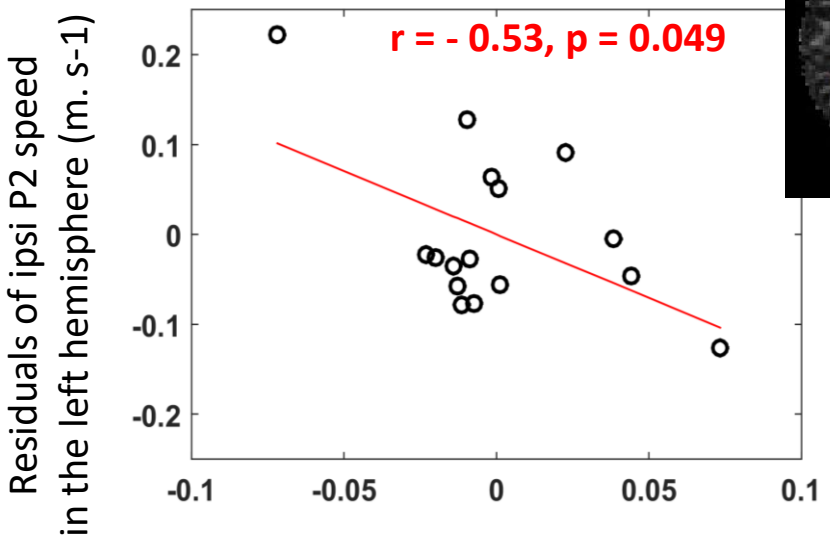
➢ No relation between the speed of P2 responses and the maturation of acoustic radiations ➡ P2 is a late response



