Neural specialization of reading in young children

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Introduction

❖The specialization of language network is not well defined in young children. As children transition from preschool to elementary school, they show dramatic changes in their reading ability as they gain phonemic information (auditory processing of speech sounds) and semantic knowledge (storage and retrieval of word meaning) of language. Meanwhile, their brain develop rapidly during this early learning period. Examining the neural specialization of phonological and semantic processing at this critical period of development is critical to advance our understanding of the brain mechanisms supporting better reading development.

❖Past research has shown that typically developing children aged from 5-6 years already show some specialization of fronto-temporal brain regions for phonological and semantic processes. Using visual reading[2,3] and auditory tasks[4], studies have shown phonological processing recruits dorsal left IFG[1] and left STG[4], whereas semantic processing engages ventral IFG and left MTG[4].

❖However, the fronto-temporal connectivity differences between phonological and semantic processing in young children have not been studied yet. This study aims to identify the early specialization of brain networks for phonological and semantic processing in young children using functional magnetic resonance imaging (fMRI).

Materials and Methods

Participants 34 healthy native English speaking children (age range 4:06 – 6:11).

Parent questionnaire STIM Q2 preschool, Executive function/attention BROWN scales (Early childhood age 3-7).

Behavioral assessments Kaufman Brief Intelligence Test (KBIT); Letter Identification, Phonological awareness, Rapid automatic naming, Word Identification and Word attack subtest of Woodcock Reading Mastery Tests (WRMT™-III); Sight Word Efficiency and Phonemic Decoding Efficiency subtest of Test of Word Reading Efficiency (TOWRE); Word Classes subtest of CELF5.

Familiarity Task Children read thirty 3-5 letters monosyllabic words and choose the corresponding picture that represent the word. 10 out of 34 children with an accuracy of > 75% in the familiarity task were recruited for the fMRI experiment.(avg. familiarity task accuracy = 93.33 %). All were right-handed (5M, 5F; avg. age 6.26 yrs. [range: 4:07 - 6:09]; avg. IQ 110.5 ± 8.92]).

fMRI Stimuli Selection 3-5 letters monosyllabic words, were selected for the experiment. The word pairs were matched on concreteness, printed familiarity, word type (noun) and number of syllables [using the Medical Research Council (MRC) psycholinguistic database].

fMRI Measures Mock scanner training was done to familiarize the child with fMRI environment and the tasks before the fMRI session.

fMRI Data Analysis Standard preprocessing steps in SPM12 including realignment, normalization, smoothing, and artifact detection. Art Repair was used to detect outlier scans with > 5mm scan to scan motion and > 10 (z-value) global signal threshold. Four conditions — Fixation, Rhyming, Semantic and Control were modeled using the general linear model framework and analyzed at group level using a random effects model. The motion regressors and ART outlier scans were used as regressors of no interest in the GLM. PPI analysis was conducted using gPPI framework to examine task based connectivity differences between the conditions Rhyming > Semantic and Semantic > Rhyming.

