Developmental Changes in Graph Organization of the Fronto-Parietal Number Network

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Introduction

- A fronto-parietal network is critical for numerical and mathematical cognition in children and adults.[1,2]
- Network connections shift from local to global organization from childhood to adulthood.[3]
- A frontal-to-parietal shift in functional anatomy occurs from childhood to adulthood.[4,5]
- Do changes in network structure reflect these shifts?
- We hypothesized that parietal nodes would show greater connectivity (degree) than frontal nodes in older children.

Methods

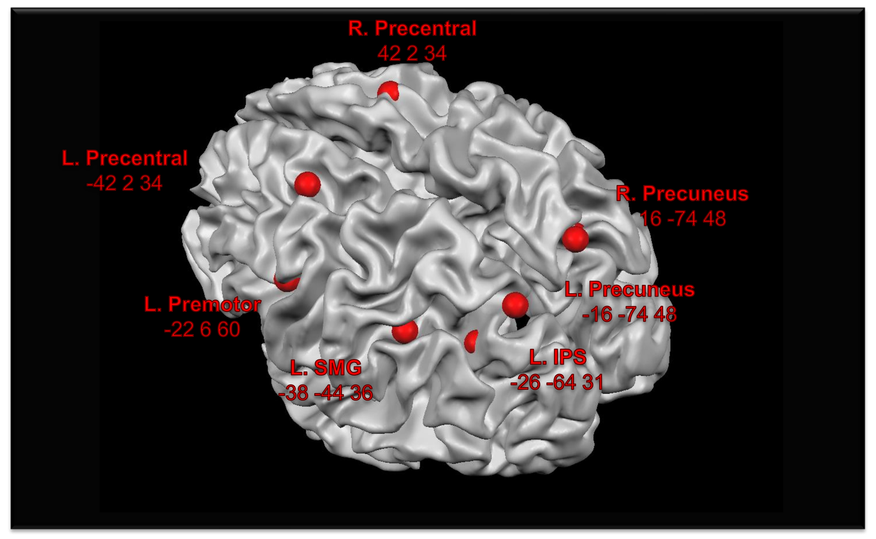
Participants: 31 2nd graders (13 female) and 29 5th graders (15 female) were recruited for fMRI scanning from a longitudinal behavioral study of fractions processing.

In-scanner task: Participants were instructed to stay awake and fixate on a centrally presented cross ("eyes-open resting state"). No task or stimuli were presented

Image acquisition: 3T GE MRI Scanner. Voxel size 1.75x1.75x3 mm; 38 horizontal slices per volume.

Node selection: previously identified coordinates from previous meta-analyses of numerical cognition[1,2]

Frontal nodes: precentral, premotor. Parietal nodes: SMG, precuneus, IPS. (R-L ITG also in network)

