Neural Markers of Developmental Processing of Grammaticality from Childhood to Adolescence

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Summary

- Errors in the acquisition of grammatical morphology characterize developmental stages of children's acquisition of overt tense and aspect marking.
- In English, a common developmental error is the use of infinitive verb forms where finite forms are required, optional infinitive (OI) errors (Schütze & Wexler, 1996; Wexler, 1994, 1998, 2003)
- Other kinds of overt tense and aspect marking errors, such as the subject and auxiliary form mismatch are not attested in development (GE errors)
- Little is known about the development of the neural bases of grammatical error processing, including whether there is differential sensitivity to the kinds of grammatical errors that children do vs. do not make during development

Purpose

The purpose of this study was to examine the maturation of grammatical processing across development using a grammatical vs. ungrammatical fMRI judgment task to compare brain activation for sentences that were grammatically correct vs. those with either developmental (OI) or non-developmental tense/aspect agreement (GE) errors

Methods

Participants: Native English-speaking children (*N* = 87; 39 female, 48 male; age 5-18; *M* = 10.4 years, *SD* = 3.3). All children reported typical hearing, language, and cognition.

Stimuli: The grammaticality judgment task (fMRI task) used for this study was modeled after the comprehension section of the Test of Early Grammatical Impairment (TEGI; Rice & Wexler, 2001). The task included 108 sentences presented auditorily under the following 3 sentence conditions (Wagley et al., 2019).

Table 1. Example stimuli sentences

Developmental Errors (OI)	
▪ Past tense -ed omission	*Last night, the baby cry.* *Last year, Bob play football.*
▪ Present tense -s omission	*My brother always hurry home.* *She call her uncle weekly.*
▪ Copula (am/ is/ are/ was/ were) omission	*He * the tallest in town.* *I * in front of him.*
Non-Developmental Errors (GE)	
▪ present progressive -ing omission	*He is kick the ball.* *They are make some lunch.*
▪ to be tense agreement error	*She are buttoning her shirt.* *We am seeing a movie.*
Grammatically Correct (C)	
	I brushed my teeth today. *He copies my answers.* *She is the nicest cat.* *They are jumping rope.* *We are trying the cheese.*

fRMI Image Acquisition was collected on the Siemens 3T Trio scanner at MIT using sparse-sampling acquisition with a 6-s TR (4-s delay and 2-s acquisition) for a total of 146 TRs (Hall et al., 1999; for review, see Perrachione & Ghosh, 2013).

fMRI Data Analysis was conducted using *Lyman* 1.0.0. Regions of interest (fROIs) were selected in frontal and temporal regions based on the probabilistic atlas of the adult language network defined in Lipkin et al. (2022).
We conducted fixed-effects models to evaluate the effect of age on functional activation in response to the grammatical (C) and ungrammatical conditions (OI and GE).
In addition, we used multi-voxel pattern analysis (MVPA) to examine how neural response profiles for the different conditions compare as children get older.

Results

Mean Activation by Condition (selected fROIs)

Figure 1. Mean activation by Age in L posterior STG/MTG

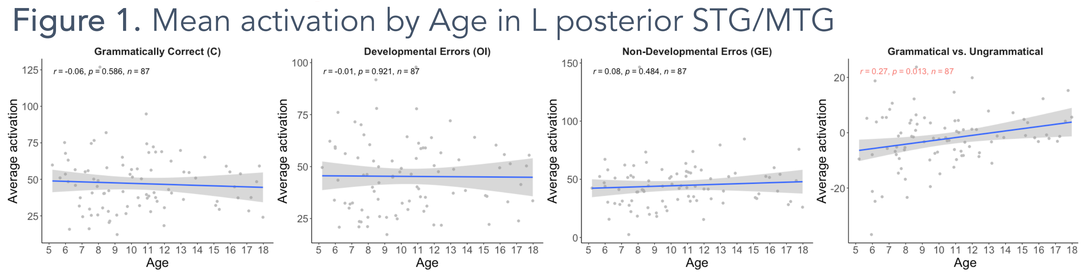


Figure 2. Mean activation by Age in L IFG pars opercularis

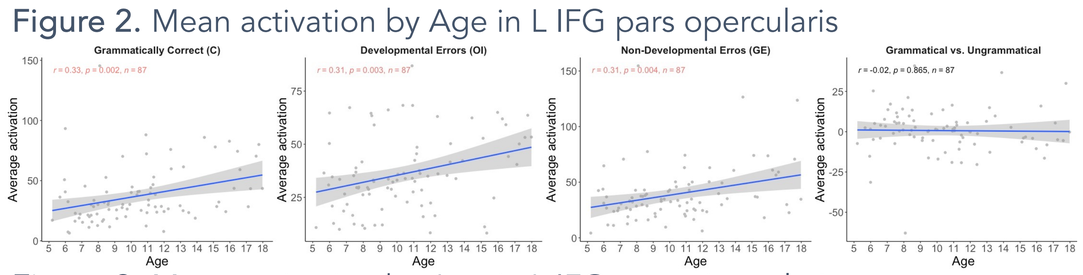
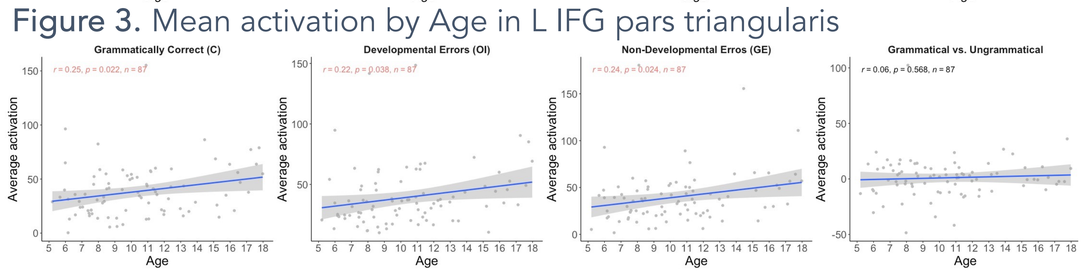


