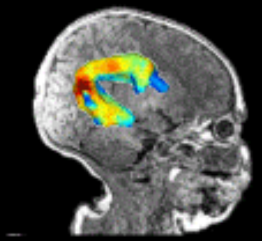
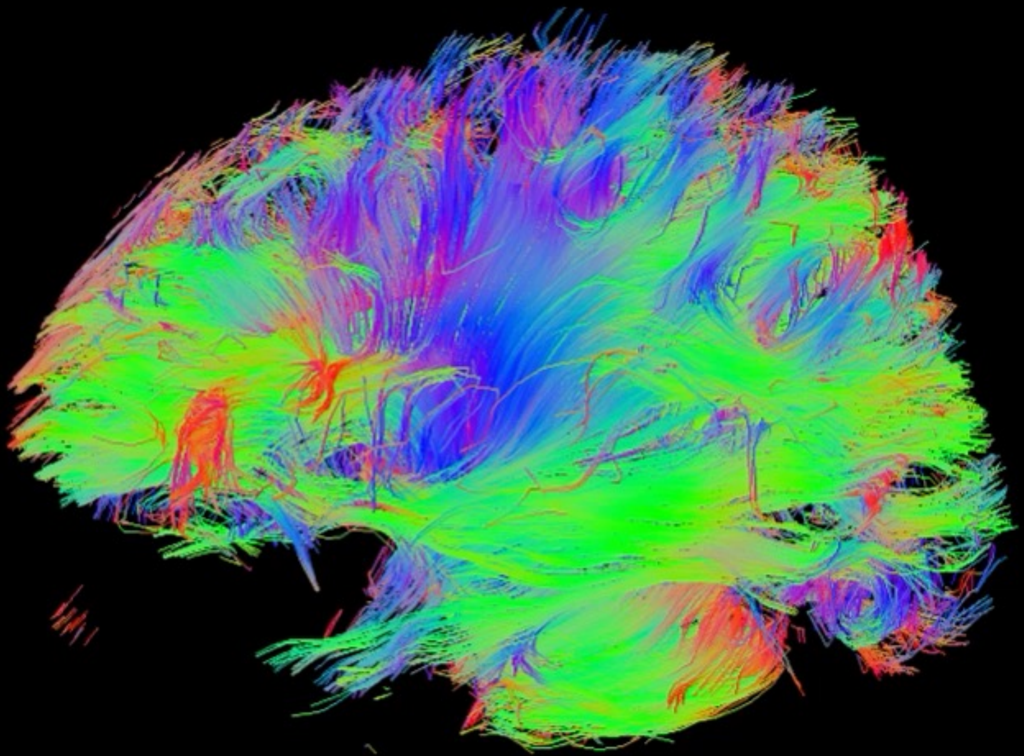
Z·LAB



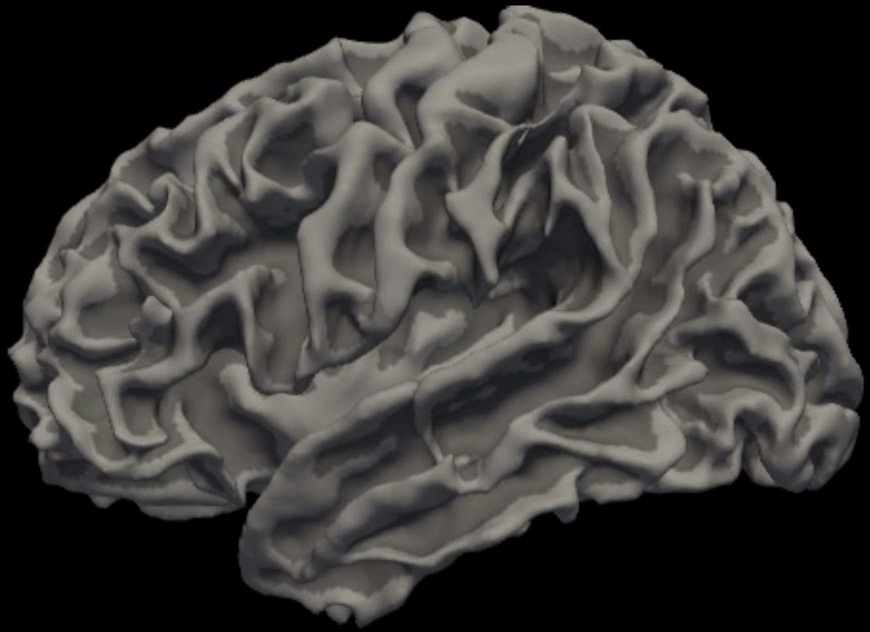
Developmental brain imaging of human cognition

Zeynep M. Saygin
saygin.3@osu.edu

- How much of the human mind is determined at birth?
- How do we gain new skills that are uniquely human and is there a limit to our potential based on what we are born with?