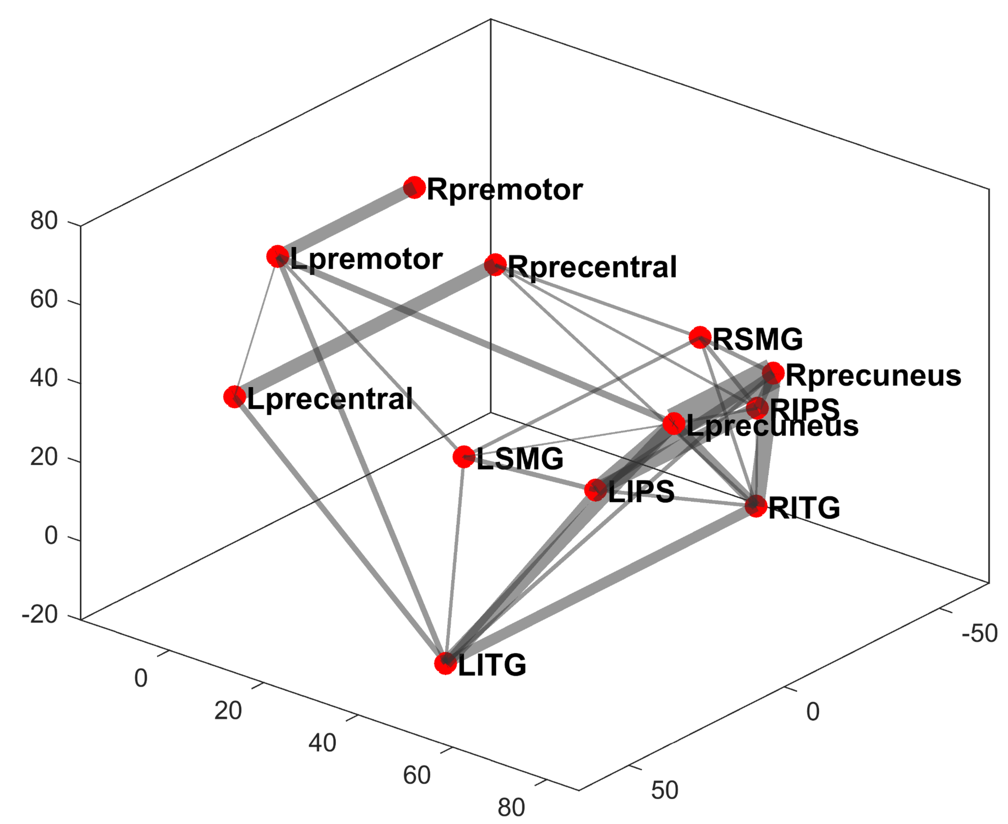


Functional connectivity analysis:

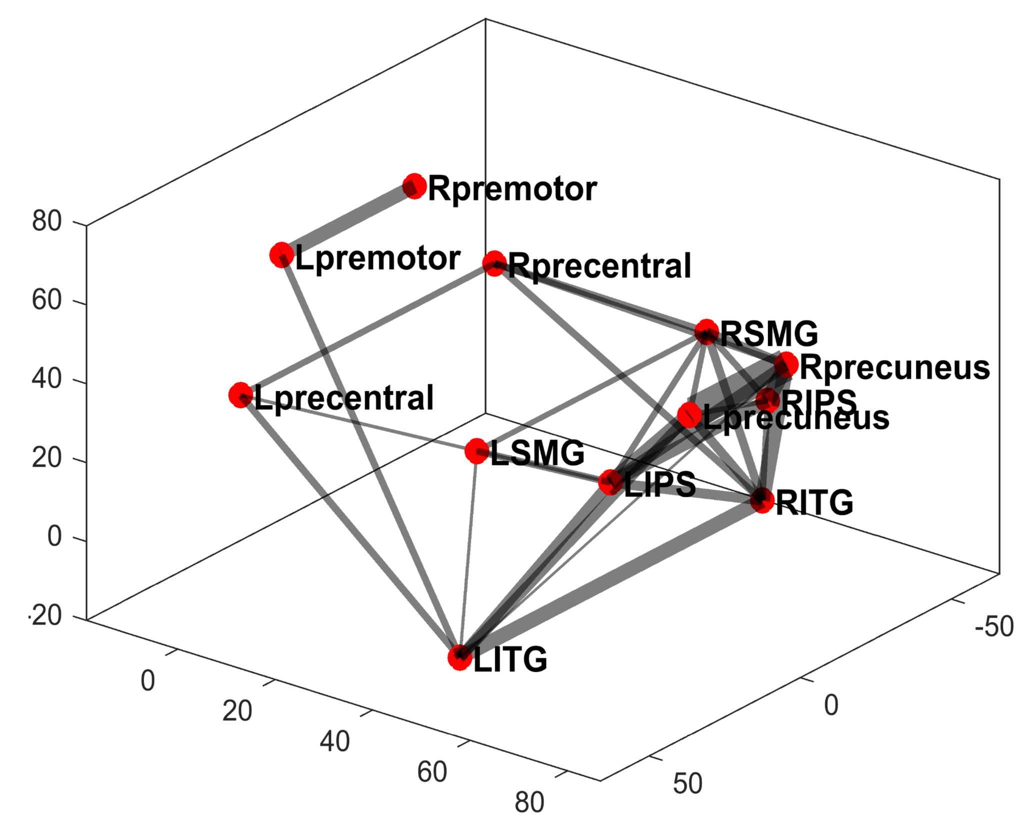
- Preprocessing in AFNI included motion censoring (.3mm), high-pass filtering, smoothing (4mm),
- We included regressors for motion and global mean signal (white matter) in a GLM analysis
- BOLD time series correlations between pairs of nodes (ROIs) were computed in AFNI for each subject

