Neural Signatures of Phonological Working Memory and Grammatical Processing in Autism Spectrum Disorders

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Introduction

Autism spectrum disorder (ASD) is characterized by core deficits in social communication which can include atypical language development. Diagnostic criteria for ASD include the late onset or absence of spoken language in children; the severity of these deficits have also been related to long term prognosis of ASD symptom severity [1]. Behavioral studies have documented reduced phonological working memory capacity [2,4] and impaired grammatical processing in children with ASD [3,4]. The current study is the first to investigate the neural characteristics of these two key language functions in children with ASD and their typically developing (TD) counterparts.

Experiment 1 investigated children's **phonological working memory** using a nonword repetition task. The task taps into children's ability to process, store and repeat the verbal information in speech and is an effective clinical assessment for developmental language disorders [5,6].

Experiment 2 investigated children's **grammatical processing** by testing their ability to detect a variety of morphosyntactic errors in different sentences. The task was modeled after the Rice / Wexler Test of Early Grammatical Impairment (2001) [7].

Participants

Standard Assessments:
- Nonverbal IQ: Kaufman Brief Intelligence Test (KBIT; Kaufman & Kaufman, 2004)
- Language Abilities: Clinical Evaluation of Language Fundamentals (CELF-4; Semel, et al, 2003)
- Comprehensive Test of Phonological Processing – Nonword Repetition (CTOPP-NWR; Wagner, et al., 1999)
- Grammar: Test for Reception of Grammar (TROG-2; Bishop, 2005)

Autism Diagnosis:
- DSM-IV criteria (American Psychiatric Association, 1994)
- Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000)

Experiment 1: 11 ASDs and 11 matching TDs

| Groups	Age (years)	Nonverbal IQ	CTOPP-NWR**	CELF ¶	ADOS ***
ASD (3 girls)	13.26 (2.51)	111.82 (18.26)	8.00 (2.14)	103.45 (18.53)	8.89 (3.08)
TD (3 girls)	12.75 (3.33)	115.91 (15.88)	10.6 (1.84)	115.82 (13.86)	1.13 (1.29)

Experiment 2: 16 ASDs and 16 matching TDs

Groups	Age (years)	Nonverbal IQ	TROG**	CELF	ADOS ***
ASD (4 girls)	12.86 (2.68)	111.38 (16.99)	100.44 (11.62)	103.63 (17.17)	9.64 (3.71)
TD (5 girls)	11.40 (3.75)	110.50 (17.61)	116.27 (12.80)	105.53 (11.31)	1.82 (2.27)

¶: $p < .1$; **: $p < .01$; ***: $p < .001$. Otherwise, p's > .2
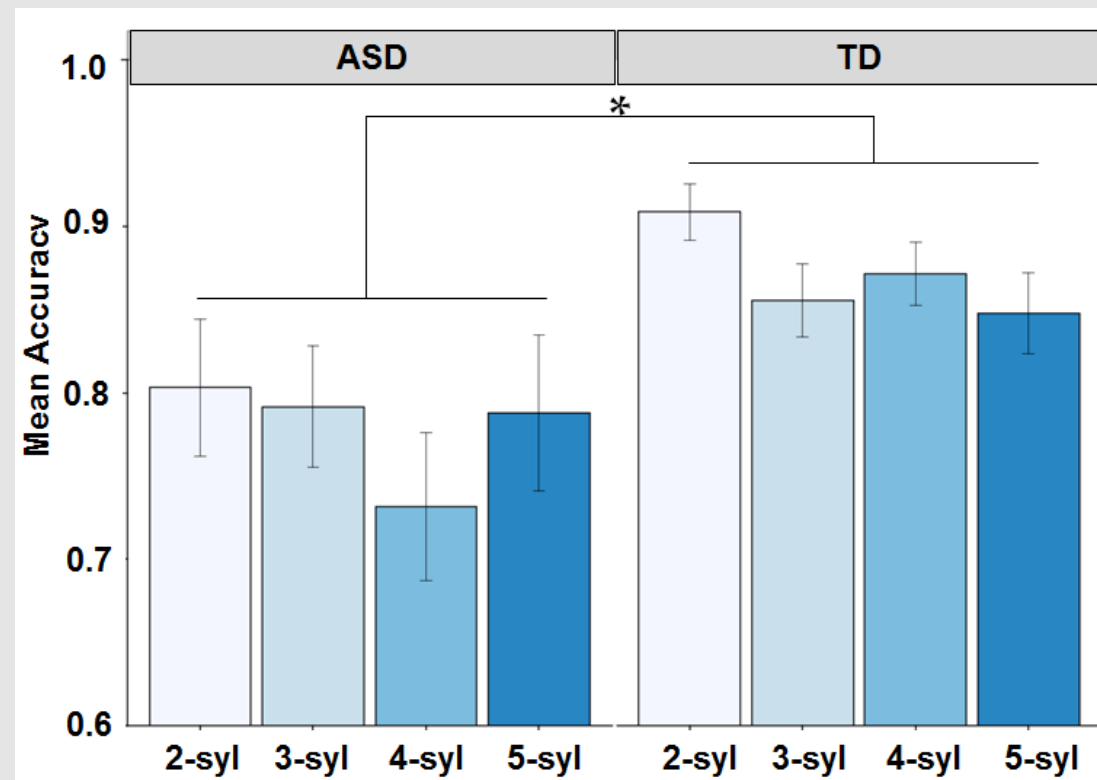
Experiment 1: Nonword Repetition

