RESEARCH ARTICLE

Severity of Autism is Related to Children's Language Processing

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Problems in language processing have been associated with autism spectrum disorder (ASD), with some research attributing the problems to overall language skills rather than a diagnosis of ASD. Lexical access was assessed in a looking-while-listening task in three groups of 5- to 7-year-old children; two had high-functioning ASD (HFA), an ASD severe (ASD-S) group ($n = 16$) and an ASD moderate (ASD-M) group ($n = 21$). The third group were typically developing (TD) ($n = 48$). Participants heard sentences of the form "Where's the x?" and their eye movements to targets (e.g., train), phonological competitors (e.g., tree), and distractors were recorded. Proportions of looking time at target were analyzed within 200 ms intervals. Significant group differences were found between the ASD-S and TD groups only, at time intervals 1000–1200 and 1200–1400 ms postonset. The TD group was more likely to be fixated on target. These differences were maintained after adjusting for language, verbal and nonverbal IQ, and attention scores. An analysis using parent report of autistic-like behaviors showed higher scores to be associated with lower proportions of looking time at target, regardless of group. Further analysis showed fixation for the TD group to be significantly faster than for the ASD-S. In addition, incremental processing was found for all groups. The study findings suggest that severity of autistic behaviors will impact significantly on children's language processing in real life situations when exposed to syntactically complex material. They also show the value of using online methods for understanding how young children with ASD process language. ***Autism Res*** *2014, 7: 687–694*. © 2014 International Society for Autism Research, Wiley Periodicals, Inc.

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Introduction

Communication difficulties are characteristics of autism spectrum disorders (ASD) and one of the hallmark features used in diagnosing ASD. However, ASD is heterogeneous and there is variability in the verbal skills of these individuals [Tager-Flusberg, Paul, & Lord, 2005]. Variability is also found in nonverbal abilities and behavioral characteristics. An IQ score of ≥ 70 on a standardized assessment with a mean of 100 identifies high-functioning autism (HFA). Even within HFA, there is variability in the severity of autism, a focus of the current paper. This is typically determined on the basis of the Autism Diagnostic Observation Schedule—Generic [ADOS-G; Gotham, Pickles, & Lord, 2009].

A cognitive deficit, or bias, associated with the integration of information has been a focus of much literature on autism [e.g., Frith, 1989; Minshew, Goldstein, & Siegel, 1997]. In the "Weak Central Coherence" account [Frith, 1989; Happé & Frith, 2006], individuals with ASD are argued to be biased to a detail-focused processing style rather than extracting a global meaning. This attention to detail may partly explain their superior performance reported in block design subtests in nonverbal IQ assessments [e.g., Happé, 1994], although Mottron, Dawson, Soulières, Hubert, and Burack [2006] argue that it can be explained by enhanced perceptual functioning. Other researchers have suggested that thinking in individuals with autism may be predominantly visual rather than verbal [Kamio & Toichi, 2000].

In typical populations, auditory verbal input is processed incrementally; information is updated as more acoustic-phonetic information becomes available. Thus, multiple words will be accessed from the onset of a word and as more acoustic information is available the intended word will be identified. In a study by Allopenna, Magnuson, and Tanenhaus [1998], when adults were presented with the word *beetle*, they looked more at an object with the same onset (*beaker*) than at a phonologically unrelated object. Incremental processing of speech input has been reported even for 2-year-old children with typical development (TD). Swingley, Pinto, and Fernald [1999] presented 24 month olds with a word while showing them two pictures, using the intermodal

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preferential-looking paradigm. When the labels of the pictures were similar in onset (*dog* vs. *doll*), the children's recognition was delayed, indicating incremental processing of the input from the onset, rather than waiting until the word was complete. To date, research has not investigated whether young children with ASD show incremental processing. If they do not, it would suggest different organization of the lexicon, or different mechanisms for processing language input; this could impact their processing of complex syntactic structures which involves rapid integration of words into longer units.

