

Functional Imaging of Speech Production and Fine Motor Skill in Children with Persistent Speech Delays

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Background

-Speech production deficits in children with Persistent Speech Delay (PSD) can impact not only intelligibility, but language, literacy, educational outcomes, and family interactions.^{1, 2, 3}

-Fine motor differences have been reported in young children with Speech Delay as well, suggesting that such deficits may reflect a general neurodevelopmental delay.^{2,4,5}

-Both speech and fine motor praxis require advanced motor control and may be sensitive markers of a general neurodevelopmental delay.⁶

-PSD, the persistence of speech sound deletions and substitutions of unknown origin in school-aged children⁷, may be a clinically sensitive sign of more generalized aberrant neurological development.

-The probability of normalization of PSD markedly declines after 8.5 years of age.⁸

-Children with speech errors limited to speech sound distortions may also demonstrate general motor deficits.⁹

-This study examined the neural substrates supporting speech and fine motor praxis in children with PSD.

Method

Participants: 12 children with PSD ages 5-9, 4F

Control Group: 12 children with typical speech development (TSD) ages 6-10, 4F

Procedure: Participants completed the Syllable Repetition Task (SRT)¹⁰ and a Fine-motor Praxis Task (FMPT) during fMRI scanning. All scans lasted 11 seconds.

Behavioral Testing: All participants completed standardized speech and language assessments including the Goldman-Fristoe Test of Articulation-2 (GFTA-2)¹¹, the Clinical Evaluation of Language Fundamentals-4 (CELF-4)¹², and the Comprehensive Test of Phonological Processing (CTOPP)¹³. Fine-motor praxis was assessed with the Purdue Pegboard Test¹⁴.

fMRI Task Design

Syllable Repetition Task (SRT):

-The speech production paradigm used in this study consisted of an active condition where participants heard an auditory stimulus to repeat. Stimuli consisted of 2, 3, or 4 syllables, such as "bama" or "nadamaba." Only early developing consonants /b, d, m, n/ were used in the stimuli.

-The control condition was listening to the same auditory stimulus without response; the contrast highlighted speech production.

-Responses were recorded and scored to assess speech accuracy and ensure compliance.

-fMRI data were acquired at 3T using a sparse acquisition approach so that auditory stimuli were presented and verbal responses were recorded during the silent intervals.