Results

Second Graders



Fifth Graders



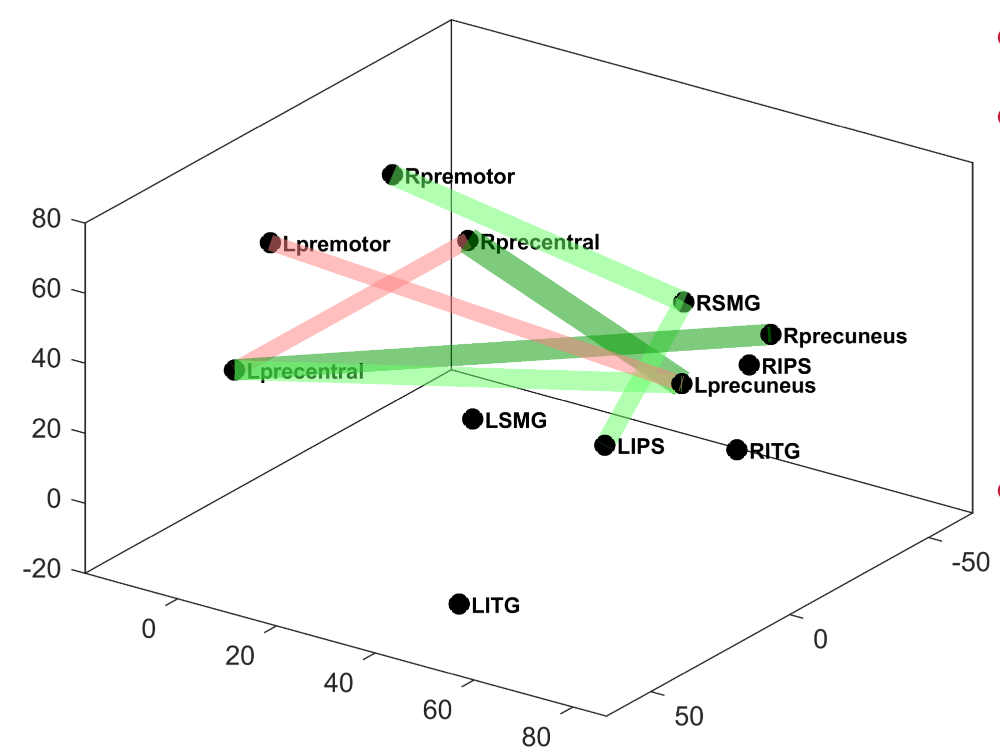
Node Degree Analysis: The "degree" of a node is the number of connections (edges) between that node and other nodes. We compared mean degree per node across grades. Line thickness is proportional to edge weight.