Figure 3. Mean activation by Age in L IFG pars triangularis



Multilevel Model Predicting Activation in OI-v-C ~ GE-v-C comparison

Table 2. Fixed and Random Effects

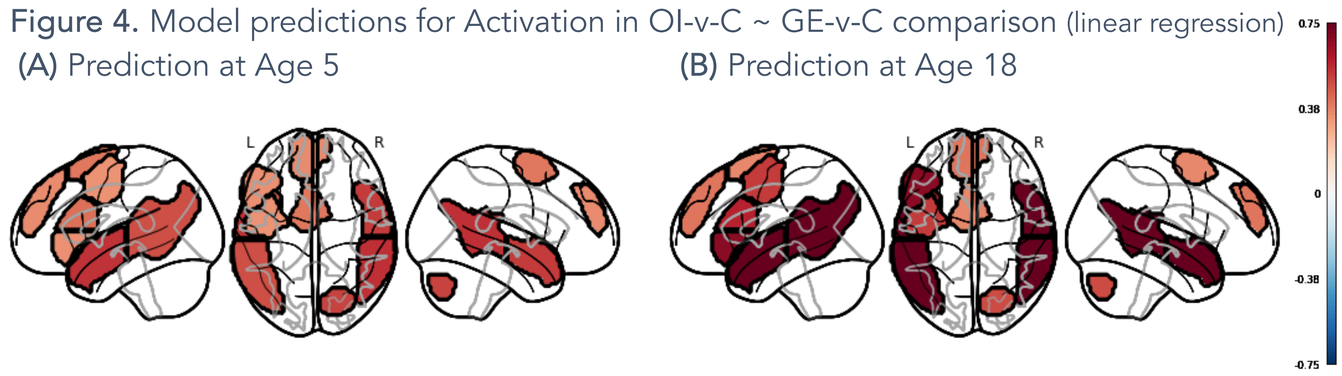
Fixed Effects	*Estimate*	*S.E.*	*95% CI*
	df = 86	*n* = 841	groups = 87
Mean Activation (intercept)	0.670***	0.048	[0.576, 0.764]
Age in years (centered @ 5 years old)	-0.015*	0.007	[-0.030, 0]

Note. *** *p* = <.001; ** *p* = <.01; * *p* = <.05.

Random Effects		*95% CI*
Level 1 participant (intercept) - σ^2	0.041	[0.028, 0.059]
Level 1 fROI area (intercept) - σ^2	0.001	[0, 0.005]
Corr of fixed effects: Mean Activation and Age - *r*	-.836	

Predictions for Activation in OI-v-C ~ GE-v-C Comparison (at each fROI)

Figure 4. Model predictions for Activation in OI-v-C ~ GE-v-C comparison (linear regression)



References

Hall et al. (1999). *Human Brain Mapping*; Lipkin et al. (2022). *Scientific Data*; Perrachione & Ghosh. (2013). *Frontiers in Neuroscience*; Rice & Wexler. (2001).; Schütze & Wexler. (1996). *BU CLD*; Wagley et al. (2019); Wexler (1994); Wexler (1998). *Lingua*; Wexler (2003).

Acknowledgments

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Discussion

Mean activation by contrast was only significantly associated by age in 3 regions of the language network we identified:

- Although mean activation in the different experimental conditions (**C, OI, and GE**) was not significantly associated with increasing age in the **L posterior STG/MTG**, these relationships are mostly negative, suggesting decreased activation with age
- Further, significant associations were found between increasing age and average activation in the contrast between **Grammatical vs. Ungrammatical** in the **L posterior STG/MTG.** This finding supports this area's involvement in grammatical detection and shows maturation of the area throughout childhood and adolescence.
- Mean activation in these experimental language conditions (**C, OI, and GE**) was significantly positively associated with increasing age in the **L IFG pars opercularis and pars triangularis**, consistent with prior evidence suggesting these are late developing language areas

Mean activation for the comparison of activation in contrast OI-v-C to activation in contrast GE-v-C:

- Age was a significant predictor in this model, the negative coefficient suggests grammatical maturation of the system, with less sensitivity for developmental vs. non-developmental errors, i.e., decreased difference in activation for Developmental Errors compared to Grammatical stimuli compared to activation for Non-Developmental Errors compared to Grammatical stimuli over time.