- 96 pseudowords in 2, 3, 4 or 5-syllable length
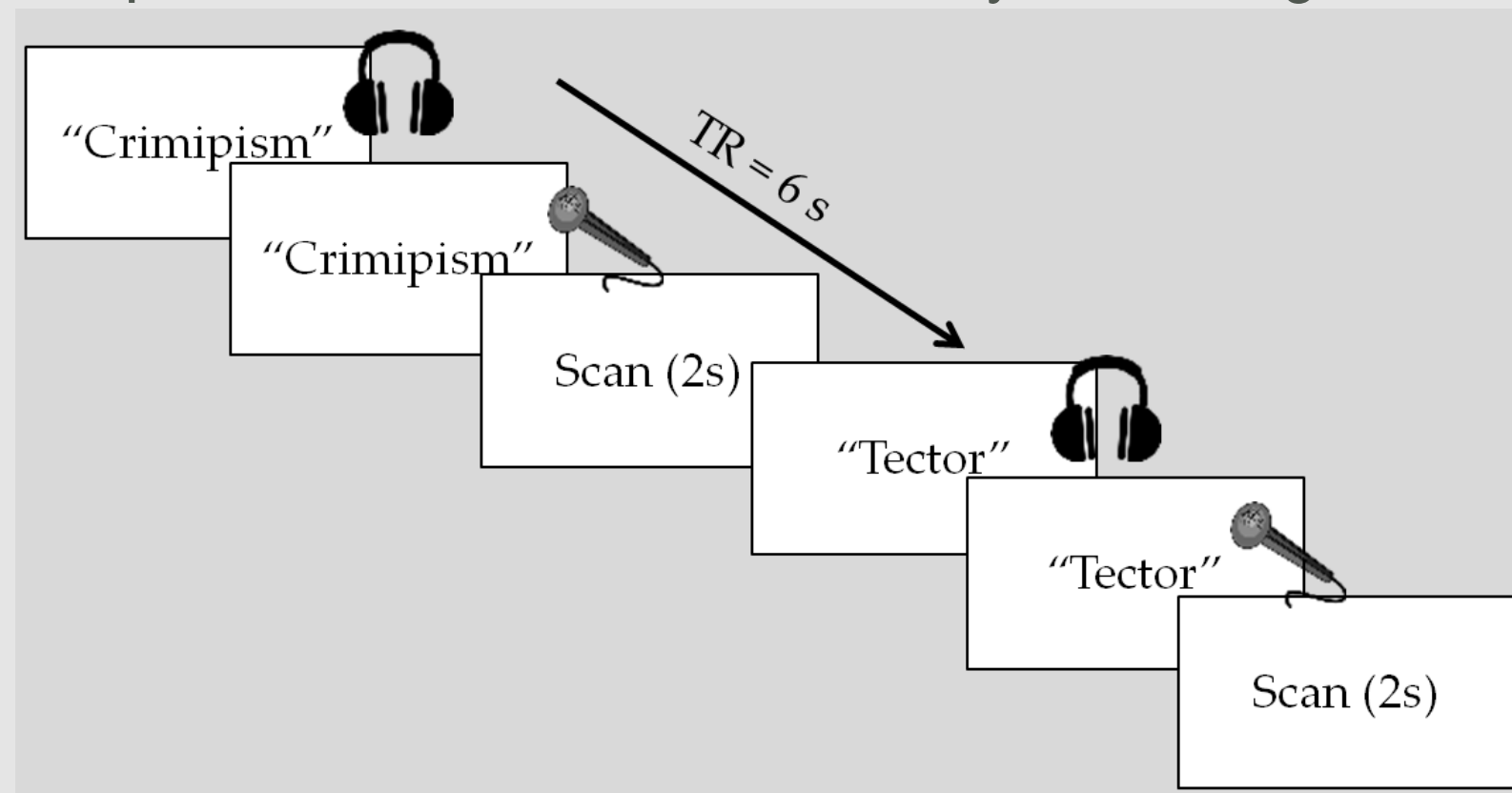
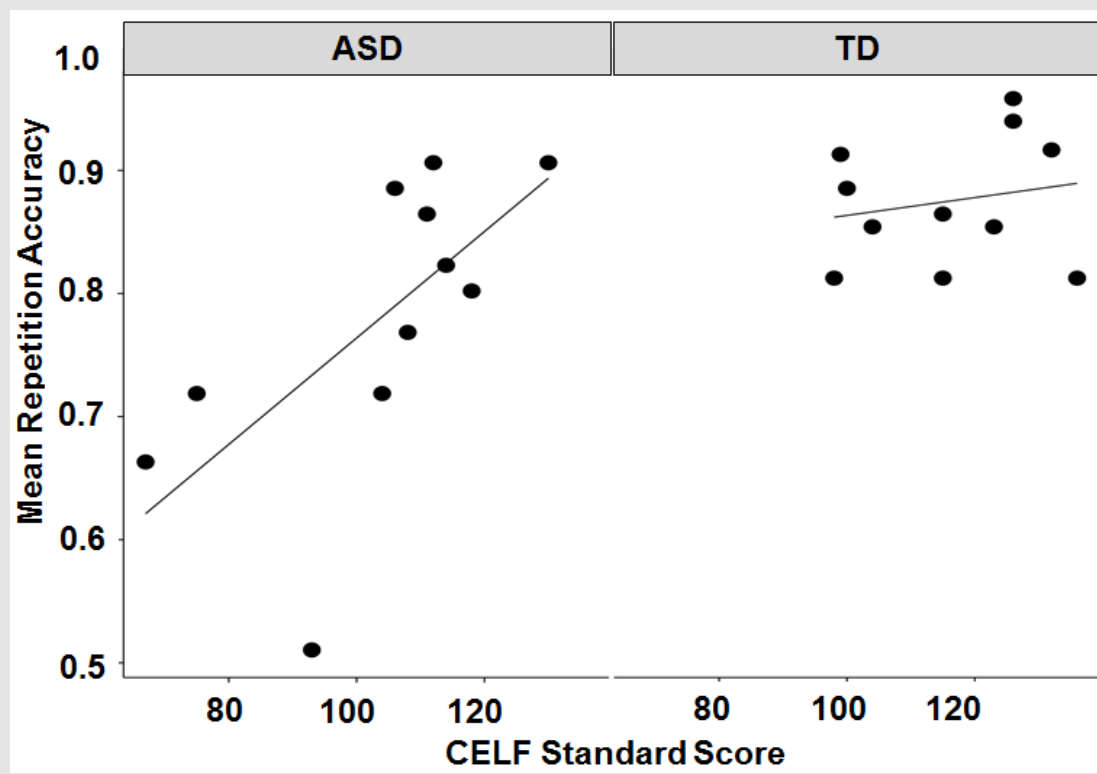
Behavioral Results

