Natural language processing of fMRI reveals cognitive learning induced changes in brain circuit dynamics

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Introduction

- Very few studies have examined learning related changes in functional brain dynamics in children, especially in academic domain like mathematics

- Current computational methods to measure functional brain dynamics are limited in scope and efficacy

- Promising methods for uncovering time-varying structure have been developed for use in natural language processing (NLP) in text

Research Question

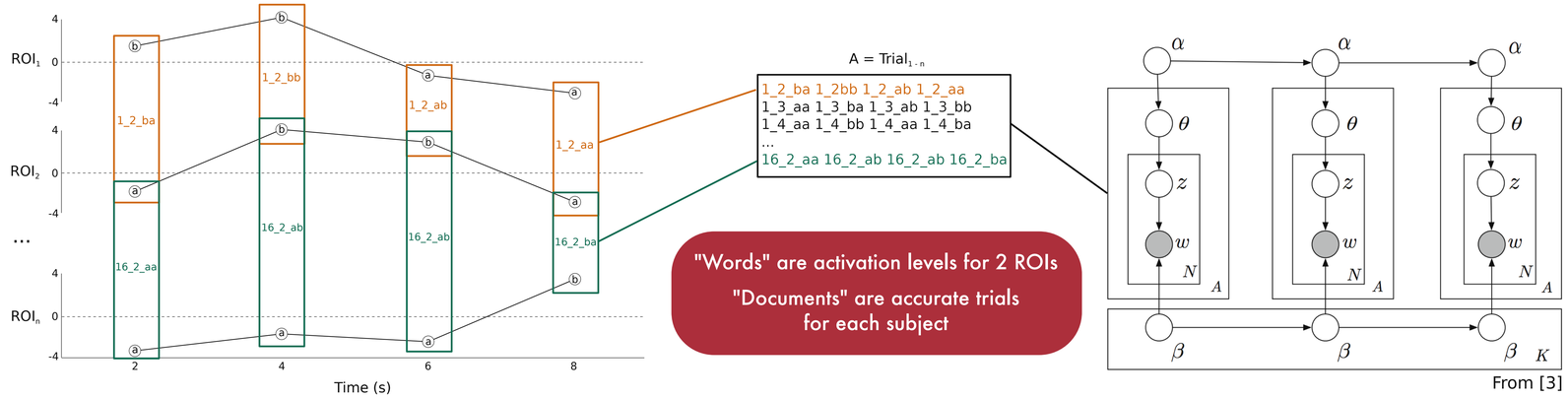
Can NLP algorithms be used to uncover changes in functional brain dynamics associated with math learning in children?

Methods

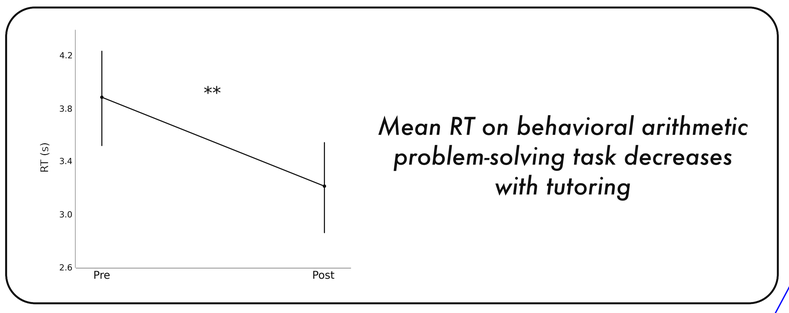
Participants: 35 children in 3rd grade (20 F, $Age_{\mu} = 8.71, \sigma^2 = 0.47$, $FSIQ_{\mu} = 106.23, \sigma^2 = 12.99$) underwent 8 weeks of one-to-one math tutoring designed to strengthen arithmetic fluency and number knowledge [1]

fMRI task: A fast event-related arithmetic verification task was performed requiring each child to verify 12 addition questions (i.e. 2 + 4 = 6) where half were correct and half were incorrect (i.e. 2 + 4 = 7) [1]

Symbolic Aggregate Approximation [2] → Document Creation → Dynamic Topic Modeling [3]

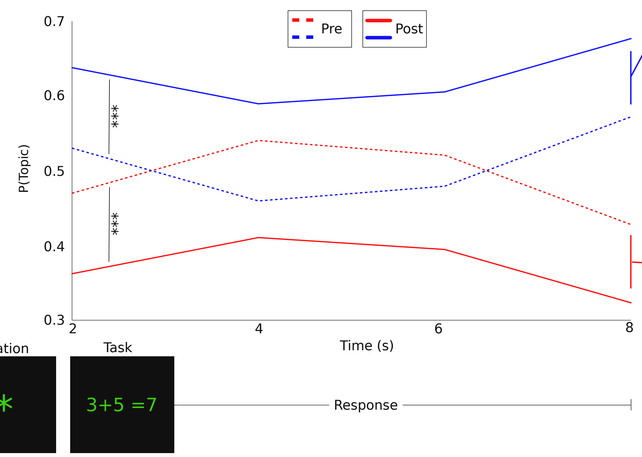


Results

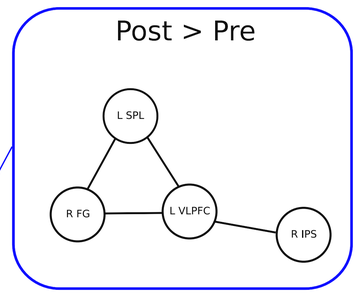


Mean RT on behavioral arithmetic problem-solving task decreases with tutoring

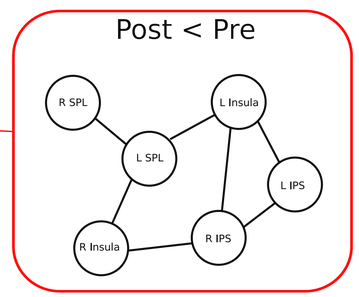
The trajectory of functional task-network dynamics changes with tutoring

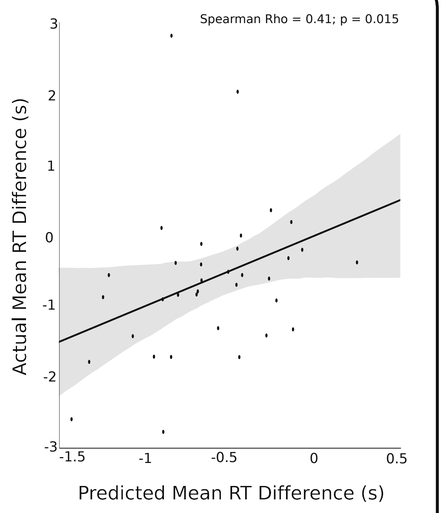


Increased functional coupling in fronto-parietal network with tutoring



Decreased functional coupling between insula and parietal network with tutoring





Larger tutoring-induced changes in task-network dynamics associated with improved performance

Conclusions

- Children's math performance improved both behaviorally and within the scanner following 8 weeks of one-to-one math tutoring

- Significant differentiation in the trajectory of functional brain dynamics corresponding to fronto-parietal and insula-parietal task-based networks occurred with tutoring

- Changes in network dynamics are associated with tutoring-induced changes in reaction time

- NLP based methods can be used to uncover functional brain dynamics in fast event-related task-based fMRI

References

[1] Iuculano, T., et al. Nature Communications (2015) 6: 8453.

[2] Lin, J., Keogh, E., Wei, L. et al. Data Min Knowl Disc (2007) 15: 107.

[3] Blei, D., Lafferty, J.D. Proceedings of the 23rd International Conference on Machine Learning (2006) 113-120.

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