Relationship between linguistic statistical learning and grammar development in children with Autism Spectrum Disorder

Children with autism spectrum disorder (ASD) exhibit highly variable language abilities (Kjelgaard & Tager-Flusberg, 2001). Nevertheless, the cognitive mechanism underlying the heterogeneity among ASD language profiles is still largely unknown. There is a great interest in whether statistical learning (SL), a fundamental mechanism that supports language acquisition in typically developing children (TD), is atypical in ASD. Nevertheless, research findings are mixed (e.g., Mayo & Eigsti, 2012; Scott-Van Zeeland et al., 2010; Roser et al., 2015). Furthermore, recent studies suggest healthy individuals vary in their SL ability across linguistic and non-linguistic domains, as well as across visual and auditory modalities (Siegelman & Frost, 2015; Qi et al., 2018). The current study investigates the contribution of SL across linguistic and non-linguistic domains in explaining the language variations in children with ASD.

31 children with ASD (Mean Age = 8;44, SD = 1;35; 9 Girls; Mean SCQ = 20.64, SD = 6.25) and 33 age- and gender-matched TD children (Mean Age = 9;01, SD = 1;89; 16 Girls; Mean SCQ = 2.31, SD = 1.7) completed four SL tasks: visual non-linguistic ***images***; visual linguistic ***letters***; auditory non-linguistic ***tones***; or auditory linguistic ***syllables***. Across all tasks, children were exposed to a continuous stream of stimuli. Each stream is composed of four **target triplets** and lasts about 5 minutes. In each task, children were asked to press a key for the third stimulus in a randomly chosen target triplet. The slope for change in reaction time (RT) was calculated. The exposure phase was followed by 32 two-alternative forced-choice trials distinguishing between target triplets from the exposure phase and ***foils***. Age-normed standardized scores from an auditory grammaticality judgment task (Rice, Hoffman, & Wexler, 2009) was also used to measure children's grammatical ability (ASD: Mean = 69.2, SD = 24.8; TD: Mean = 88.2, SD = 23.3, $t(31.3) = 2.41$, $p = 0.02$).

During the exposure phase, we found a marginally significant interaction between group and task domains (linguistic vs. non-linguistic) in RT slope, reflected as a greater advantage in TD over ASD for the linguistic SL tasks (faster RT acceleration), compared to the non-linguistic SL tasks (Figure 1A). During the test phase, both the TD and the ASD groups performed significantly above chance for all SL tasks (Figure 1B). Generalized mixed-level modeling on binomial accuracy data revealed better performance in TD than ASD. Multiple linear regression revealed a significant relationship between SL accuracy and grammaticality judgment score when combined across groups and SL tasks (Figure 2A). K-means clustering analysis further showed children who performed better in linguistic SL tasks also scored higher in grammaticality judgment (Figure 2B).

These results suggest children with ASD, compared to TDs, show poorer statistical learning outcomes and specific weaknesses in acquiring linguistic SL in real time. Our findings also suggest variabilities of grammatical ability in children are related to SL in the linguistic domain. Our ongoing data collection will provide associations between standardized language measures and linguistic SL in TD and ASD to verify this finding.