- Children performed less accurately for increased syllabic length ($p < .05$);

- TD group overall performed more accurately than ASD group (0.87 vs. 0.78, $p < 0.05$).

- Nonword Repetition Accuracy correlates with children's CELF scores ($r = .61$; $p < .005$) across all participants and also within the ASD group ($r = .66$, $p < .05$).

Imaging Results
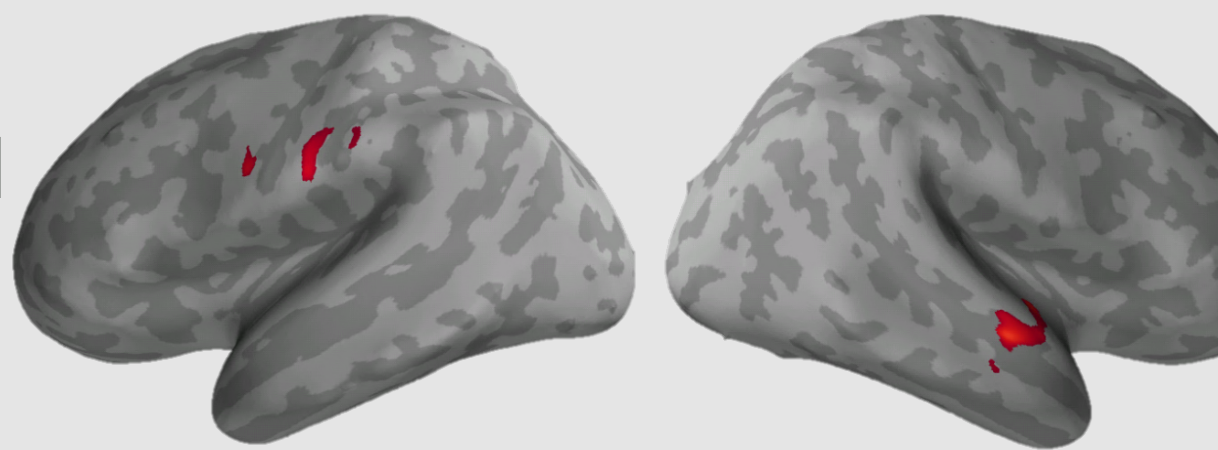
Overall Parametric Effect
Increasing syllabic length was associated with increasing activation in left superior temporal gyrus (STG) and right supplementary motor area (SMA) (FDR < .05, $q < .005$)
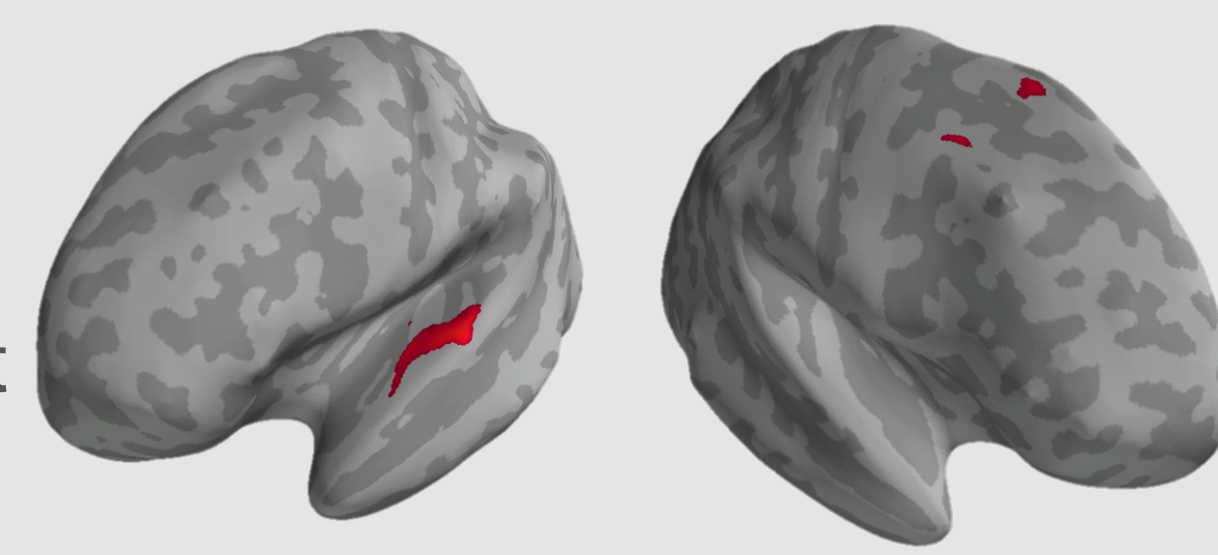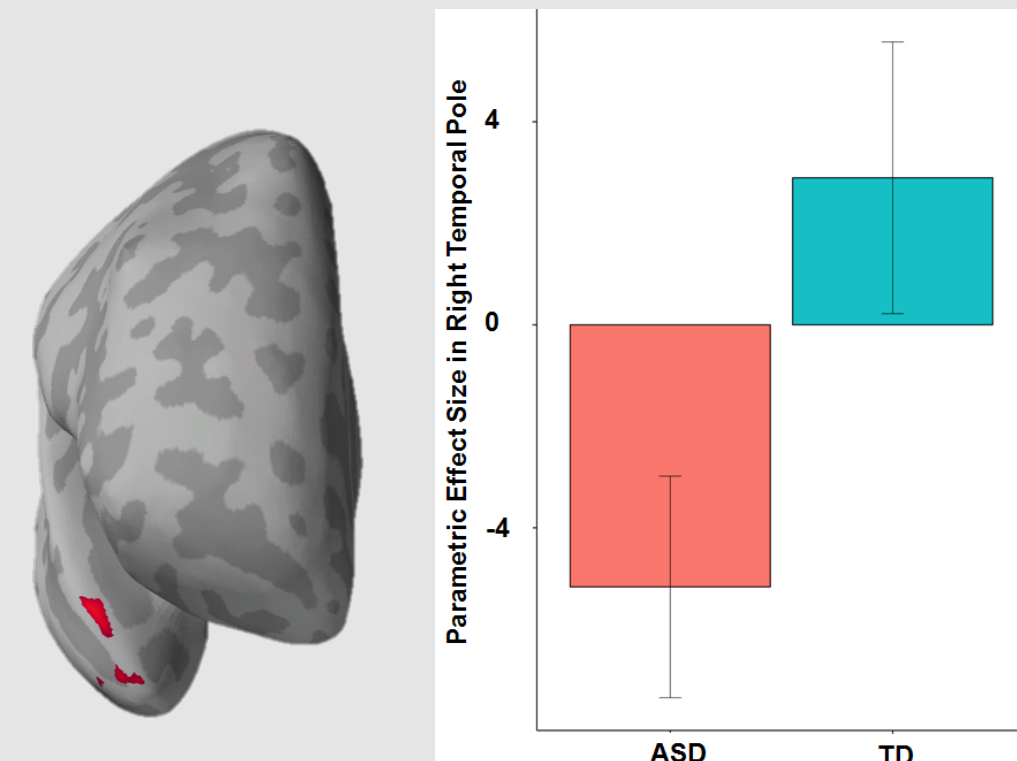