Daneshvarfard *et al*., Brain Struc and Func, 2020

Ipsilateral P2 latency in left hemisphere ➡

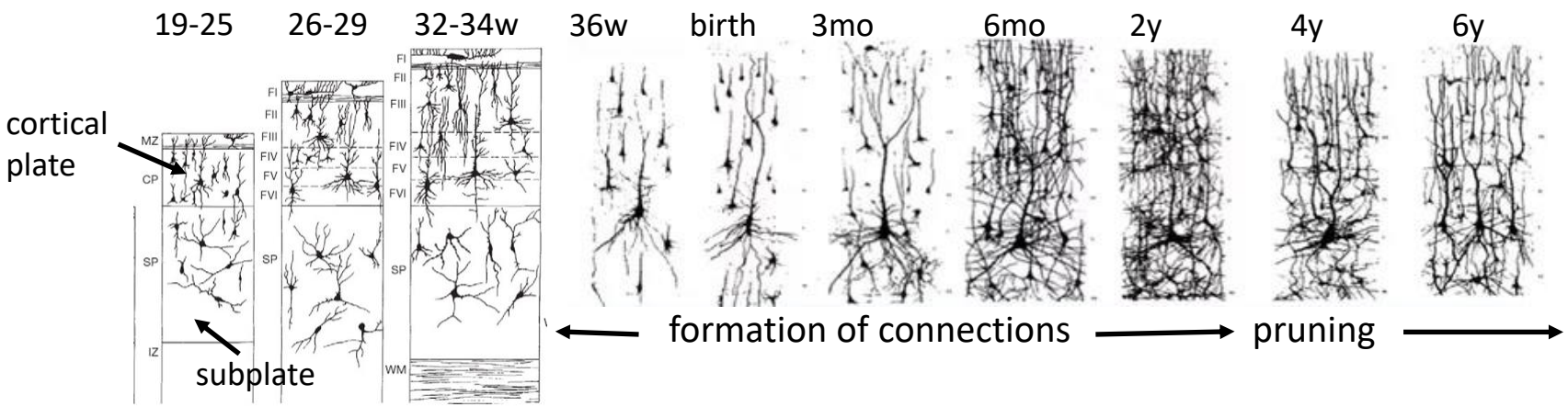


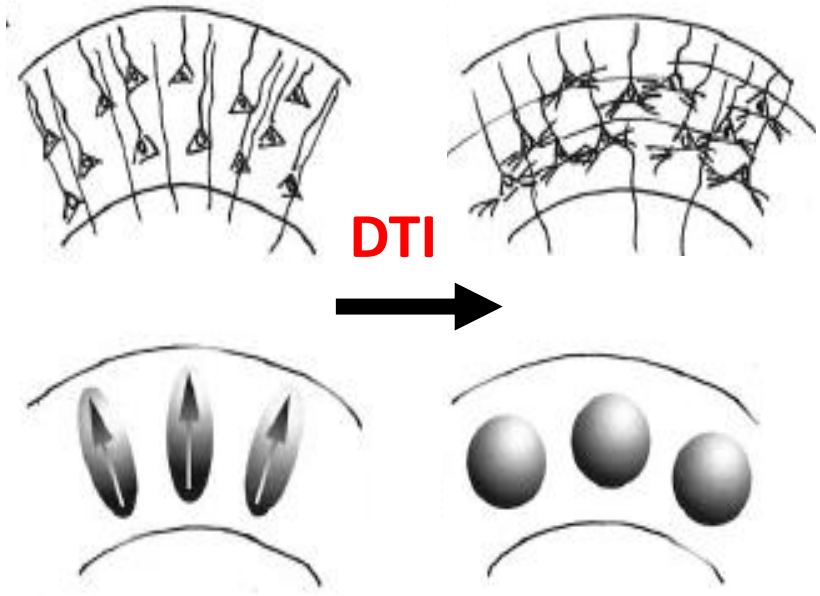


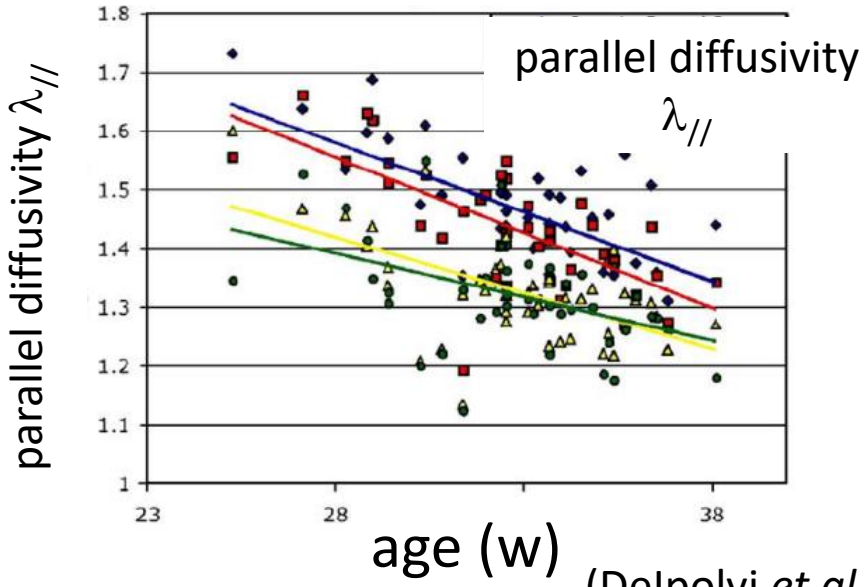
Cortical maturation

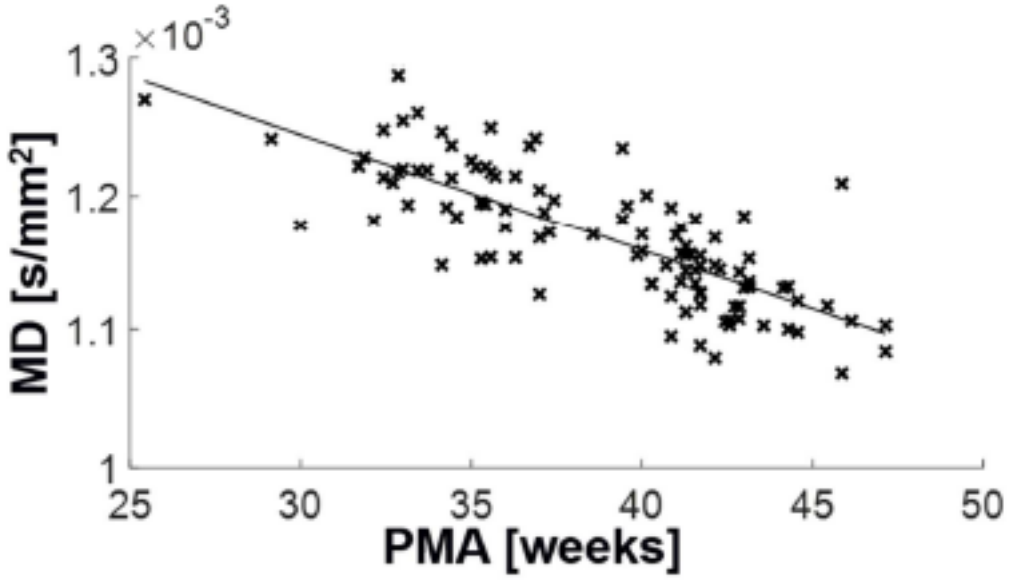
Growth of dendritic arborization and synaptogenesis