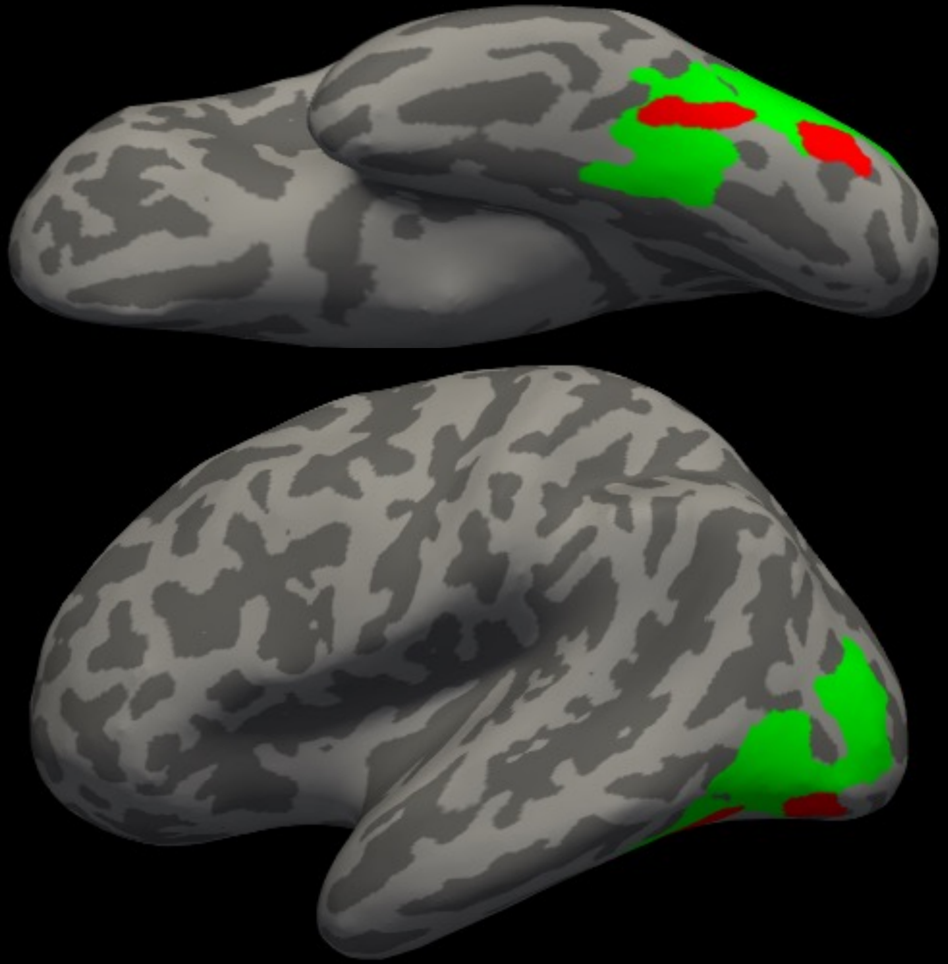
Rich organization of the human brain



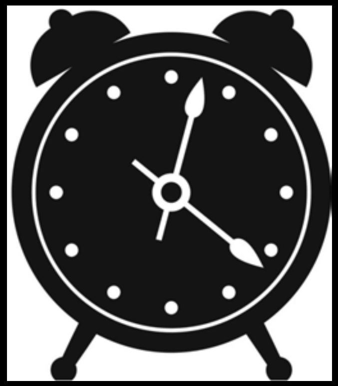
Rich organization of the human brain

Face perception

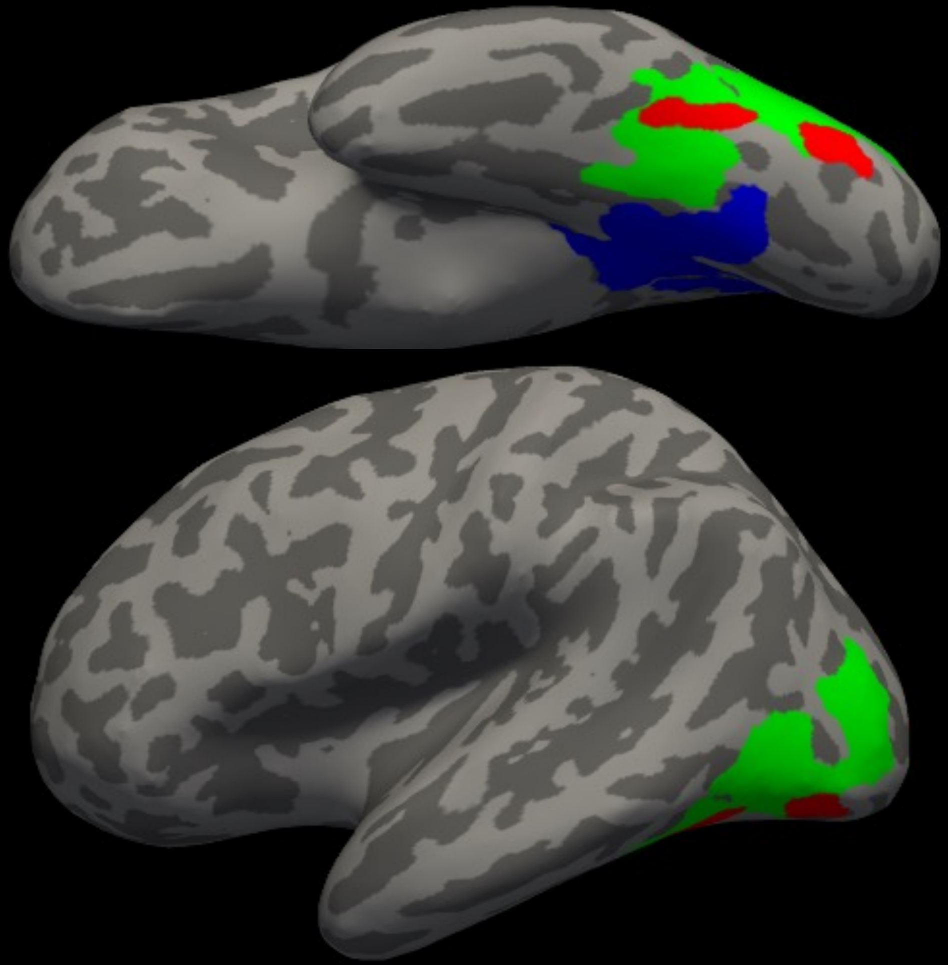
Rich organization of the human brain



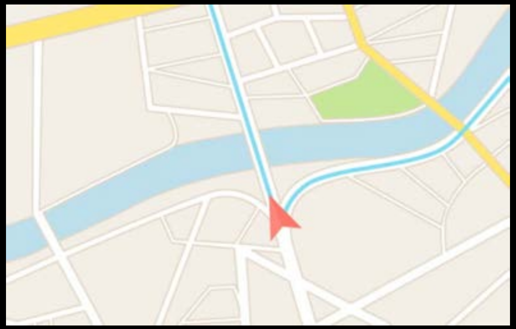
Object perception



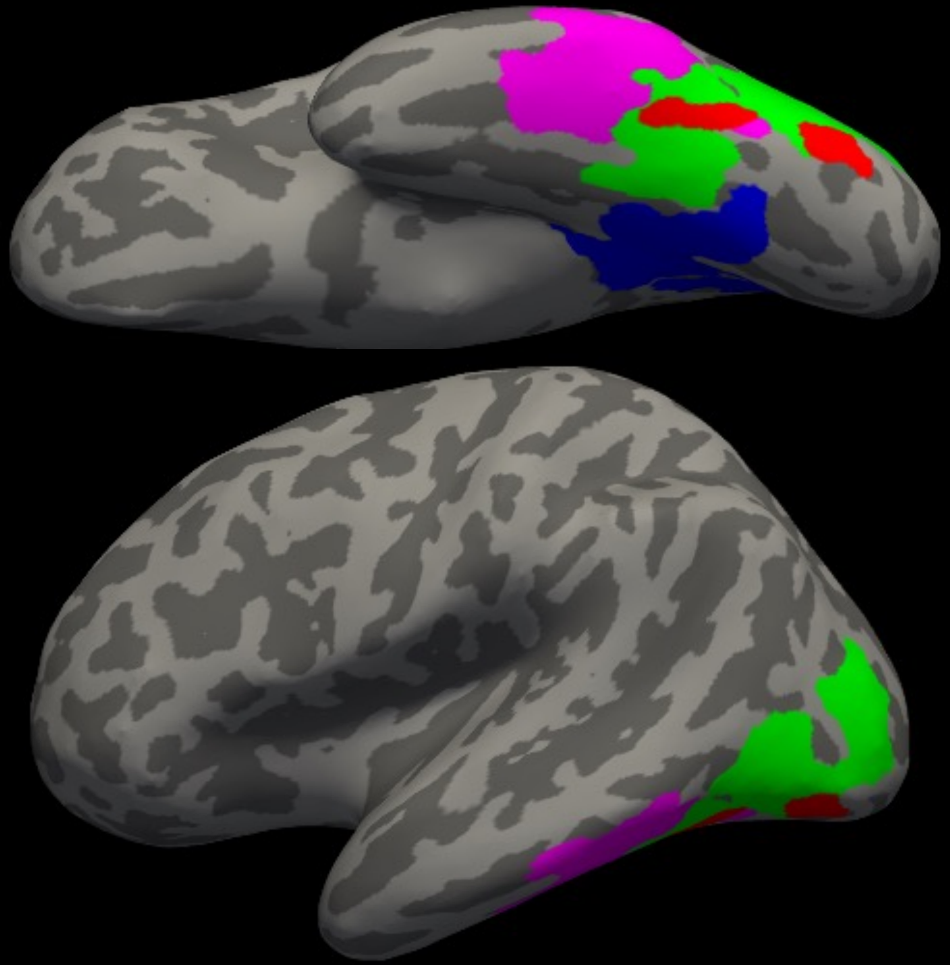
Rich organization of the human brain



Scene perception

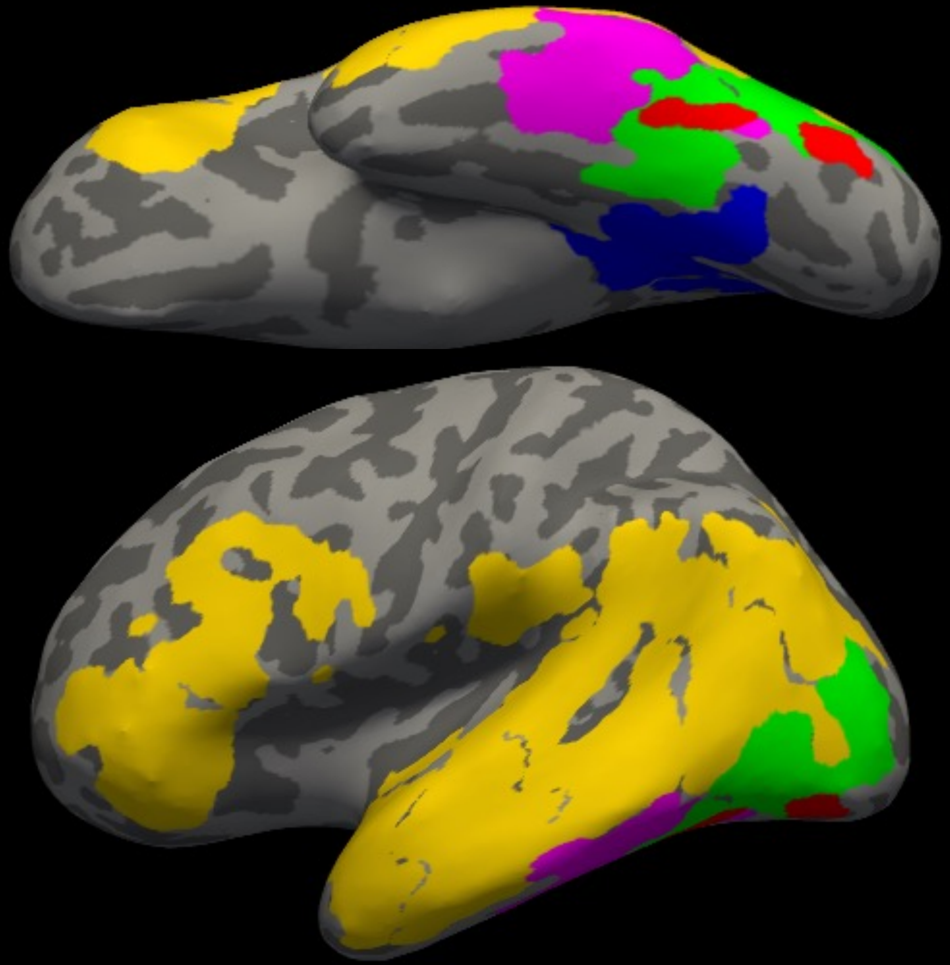


Rich organization of the human brain



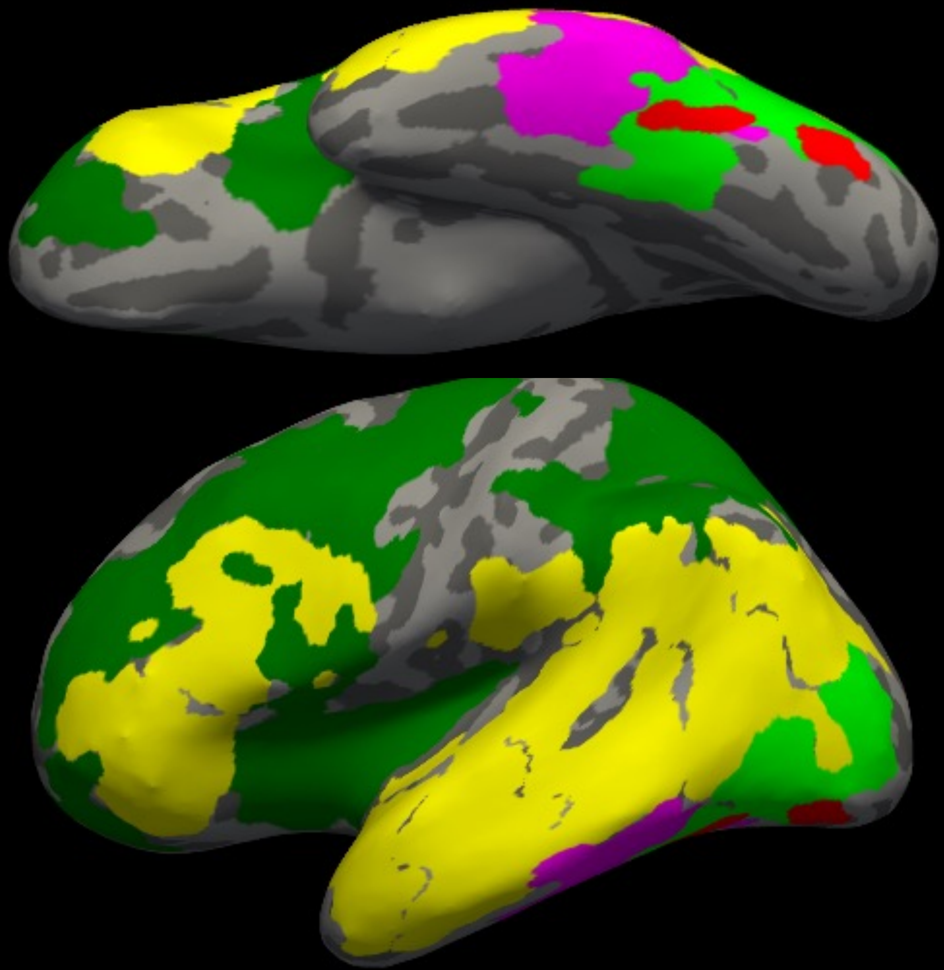
VWFA (reading)

Rich organization of the human brain



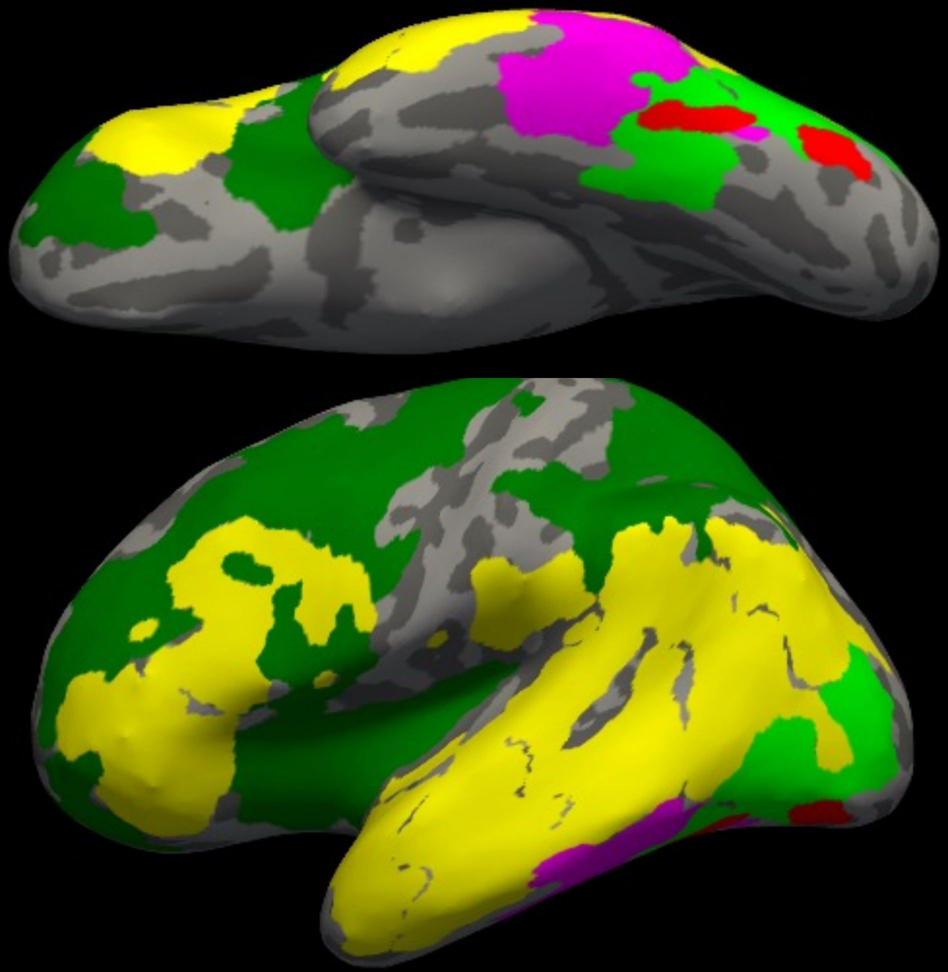
Language

Rich organization of the human brain



Domain-general
(Executive control)

Rich organization of the human brain



Does this organization already exist at birth?

Yes

- Some regions are functional from birth (evolutionary pressure)

- Other regions are predisposed for their function because of connectivity

Neuroimaging

Computational
Modeling

Predictions of
future outcome in
each child

Importance

Understanding how early anatomy influences later mental function is important because:

- Answers fundamental questions
  - How did I become the person I am today?
  - What makes me unique?
  - What makes me human?

Importance

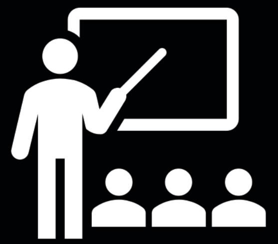
Understanding how early anatomy influences later mental function is important because:

- Answers fundamental questions
- Informs cognitive science more broadly (understanding the brain is understanding the mind)
  - Which neural mechanisms are online early?
  - Which mental representations are distinct?

Importance

Understanding how early anatomy influences later mental function is important because:

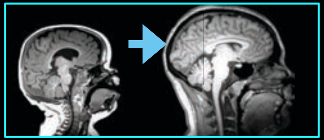
- Answers fundamental questions
- Informs cognitive science more broadly
- Informs education research
  - – Predicting our ability to learn new skills allows early practice, targeted teaching
- Has broad practical/clinical applications
  - – Predicting later behavior allows early diagnosis & intervention



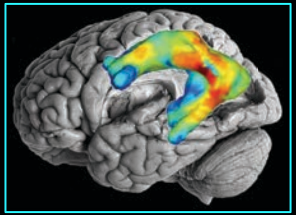
How does the architecture of the mind arise?

Infants

Children



Disorders

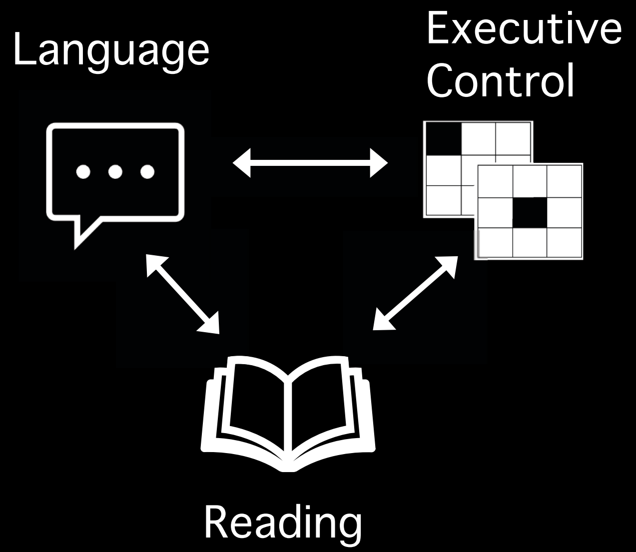


MRI (fMRI, DWI)
Cross-sectional & longitudinal
Behavioral assessments
Computational modeling

How does the architecture of the mind arise?

- Is neural machinery for language distinct from other thought in early childhood?

- How do new cultural inventions (written language) arise?
  - Can connectivity predict future location of the visual word form area (VWFA) in children & newborns?
  - Can connectivity predict future reading difficulty?



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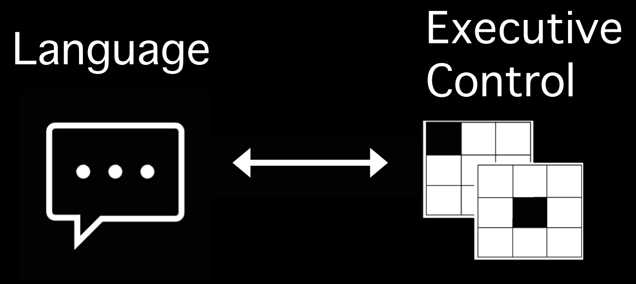
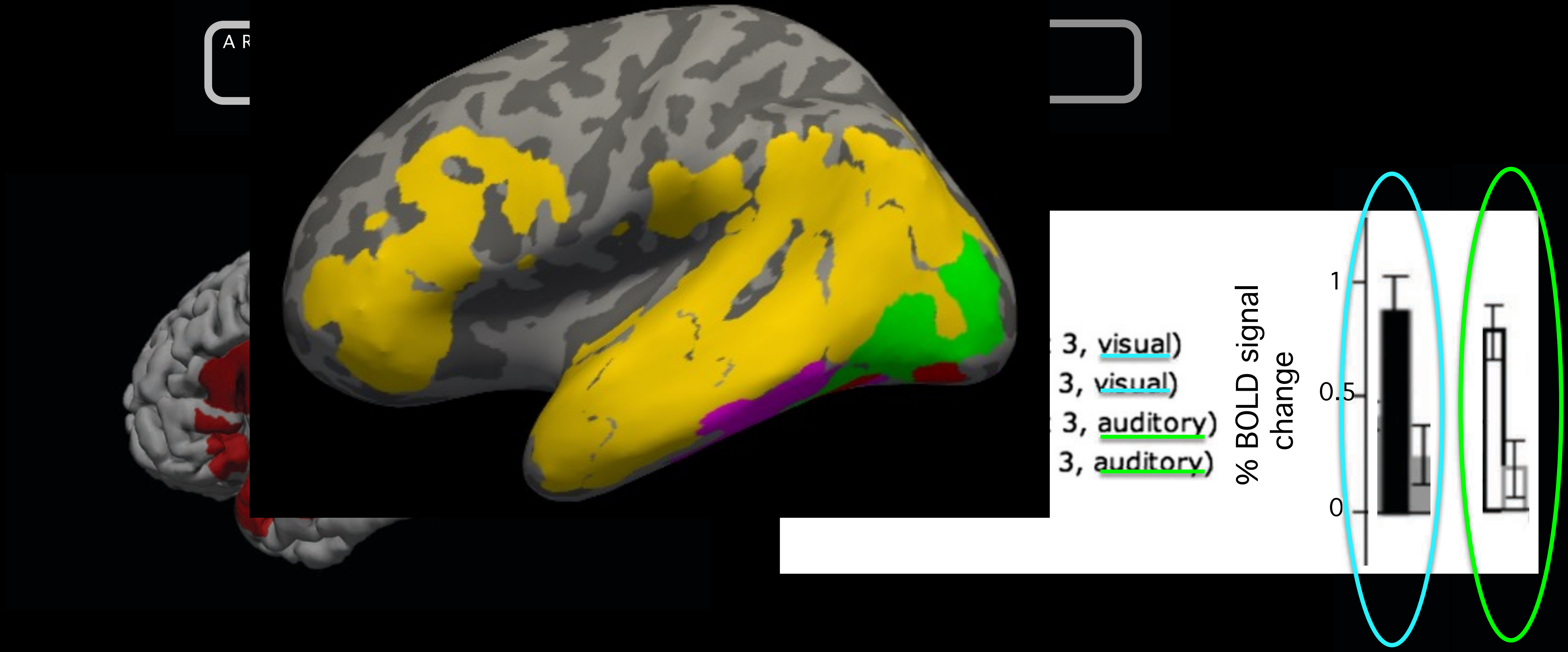


Regions for High-Level Language Processing

Brain regions that respond to language can be localized like this:

Contrast two conditions: **sentences** vs non-words



Fedorenko et al. (2010), J. Neurophys.

