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Research Report

Online processing of sentences containing noun modification in young children with high-functioning autism

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Abstract

Background: There is variability in the language of children with autism, even those who are high functioning. However, little is known about how they process language structures in real time, including how they handle potential ambiguity, and whether they follow referential constraints. Previous research with older autism spectrum disorder (ASD) participants has shown that these individuals can use context to access rapidly the meaning of ambiguous words. The severity of autism has also been shown to influence the speed in which children with ASD access lexical information.
Aims: To understand more about how children with ASD process language in real time (i.e., as it unfolds). The focus was the integration of information and use of referential constraints to identify a referent named in a sentence.
Methods & Procedures: We used an eye-tracking task to compare performance between young, high-functioning children with autism (HFA) and children with typical development (TD). A large sample of 5–9-year-old children (mean age = 6;8 years), 48 with HFA and 56 with TD participated; all were attending mainstream schools. For each item participants were shown a display of four images that differed in two dimensions. Each sentence contained an adjective and noun that restricted the choice from four to two (the target and competitor), followed by a prepositional phrase (e.g., *the blue square with dots*); this added modifying information to provide a unique description of the target. We calculated looking time at the target, the competitor and the two distractors for each 200 ms time interval as children processed the sentence and looked at the display. Generalized estimating equations were used to carry out repeated-measures analyses on the proportion of looking time to target and competitor and time to fixate to target.
Outcomes & Results: Children in both groups (HFA and TD) looked at the target and competitor more than at the distractors following the adjective and noun and following the modifying information in the prepositional phrase more at the target. However, the HFA group was significantly slower in both phases and looked proportionally less at the target. Across the sample, IQ and language did not affect the results; however, age and attention had an impact. The older children showed an advantage in processing the information as did the children with higher attention scores.
Conclusions & Implications: The HFA group took longer than the TD group to integrate the disambiguating information provided in the course of processing a sentence and integrate it with the visual information, indicating that for the ASD group incremental processing was not as advanced as for children with ASD, and they were less sensitive to referential conventions. Training for young children with ASD on the use of referential conventions and available contextual clues may be of benefit to them in understanding the language they hear.

Keywords: high-functioning autism, children, eye tracking, language processing, noun phrase modification.

What this paper adds

What is already known on this subject?

There is variability in the language of children with autism, even those who are high functioning. However, little is known about how they process language structures in real time, including how they handle potential ambiguity,

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and whether they follow referential constraints. Previous research with older ASD participants has shown that these individuals can use context to access rapidly the meaning of ambiguous words. The severity of autism has also been shown to influence the speed in which children with ASD access lexical information.

What this paper adds
This study shows that although high-functioning children with ASD are slower than TD peers to integrate linguistic information with visual information to restrict reference, they are capable of combining these two sources of information during sentence processing. Another important addition to the literature is the demonstration that the ability to use referential information in language processing develops with age. Training in understanding referential conventions might be of benefit to young children with ASD.

Introduction

Communication problems are a core feature of autism spectrum disorder (ASD). The language abilities of children with ASD vary greatly, with many being non-verbal and some performing in the normal range on standardized tests of lexical and grammatical knowledge (Tager-Flusberg *et al.* 2005). While this variability is well documented, we know comparatively little about how children with ASD process language structures in real time. That is, how do the processing strategies of children with ASD compare with those of children with typical language development (TD), and does the development of the language processing mechanism follow a similar developmental trajectory? Research on how young children with ASD process sentences can provide important information that may help explain some of their problems in communicating with others.

Experimental studies using eye-tracking techniques are valuable in identifying specific influences on sentence interpretation. Eye tracking provides a continuous (online) measure of language processing rather than of post-processing (as in other methods, including act-out tasks, picture pointing, completing sentences or making meta-linguistic judgments), and so the strategies employed in processing language input can be investigated with relatively minimal task demands (e.g., Huettig and Altmann 2005, Tanenhaus *et al.* 1995, Trueswell *et al.* 1999, Yee and Sedivy 2006). Eye tracking is appropriate for studying child samples where developmental skills for language processing can be readily examined.