Experimental Paradigm

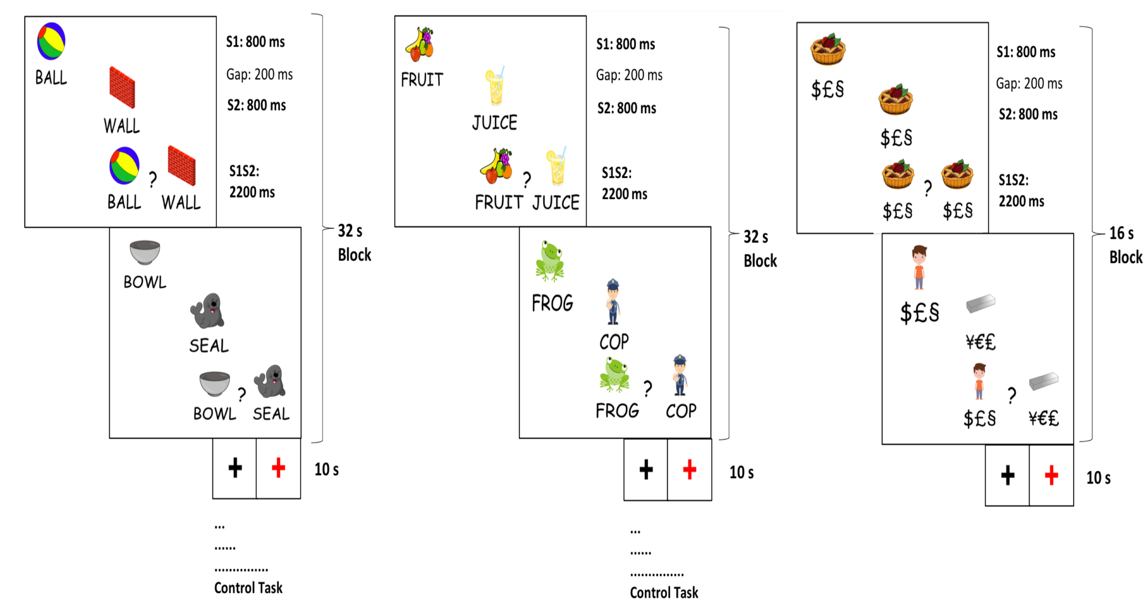


Figure 1. Schematic of the Experimental paradigm

A. presents the visual rhyming condition. The child was asked to determine whether two words presented rhyme or not by button pressing. To reduce the working memory loads, all words were presented with a corresponding image. B. presents the semantic condition. The child was asked to determine whether two words presented were related or not by button pressing. C. presents the control condition for both task