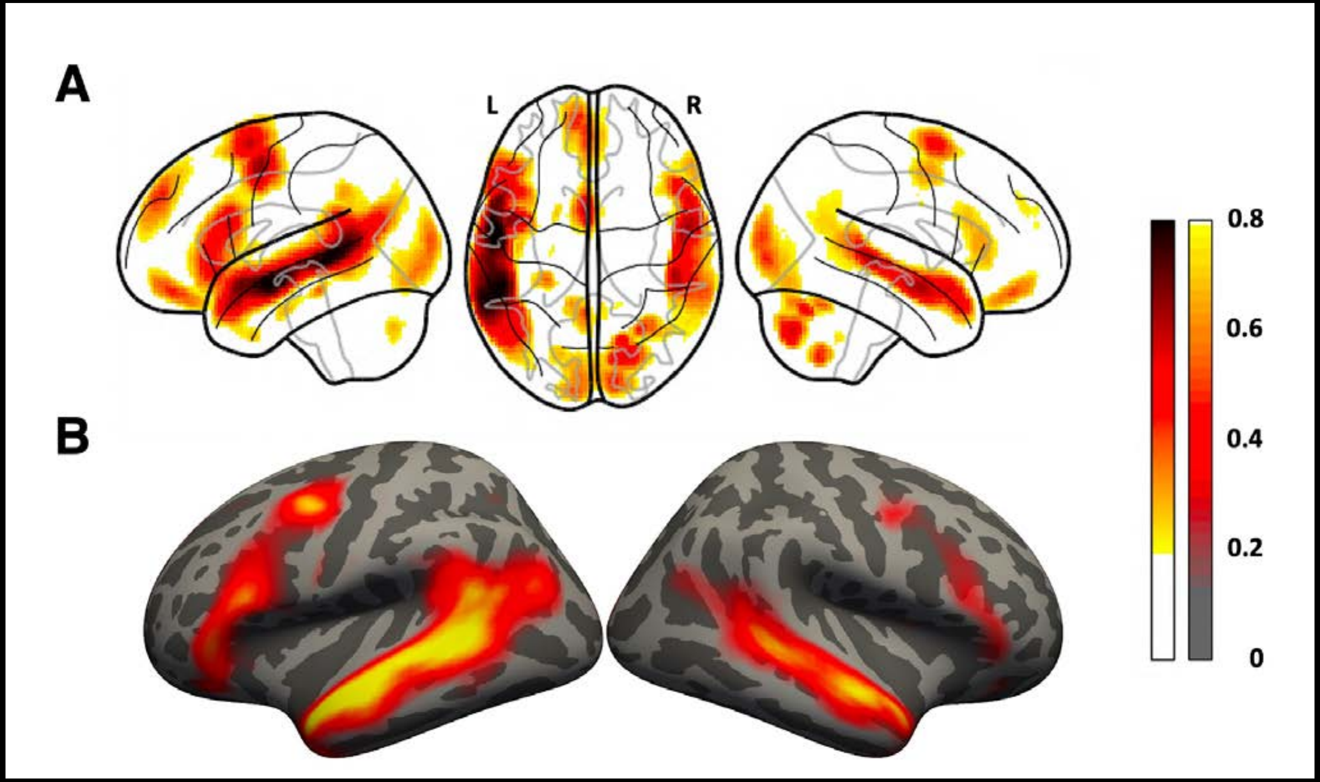
Regions for High-Level Language Processing

Brain regions that respond to language can be localized like this:

Contrast two conditions: **sentences** *vs.* non-words

A RUSTY LOCK WAS FOUND IN THE DRAWER

DAP DRELLO SMOP UB PLID KAV CRE REPLODE



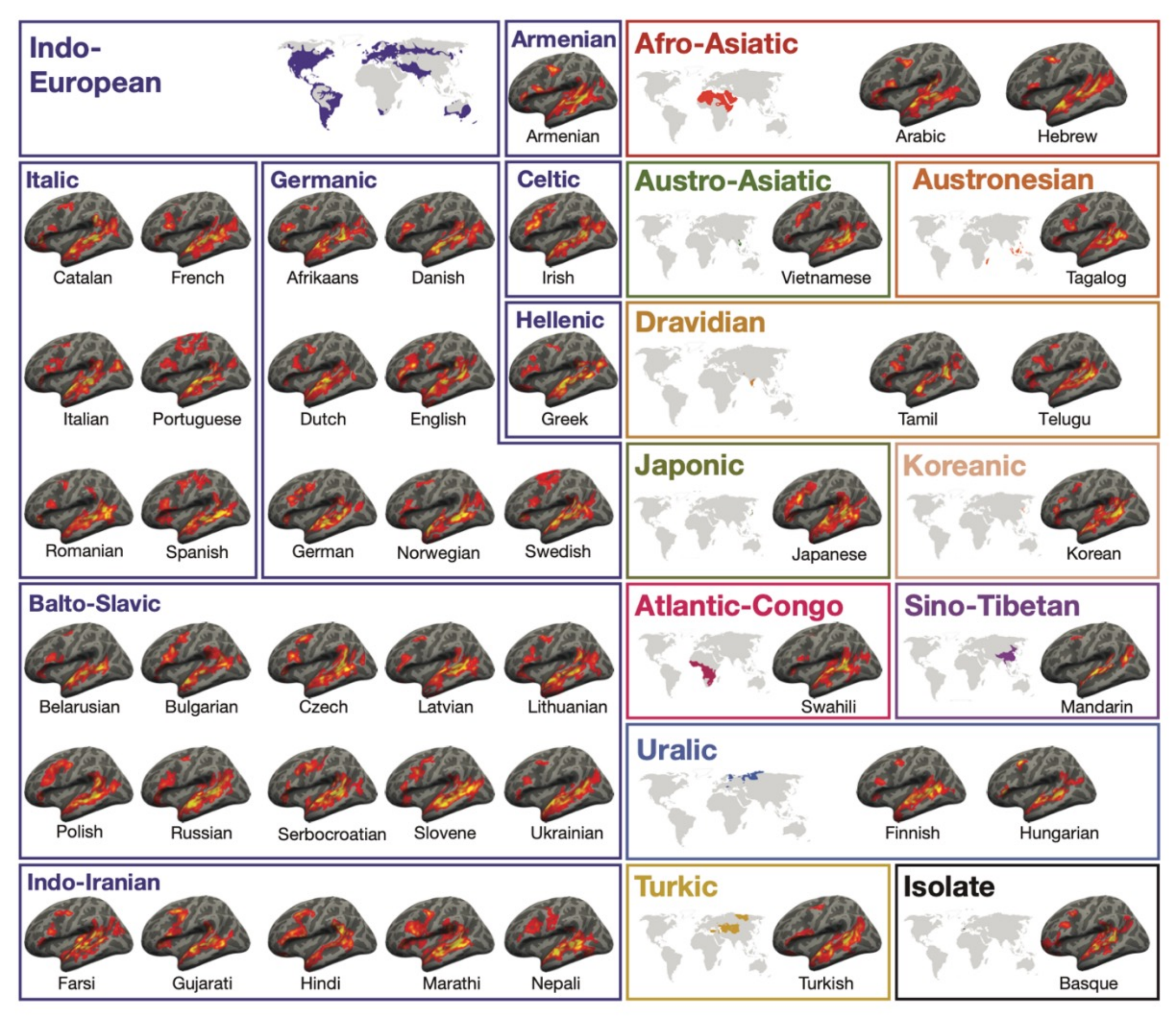
Atlas of >800 subjects

- See the same frontotemporal regions across experiments
- Left-lateralized
- Location is variable across subjects

Fedorenko et al. (2010), J. Neurophys.

Lipkin et al. 2022

Regions for High-Level Language Processing



- All languages seem to activate the same cortex
  - Even sign language
- Lateralized
- Doesn't matter if stimuli are presented visually/auditorily (amodal)
- *Support for pre-programmed neural basis of language*

Ayyash et al. 2021

When does language cortex develop and specialize?

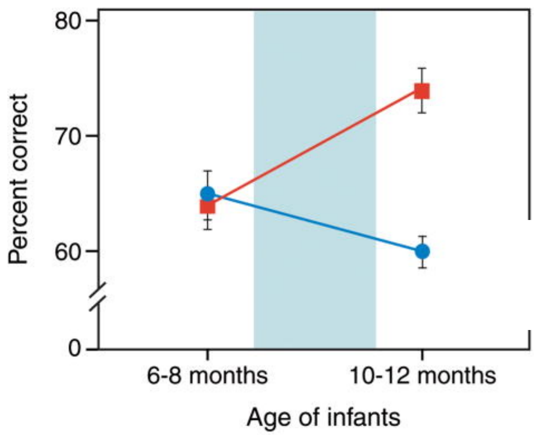
- Perceptual learning starts in utero:
  - By the third trimester, fetuses can hear
  - Newborns prefer mom's voice & language over others

- Initially, babies can distinguish among non-native phonemes e.g. babies in Japan can hear a /ra/ vs /la/ difference

- Between 6-12 months, infants TUNE to native language
  - KEEP sensitivity to their native phonemes
  - LOSE sensitivity to non-native phonemes

- Yet, language skills are underdeveloped even by age 5

/ra/ vs. /la/ performance



(*Kuhl 2011 Neuron*)

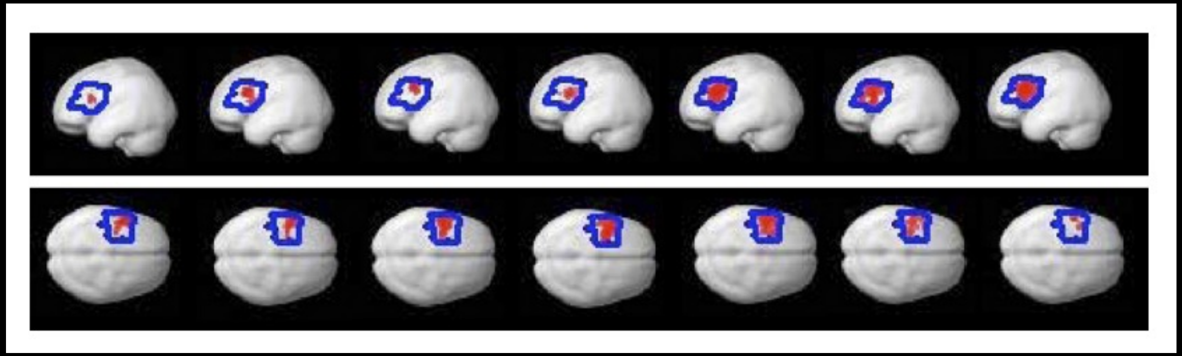
Do young children have specialized language cortices like adults?

Is language cortex already specialized in kids?

Kelly Hiersche

Passive language fMRI task in 2-9 year olds (34 kids, 14 longitudinal)

- Listen to spoken <u>sentences</u> vs. <u>nonword sentences</u> (control)

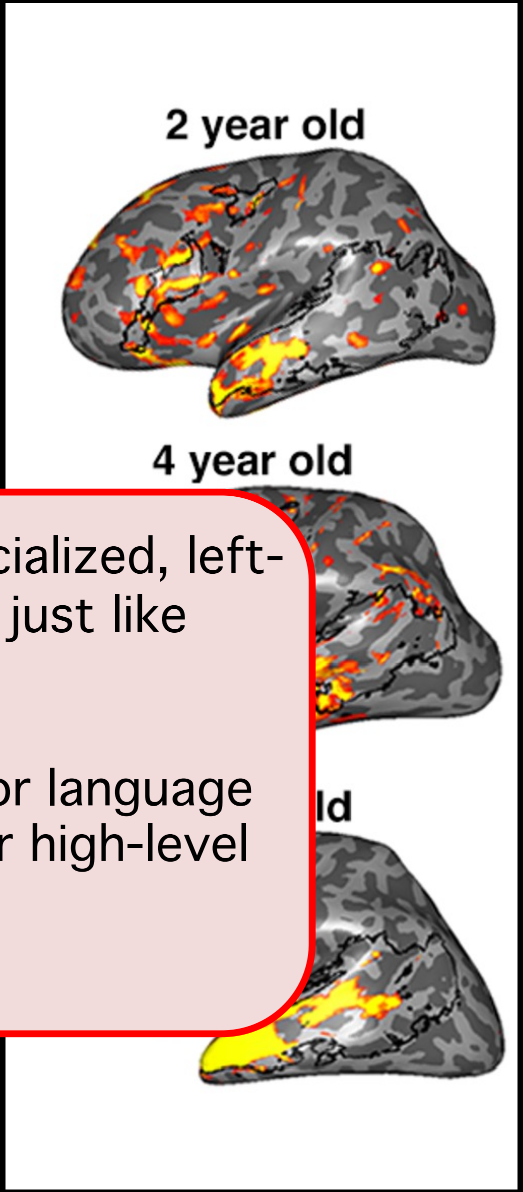


Fedorenko et al. (2010), J. Neurophys

- Capturing individual variability: use precision fMRI to define each child's network based on how their own brain responds

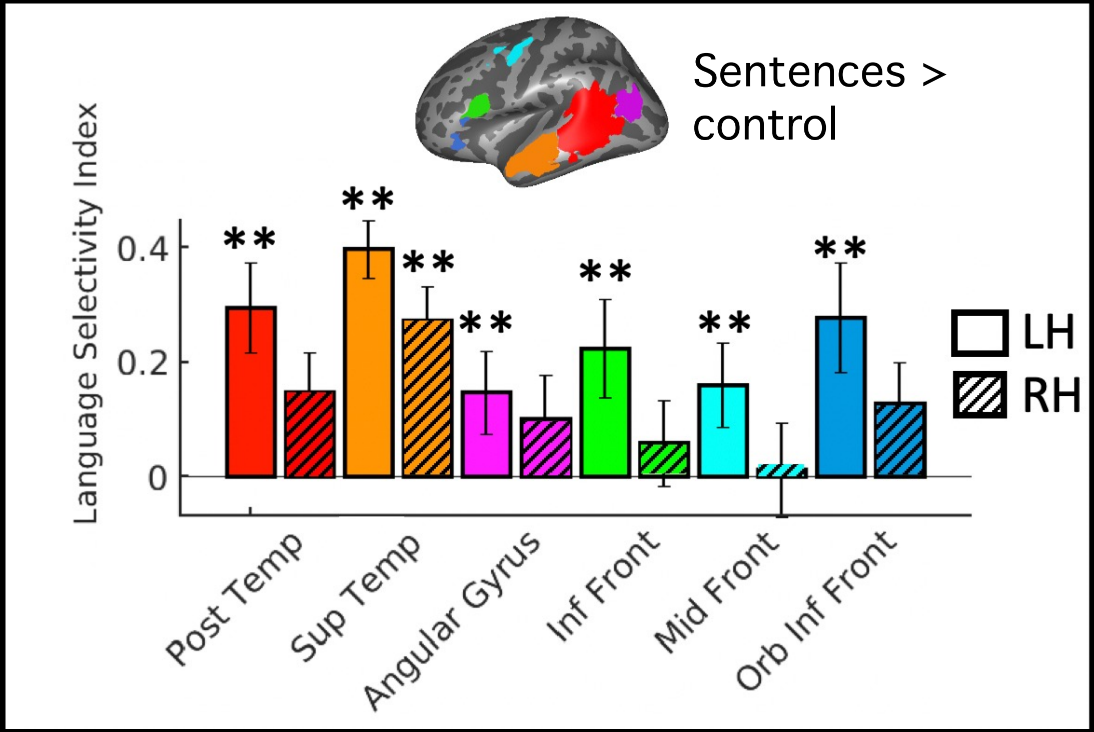
Is language cortex already specialized in kids?