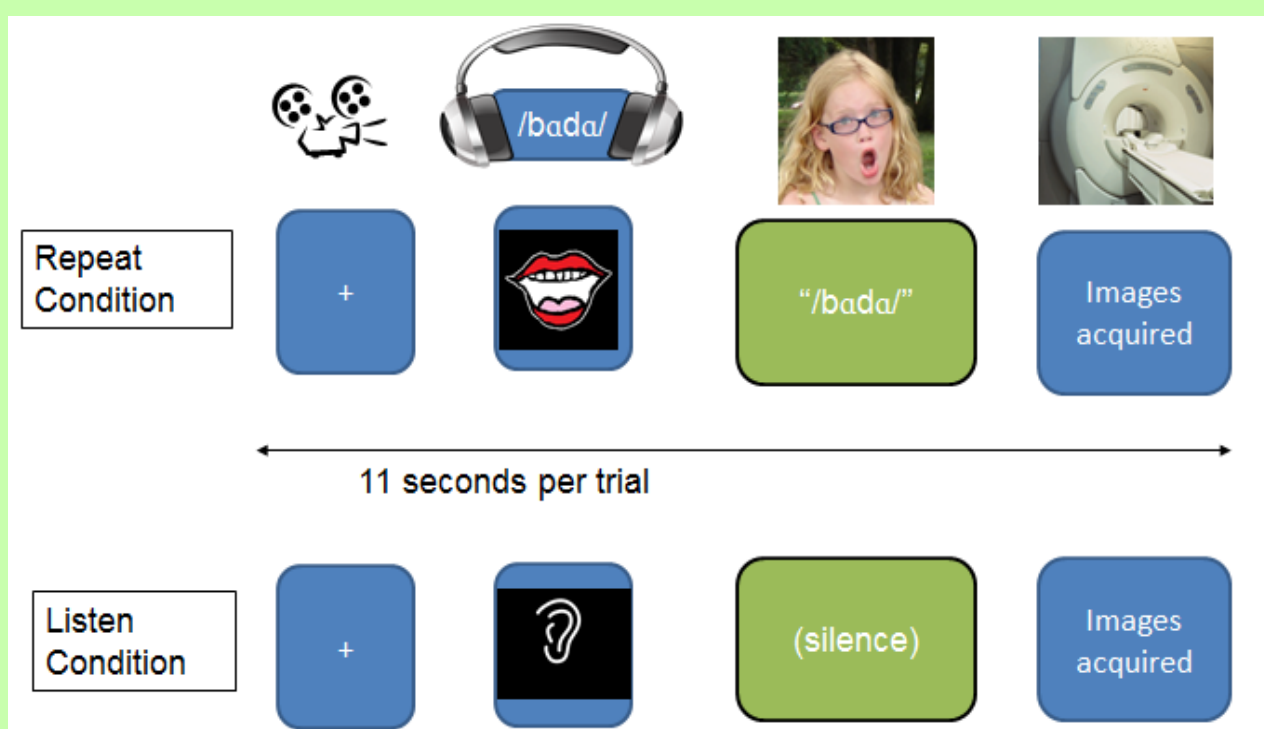


Figure 1: Overview of the SRT paradigm

fMRI Task Design, contd.

Fine-motor Praxis Task (FMPT):

-Participants heard a sequence of 1-4 tones then tapped sequential fingers to the thumb bilaterally, matching the number of finger taps to the number of tones.

-The control condition was passive listening to the same tones without response; the contrast isolated neural activity associated with fine-motor praxis.

-Participants were videotaped to ensure compliance.



Figure 2: Overview of the FMPT

fMRI Data Analysis

-After spatial normalization into MNI space a general linear model and random-effects analysis determined significant group activations using FSL.

Region of Interest (ROI) Analysis:

-Regions were defined based on the combined composite map of both groups.

-Large clusters were divided anatomically using Harvard-Oxford cortical and subcortical atlases.

-Mean z-scores were compared between groups in each ROI.

-A correlation analysis was also conducted on the SRT data to identify the ROIs that were significantly correlated with in-scanner task performance.

Results: Behavioral Testing

-Children with PSD scored significantly lower than children with TSD on the GFTA-2, the CELF-4, and the Phonological Awareness (PA) and Phonological Memory (PM) tasks in the CTOPP (*p<.01).

	GFTA-2*	CTOPP PA *	CTOPP PM *	CELF-4*
PSD	79.8(16.9)	81.1(16.9)	83.0(17.2)	86.5(20.7)
TSD	104.9(2.9)	107.1(18.7)	103.7(11.1)	108.5(16.3)

Table 1: Mean Scores (Standard Deviation) for Behavioral Tests for the PSD and TSD groups

SRT Results (during scanning)

PSD mean=10.6 (SD=3.5)

TSD mean=12.5 (SD=3.0)

p=0.16

Purdue Pegboard (both hands)

PSD mean= 6.83 (SD=1.5)

TSD mean=8.42 (SD=1.7)