Group Comparison
- Task vs. Rest:
Compared to ASD, TD showed stronger activation in left precentral and postcentral gyri, as well as right STG (FDR < .05, $p < .005$).

- Parametric Effect:
Compared to ASD, TD showed larger increase of activation associated with syllable length in right temporal pole (FDR < .05, $p < .005$).

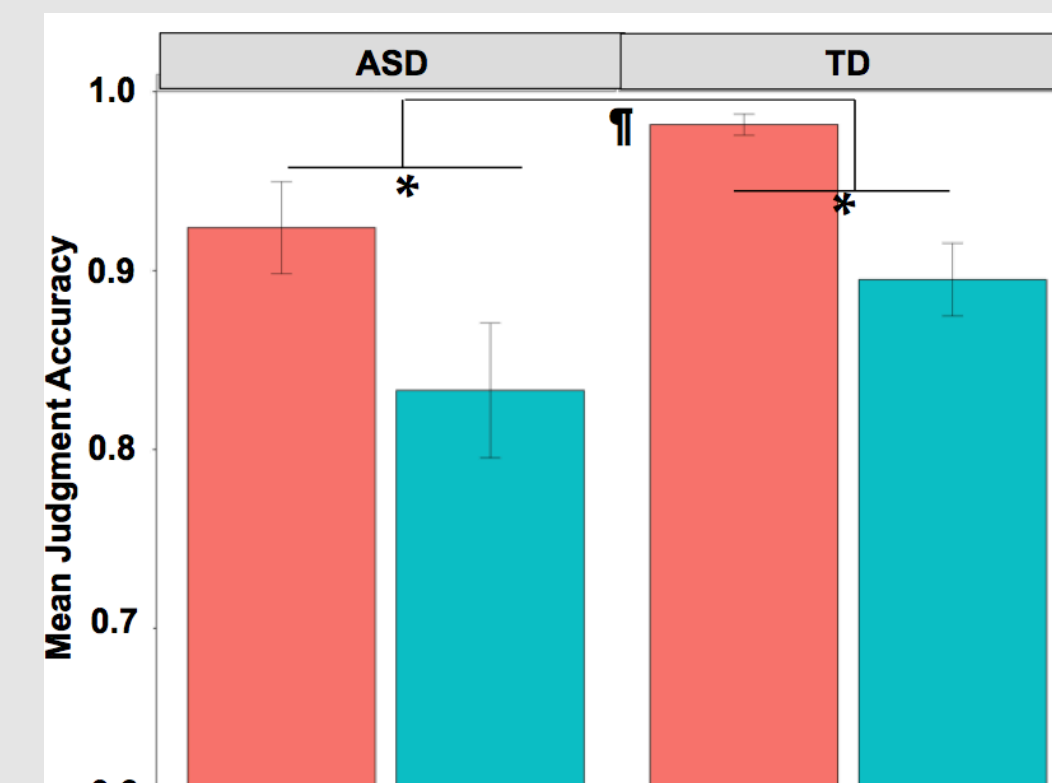## Experiment 2: Grammaticality Judgment