Kelly Hiersche



By age 2, children have specialized, left-lateralized language regions just like adults.

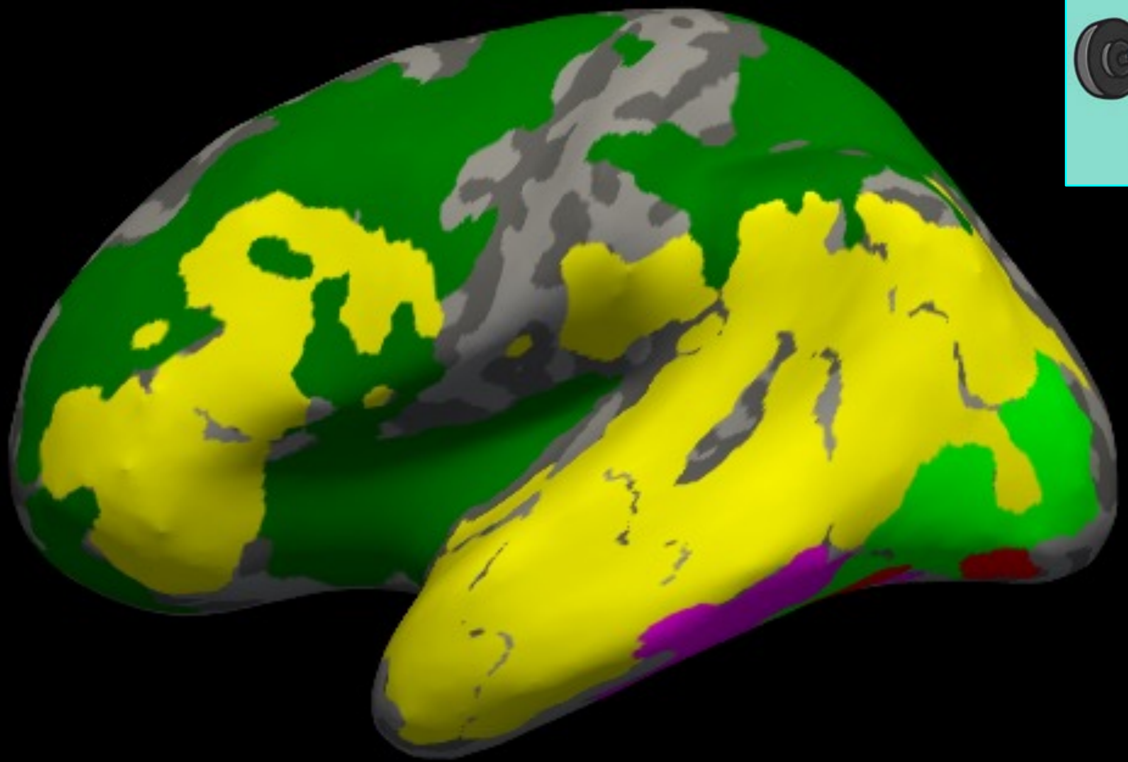
Are these regions *specific* for language or are they engaged in other high-level processing as well?

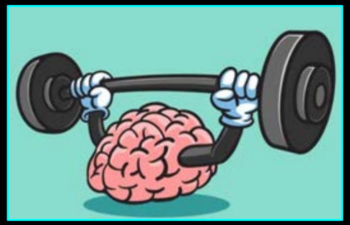


Hiersche et al. (in review)

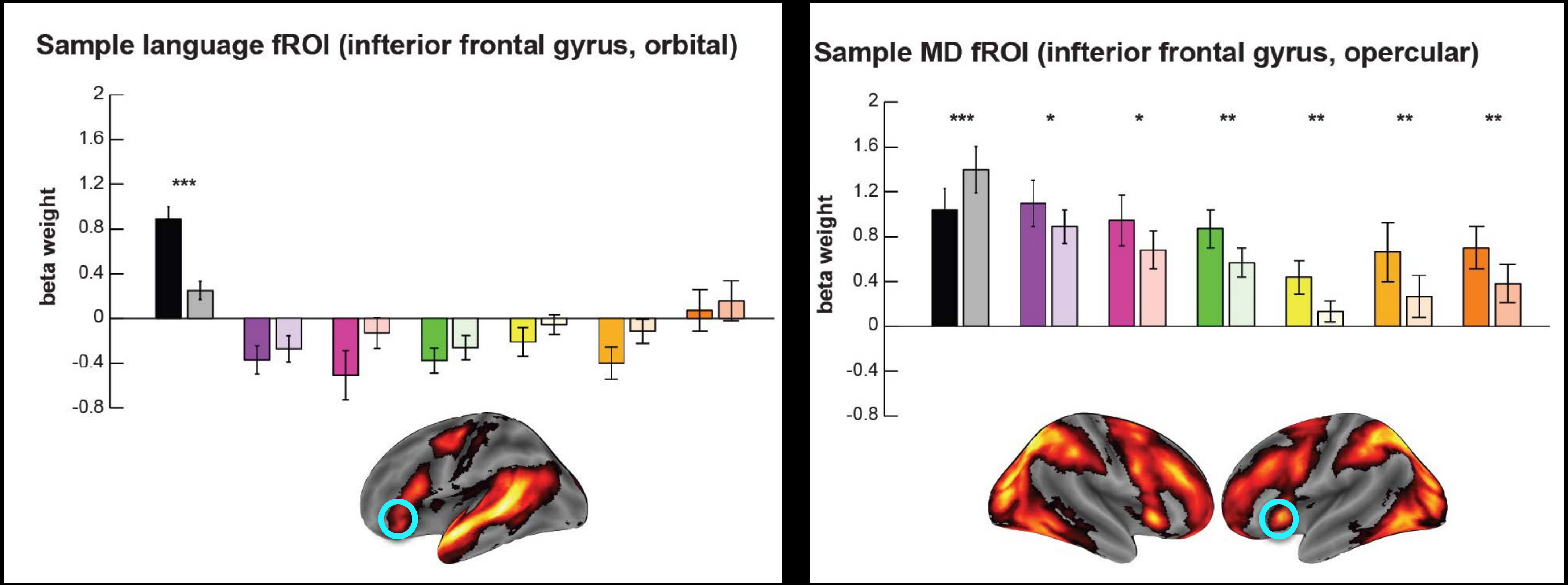
Executive control

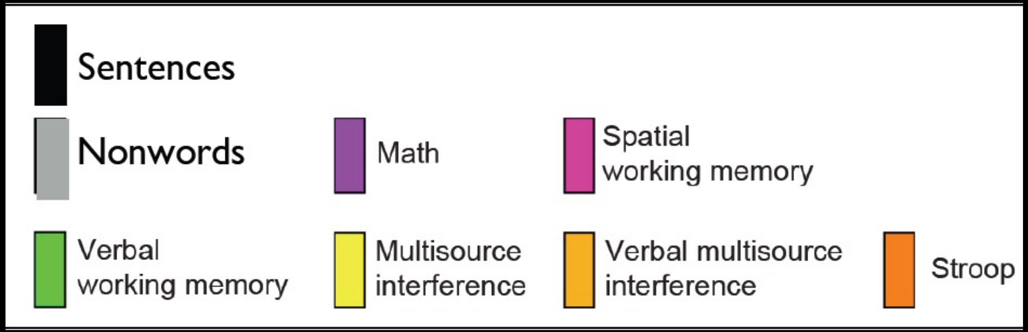
- Discovery that many abilities positively correlate
- Perhaps a general factor (g) or fluid intelligence contributes to success on any task
  - Central executive (or executive control)
    - Involves working memory, cognitive shifting, inhibitory control





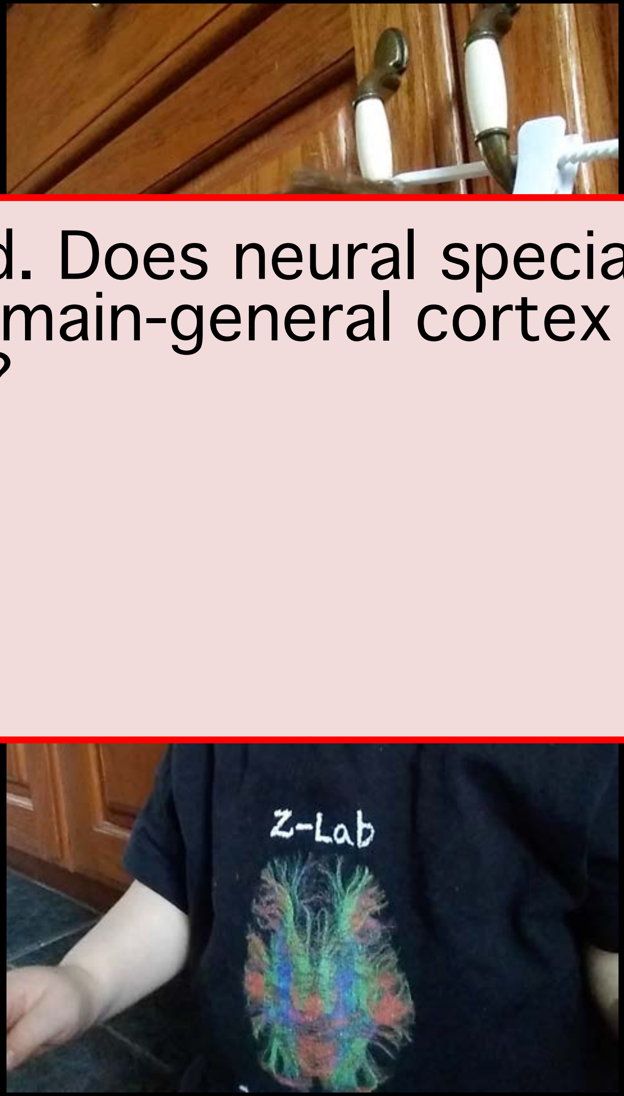
Language cortex is distinct from MD cortex in adults





Fedorenko et al. 2011, 2013 PNAS;
Fedorenko et al. 2012 Curr Biol;
review: Fedorenko & Blank 2020 TiCS

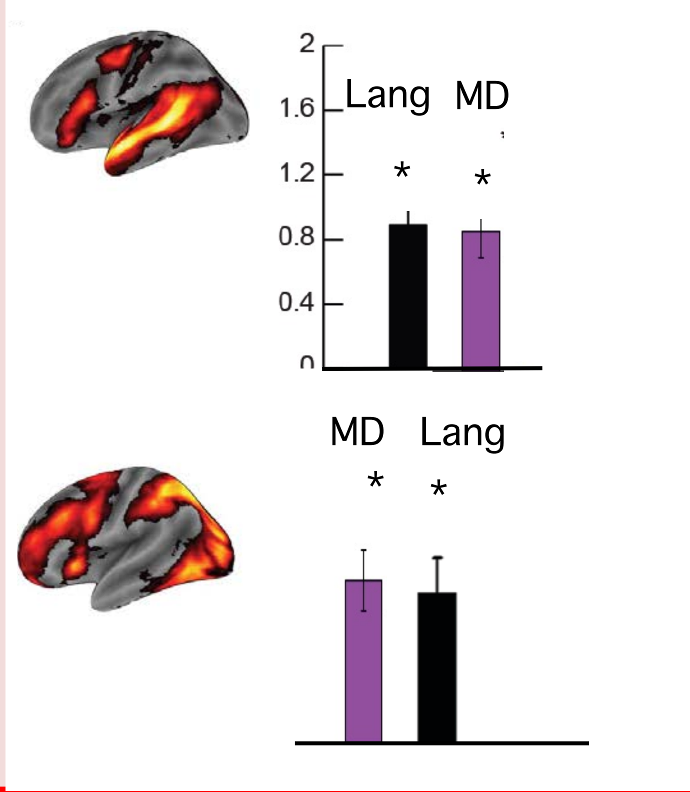
Is neural machinery for language distinct from other thought in early childhood?



- Language is hard. Does neural specialization for language develop from domain-general cortex that facilitates general learning?

Is neural machinery for language distinct from other thought in early childhood?

- Does neural specialization for language develop from domain-general cortex?

