Brain maturation related to executive function from infancy to late childhood

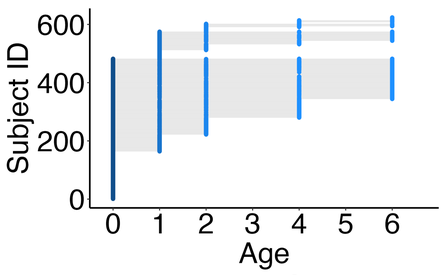
Yuyao Zhao[a], Rebecca L. Stephens[b], Martin Styner[b], John H. Gilmore[b], Jessica R. Cohen[a]

a. Department of Psychology and Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina; b. Department of Psychiatry, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina

Background

- The brain undergoes massive changes from infancy to childhood.
- Although the structural organization becomes more segregated with age, the strengths of within-network connections keep increasing[1], which predicts executive function (EF) development.
- However, we still lack an understanding of **(1)** the EF-related structural organization during early life development (0-6); and **(2)** the relationship between co-maturation of regions within the EF-related network and future EF performance.

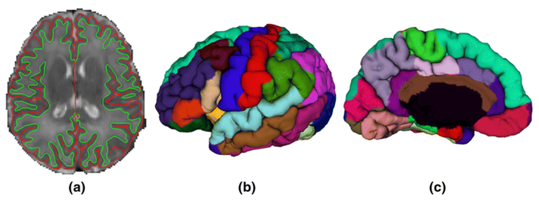
Methods



Participants

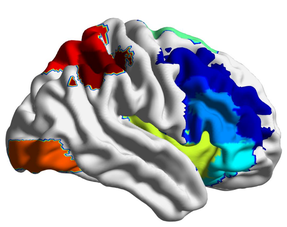
- Imaging data: 624 children
- (0-6 years, 49% female)
- Behavioral data: 33 children
- (8 years, 45% female)

Cortical thickness[2]



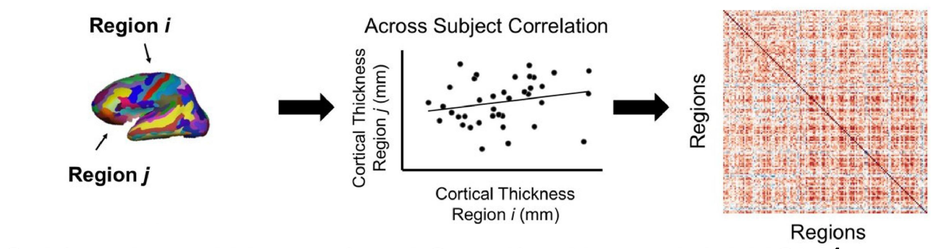
(a) Reconstructed inner and outer cortical surfaces
(b,c) Parcellated into 78 AAL cortical regions

EF network definition

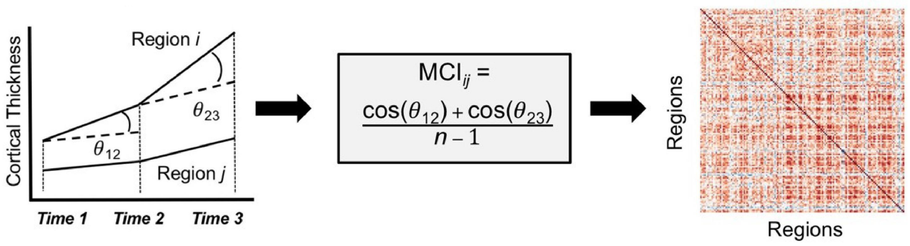


20 AAL regions overlapped over 30% with the thresholded Meta-analysis maps of "working memory" or "attention" from BrainMap[3]

Structural Covariance Network (SCN)[4]



Subject-based Maturational Coupling Network (sbMCN)[4]