Eye tracking is a powerful method used in research on language processing. Research with typical adult and child populations has shown, for example, that linguistic context can speed up processing; that is, specific verbs bias listeners to particular objects (e.g., hearing the verb "eat" leads to predictive looks to edible objects [Altmann & Kamide, 1999]). Brock, Norbury, Einav, and Nation [2008] used eye tracking to compare the language processing of adolescents with HFA to a group of adolescents, some with TD and some with language impairment. Specifically, they assessed the influence of sentence context on participants' eye movements. Test sentences contained a target word, with half including a biasing verb (e.g., *stroked* with the target *hamster*) and the others neutral verbs (e.g., *chose* with the target *hamster*). In the neutral condition, both groups accessed a phonological competitor (i.e., a word with the same phonological onset as the target). In the biasing context, both groups anticipated the object. The researchers also found that adolescents with lower language (whether TD or ASD) spent more time looking at the phonological competitor. Less sensitivity to sentence context was attributed to poor language, not autism.

In a study with 3-year-old children with ASD [Groen et al., 2012], children with more-severe symptoms, as reflected in higher ADOS scores, spent less time watching relevant information in simple movies than those with less-severe autism. However, severity of ASD symptoms has not been systematically examined in relation to language processing. This study used eye tracking to examine whether autism severity affects 5- to 7-year-old children's looking patterns to a target picture as they listened to a sentence in which the target item was named. The age group was chosen because it covers the first years of formal schooling, in which children are expected to process language input in classroom contexts. For each test item, one object presented in a visual display of four pictures matched the named target and another (the competitor) shared the same phonological onset as the target (e.g., target = *box*; competitor = *boy*). We also investigated whether language, attention, and IQ scores were significantly associated with the children's looking patterns and whether the children in the HFA groups as well as the children with TD accessed words incrementally. If so, it is expected that participants would anticipate the word based on the first sound. That is, they should look more at the target or competitor than at the two distractors following the onset of the target word; moreover, as they continue to process the word, looking to the competitor should decrease.

Method

Participants

Participants comprised two groups of children with HFA, and a group with TD, all aged 5–7 years. The children with HFA were all in mainstream schools and were recruited from a metropolitan area in Australia, as were the children with TD. All the children had IQ scores above 70. Those with HFA met criteria for ASD on the ADOS-G [Lord et al., 2000]. The ADOS-G scores for the children with HFA ranged from 8 to 29 (maximum possible score = 43), with higher scores indicating higher symptom severity. A median split on ADOS scores was used to determine the two groups: a high-symptom severity group, ASD severe (ASD-S; ≥ 15, $n = 16$) and a moderate symptom severity group, ASD moderate (ASD-M; ≤ 14, $n = 21$). There were 48 children in the TD group. In the ASD-S group, 14 of the 16 participants (87.5%) were male whereas 17 of the 21 participants (81%) in the ASD-M group were male and 36 of the 48 participants (75%) in the TD group were male. Fisher's exact test revealed no significant differences in the relative frequency of males and females across the three groups ($P = 0.589$). Additionally, there was no significant difference when comparing just the ASD-S and TD groups ($P = 0.487$).

Measures

Participant details and scores from the assessments and the Social Communication Questionnaire [SCQ; Rutter, Bailey, & Lord, 2003] are presented in Table 1.

Language

The Clinical Evaluation of Language Fundamentals—Fourth Edition [Semel, Wiig, & Secord, 2003] was administered to assess receptive and expressive language skills.