Some of the eye-tracking research on the language processing skills of children with TD has focused on processing when there is temporary ambiguity in a sentence. For example, Trueswell *et al.* (1999) investigated whether 5-year-old children initially interpreted a temporary ambiguous prepositional phrase in a sentence ('on the napkin' in 'Put the frog on the napkin in the box' was a destination and whether they revised their initial interpretation when the additional information in the sentence was processed. That is, was 'on the napkin' reanalysed as a modifier of 'the frog' and 'in the box' as the destination. Adults have been shown to treat such potentially ambiguous phrases as a noun modifier if there are two same kind objects (e.g., two frogs) shown in the visual display. The syntax provides ambiguity but the referential context provides motivation for assuming that information will be provided by the speaker to disambiguate the two objects, that is, which frog is intended. However, when only one possible referent is available (one frog), adults are more likely to interpret 'on the napkin' as a destination (e.g., Tanenhaus *et al.* 1995). Thus, when processing syntactic alternatives, adults are influenced by the referential context. However, the 5-year-old children in Trueswell *et al.*'s (1999) study were not influenced by the presence of two frogs; they were influenced by the semantics of the verb 'put', choosing a destination interpretation for 'on the napkin', whether one or two frogs were shown, and they did not revise this initial interpretation.

Lexical biases are strong constraints for young children, as well as for adults, but adults can override them if other constraints are applicable. The semantics of the verb in a sentence can influence listeners to predict following information (e.g., an edible object follows *eat*, and a flexible item follows *fold*). This affects the speed of processing sentences. The verb bias is a reliable constraint of sentence processing: the semantics of the verb is part of the knowledge an individual has about a verb and so is always available, whereas referential cues are not. When the context requires it, adults typically use modifiers uniquely to identify a reference. Children need to learn the conventions of reference from the language they hear and need sufficient exposure to identify the patterns.

Mature language users have an expectation about 'communication informativeness'—an adjective is interpreted as indicating a contrast between two items of the same kind (e.g., Sedivy *et al.* 1999). Five-year-olds have also been found to be influenced by contrast (Huang and Snedeker 2013), and in a study by Nadig *et al.* (2003) sensitivity to referential context by 5–6-year-olds was reported. Two conditions were included in that study. In one condition (Contrast), two examples of the same item were shown (e.g., one big car and one small car).

An adjective (e.g., *big*) before the noun in the test sentence identified which of the two items was the intended target. Also included was a competitor, another large object (a big tortoise). In the No Contrast condition, the competitor was replaced by a 'neutral' item. Eye-tracking data showed that adults identified the target faster in the Contrastive condition; they looked at both the target (big car) and the contrastive item (small car). In addition, they spent more time looking at the contrast item in the Contrast condition than at the competitor in the No Contrast condition. In a separate experiment reported in the paper, children aged 5–6 years were tested with the same materials. Unlike the adults, the children took longer to fixate on the target in the Contrast condition than in the No Contrast condition; having two items of the same kind increased processing time. That the children were sensitive to the presence of two items of the same kind indicates some developing awareness of the referential context. The looking time to the distractor and competitor did not differ significantly, indicating that the competitor was not viewed as a possible target.

While eye-tracking research on sentence processing with young children with TD has provided some insights into developing processing skills, such research is sparse with young children with developmental disabilities. In an eye-tracking study on lexical access with 5–7-year-old children with ASD who were high functioning (those with an IQ above 70) and children with TD of the same age, both groups were found to access words incrementally (Bavin *et al.* 2014). That is, before the target word had been completed they looked significantly longer at both a target word and a phonological competitor (an item which had the same phonological onset as the target) than at two distractors. However, the children with HFA with higher severity scores on the Autism Diagnostic Observation Schedule—Generic (ADOS-G; Gotham *et al.* 2009) took longer to fixate on the target and spent less time looking at it than the TD group. These findings suggest that more severely affected children with ASD may have a preference for visual over auditory stimuli, which has been a conclusion drawn in previous research (e.g., Kamio and Toichi 2000). Alternatively, they may have problems integrating information from different sources (Happé and Frith 2006, Mottron *et al.* 2006).

Eye tracking has also been used to study the effect of context on lexical processing in samples with older participants with ASD. For example, Brock *et al.* (2008) tested adolescents with ASD and no intellectual impairment and compared their performance with that of a group of adolescents with TD and some additional participants with low language scores. These were included to provide a wide spread of scores to enable the researchers to investigate the effect of language knowledge on patterns of eye gaze. In addition to including the target word, half the test sentences contained a neutral verb (e.g., *chose* with the target *hamster*) and the other half contained a biasing verb (e.g., *stroked* with the target *hamster*). Similar patterns of eye movements were reported for both groups: both accessed a phonological competitor when listening to the neutral sentences, and in the biasing sentences both groups anticipated the object. Also reported was that poor language scores were significantly associated with less sensitivity to context, regardless of diagnosis.