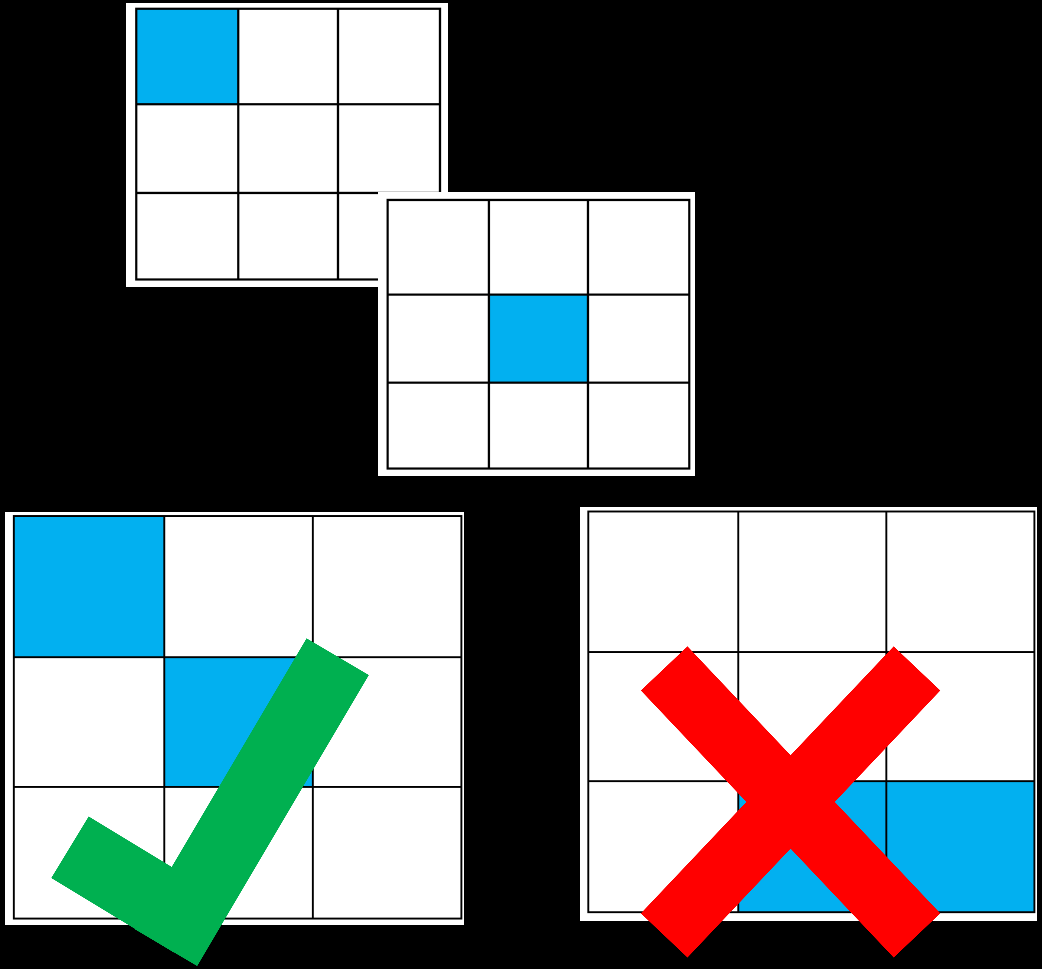


MD task in children

Spatial working memory task

Hard vs. Easy condition

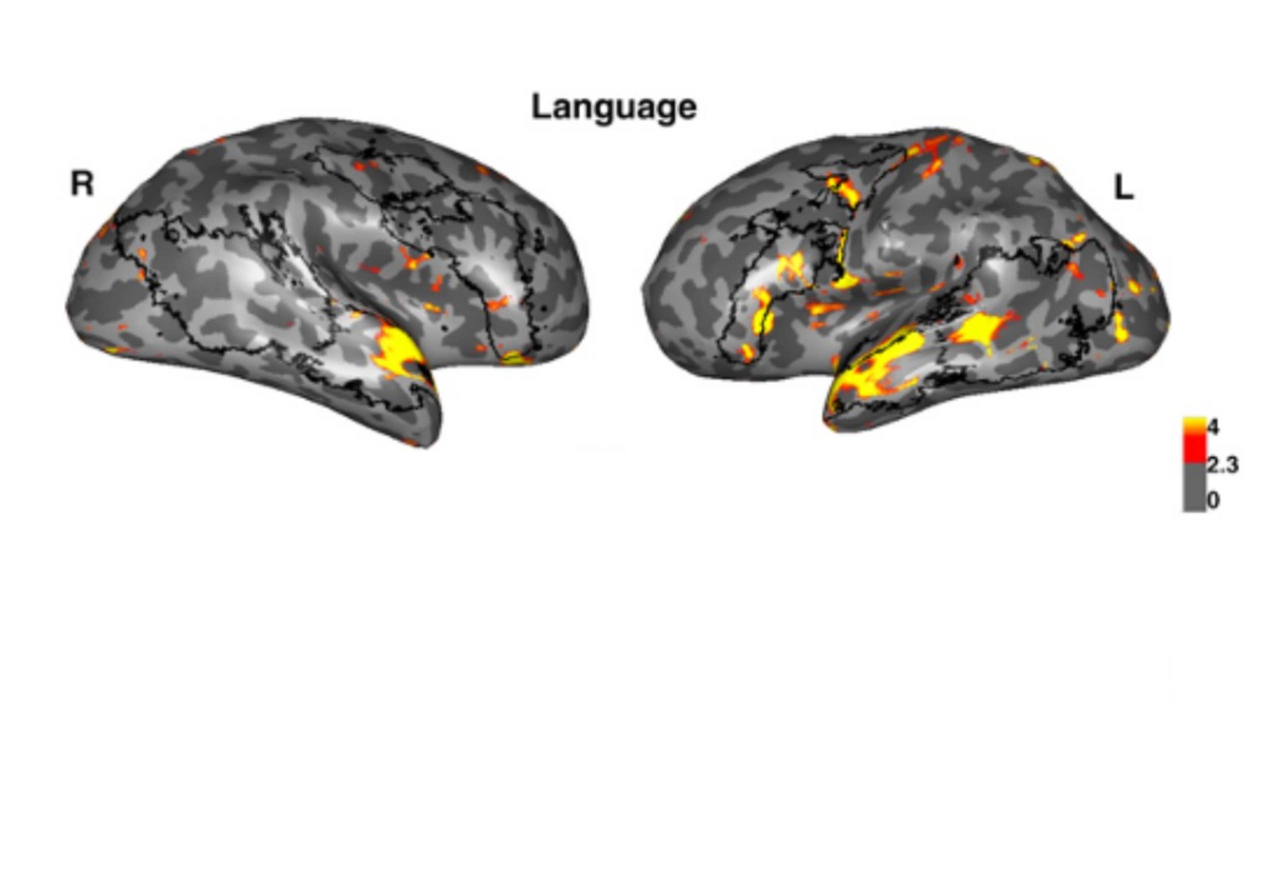
- 2 squares lit up at a time vs 1square



Kelly Hiersche

Elana Schettini

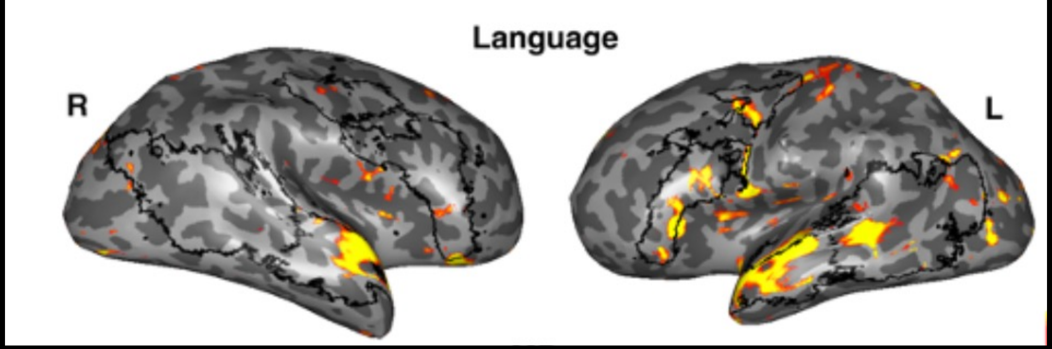
Is neural machinery for language distinct from other thought in early childhood?



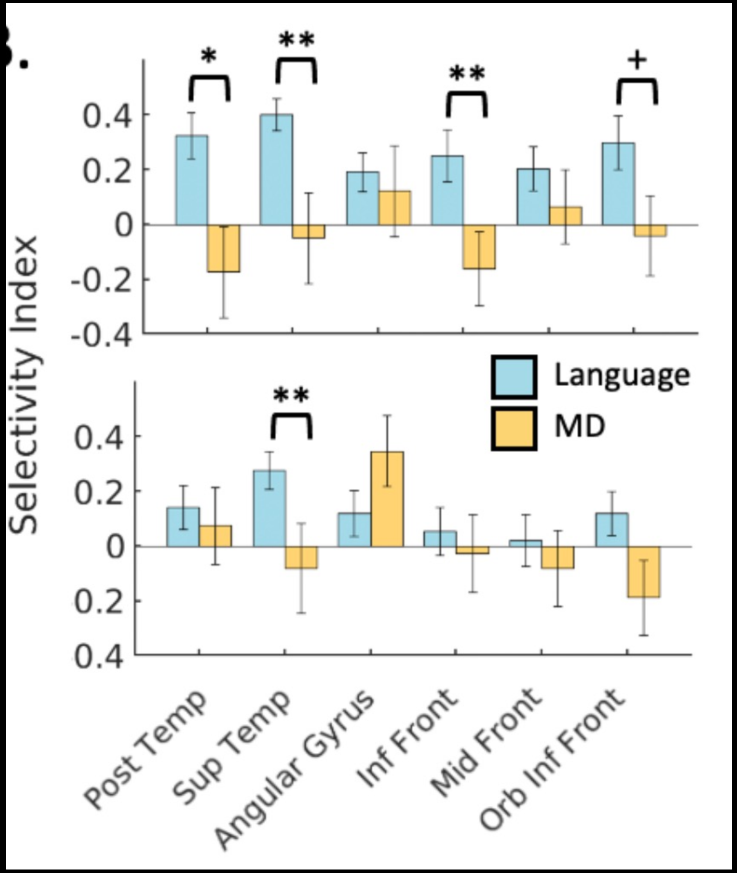
Hiersche et al. e-Life (in review)

Is neural machinery for language distinct from other thought in early childhood?

Do language regions respond to MD?



Language regions do not respond to MD



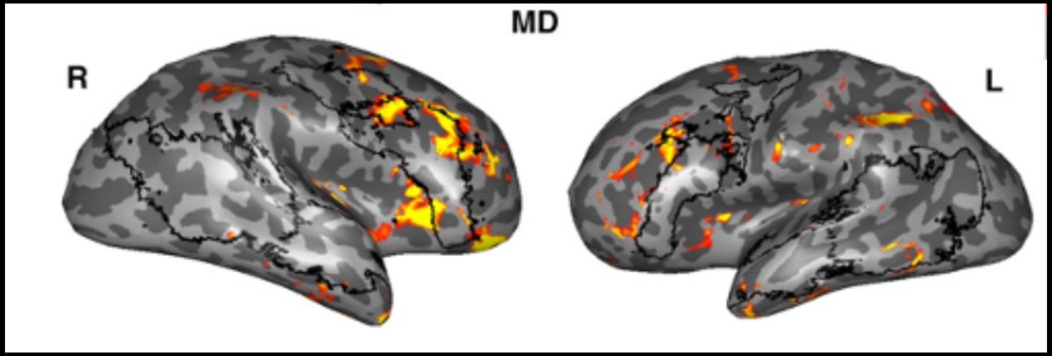
Left

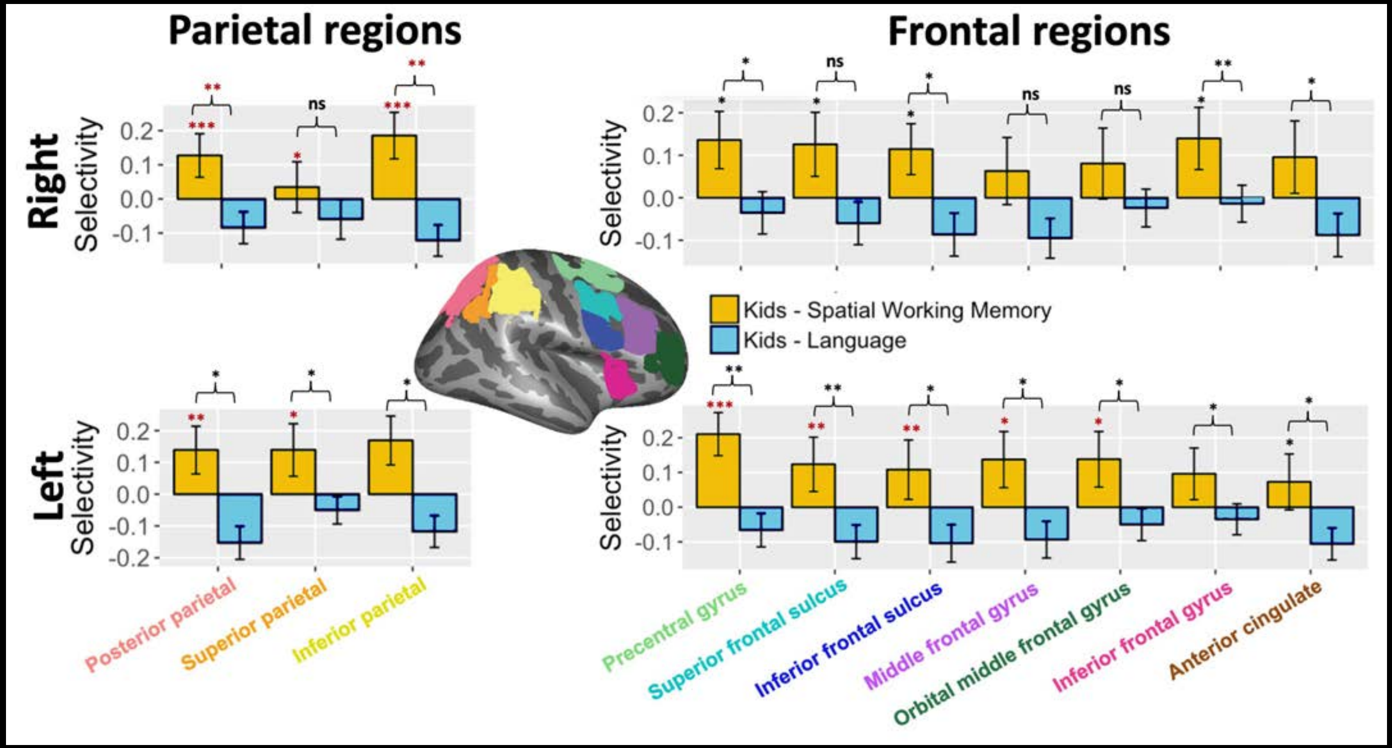
Right

Hiersche et al.(in review)

Is neural machinery for language distinct from other thought in early childhood?

Do MD regions respond to language?