Intelligence

Nonverbal IQ (NV-IQ) was assessed with the Block Design and Matrix Reasoning subtests of the Wechsler Preschool and Primary Scale of Intelligence—Third Edition [Wechsler, 2002] or the Wechsler Intelligence Scale for Children—Fourth Edition [Wechsler, 2003], depending on the child's age. Verbal IQ (V-IQ) was assessed with the Vocabulary and Information subtests. The average of the

Table 1. Means and Standard Deviations for the Dependent Variables for the TD and ASD-S, ASD-M Groups

	TD			ASD-M			ASD-S		
	*n**	*M*	*SD*	*n**	*M*	*SD*	*n**	*M*	*SD*
Age	48	6.33	.72	21	6.35	.77	16	6.48	.67
ADOS Severity Score	–	–	–	21	11.52	2.42	16	20.50	4.72
Language									
Receptive	48	97.65	13.54	20	98.10	14.09	16	99.75	17.80
Expressive	48	105.35	11.26	20	98.65	18.28	16	93.00	16.37
Total	48	103.79	11.77	20	99.50	16.54	16	91.13	18.68
Intelligence									
NV- IQ[a]	48	10.35	2.20	18	9.69	1.87	16	12.56	1.85
V-IQ[b]	48	10.25	1.72	17	9.53	2.35	16	8.69	2.27
FSIQ[c]	48	99.87	10.28	18	96.06	11.18	16	99.00	11.05
Auditory Attention	48	10.63	2.77	19	11.05	2.80	14	10.08	4.21
SCQ	43	4.05	3.29	20	16.90	4.35	16	20.75	7.38

**n* is reduced for some of the variables, as some children did not complete all the tasks.
[a]NV-IQ scores are calculated as the average of the scaled scores from the matrix reasoning and block design subtests.
[b]V-IQ scores are calculated as the average of the scaled scores from the vocabulary and information subtests.
[c]FSIQ scores are derived from Sattler [2004].
ADOS, Autism Diagnostic Observation Schedule; ASD-M, autism spectrum disorders moderate; ASD-S, autism spectrum disorders severe; FSIQ, full-scale IQ; SCQ, Social Communication Questionnaire; NV-IQ, nonverbal IQ; SD, standard deviation; TD, typically developing; V-IQ, verbal IQ.

standard scores from the two nonverbal subtests was included as the NV-IQ measure and the average of the standard scores from the two verbal subtests was included as the V-IQ measure. These measures were included as covariates in analyses.

Auditory Attention

Sustained attention was measured using the Auditory Attention task of the Developmental Neuropsychological Assessment—Second Edition [Korkman, Kirk, & Kemp, 2007]; scaled scores were used as a covariate.

Autistic Behaviors

We included the Lifetime version of the SCQ [Rutter et al., 2003], a brief parent report inquiring about autistic behaviors, to obtain severity scores for *all* participants.

All children in the two ASD groups scored above 11, whereas none of the children with TD had SCQ scores of ≥ 11. The SCQ has shown strong discrimination between ASD and non-ASD cases (sensitivity 0.89, specificity 0.89) when using 11 as the cut-off [Wiggins, Bakeman, Adamson, & Robins, 2007].

Eye-Tracking Task

Children listened to a series of nine sentences of the form “Where’s the x?” These were prerecorded in a soundproof studio by a female, native speaker of Australian English. The visual display contained four pictures: the target, competitor, and two unrelated (distractor) items. The pictures were located in the four corners of the monitor; the location of each picture type was randomly distributed across items. The items were highly frequent (surface frequency > 6 million); the target and competitor were matched on concreteness and imageability [Coltheart, 1981; Leech, Rayson, & Wilson, 2001]. They were presented via a Tobii T120 Eye Tracker, V 2.2.8 (Tobii Technology AB, Danderyd, Sweden), which recorded the participants’ eye movements. The audio started 1 s after the visual display appeared. Two versions of test sentences were used; the competitor and target in version 1 were switched in version 2, making a total of 18 target items. The same four pictures were used in both versions. Participants in each group were assigned semirandomly to one of these versions, and half the participants in each version heard the sentences in the reverse order.

Data Analysis

The audio recordings were imported to the Sound Forge (Version 9.0) software program (Sony Creative Software Inc. Middleton, WI, USA) to obtain the onset time for each target word. Average percentage of looking time to each picture was calculated in 200 ms intervals, from the target word onset to 1400 ms postonset. The eye-tracking data provided 12 responses within each 200 ms interval, each with five possible outcomes: the item looked at (four possibilities) or no item looked at. If participants looked away for 67% or more of a single interval, the interval was coded as missing and was excluded as per Thothathiri and Snedeker [2008a, 2008b]. The total %s of missing intervals by group were: TD (6.51), ASD-S (8.53), ASD-M (10.3).