Cortex : during gestation / after birth





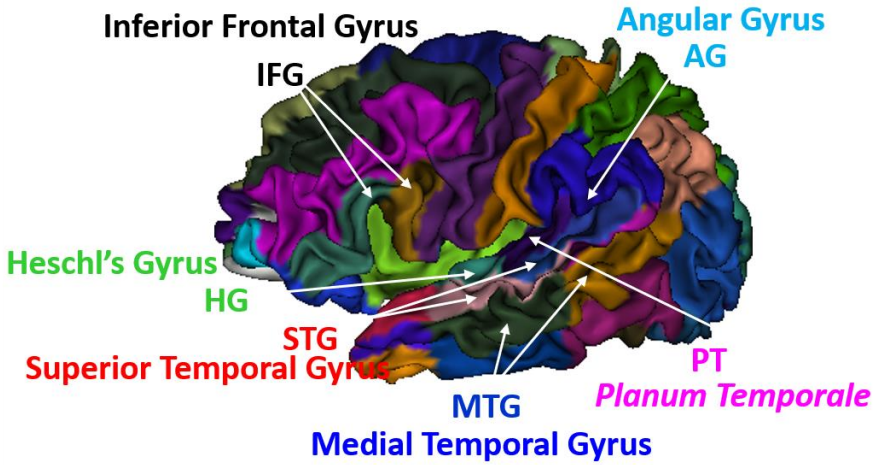




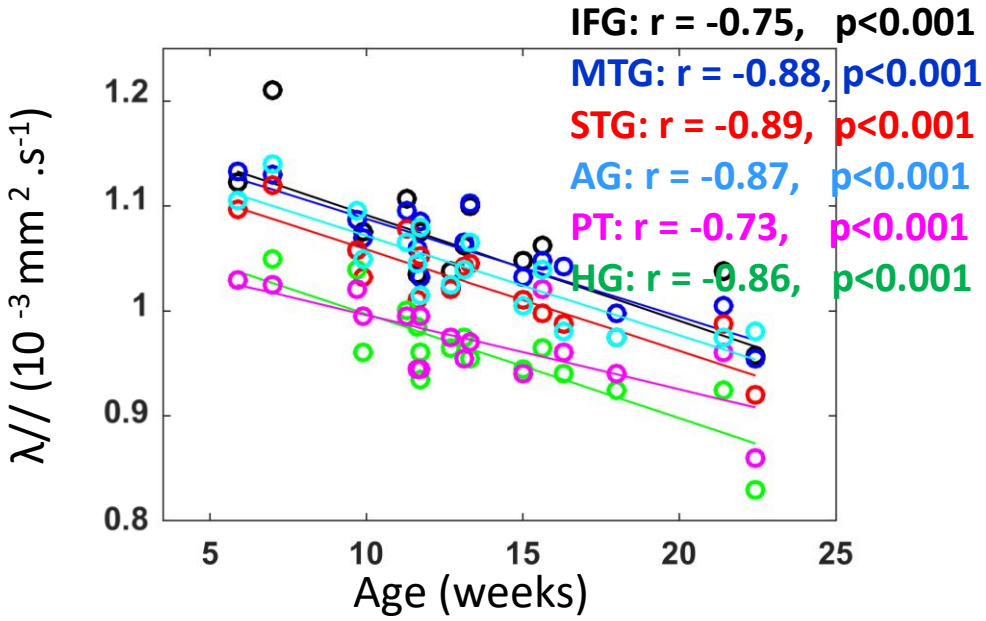
(DeIpolyi *et al*, Neuroimage 2005; Batalle *et al*, Neuroimage, 2019)