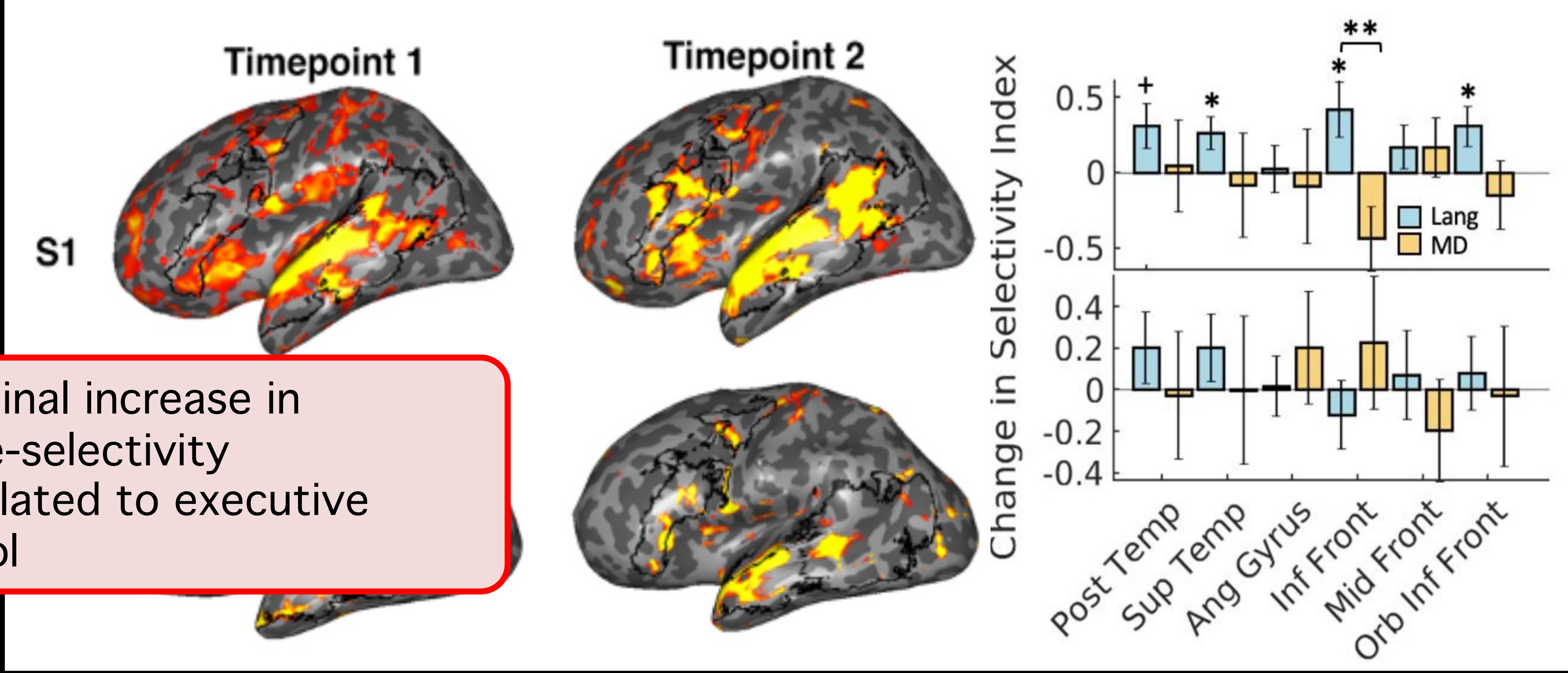
MD regions do not respond to language

Schettini et al. (in review)

Is neural machinery for language distinct from other thought in early childhood?

Kelly Hiersche

Longitudinal data



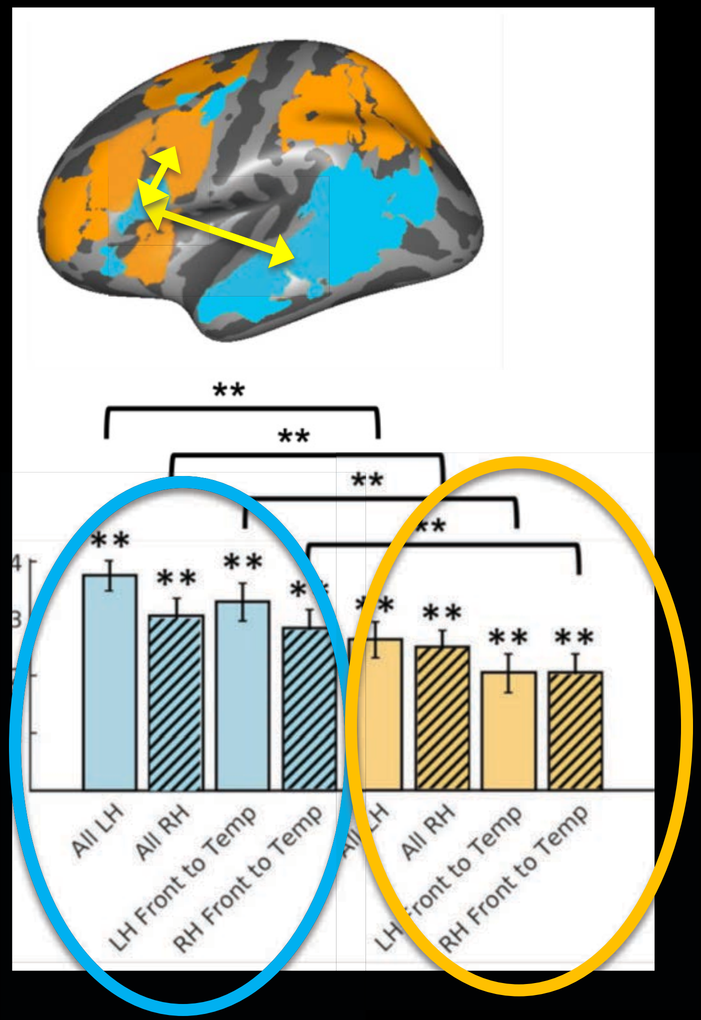
Longitudinal increase in language-selectivity

- not related to executive control

Hiersche et al. (in review)

Is neural machinery for language distinct from other thought in early childhood?

Connections of language regions to other language regions



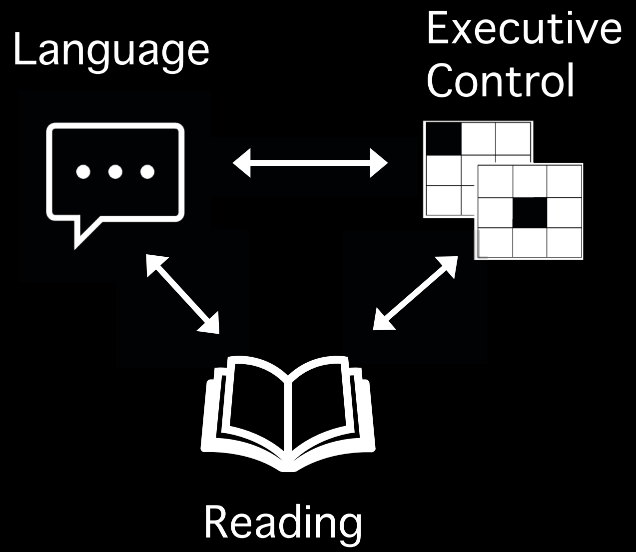
Connections of language regions to MD regions

Language and MD networks communicate with themselves not with each other

Hiersche et al. (in review)

How does the architecture of the mind arise?

- Is neural machinery for language distinct from other thought in early childhood?
  - Language cortex is online and SPECIFICALLY tuned for linguistic content very early on in life
  - Mechanisms that help boost cognitive control as children get older are independent of “domain-specific” language cortex



How does the architecture of the mind arise?

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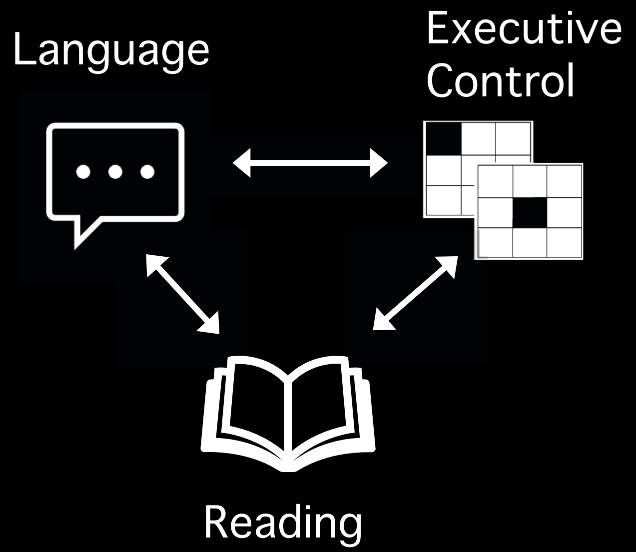
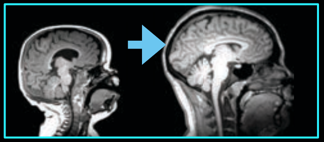
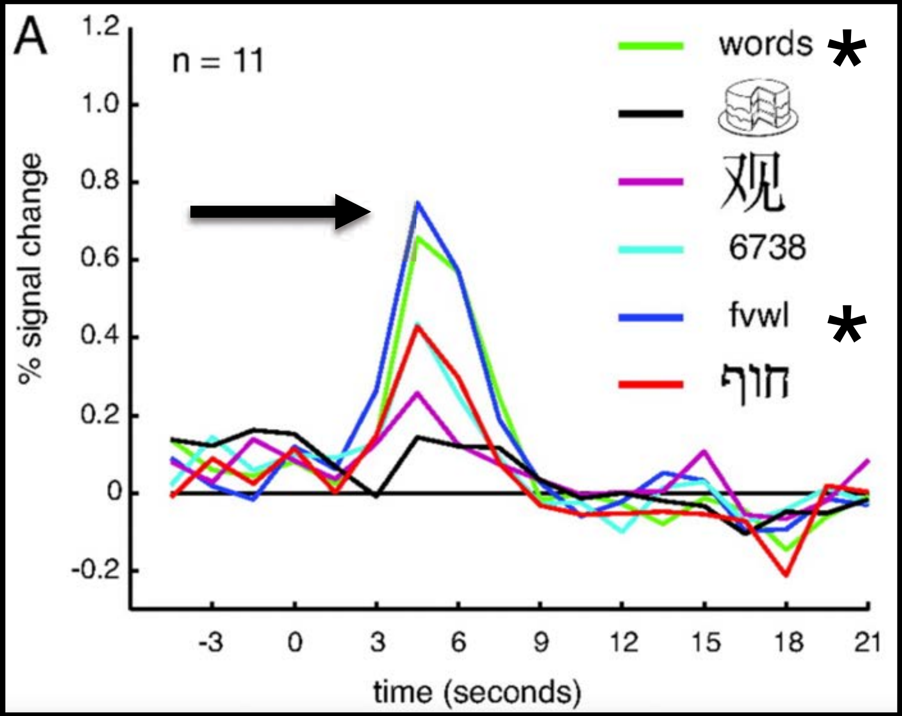


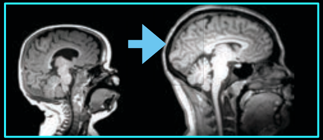
Visual word form area (VWFA)

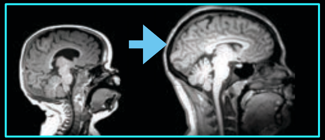
- Dedicated brain region for orthography
- Roughly same location in every individual





Baker et al. 2007



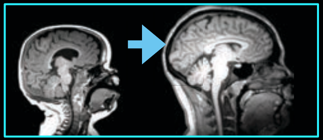
Visual word form area (VWFA)

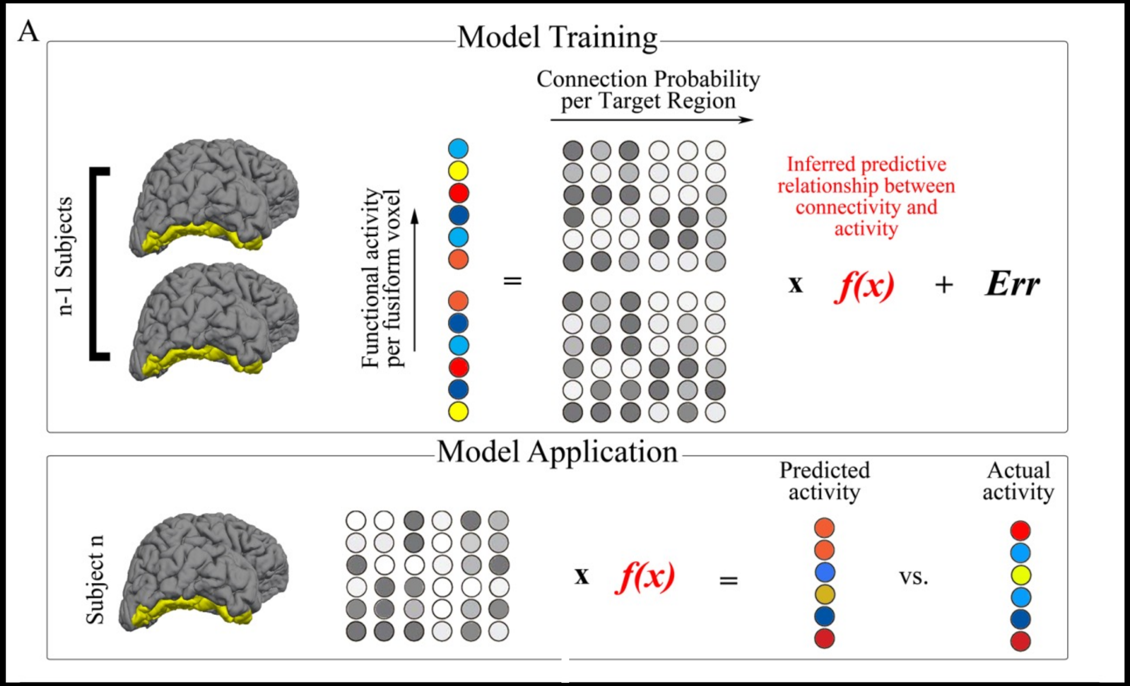
- – Dedicated brain region for orthography
- – Roughly same location in every individual
- – Reading is a recent cultural invention (~3000 BC)
- – Neural specialization could not have arisen through natural selection

- Why does it show up there?
  - – Specialized connectivity patterns may determine the location of functionally-selective brain areas
    - VWFA offers a great test of this hypothesis because it does not exist before reading acquisition

  - – Connectivity before & after reading acquisition

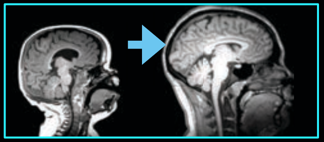
Can early connectivity predict later location of the visual word form area (VWFA) in children?

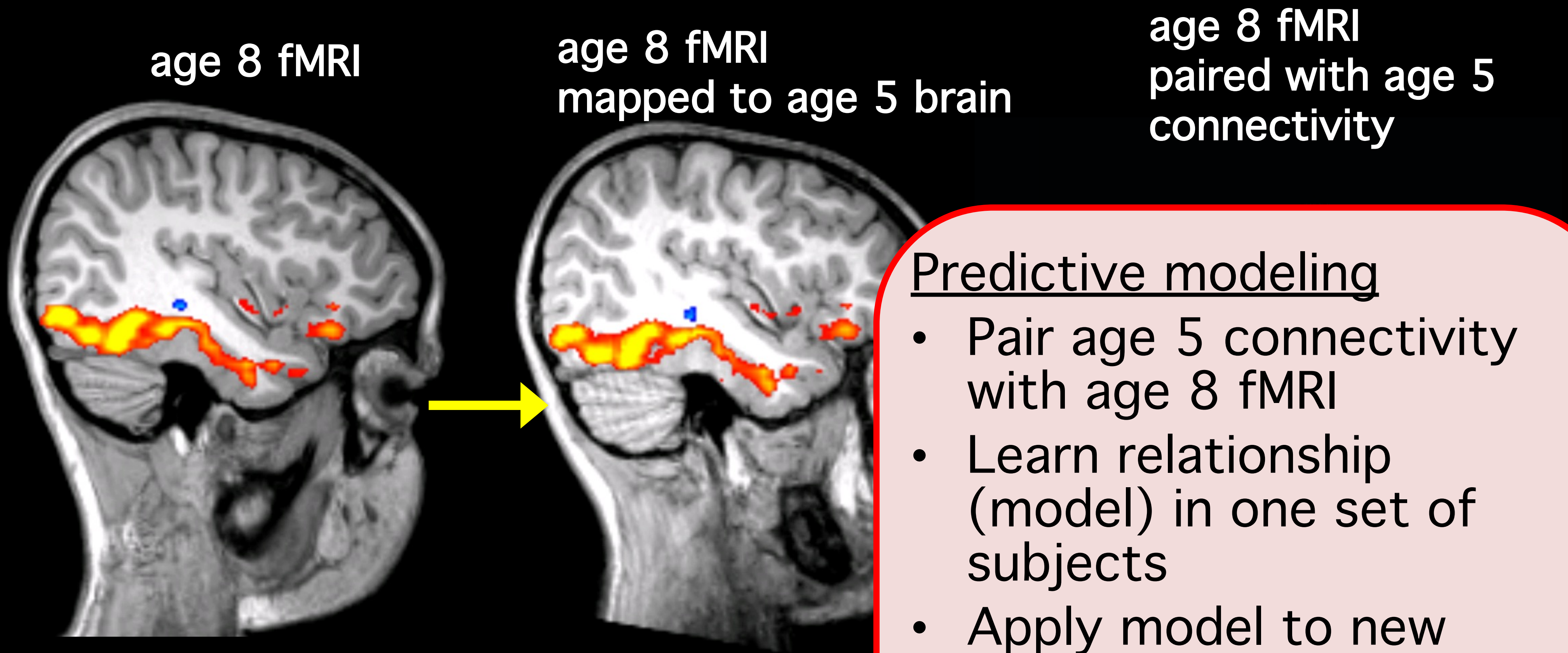




Saygin, Osher et al. 2011 Nature Neurosci; Osher et al. 2015 Cerebral Cortex

Can early connectivity predict later location of the visual word form area (VWFA) in children?