64 target sentences containing morphosyntactic errors randomly intermixed with grammatically correct sentences
- Tense marker dropping errors (e.g. *He always copy* his brother* – also known as optional infinitive errors (OI))
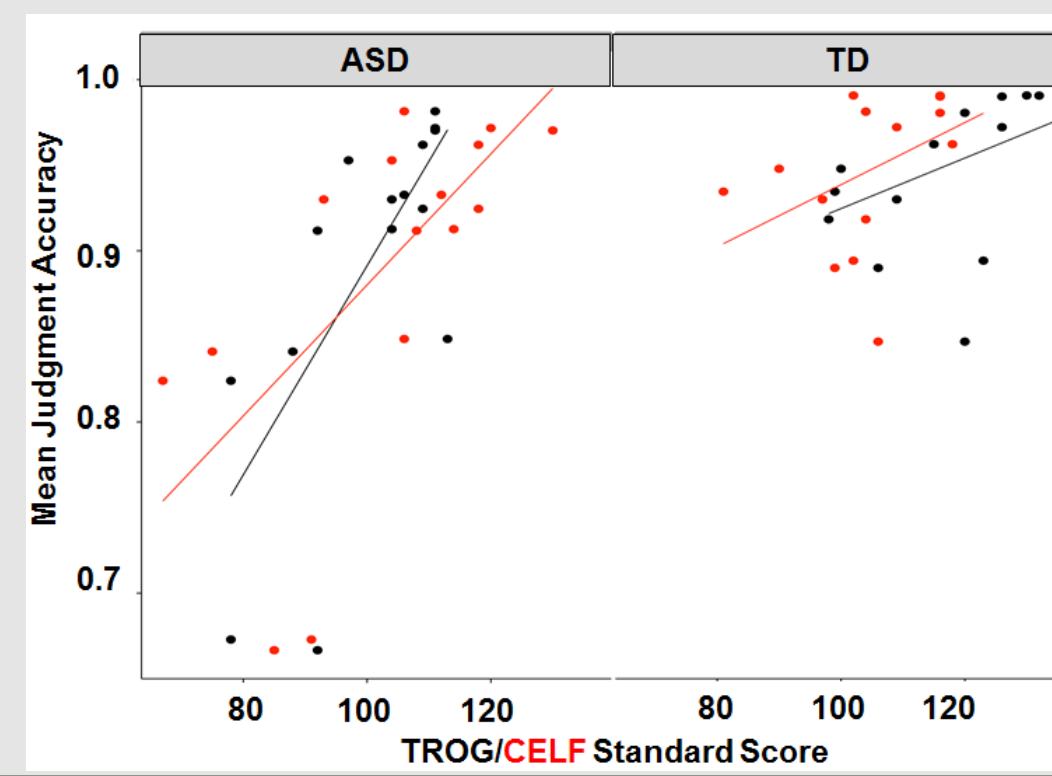- General error (e.g. *She are* buttoning her shirt*, GE)
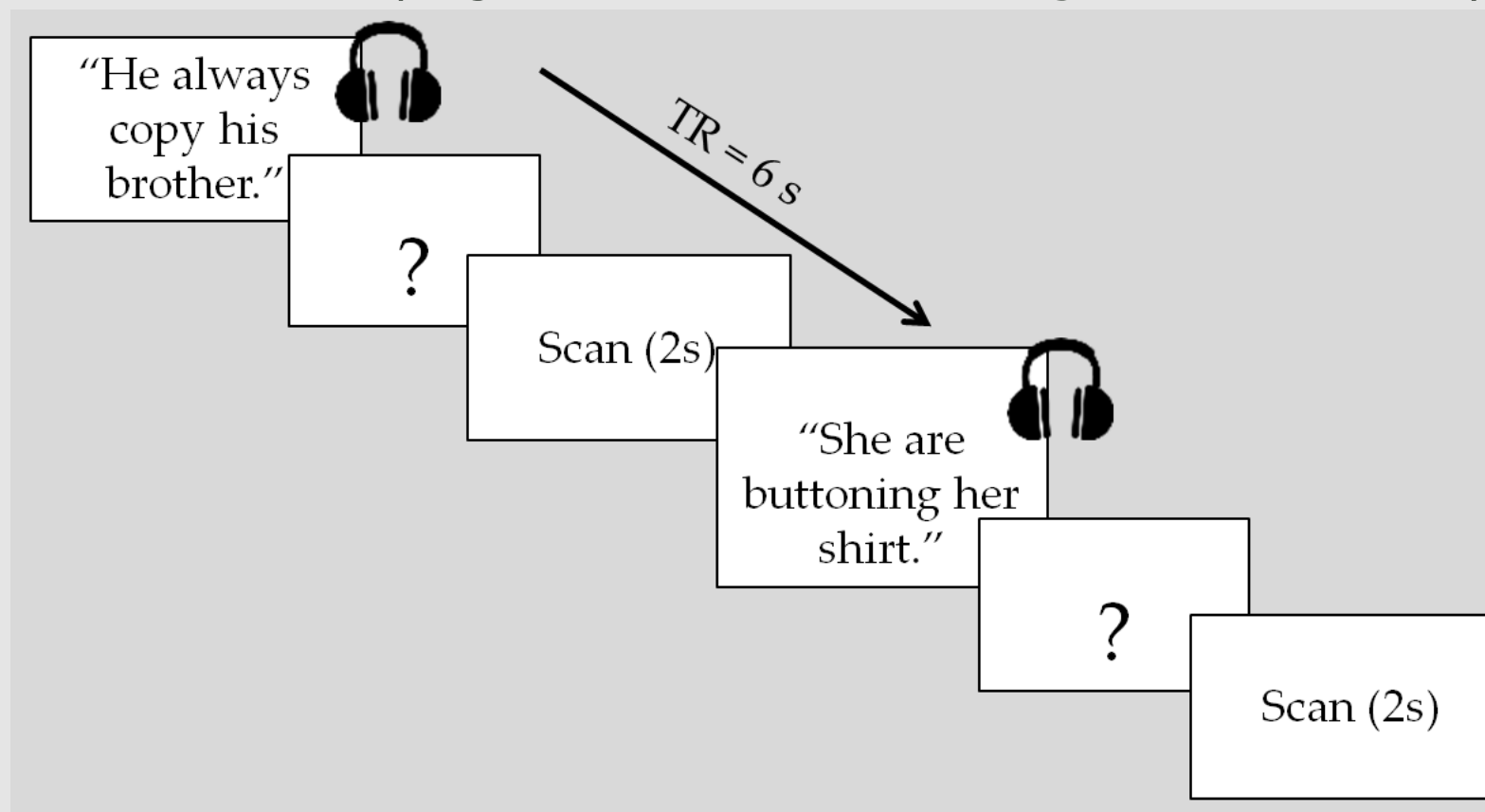
Behavioral Results