Correlations between structural and functional maturation

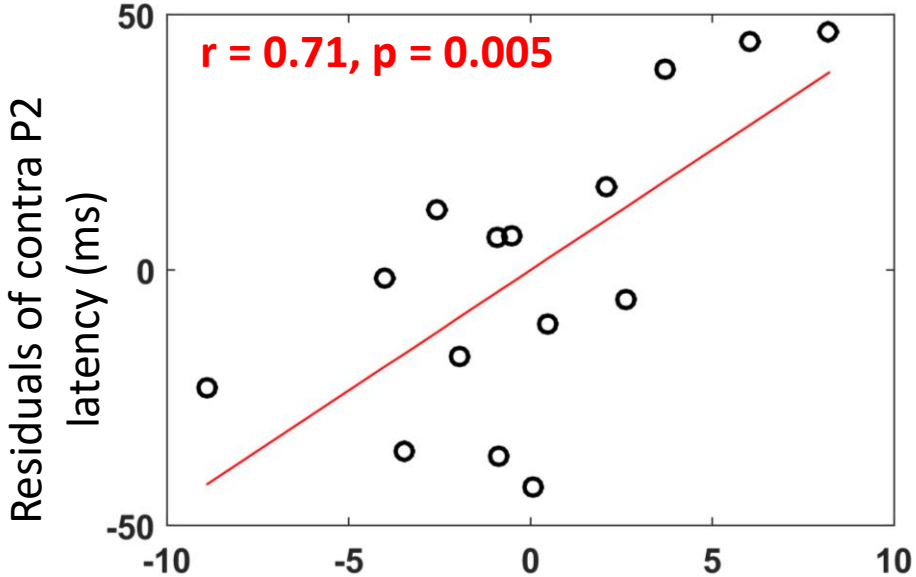
Cortical parcellations in infants



Maturation of cortical perisylvian regions



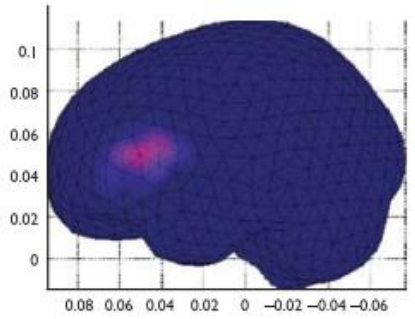
Adibpour *et al.*, Developmental Cognitive Neuroscience, 2020



- Variability in the response latencies relates to the maturation of Inferior Frontal Gyrus

Source reconstruction of activity between 210-300 ms

6 month old



Imada *et al.*, Neuroreport, 2006; Bristow *et al.*, J Cognitive Neuroscience, 2009

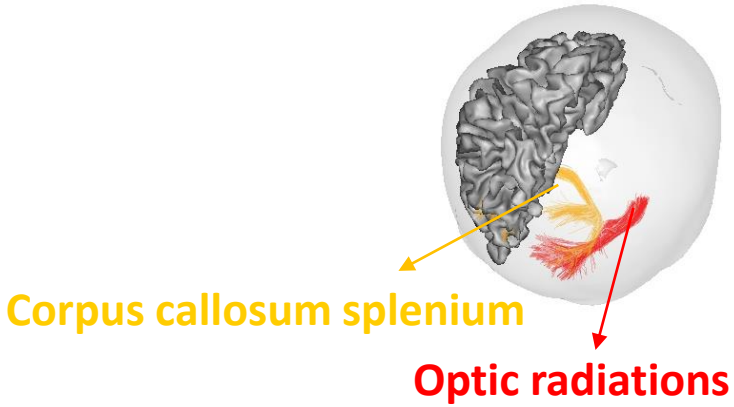
Linking structural and functional maturation

Visual network

Projection pathways
(Optic radiations)

P1

cortico-cortical pathways
(Visual callosal fibers)