Preliminary analysis showed no effect of item or version and so data from the different versions were collapsed. R version 2.13.1 [R Core Team, 2013] was used for the analysis and R package "geepack" was used to model the data using Generalized Estimating Equations (GEE) [Højsgaard, Halekoh, & Yan, 2006; Yan & Fine, 2004]. GEE were used because they provide a valid model to fit this type of data (ordinal response).

Results

The average proportions of looking times to target or competitor pictures for the three groups are illustrated in Figure 1A. In Figure 1B the looking times to target and to competitor are separated. Figure 1C illustrates the proportion of looking times to the distractors (the total time looking to the distractors divided by 2). Figure 2 shows the looking patterns to target, competitor and distractors for each group separately.

The average proportion of looking times to the target comparing groups was carried out using Kruskal–Wallis ANOVA followed by pairwise post hoc Mann–Whitney *U*-tests with *P* values corrected for multiple comparisons using the Holm procedure. Significant group differences in proportion of looking time at target were detected at time intervals 1000–1200 ($P = 0.003$) and 1200–1400 ($P = 0.002$). The TD group looked more at target than did the ASD-S group.

The first primary analysis, on the distribution of the dependent variable (proportion of looking time to target), compared the number of children within each group who

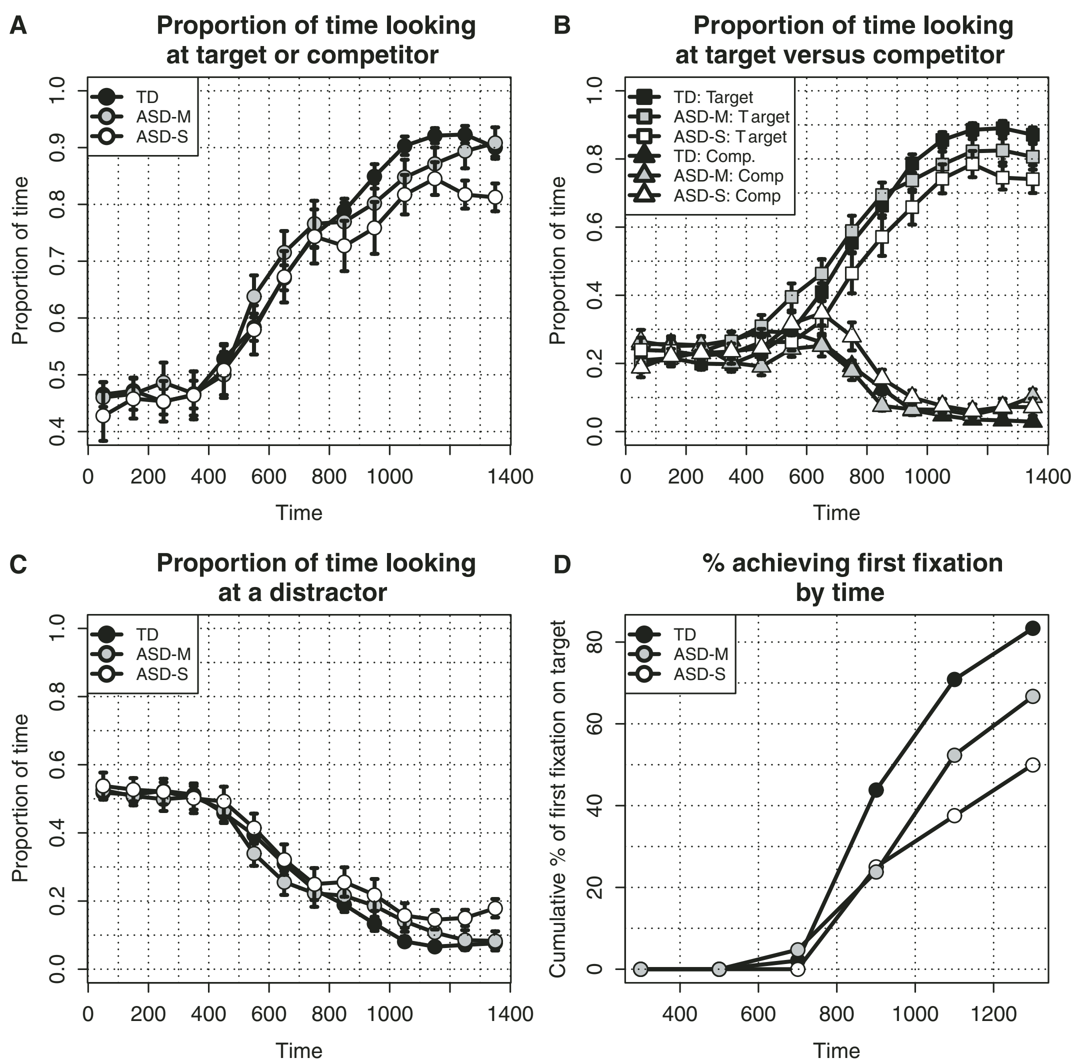

Figure 1. Proportion of looking time by group across time intervals: (A) to target or competitor, (B) to target vs. competitor, (C) to distractors, and (D) % of children achieving first fixation by time interval. ASD-M, autism spectrum disorders moderate; ASD-S, autism spectrum disorders severe; TD, typically developing.