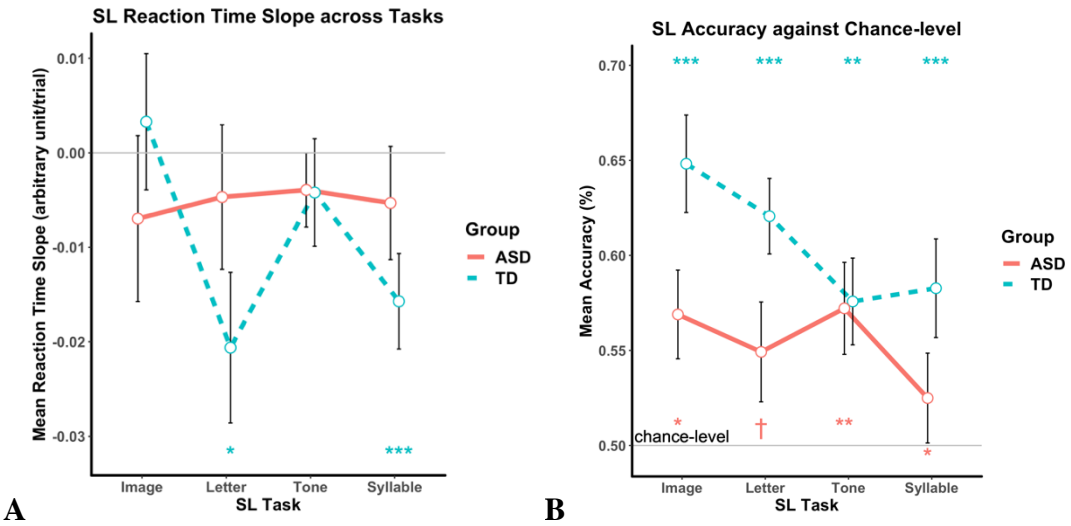

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Figure 1. (A) Mean reaction time (RT) slope during the exposure phase of statistical learning (SL) tasks. Typically developing children (TD) showed a faster RT acceleration than children with autism spectrum disorder (ASD) for the linguistic SL tasks (b = -0.02, SE = 0.01, t = -1.91, p = 0.06). Grey line represents zero (one-tailed p against zero: *p < 0.05, ***p < 0.001). (B) Mean SL accuracy in the test phase. Collapsed across tasks, the TD group showed better SL accuracy than the ASD group (b = 0.23, SE = 0.11, z = 1.98, p = 0.05). Grey line represents the chance level (one-tailed p against chance-level: $^{\dagger}p$ = 0.08; *p < 0.05, **p < 0.01, ***p < 0.001). Error bars indicate standard errors of the means (SEM).

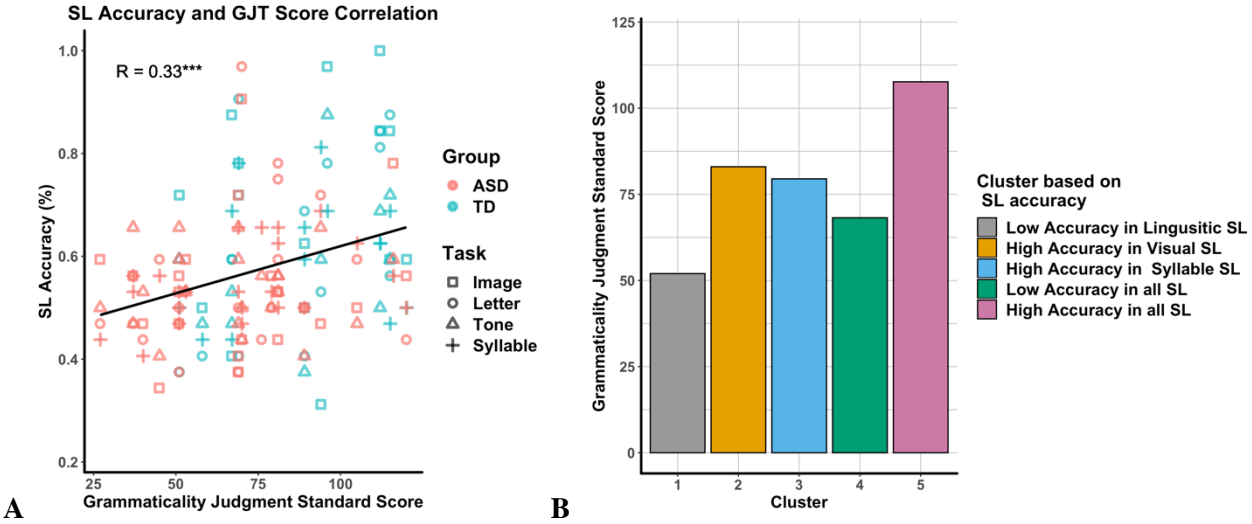

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Figure 2. (A) Pearson correlation between GJT score and SL accuracy combined across groups and SL tasks (***p < 0.001). (B) K-means clustering of all children (TD and ASD groups combined) based on SL accuracy showed different grammaticality judgment performance (Cluster 5 > Cluster 2 > Cluster 3 > Cluster 4> Cluster 1). Cluster 5 (N = 6) showed high accuracy in all SL tasks; Cluster 2 (N = 6) showed the best visual (Letter + Image) SL accuracy among all children; Cluster 3 (N = 12) showed the best Syllable SL accuracy among all children; Cluster 4 (N = 16) performed poorly in all four SL tasks; Cluster 1 (N = 7) performed poorly only in the linguistic (Letter + Speech) SL tasks.