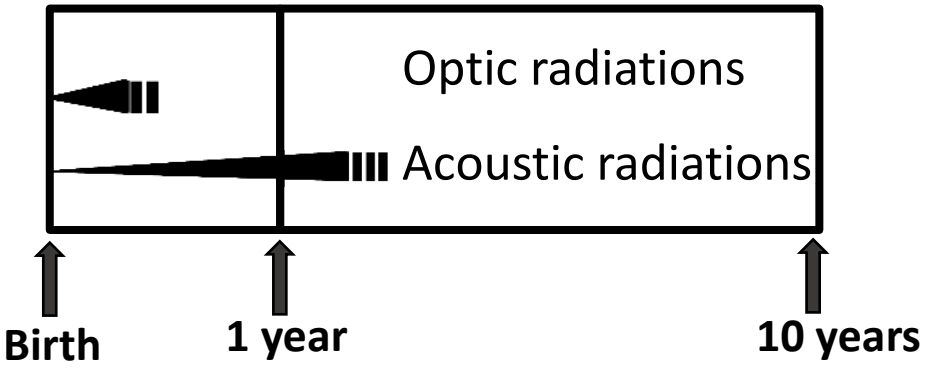
Auditory network

Projection pathways
(Acoustic radiations)

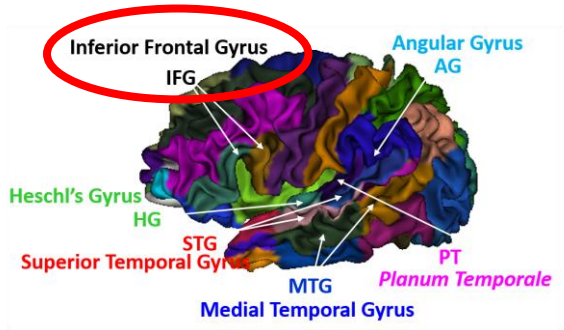
P2 ?

cortico-cortical pathways
(Auditory callosal fibers)

Myelination of pathways



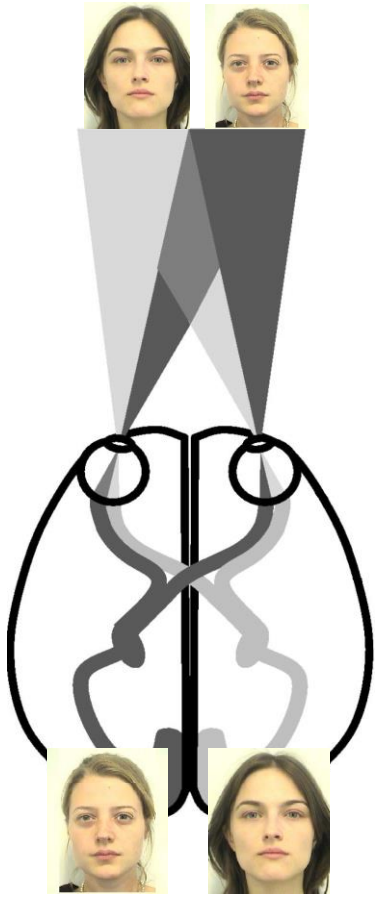
Yakovlev and Lecours, 1967

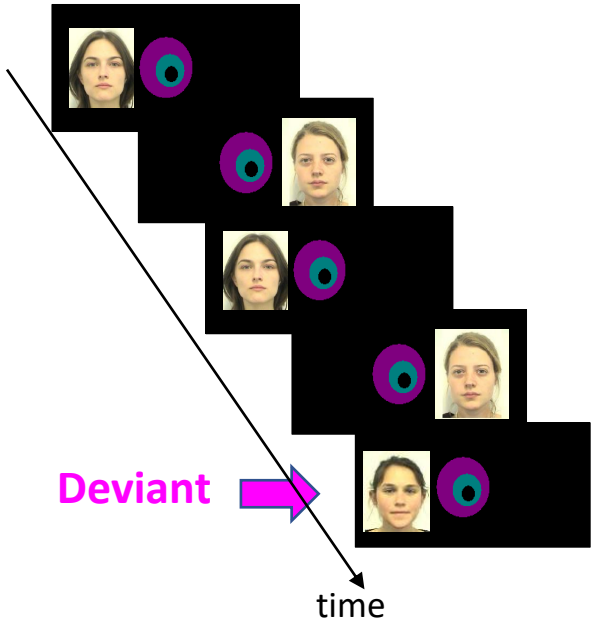


- Early interhemispheric transfer of neural activity, supported by microstructural maturation