condition, the child was asked to judge whether symbol strings (non-alphabetic glyphs) presented matched or not. To match the image stimuli in the task condition, child friendly images were also shown with the strings. Besides, fixation condition were included as a baseline. In the fixation condition, a black fixation cross was presented and the child was instructed to press any button when the black fixation changed color from black to red.

Results

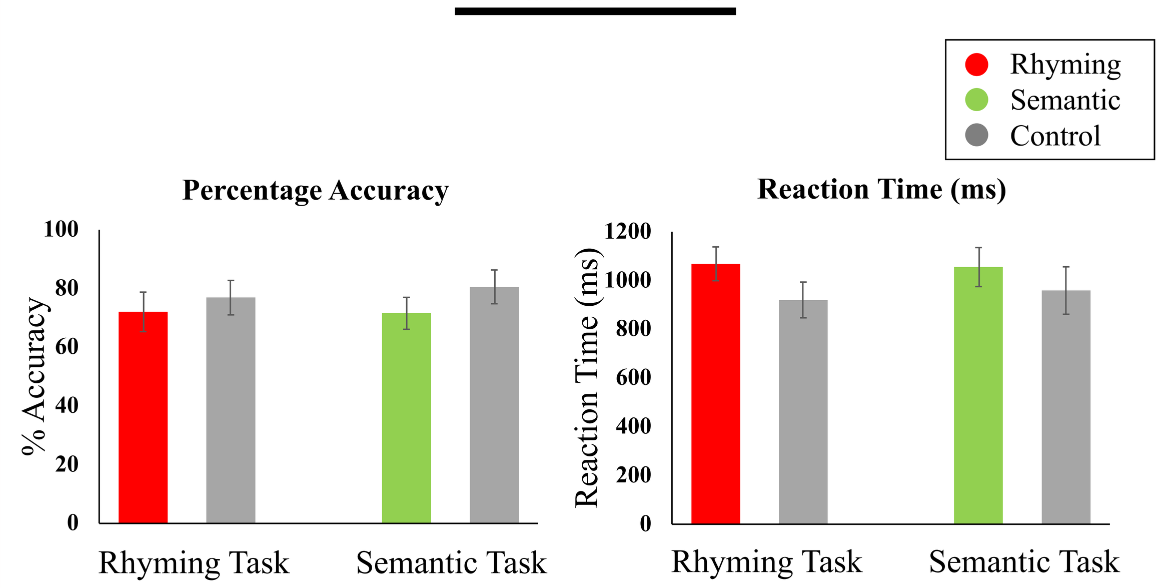
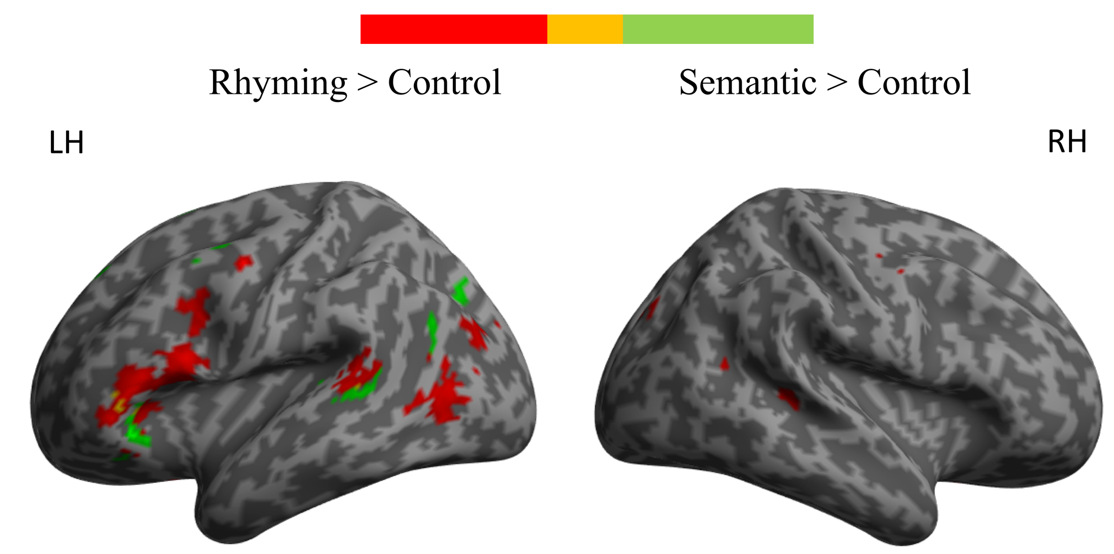