p=0.024

Acknowledgements

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Results

SRT Results

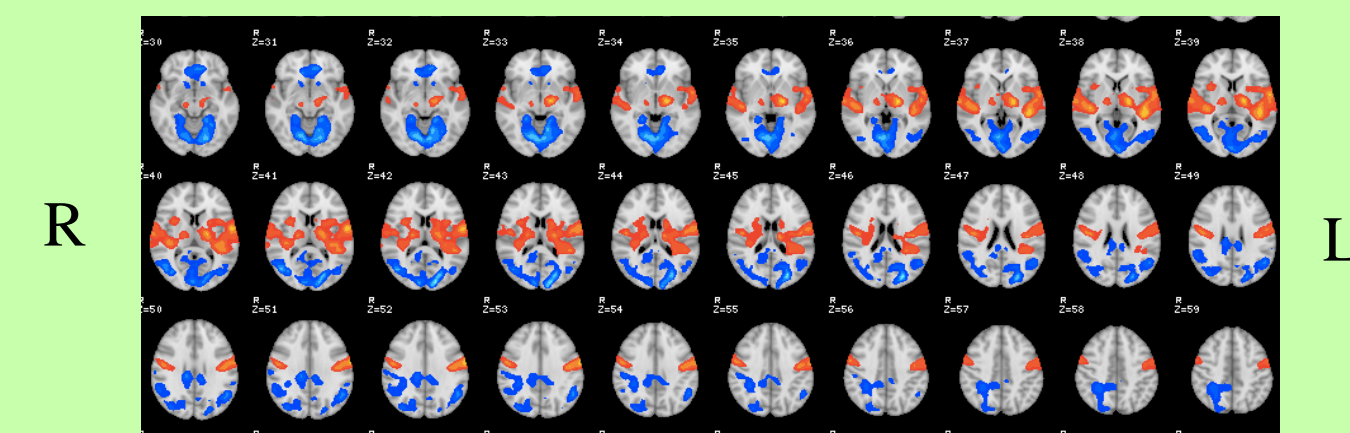


Figure 3: Group map of PSD performing SRT; **Repeat>Listen** [z(voxel-wise)>2.3, cluster corrected p<.05]

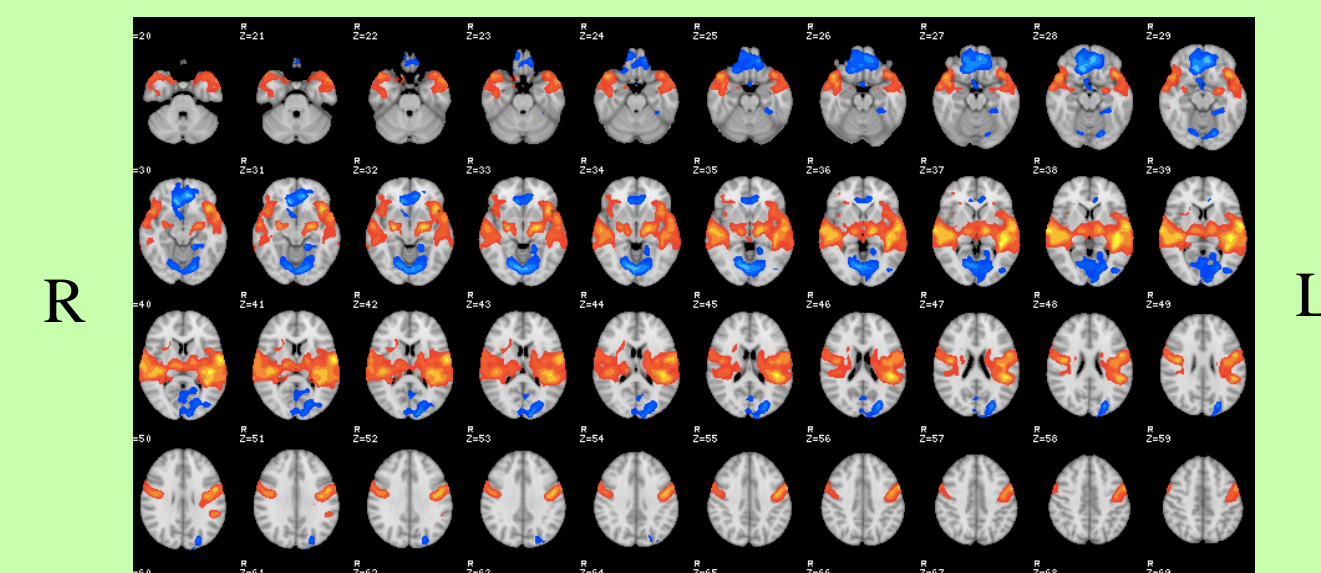


Figure 4: Group map of TSD performing SRT; **Repeat>Listen** [z(voxel-wise)>2.3, cluster corrected p<.05]