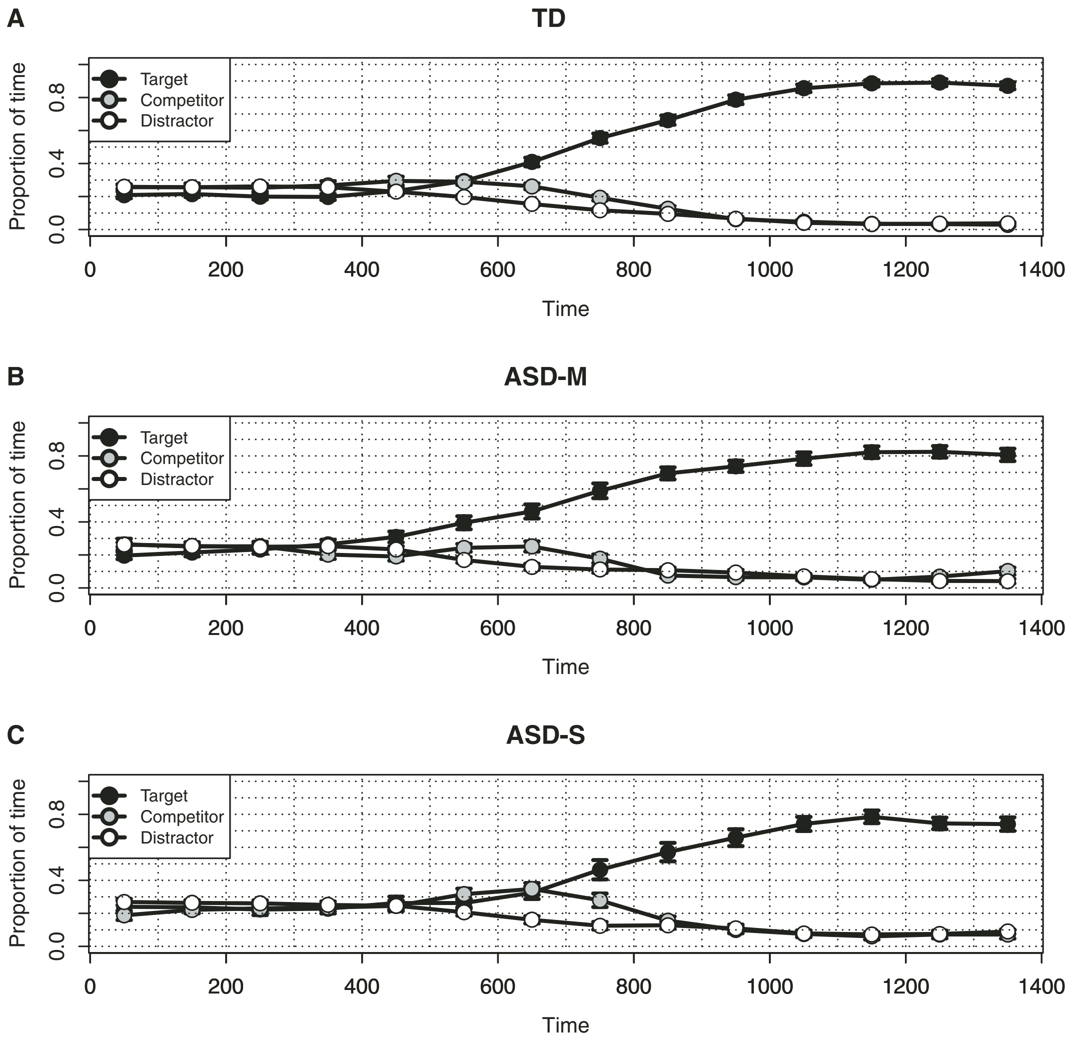

Figure 2. Looking time to target, competitor and distractors for each group (A) typically developing (TD), (B) spectrum disorders moderate (ASD-M), and (C) autism spectrum disorders severe (ASD-S).

focused on the target for ≥ 80% of the time within each of the intervals. Fisher's exact test was used to test for significant differences between the groups. Given that there were nine items per child, a repeated measures analysis was conducted using GEE assuming an exchangeable correlation structure within children and between tasks, and which adjusted for the covariates receptive language, expressive language, V-IQ, NV-IQ, and attention to determine if they contributed to any group differences in looking patterns. The proportions of looking to target, competitor or distractor within an interval are ordered factors with 13 levels: 0/12, 1/12, . . ., 12/12. For computational purposes, the 13 level "proportion at target" variable was collapsed to three levels: (0) looked at target < 20%, (1) looked at target > 20% and < 80%, and (2) looked at target ≥ 80%.[1] After adjusting for the covariates, the analysis showed that the TD participants were significantly more likely to be looking at targets when compared with the ASD-S group in the intervals 1000–1200 (odds ratio = 2.82, $P = 0.02$) and 1200–1400 (odds ratio = 2.74, $P = 0.01$). There were no significant contributions from the covariates.

We also performed a confirmatory analysis in which we modeled proportion of time looking at target using a GEE generalized linear model, which assumed that the dependent variable was a binomial proportion and with a logit link function. While technically not a binomial proportion, this analysis returned identical results and therefore is not reported.