Figure 2. Behavioral Analysis Results

Average percent accuracy and reaction time (in ms) (N = 10) for rhyming (red), semantic (green) and control (gray) task. The participants showed greater than 60% accuracy in all the tasks.

fMRI Results



(A) Rhyming > Control (Red)

L IFG (Tri and Oper)/MFG
L MTG/STG
L Precentral and SMA
L Mid/Sup Occipital
Bilateral Lingual

(B) Semantic > Control (Green)

L IFG (Tri and Orb)/MFG
L MTG/STG
L SMA
L Mid Occipital
L Angular Gyrus

(C) Overlap (Yellow)

L IFG (Tri)
L SMA
L MTG

Figure 3. Group fMRI Results

Voxel-wise significant activation for contrast (A) Rhyming > Control (red), (B) Semantic > Control (green) and (C) Overlap between Rhyming > Control and Semantic > Control (yellow) at voxel level threshold of p < .001 uncorrected with cluster size k >15.

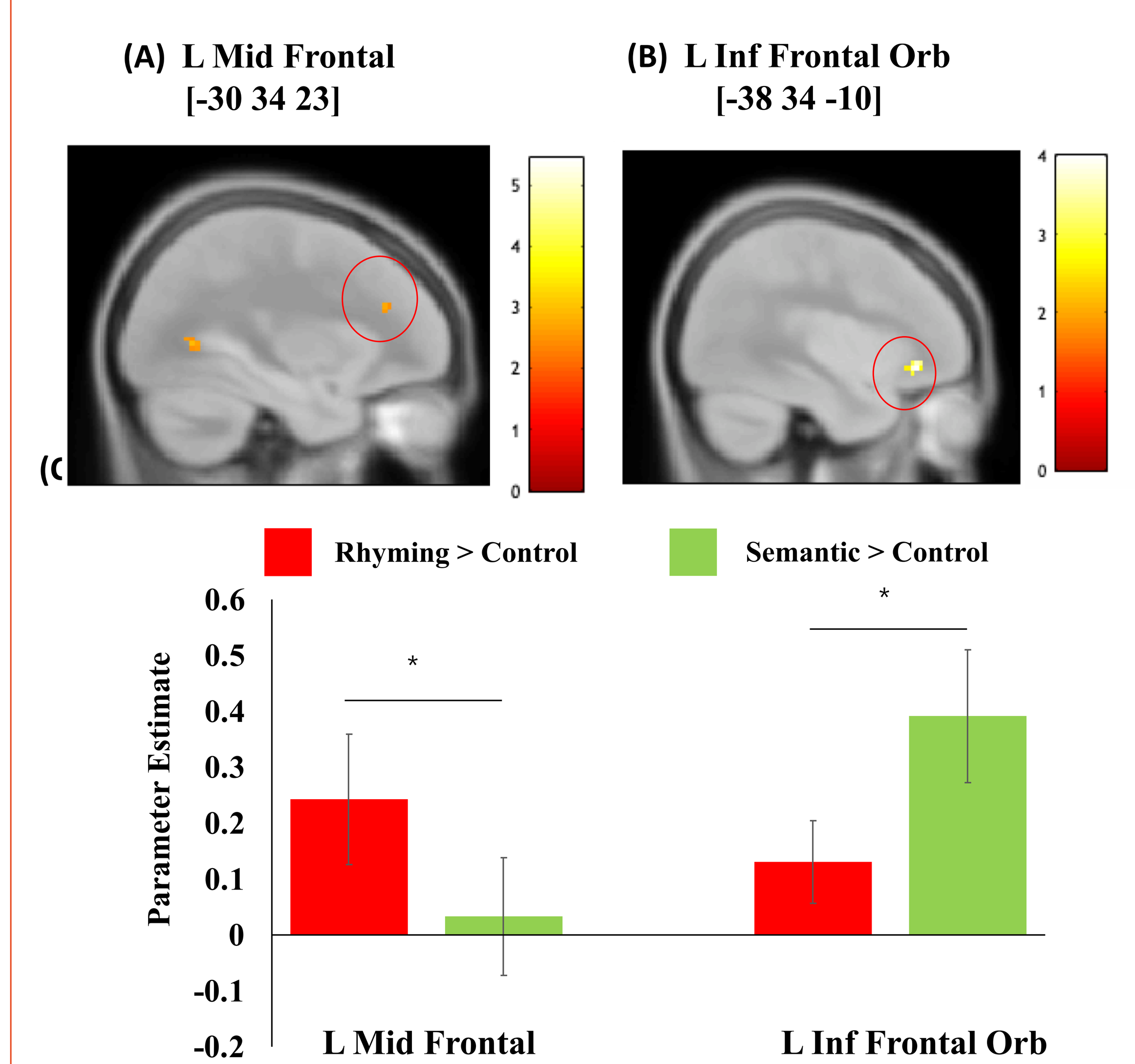


Figure 4. Within Subject Analysis of Task Conditions

Within subject paired t-test showed significantly greater activation in L Mid Frontal (-30 34 23) for the contrast Rhyming > Semantic (A) (uncorrected p<0.01, k>15) and L Inf Frontal Orb (-38 34 -10) for the contrast Semantic > Rhyming (B) (uncorrected p<0.01, k>15).

(C) shows bar graph of the different levels of activity observed in L Mid Frontal for the contrast Rhyming > Control (red) and in L Inf Frontal Orb for the contrast Semantic > Control (green).