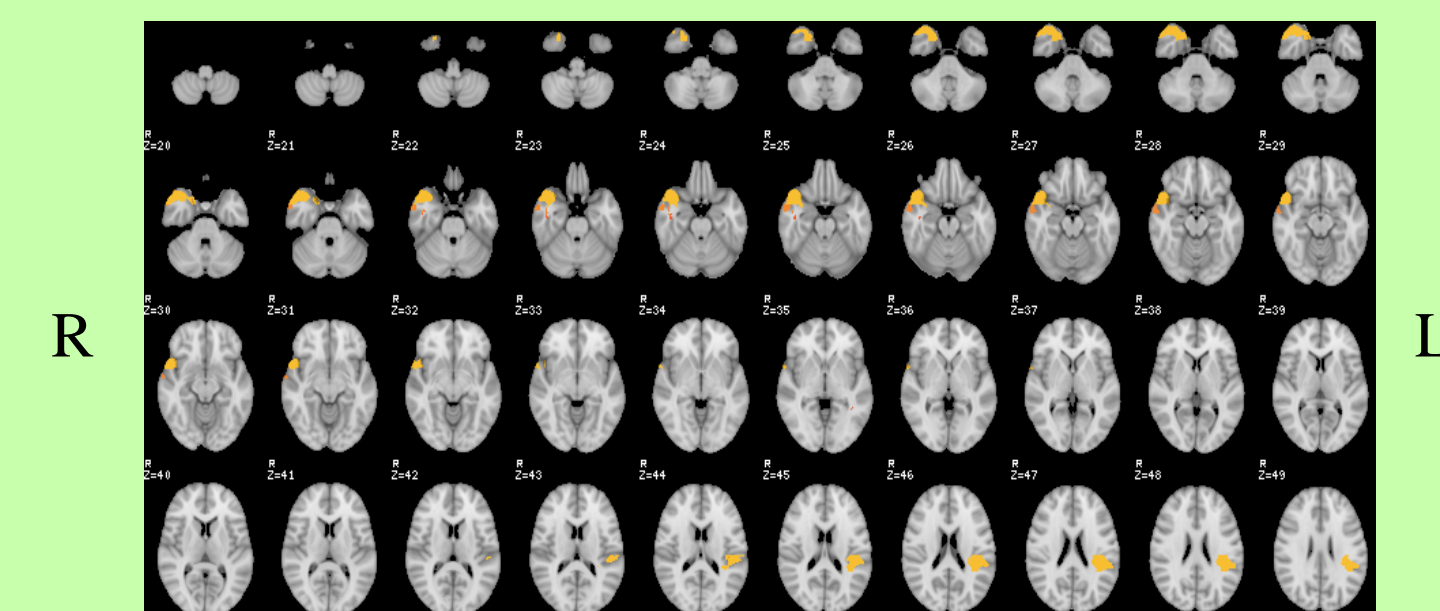


Figure 5: ROI with higher mean z for Controls>PSD: R Temporal Pole, L temporal parietal junction (TPJ), p<.05