- Children performed less accurately in detecting OI-type of errors ($p < .001$)

- TD group performed marginally better than ASD group (0.95 vs. 0.89, $p = .076$).

- Grammaticality Judgment Accuracy significantly correlates with TROG ($r = .63$, $p < .001$) and CELF scores ($r = .59$, $p < .001$), and also within the ASD group (r's > .65, p's < .005)
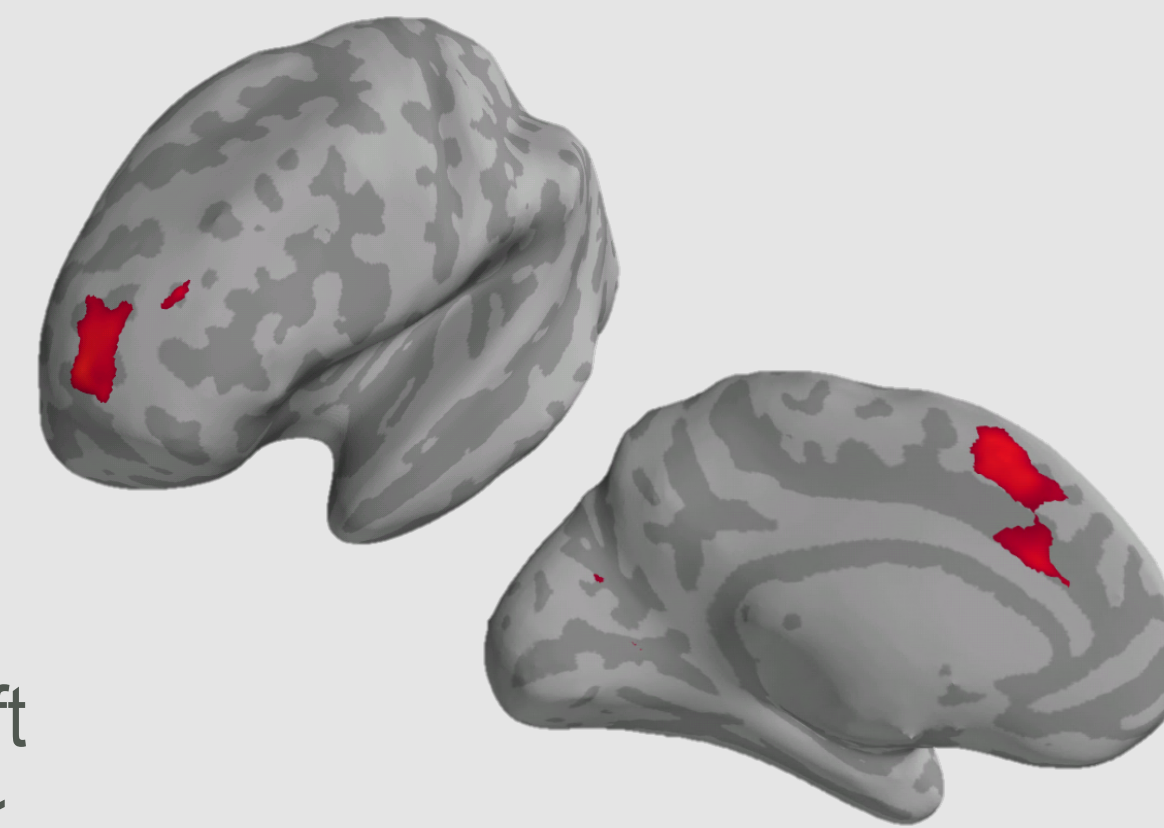