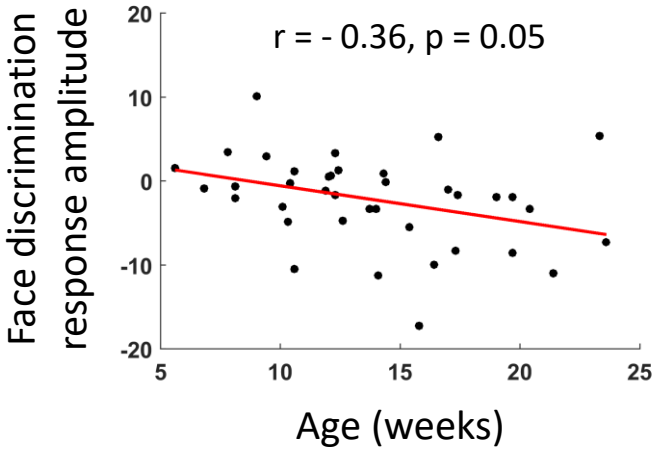
Functional maturation beyond sensory processing

Face discrimination task

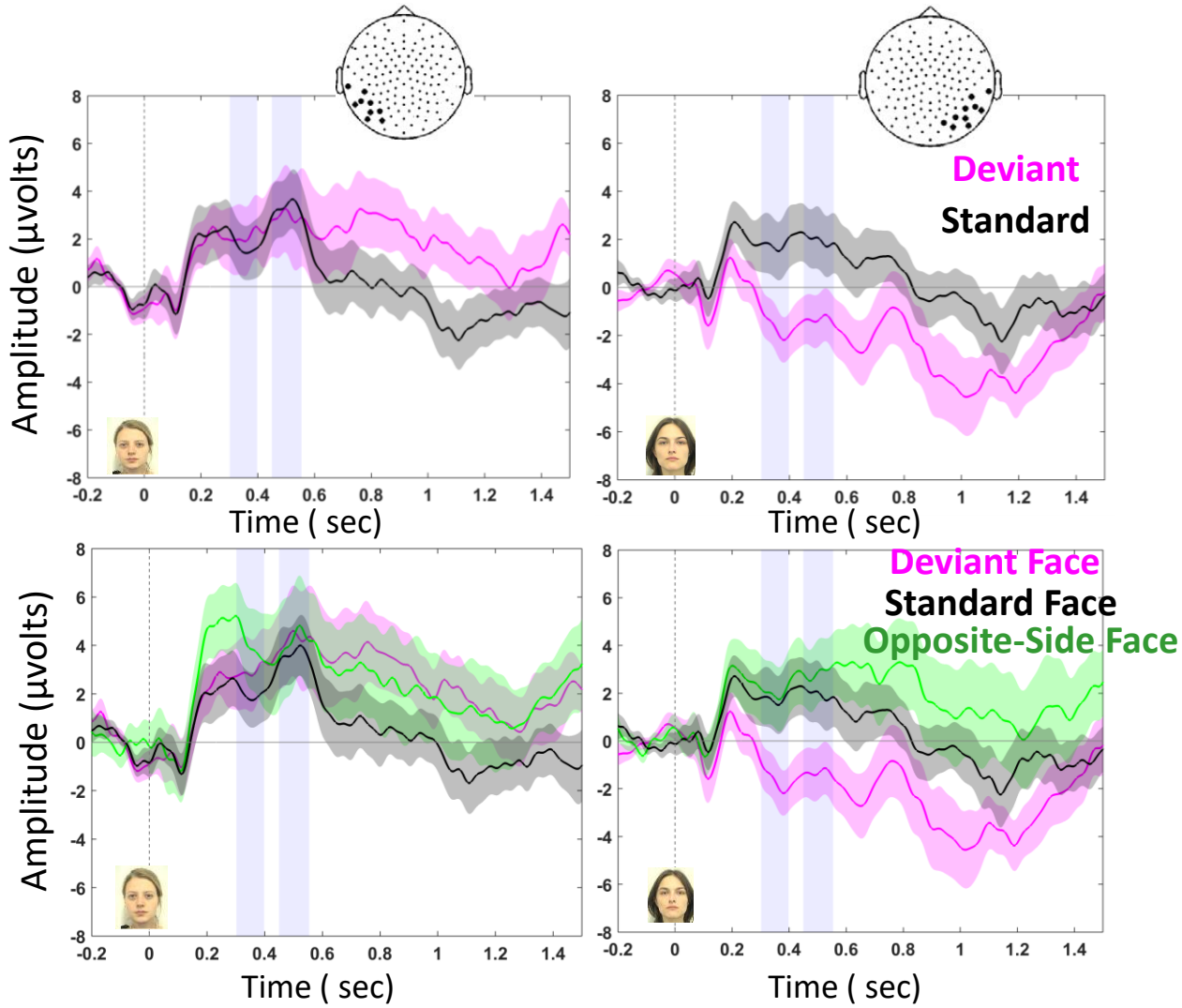




Maturation of discrimination responses vs age



Right Hemifield / Left Hemisphere **Left Hemifield / Right Hemisphere**



Missing link to structural maturation?

Adibpour *et al.,* Nature Human Behavior, 2018

Perspectives :