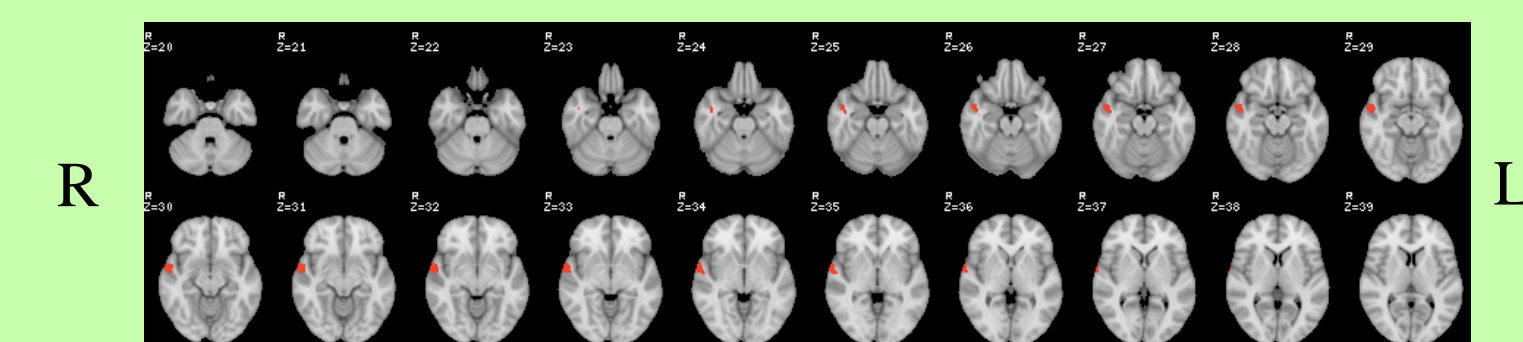


Figure 6: Region positively correlated with total SRT score (across both groups) (R anterior superior temporal gyrus/temporal pole) p<.05

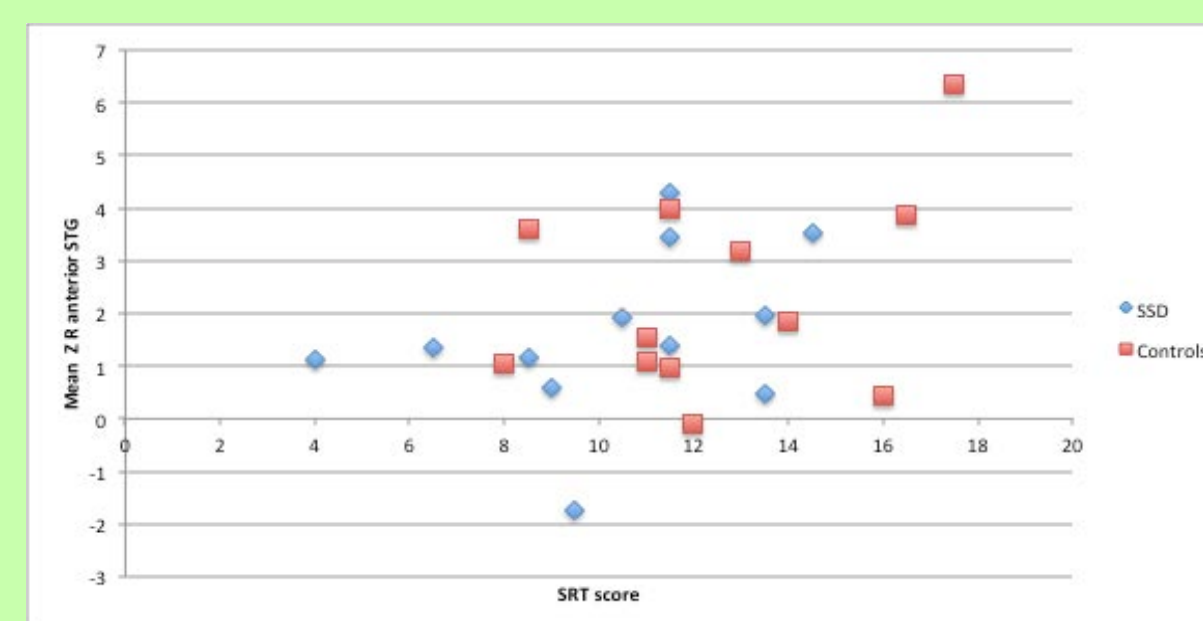


Figure 7: Scatterplot of mean SRT score and activation in the R anterior superior temporal gyrus