Network metrics

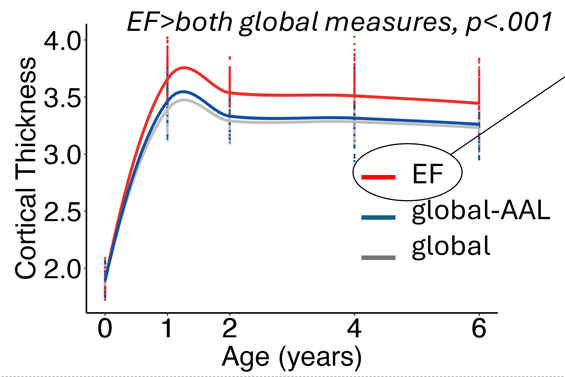
- Global efficiency: the efficiency of information transformation within the network.
- Modularity: the strength of segregation into distinct networks.

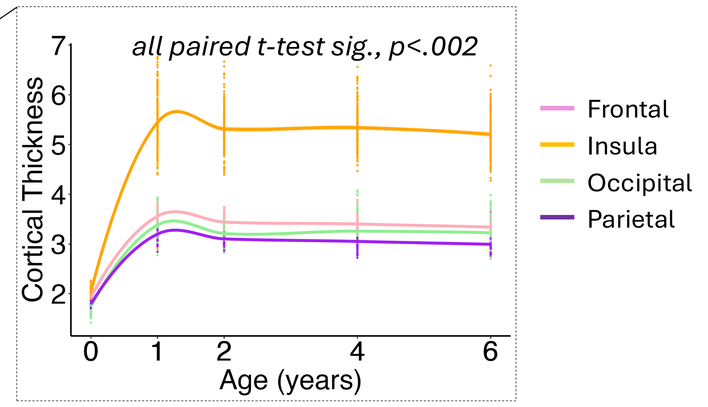
EF behavioral measurements

- NIH Toolbox Cognition Battery
  - Flanker Inhibitory Control and Attention: Inhibition
  - Dimensional Change Card Sort: Shifting
  - Pattern comparison Processing Speed: Processing Speed

Results

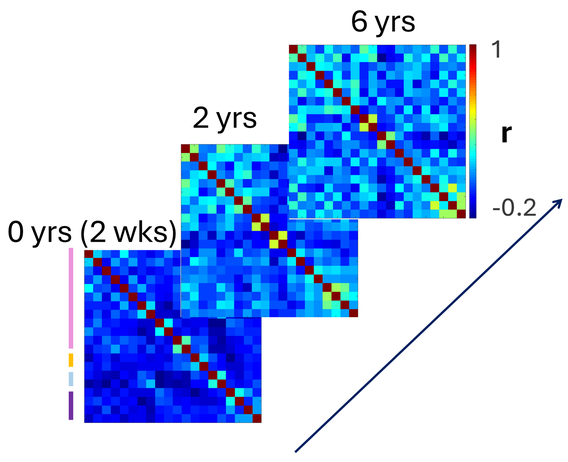
Trajectories of cortical thickness



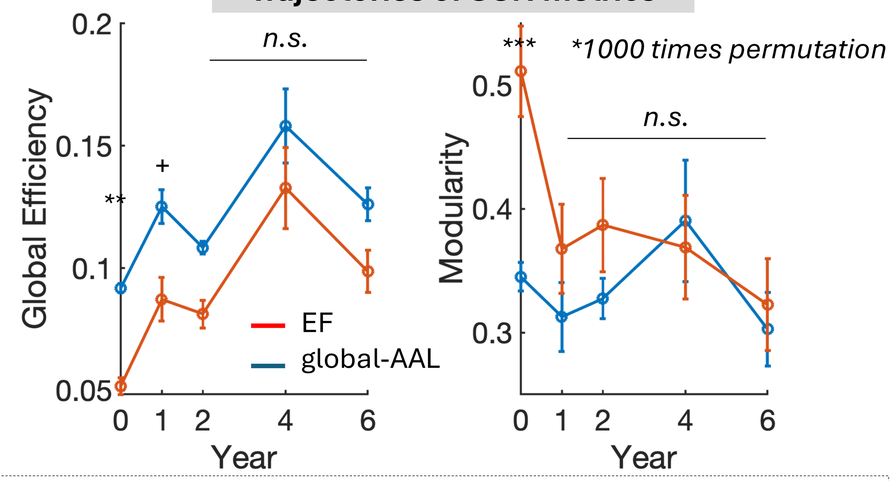


- Cortical thickness **increased rapidly**, then **slightly decreased and stabilized in the first two years**.
- The cortical thickness of the **EF-related network increased faster** and **to a greater extent;** the cingulo-opercular regions showed the highest cortical thickness, while the parietal regions had the lowest.