Structural maturation

MRI

Functional maturation

EEG/MEG (fMRI)

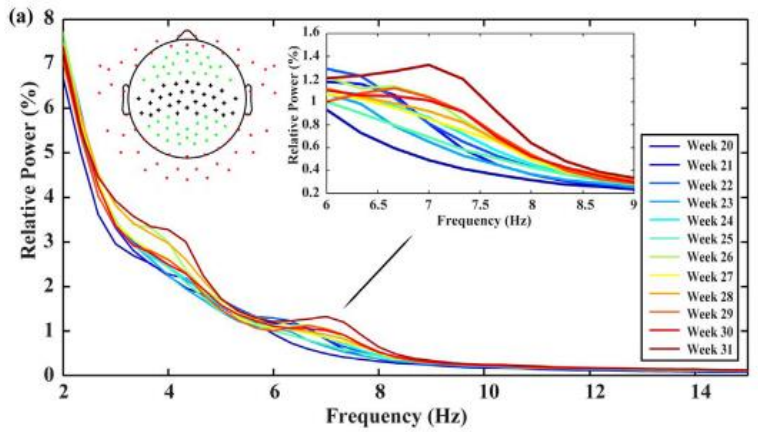
Behavioral acquisitions

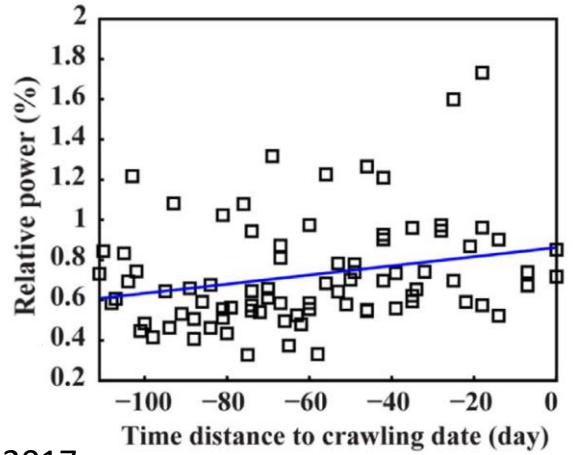
Sensori-motor acquisitions in relation with functional response maturation

Mu rhythm and motor acquisitions

Crawling

- 5-7 months
- Rest-state recording
- The mu rhythm power specifically correlated to the crawling onset.