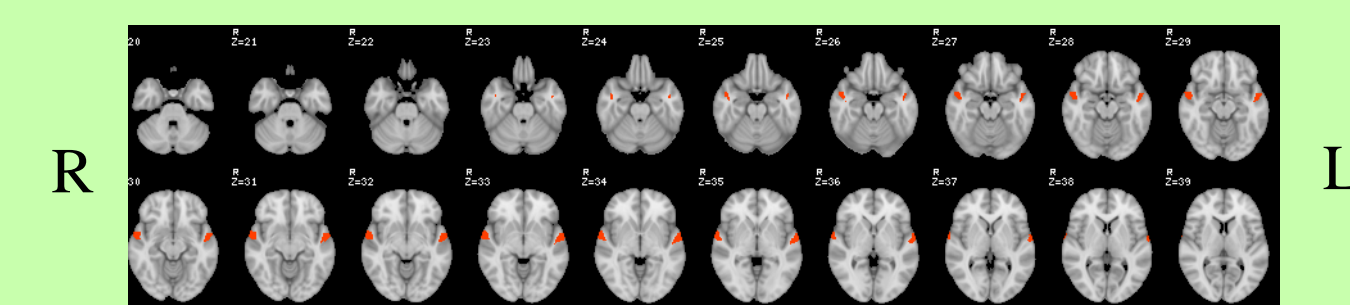


Figure 8: Regions positively correlated (bilateral temporal poles) with the 4 syllable SRT score, p<.05

SRT Summary

-In group comparison using ROI, children with TSD showed higher activation in the L temporal parietal junction and R temporal pole. (fig. 5)

-Activation of the R anterior superior temporal gyrus/temporal pole positively correlated with the SRT scores. (fig. 6)

-Based on correlation results for SRT performance we further examined the group comparison ROI results for the left temporal pole and left inferior frontal gyrus; the p value for both comparisons was 0.06.