Further analysis including the SCQ scores as a covariate showed that SCQ was negatively associated with proportion of looking at target in the intervals 800–1000 (odds ratio = 0.97, $P = 0.01$), 1000–1200 (odds ratio = 0.95, $P = 0.0006$) and 1200–1400 (odds ratio = 0.97, $P = 0.03$) when adjusted for receptive language, expressive

[1]It is common to model ordinal data using just a few levels.

language, V-IQ, NV-IQ, and attention scores. That is, higher SCQ scores among all children were associated with less looking at target.

The second primary analysis examined the first look at the target (see Fig. 1D). For this analysis, the number of children who looked for more than 80% of the time at least once, on average over items, either in the nominated interval or preceding intervals, were counted. Fisher's exact test was used to detect significant differences between groups. For GEE, odds ratios are reported. For odds ratios associated with the continuous covariates, the odds ratio is associated with a single unit change in the covariate. For example, an odds ratio of 0.97 for SCQ equates to a 3% decrease in odds for every one unit increase in SCQ, that is, an increase of one in the score. The TD participants were more likely than the ASD-S group to have fixated at least once by interval 1000–1200 (odds ratio = 2.75, $P = 0.01$) and 1200–1400 (odds ratio = 1.99, $P = 0.05$). None of the covariates considered previously were significant.