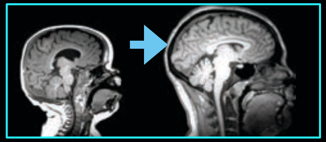




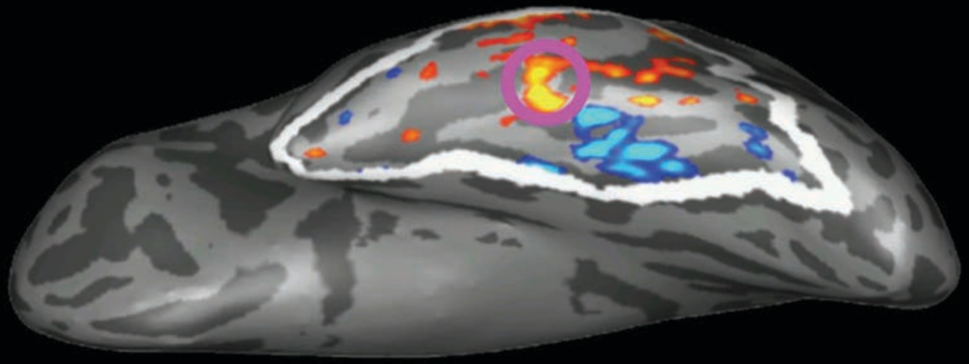
<u>Predictive modeling</u>

- Pair age 5 connectivity with age 8 fMRI
- Learn relationship (model) in one set of subjects
- Apply model to new subject's age 5 connectivity to predict their age 8 word-selectivity

. 2016
urosci

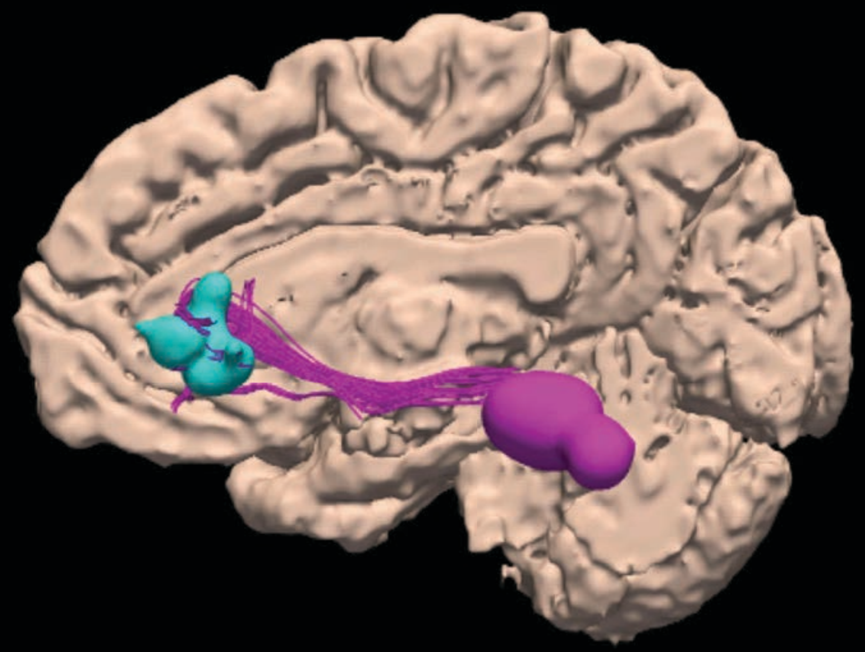


Actual reading area



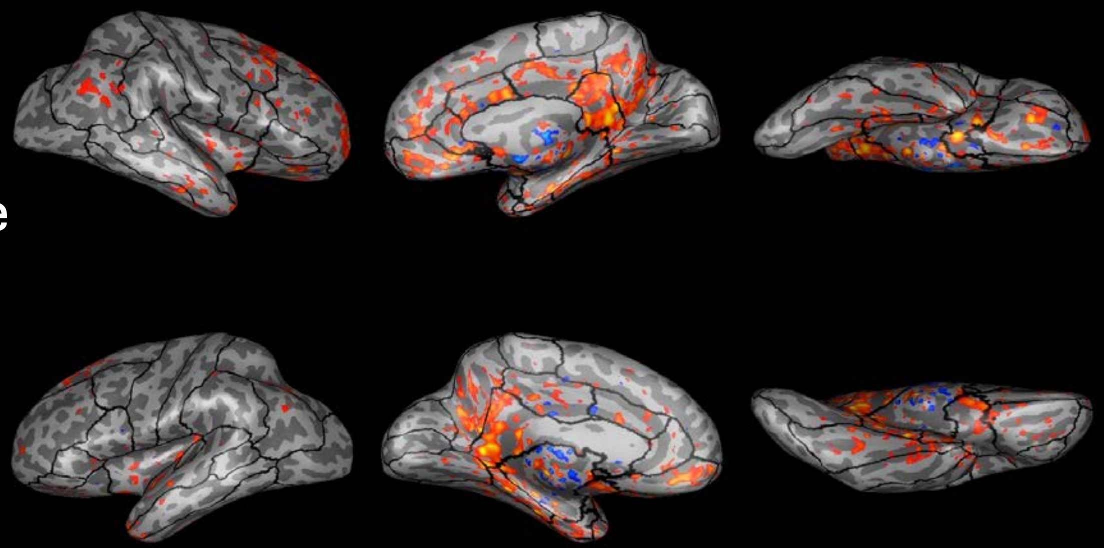
We can use a brain scan at an early age to predict where in the brain of each individual child a reading area will later show up.

Saygin et al. 2016
Nature Neurosci

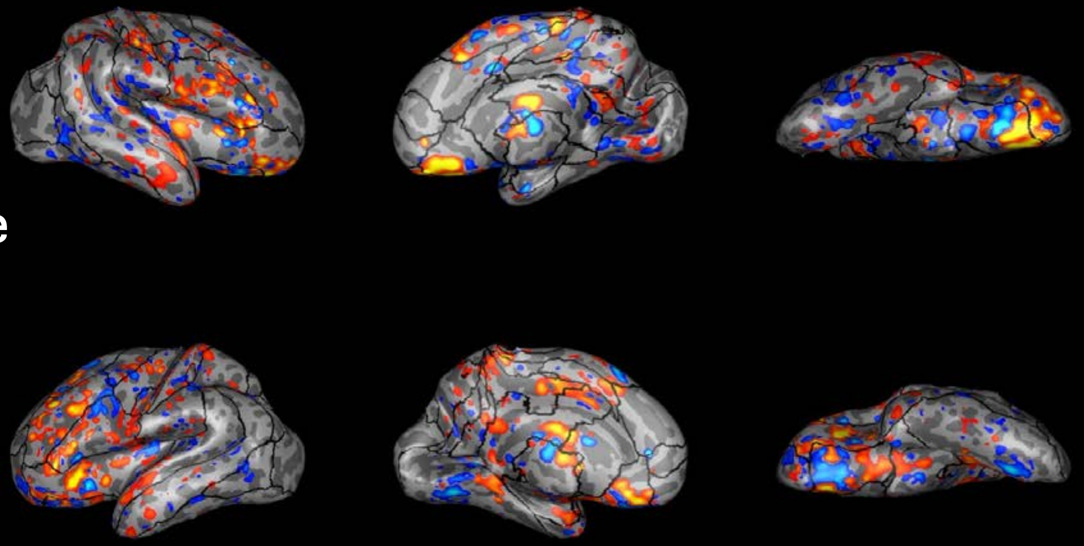


Is this connectivity pattern innate?

Resting state connectivity
Adults

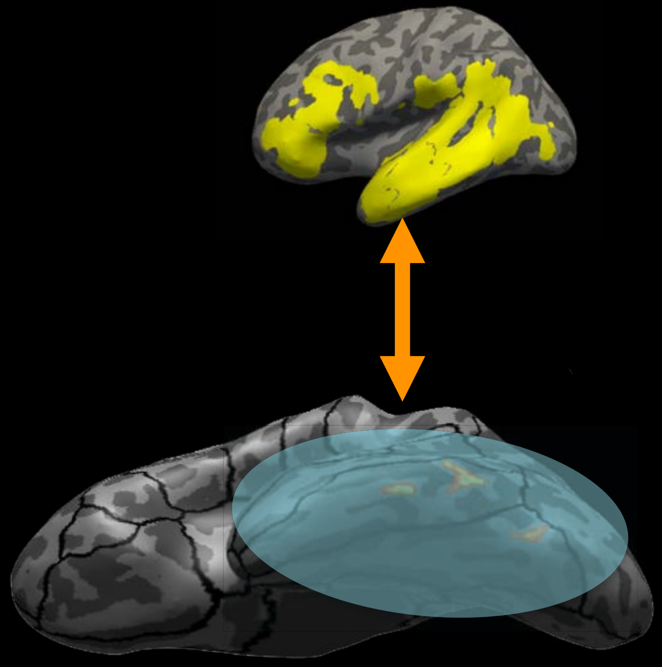


Resting state connectivity
Neonates

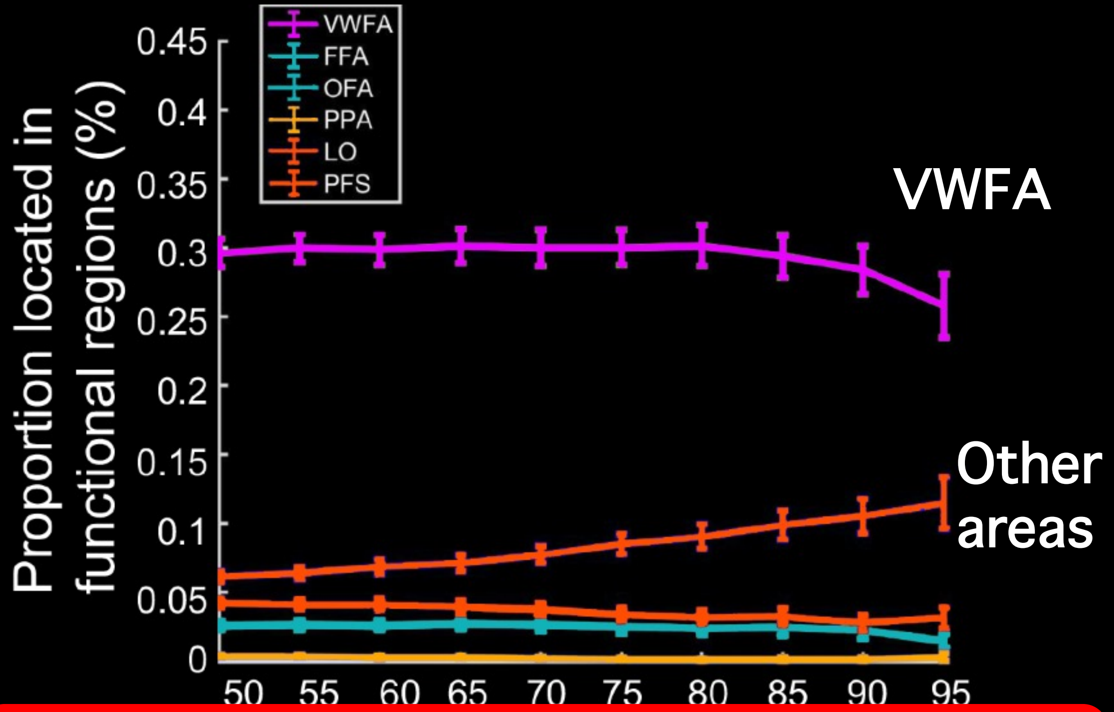


Jin Li

Is this connectivity pattern innate?