PPI Analysis Results

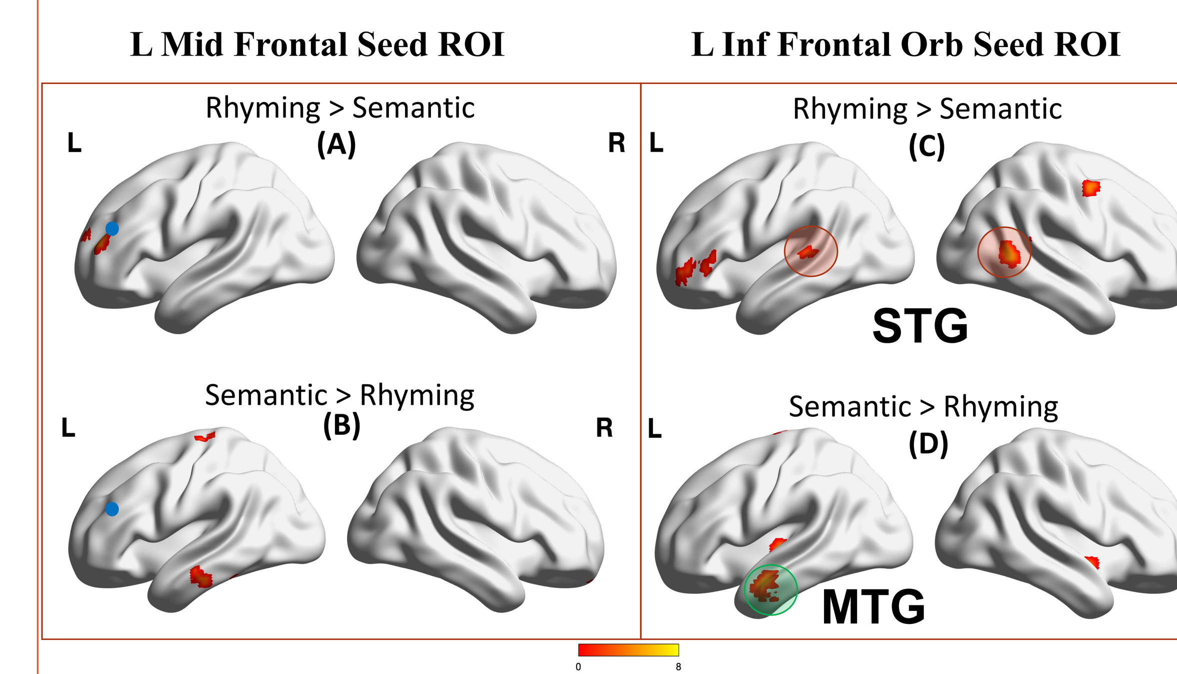


Figure 5. PPI results

PPI results when seeding from L Mid Frontal (blue seed) (A and B) and L Inf Frontal Orb (yellow seed) (C and D) in the Rhyming > Semantic and Semantic >Rhyming contrasts at p<0.01 with cluster size k>25.

Conclusions

❖Double dissociation between phonological and semantic tasks occurs in left frontal areas. Left Mid Frontal region shows greater activity during phonological processing, while Left Inf Frontal Orb region shows greater activity during semantic processing.

❖The results of PPI analysis conducted to assess left Inf Frontal Orb functional connections reveal enhanced coupling with bilateral STG in rhyming vs. semantic task and with left MTG for semantic vs. rhyming task condition.

❖Our preliminary findings suggest that by the age of 4-6 years, typically developing children already established the fronto-temporal network specialized for phonological (rhyming judgment) and semantic processing (meaning judgment).

References

1. Bach, S., Brandeis, D., Hofstetter, C., Martin, E., Richardson, U., Brem, S., 2010. Early emergence of deviant frontal fMRI activity for phonological processes in poor beginning readers. Neuroimage 53, 682–693. https://doi.org/10.1016/j.neuroimage.2010.06.039

2. Cao, F., Peng, D., Liu, L., Jin, Z., Fan, N., Deng, Y., Booth, J.R., 2009. Developmental differences of neurocognitive networks for phonological and semantic processing in Chinese word reading. Hum. Brain Mapp. 30, 797–809. https://doi.org/10.1002/hbm.20546

3. Liu, L., Cao, F., Peng, D., Deng, Y., Jin, Z., Booth, J.R., Fan, N., 2008. Developmental differences of neurocognitive networks for phonological and semantic processing in Chinese word reading. Hum. Brain Mapp. 30, 797–809. https://doi.org/10.1002/hbm.20546

4. Weiss, Y., Cweigenberg, H.G., Booth, J.R., 2018. Neural specialization of phonological and semantic processing in young children. Hum. Brain Mapp. 39, 4334–4348. https://doi.org/10.1002/hbm.24274

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