FMPT Results

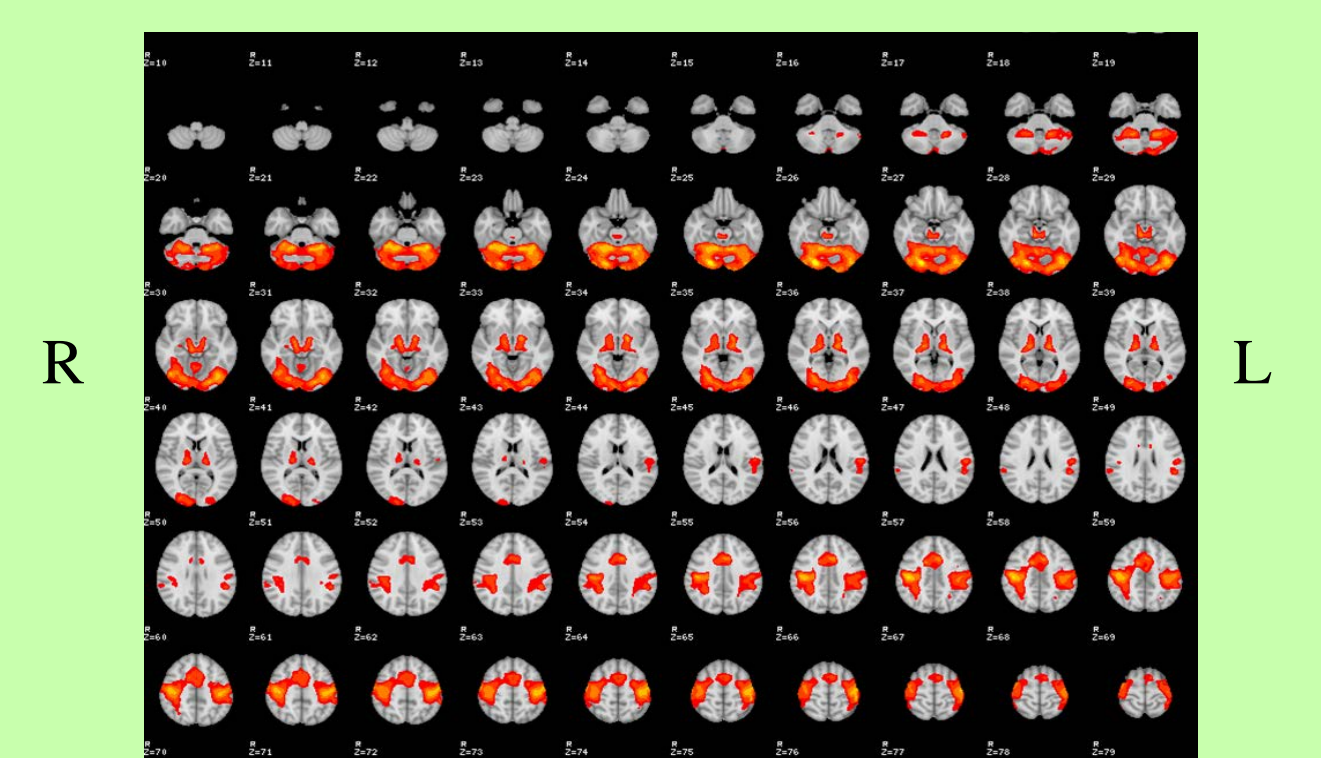


Figure 9: Group map of PSDs performing FMPT **Tap>Rest** [z >2.3, p<.05 cluster-based inference]

Results cont.

FMPT cont.

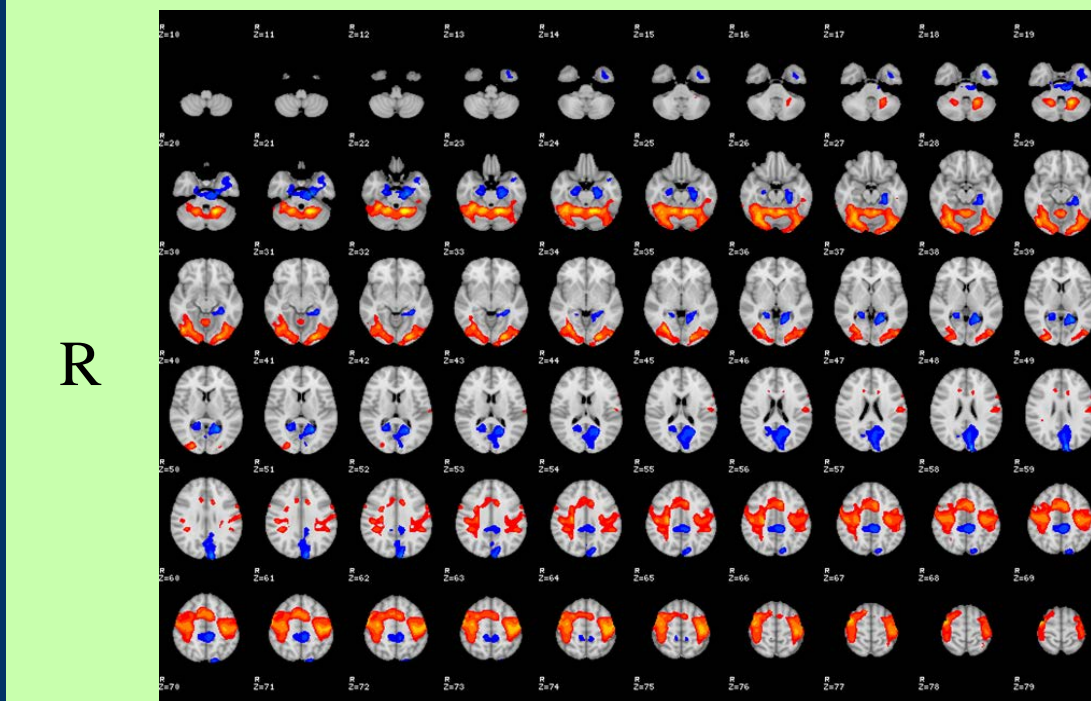


Figure 10: Group map of TSD performing FMPT **Tap>Rest** [z >2.3, p<.05 as determined by cluster-based inference]