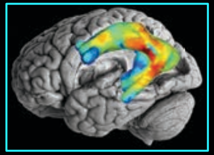
Jin Li



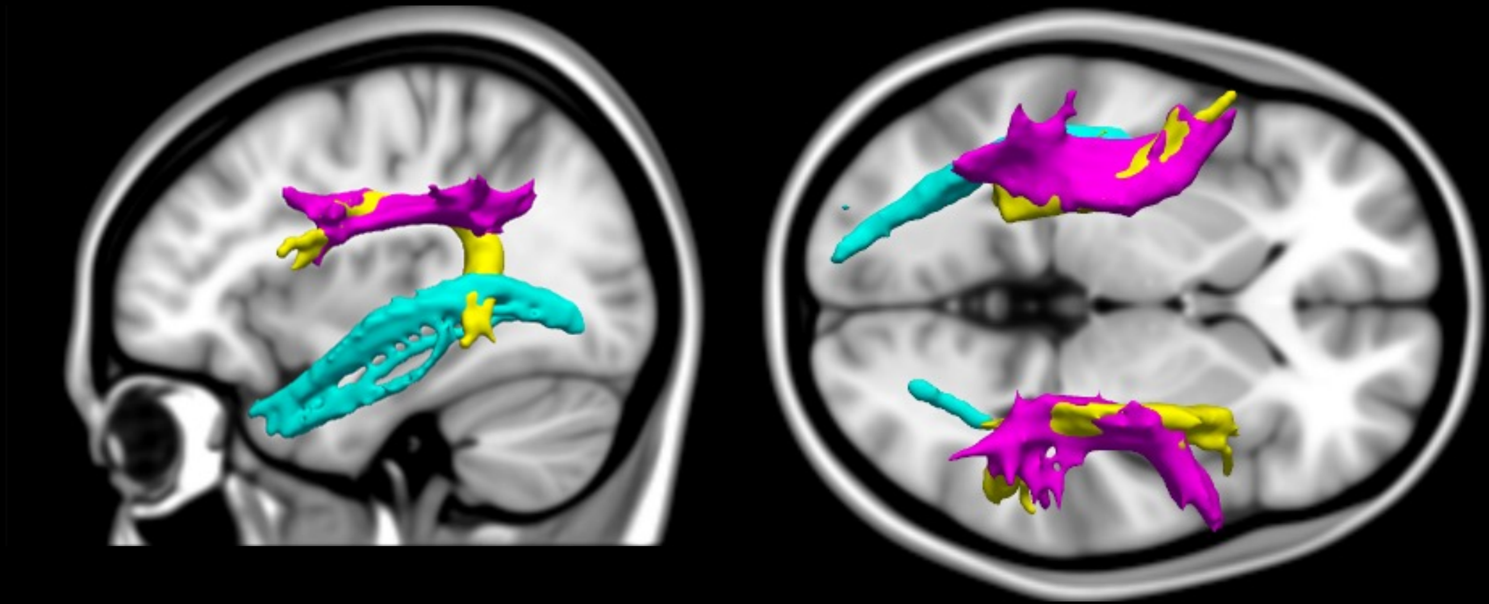
VWFA connectivity is largely innate

Li et al. Scientific Reports 2020

Predictions of dyslexia

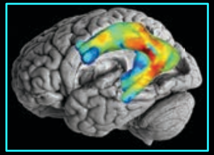


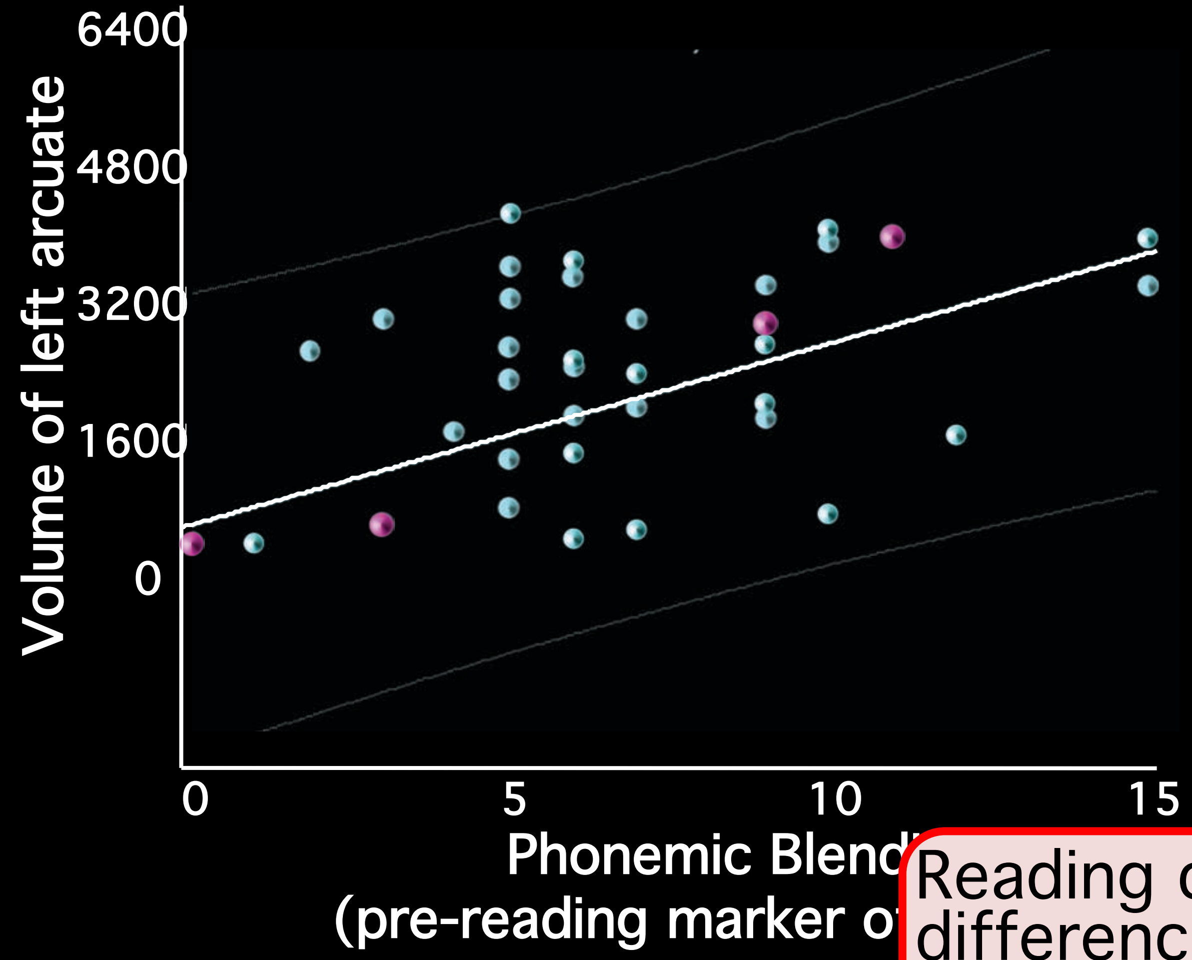
- Certain circuitry is different in older children & adults with dyslexia

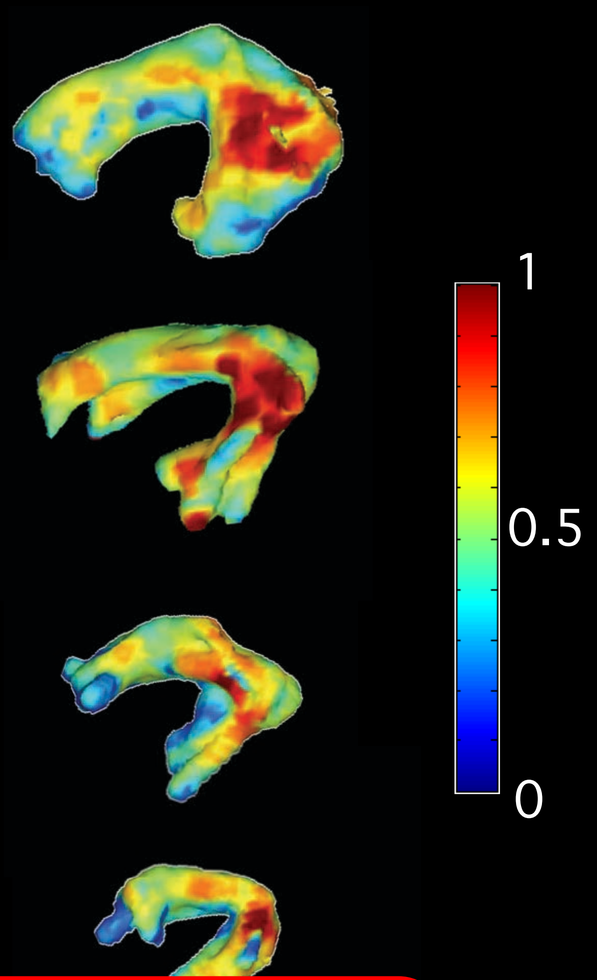


- Cause or consequence of dyslexia?

Predictions of dyslexia







Reading circuitry differences exist even in pre-readers

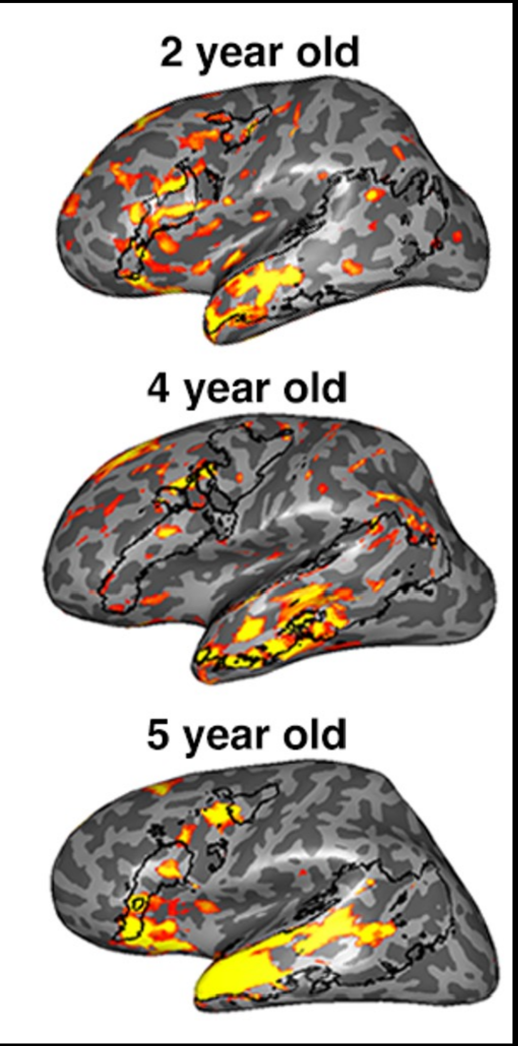
J. Neuroscience, 2013

How does the architecture of the mind arise?

Connectivity drives & predicts development of new skills

Domain-specific cortex develops early

- Language
  - develops early
  - specific for domain of language not other thought



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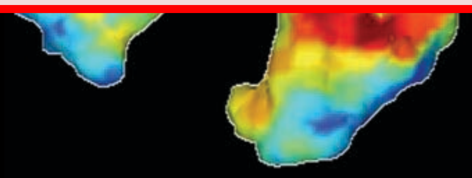
  - Language-visual connectivity predicts dyslexia

Connectivity as a neural marker for typical & atypical development



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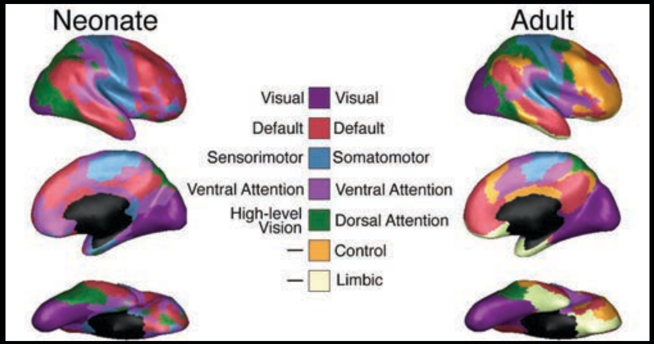
  - Language-visual connectivity predicts dyslexia (neural marker)

Experience and maturation shape connectivity and neural organization

Domain-general cortex develops later

- Executive function
  - supported by distinct, domain-general cortex
  - prolonged development
  - most variable and least mature network at birth

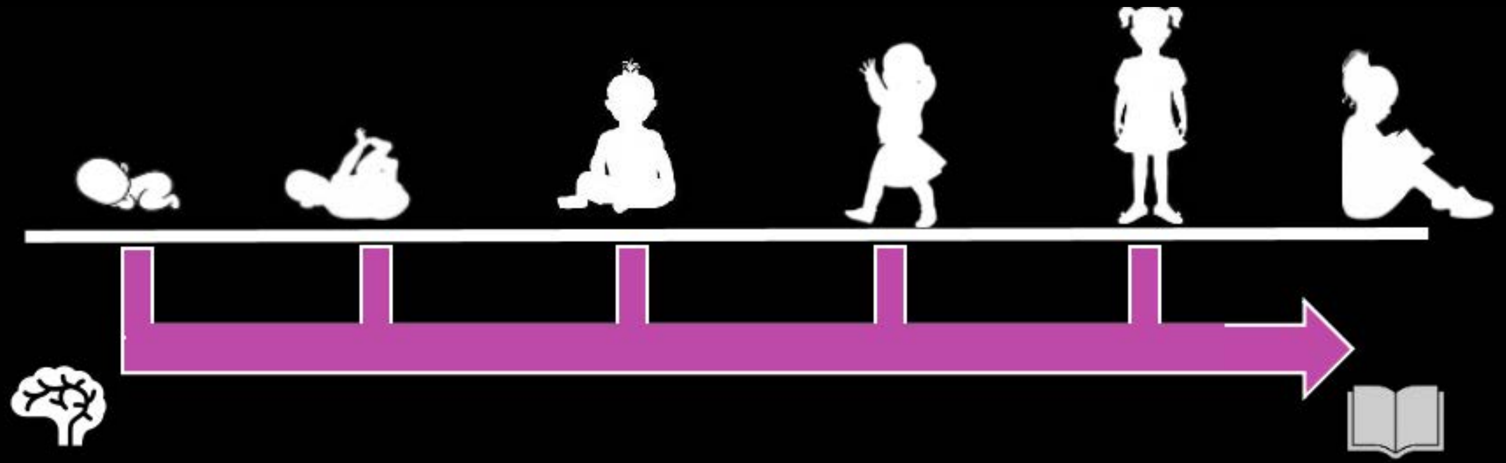


Molloy & Saygin NeuroImage 2022

Current & future directions

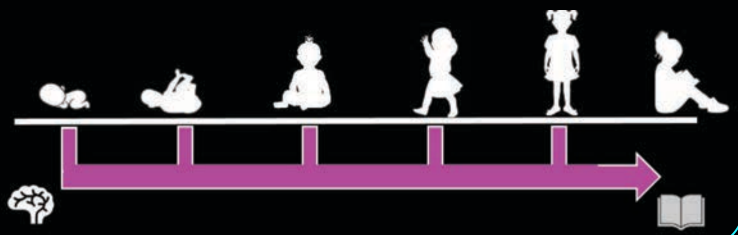
Predict future skill-learning (reading, math, executive control, academic readiness)

- Early neural markers of later developing skills & individual variability therein



Current & future directions

Predict future behavior with early neural markers

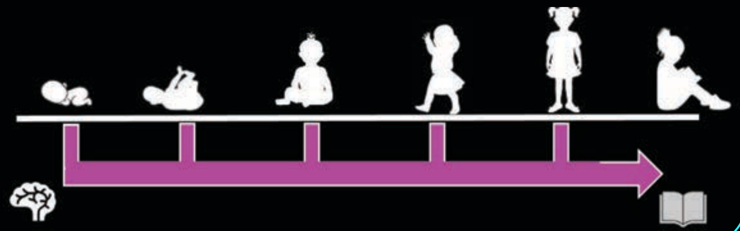


Characterize pre-verbal & pre-literate brain structure & function

- By knowing what these regions 'like', we can develop curriculums to bolster their development

Current & future directions

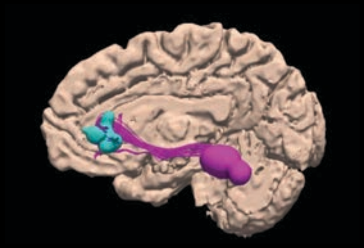
Predict future behavior with early neural markers



Characterize pre-verbal & pre-literate brain structure & function

Plasticity due to intervention or injury

- How does pre-school intervention strengthen connectivity & selectivity of these regions?



- How does pediatric neurotrauma impact typical development? Targeted treatments?

Thanks!

Analyses were completed using the Ohio Supercomputer

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