EF SCNs



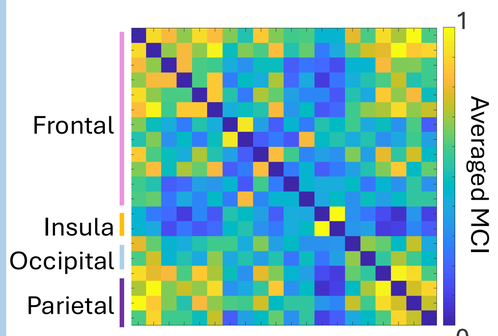
Trajectories of SCN metrics



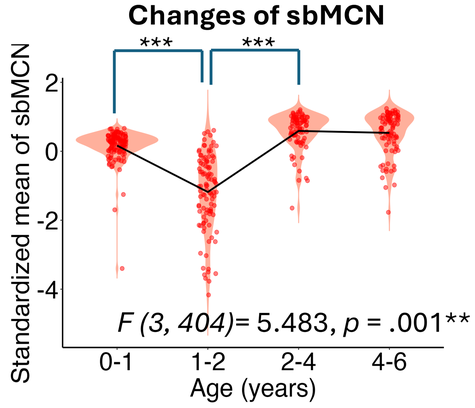
- The cortical thickness of EF-related regions **became more coordinated** across subjects over six years.
- Compared to the global network, the EF-related network showed a pattern of (1) **lower global efficiency** but (2) **higher modularity** in the first year.

sbMCN of the EF-related network from 0-6 years

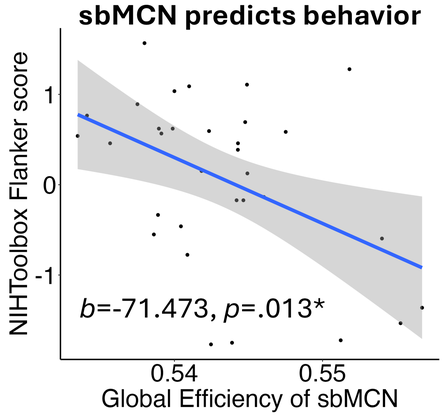
averaged sbMCN



Changes of sbMCN



sbMCN predicts behavior



- The highest maturational coupling was observed in **frontal and parietal regions** across the first six years.
- Less **coordinated maturation** and **higher individual variability** within the EF-related network from age 1 to 2.
- Lower global efficiency of sbMCN from 0 to 6 predicted better EF performance on the Flanker task at age 8.

Conclusions

Our study identified unique patterns of structural maturation associated with EF in early life. On the group level, the EF-related network exhibited lower global efficiency and higher modularity compared to the whole brain in the first year. Individually, the frontal and parietal regions showed more coupling maturation over the six years. Between ages 1 and 2, regions within the EF-related network developed at varying rates. Notably, the coordination of maturation among regions in early life also impacted future EF. These distinctive features in EF-related brain maturation may help elucidate individual differences in cognitive function and further contribute to our understanding of cognitive deficits.

References: 1:Modular Segregation of Structural Brain Networks Supports the Development of Executive Function in Youth. 2017. Baum., et al. 2: Cortical thickness and surface area in neonates at high risk for schizophrenia. 2014. Gang., et al. 3: Mapping context and content: The BrainMap model. 2002. Fox., et al. 4: The maturation and cognitive relevance of structural brain network organization from early infancy to childhood. 2021. Woodburn., et al.

Supported by: R01 MH070890, R01 MH123747, R01 MH111944. **For questions**: yuyzhao@unc.edu