Using functional connectivity MRI to study advanced theory of mind in 6-year old children

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Introduction

Significant development in theory of mind reasoning occurs during early childhood. Around 6 years of age, children can report on someone's belief about someone else's false belief (second order false belief), develop an understanding of faux pas, and become better able to flexibly and creatively represent multiple different perspectives.

In adults, theory of mind reasoning relies on a network of regions including medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), bilateral temporoparietal junction (RTPJ, LTPJ), and bilateral superior temporal sulcus (RSTS, LSTS). These regions undergo protracted functional and structural development into adolescence (e.g., Gogtay et al., 2006) but little is known about how these brain changes underlie behavioral advances in early childhood due to the methodological difficulties in acquiring functional MRI data from young children (see Gweon et al., 2012).

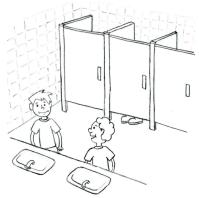
We present a novel approach in which we use functional connectivity MRI, collected during a 6-minute scan with no task requirements (i.e. resting-state), to relate changes in brain network connectivity to development in theory of mind understanding.

Participants

Characteristic	Included (n=20)	Excluded (n=7)	*p* value
Sex, M/F	10/9	3/4	.66
FSIQ	115 (12.2)	107 (3.1)	.10
Verbal IQ	116 (2.9)	112 (4.3)	.46
Non-verbal VIQ	110 (3.2)	99 (3.6)	.07

Children participated in a battery of social-cognitive, executive function, and memory tasks, as well as assessment of syntactic competence (CELF) and IQ (KBIT-2)

Advanced theory of mind tasks



Faux Pas (0-4)

Joe and Peter were at the sinks. Joe said "Mike is really weird!" Mike then came out of the stall.

Second Order False Belief (0-2)

"Where does Steve think Sally will look?"

fMRI Data Collection and Processing

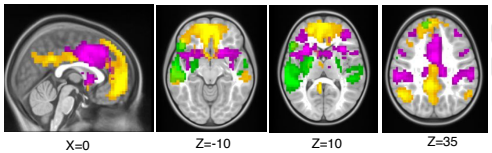
- Functional and structural data were collected at the Maryland Neuroimaging Center at the University of Maryland on a Siemens 3T Tim Trio.
- Preprocessing steps included coregistration, motion correction, smoothing, and normalization to a pediatric template (Fonov et al., 2011)
- Independent Component Analyses (FSL Melodic) were used to identify functional networks (Jenkinson et al., 2012)
- Subsequent seed-based correlation analyses were conducted using the conn functional connectivity toolbox (Whitfield-Gabrieli & Nieto-Castanon, 2002).
- Partial correlation analyses were conducted to examine the effect of task performance on normalized correlation coefficients (i.e. functional connectivity) for the 3-identified functional networks. FIQ and comprehension scores were included as covariates in the model.

Identification of Functional Networks

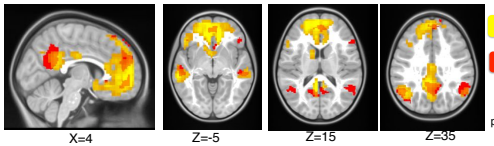
Step 1: Collect functional MRI data during a "resting-state"

Children were trained on a mock scanner with real-time motion monitoring. During fMRI data collection, children passively watched 6 minute videos of abstract patterns to stay engaged.

Step 2: Independent component analyses on functional data

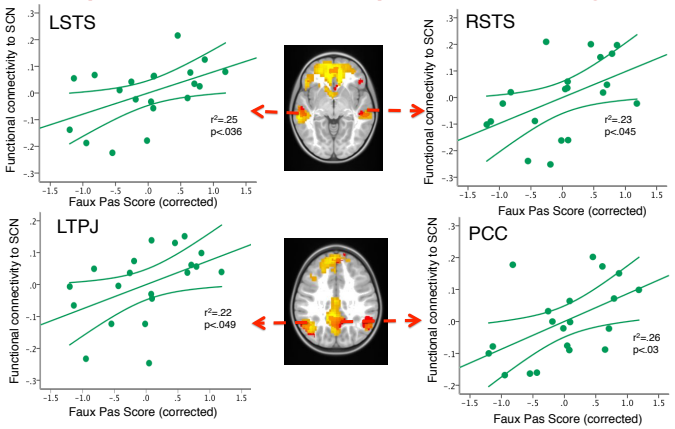


Step 3: Comparison of ICA-identified network to task-based network

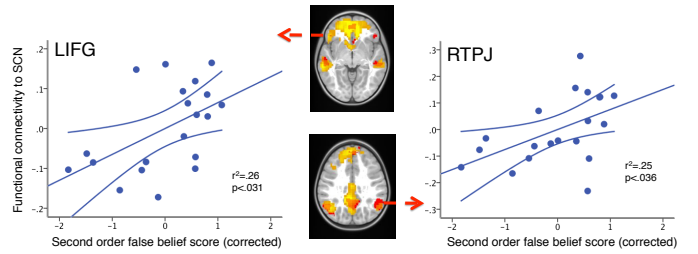


To determine whether the ICA-identified social-cognitive network was spatially similar to the theory of mind network, a standard theory of mind localizer (e.g., Saxe & Kanwisher, 2003) was collected on 20 adult participants. The theory of mind contrast (false belief > false photo) is displayed in red and overlaps spatially with the ICA-identified social-cognitive network (yellow/orange) identified in 6-year old participants.

Greater connectivity in the social-cognitive network predicts advanced faux pas understanding



Greater connectivity in the social-cognitive network predicts success on 2nd order false belief



Connectivity within language and cognitive control networks does not predict advanced theory of mind understanding

Task scores for both faux pas and second order false belief were regressed on within network connectivity values for the language and cognitive control networks separately (with the same covariates as before). No region showed a significant effect of within network connectivity for either task or network.

Conclusions

- Functional networks can be identified from a "resting-state" in 6-year old children
- Connectivity from regions of the social-cognitive network to all other regions of the network predicted behavior on 2 different advanced theory of mind tasks
- The specific regions for which greater connectivity was related to better theory of mind performance differed between the two tasks
- Connectivity within the cognitive control and language networks did not correlate with greater theory of mind performance, suggesting specificity to the social-cognitive network. However, regions across networks overlapped, suggesting some portions of the SCN network (e.g., IFG or STS) may play a domain-general role in theory of mind development
- Future studies will 1) examine connectivity effects on tasks tapping different aspects of theory of mind development, 2) examine earlier key ages for theory of mind development (e.g., 4-years), and 3) include a task-based measure to identify the social-cognitive network within the same children

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Conflict of Interest: None