Pre-registered analysis

Node	2nd mean degree	5th mean degree	*t(55)*	*p*
RIPS	6.09 (2.23)	6.29 (2.43)	-0.32	0.75
RITG	7.47 (1.89)	7.89 (1.52)	-0.94	0.35
Rprecentral	6.43 (2.12)	6.5 (2.4)	-0.12	0.91
Rprecuneus	8.12 (1.43)	7.96 (1.62)	0.39	0.70
Rpremotor	5.24 (2.08)	5.64 (2.26)	-0.70	0.49
RSMG	6.59 (2.26)	7 (1.72)	-0.78	0.44
LIPS	8.17 (1.66)	8.11 (1.73)	0.15	0.88
LITG	7.69 (1.73)	7.54 (2.08)	0.30	0.76
Lprecentral	6.28 (1.84)	6.5 (2.25)	-0.41	0.68
Lprecuneus	8.05 (1.73)	7.71 (2.46)	0.60	0.55
Lpremotor	**6.97 (1.76)**	**5.86 (2.22)**	**2.09**	**0.04**
LSMG	6.91 (2.48)	5.93 (2.51)	1.49	0.14

- No significant increases in mean node degree from 2nd to 5th grade
- One node showed a significant *decrease*
- A fully crossed 2 (Grade) x 2 (Lobe) x 2 (Laterality) ANOVA showed only a main effect of lobe (parietal > frontal $F(1,562) = 21.75$, $p < .001$), and no interactions
- Trend toward significance for laterality (left>right, $F(1,562) = 3.15$, $p = .07$)

Edge Difference Analysis: We examined the edges that showed the greatest differences in weight across grades (i.e. greatest differences in correlations between ROIs). Green = increase, Red = decrease.



- Most differences were increases
- The greatest changes were contralateral long-range increases
  - Rprecentral/Lprecuneus ($\Delta r = .11, t = 2.02, p = .048$)
  - Lprecentral/Rprecuneus ($\Delta r = .09, t = 1.96, p = .056$)
- Even the largest decreases were non-significant.
  - L-R precentral ($\Delta r = -.06$, $t = -1.2$, $p = .24$)
  - Lpremotor to Lprecuneus ($\Delta r = -.07, t = -.93, p = .35$)

Discussion & Conclusion

- We did not observe an overall shift in connectivity (degree) of frontal nodes to parietal nodes with age
- Network structure is highly conserved in this age range (7-8 to 10-11 years old)
- Observed primarily increases in connectivity, especially for long-range (functional) connections
- Non-significant decreases in weight, especially short-range (anatomical) connections
- One long-range connection decreased considerably: left premotor to left precuneus
- This pattern of results is consistent with previous findings on developmental changes in functional connectivity networks
- Changes in edge weights rather than in node degree may be more informative in this age window

Future Directions

- We are following these participants longitudinally and will therefore be able to observe within-subject developmental changes in network structure
- We anticipate more dramatic changes in the older cohort as they enter adolescence (13-14 years old)
- We will also examine the relation between network changes in network structure and behavior
- We may apply a similar analysis to task-based connectivity in children and adults

LAMBDA Longitudinal Analysis of Mathematical Brain Development and Abilities

References

1. Houdé, O., Rossi, S., Lubin, A. & Joliot, M. Mapping numerical processing, reading, and executive functions in the developing brain: An fMRI meta-analysis of 52 studies including 842 children. *Dev. Sci.* 13, 876–885 (2010).
2. Yeo, D. J., Wilkey, E. D. & Price, G. R. The search for the number form area: A functional neuroimaging meta-analysis. *Neurosci. Biobehav. Rev.* 78, 145–160 (2017).
3. Power, J. D., Fair, D. A., Schlaggar, B. L. & Petersen, S. E. The Development of Human Functional Brain Networks. *Neuron* 67, 735–748 (2010).
4. Ansari, D., Garcia, N., Lucas, E., Hamon, K. & Dhital, B. Neural correlates of symbolic number processing in children and adults. *Neuroreport* 16, 1769–1773 (2005).
5. Rivera, S. M., Reiss, A. L., Eckert, M. A. & Menon, V. Developmental Changes in Mental Arithmetic: Evidence for Increased Functional Specialization in the Left Inferior Parietal Cortex. *Cereb. Cortex* 15, 1779–1790 (2005).

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