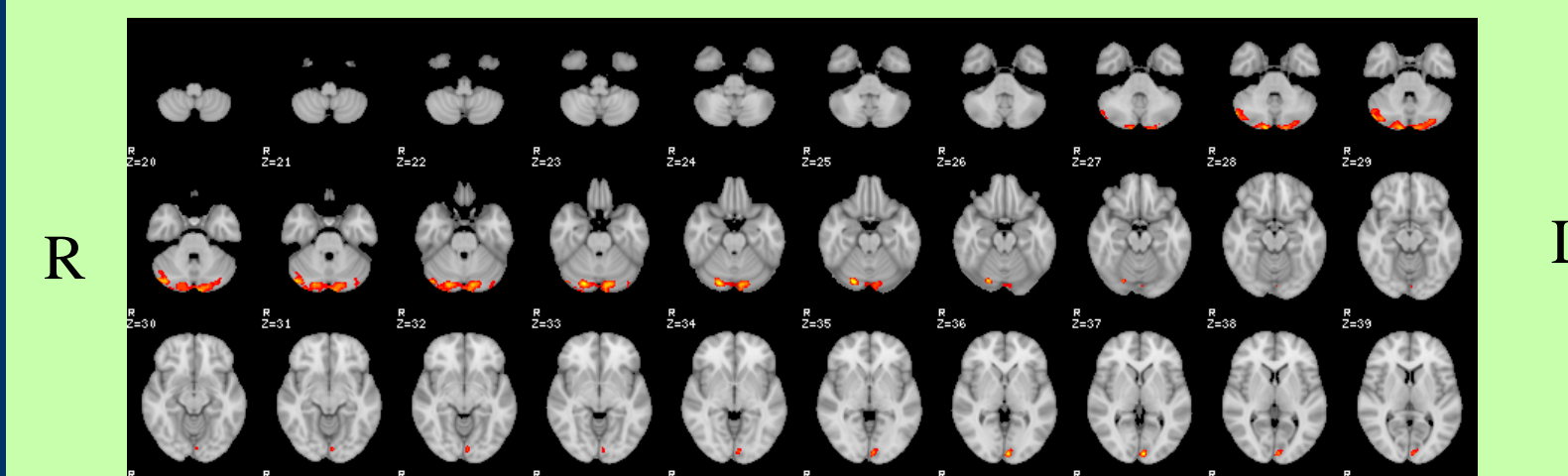


Figure 11: Group comparison with higher mean z for Controls>PSD; [z >2.3, p<.05 as determined by cluster-based inference]

-Only regions of bilateral cerebellum significant in group comparisons.

Discussion

-Significant differences were observed between the 2 groups across behavioral measures of speech, language, phonological processing, and fine motor praxis.

-Despite the known behavioral differences both groups demonstrated similar performance on the paradigm tasks.

-During the SRT children with PSD had less activation while repeating syllables in the right temporal pole and the left TPJ.

-Right temporal pole thought to be associated with object semantic representations¹⁵ and some evidence also suggests with reaction times in naming¹⁶; TSD group may be attempting to associate meaning with nonsense word stimuli more than PSD.

-A positive correlation was also noted between SRT performance and the anterior superior temporal gyri/temporal poles. Reduced R temporal pole grey matter volume reported with suspected childhood apraxia of speech (KE family).¹⁷

-In contrast, under-activation of the R temporal pole and over activation of L temporal pole noted during listening/processing in children with a history of speech sound errors.¹⁸

-With the FMPT, the only significant differences between the groups were in the cerebellum with the PSD group engaging the cerebellum less than the TSD group; under activation of the cerebellum has also been observed in children with general developmental motor coordination disorder during a fine motor task.¹⁹

-Both the SRT and FMPT were selected to minimize the potential confounder of performance; more challenging tasks may detect additional differences.

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