Imaging Results

Overall OI vs. GE Effect
Across two groups and within each group, children did not display different neural responses to OI vs. GE types of errors
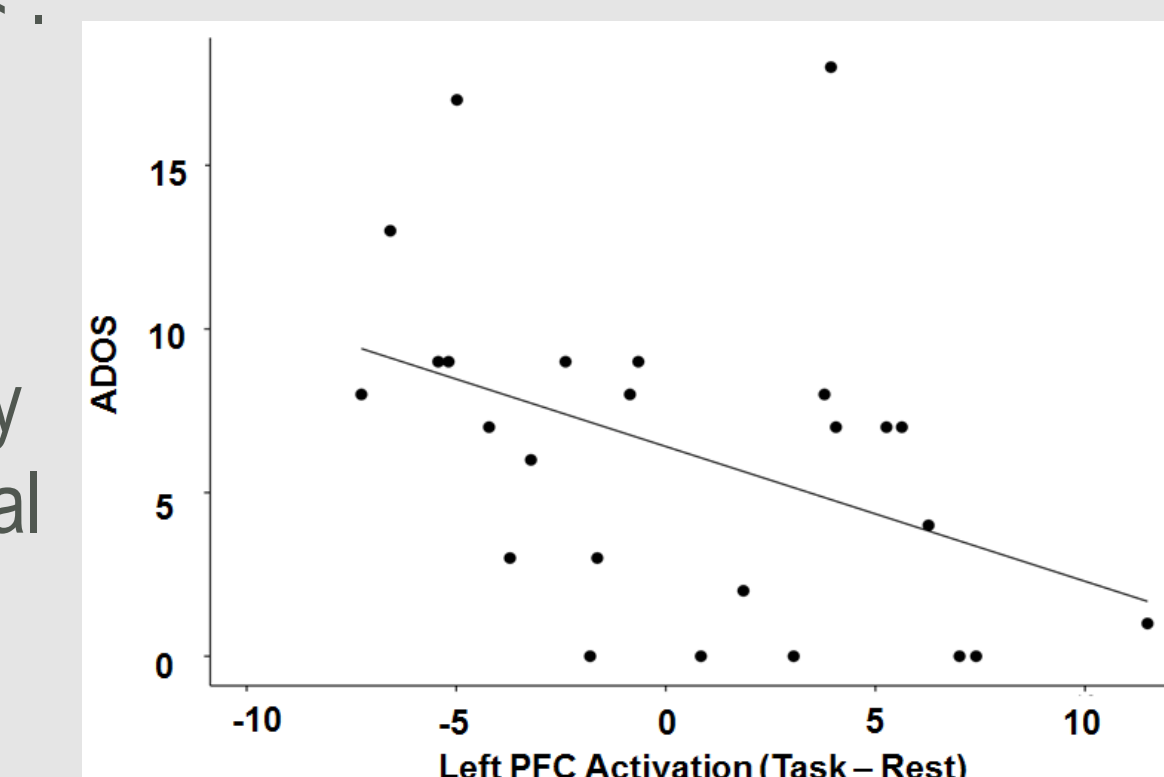
Group Comparison
- Task vs. Rest:
Compared to ASD, TD showed stronger activation in left prefrontal cortex and left cingulate cortex (FDR < .05, p < .005).

- Negative correlation between autism severity scores and left prefrontal cortex activation ($r = -.41$, $p < .05$)

Conclusion

The current study revealed distinct behavioral and neural profiles for children with ASD as compared to typically developing children.

As reflected in the significant correlation between the in-scanner performance and standardized language assessment performance (CELF and TROG), the two in-scanner tasks used in this study were sensitive enough to capture the language deficits within the ASD group. As expected, children with ASD displayed impaired phonological working memory as well as grammatical morphology.

Secondly, both TD and ASD groups showed activation in left STG when responding to increasing syllable length. This adds to research with typical adults which has shown that the cortical regions recruited by increasing phonological working memory load include bilateral STG, SMA and inferior frontal gyrus (IFG) [8]. However, the ASD group showed significantly less activation in right STG, indicating weaker neural recruitment for phonological processing.

Lastly, regarding grammatical processing, children with ASD exhibited much weaker activation in left prefrontal cortex and left anterior cingulate cortex. Both areas have been documented to be involved in varieties of language tasks. The correlation between ASD severity and left prefrontal cortex activation suggest the hypoactivation of the left prefrontal cortex may be implicated in difficulties with grammatical morphology found in children with ASD.

Future research will investigate subtypes of ASD group based on children's language profiles. Future research will also include comparisons with children with specific language impairment who do not have ASD with the hopes of advancing our understanding of the neural signatures of language deficits in atypical development.

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