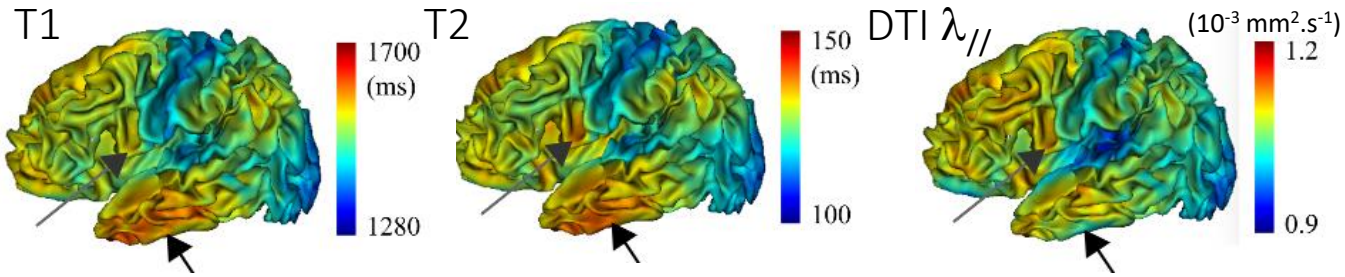
Xiao et al., Neuroimage, 2017

➢ In early developmental period, study of behavioral acquisitions are limited.

Structural maturation ⟷ **Functional maturation**

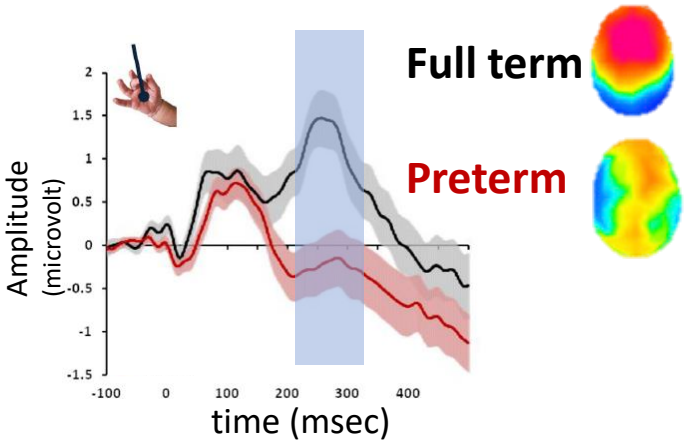
Perspectives :

- Moving towards a finer description of structure-function relationships:
  - Quantifying other functional parameters: e.g. morphology and amplitude of evoked responses
  - Quantifying other microstructural parameters (Dubois et al., Brain Plasticity, 2016)



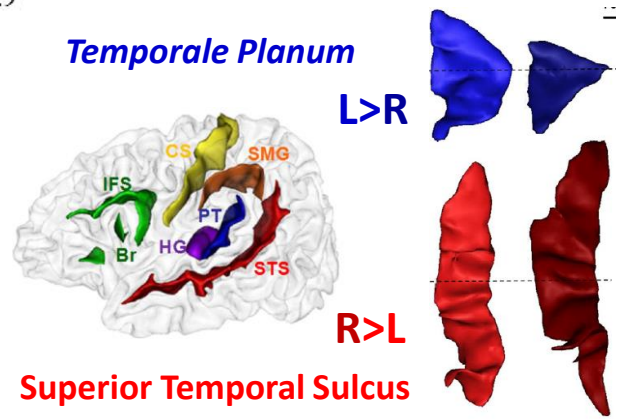
Lebenberg *et al*, IEEE ISBI 2015, Neuroimage 2019

Sensory(tactile) response maturation

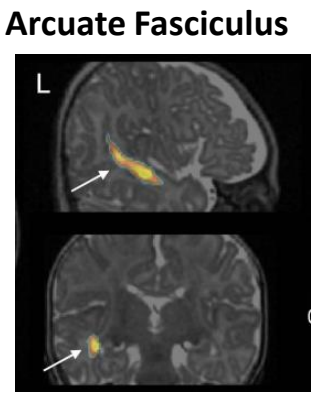


Maitre et *al*., Current Biology, 2017

- Assessing the structure-function relationships within lateralized networks, given the structural and functional asymmetries described in the infant brain.



Glasel *et a*l., Neuroimage, 2011



Dubois *et al.*, Cerebral Cortex 2009

- Investigating the predictive values of the measures for later outcomes (e.g. language)

(O'Muircheartaigh et al., J Neuroscience, 2013)

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