Our final analysis investigated incremental processing. We compared the proportion of looking time for target or competitor to looking time for the distractors for each group separately. The analysis revealed significant differences for the TD group in the interval 400–600 ($P = 0.006$) and also for the ASD-M group ($P = 0.03$) with more looking at the target or competitor than the distractors (binomial test of proportions with Yates' continuity correction, $P < 0.001$). In the interval 600–800, significant differences were found for all groups (TD: $P < 0.001$, ASD-M: $P < 0.001$, ASD-S: $P = 0.006$), showing evidence for incremental processing for all groups. In addition, a marked shift away from the competitor and a shift toward the target emerged for all groups from 400–600 ms following its onset.

Discussion

The current study primarily focused on the extent to which autism severity in young children with HFA affected performance on a lexical access task using eye tracking. We also considered if children with HFA processed words incrementally.

Of significance is that children with more severe autism, as determined from their ADOS-G scores, differed from the TD group on proportion of looking time to the target in the two time windows 1000–1200 ms and 1200–1400 ms. Children in the ASD-S group were less likely to look at the target than the TD group. No significant difference in proportion of looking time to target was found for the ASD-M group.

We included a number of covariates, NV-IQ, V-IQ, attention and expressive, and receptive language scores. None of these modified the overall results. Brock et al. [2008] found that NV-IQ did not significantly influence looking patterns. However, in their study, language skills independent of ASD status, did. Our results did not support this latter finding. The particular stimuli, task demands, and characteristics of the participants may, in part, account for the differences; because severity was not examined by Brock et al., it is unknown if participants with higher symptom severity would have performed differently.

Scores on the SCQ, a parent report of behaviors associated with ASD allowed for a measure of autistic behaviors for *all* participants. A negative association was found between these scores and the proportion of looking time to target. The children with more severe autistic behaviors spent less time looking at the target pictures. Toward the end of the time window examined, there was a drop off in proportion of looking at the target (as illustrated in Figs. 1 and 2) as children switched attention to the other pictures in the display, and this was noticeable particularly for the ASD-S group. This pattern of switching back to look at the other pictures may reflect a focus on visual stimuli over auditory, or may indicate more detailed processing of the pictures available, which would be consistent with previous literature [e.g. Happé, 1994].

Our results showed evidence for incremental processing. The ASD and TD groups accessed the target or phonological competitor following the onset of the target word. The proportion of looking to these two items was significantly greater than to the two distractors; that is, the children with and without ASD were able to access words that matched the onset prior to processing the full target word, suggesting unimpaired lexical memory in all groups. In Brock et al.'s [2008] study, older individuals with ASD were also found to access a phonological competitor. The current study is the first to date to show incremental lexical processing in young children with HFA.

In conclusion, a major finding in our study was that severity of ASD impacted how much time the children looked at the target. There was more likelihood of a mismatch between auditory and visual information for the ASD-S group. Previous research comparing language processing in HFA and TD groups has not considered symptom severity, which may account for some of the differences reported across research findings. In addition, our findings show that in the course of processing oral language input, young children with HFA, like those with TD, initially access lexical competitors as well as target words before matching the target word to the appropriate visual representation. In interpreting what others say, listeners integrate words into longer meaningful units and integrate the auditory with contextual information. Children who are slower or who are less likely to match auditory and visual information are at risk for misunderstanding the language addressed to them. Since linguistic input is so rapid, if children are slow even by a few hundred milliseconds in processing lexical items, the effect will accumulate over the course of a sentence. This has implications for how well they understand the more-syntactically complex language that they will be exposed to, which will impact on their educational outcomes. As indicated by our findings, children with ASD with higher symptom severity are at risk of this negative impact on their educational outcomes.

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