Other research has suggested that impaired structural language knowledge, rather than the diagnosis of ASD, is associated with poor language processing for children with ASD. For example, using a priming paradigm, Norbury (2005) tested 9–17-year-olds: those with and without ASD and those with and without language impairment. She found that those participants with low language skills, regardless of diagnosis, were less able to use context to resolve lexical ambiguity. Rabagliati *et al.* (2014) also reported on the effect of context on resolving lexical ambiguity with a sample of highly verbal children with ASD aged 6–9 years. The eye movement patterns of the ASD group and a comparison group with TD were not significantly different, indicating that context was used by both groups to resolve ambiguous words in a sentence.

In the current study we looked at a different aspect of language processing. The aim was to investigate the incremental semantic and syntactic processing in interpreting noun modification, specifically whether, when identifying a target, the eye movements of young children aged 5–9 years with ASD were similar to those of children with TD over the course of a sentence. To do this, they were required to link an adjective plus noun with *post-nominal* modifying information included in a prepositional phrase (e.g., the underlined phrase in *the blue square with dots*). In our example, the prepositional phrase served to distinguish one of two small blue squares. Based on past research with individuals with ASD showing slower processing speed (e.g., Kourkoulou *et al.* 2013), we predicted that when required to integrate a noun with modifying information, children with HFA would take longer than children with TD to identify the target. In much of the research literature on children with ASD, samples are drawn from a wide age range but chronological age is not included as a variable; we considered the impact of age since (1) over the first few years of formal schooling, children's experiences could be expected to influence the development of language processing skills; and (2) children's online sensitivity to referential information appears to develop in this age range (Huang and Snedeker 2013, Trueswell *et al.* 1999). We also examined the impact of other possible influencing factors on language processing, particularly language ability (as assessed by a standardized measure of language), attention and IQ.

Method

Participants

In order to represent the socio-economic spectrum, all participants were recruited from the same *mainstream* schools in three different school districts in the greater Melbourne area of Victoria, Australia. Fifty-six children with TD aged 5;1–9;1 years, and 48 children aged 5;0–9;1 years with a prior diagnosis of ASD participated in the research. The overall mean age was 6;8 (SD = 1.00). Diagnoses of ASD were confirmed with the ADOS-G (Lord *et al.* 2000), administered by a qualified assessor as part of the current project. The children with ASD were all high functioning, with IQ scores ranging from 79 to 124. Parents of all participants were asked to complete the Lifetime version of the Social Communication Questionnaire (SCQ; Rutter *et al.* 2003). None of the children in the TD group had SCQ scores $\geq$ 11, the cut off score found to show strong discrimination between ASD and non-ASD cases (Wiggins *et al.* 2007). Demographic details and scores from the standardized assessments and SCQ are shown in table 1.

Measures

Language

The standard language measure was the Clinical Evaluation of Language Fundamentals—Fourth Edition—Australian (CELF-4; Semel *et al.* 2003). It provides an expressive language score, a receptive language score and an overall score for language.

Intelligence

To measure nonverbal IQ, two subtests (Block Design and Matrix Reasoning) from the Wechsler Preschool and Primary Scale of Intelligence—Third Edition (WPPSI-III; Wechsler 2002) or the Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV; Wechsler 2003), depending on the age of the child, were used. Verbal IQ was measured with the Vocabulary and Information subtests of the same instruments. The score obtained from averaging the standard scores from the two nonverbal subtests gave an estimated NV-IQ score and the average of the standard scores from the two verbal subtests gave an estimated V-IQ score. The total IQ score was derived from the algorithm provided in Sattler (2004).

Auditory attention

We included the Auditory Attention task of the Developmental Neuropsychological Assessment—Second Edition (NEPSY-II; Korkman *et al.* 2007) as a measure of sustained attention.

Autistic behaviours

In addition to using the SCQ to ensure that the children in the TD group did not score above the cut-off, we used it as a continuous variable of autistic-like behaviours for participants in both groups.

Eye-tracking task

All six test sentences used in the eye-tracking task were of the form ‘Look at the x with x’ (e.g., *Look at the blue square with dots*). They all contained the verb *look*. In the visual display for each sentence four items of the same type were provided. Each display contained a picture of the target object; and three other items of the same type as the target. One of these three (which we will refer to as the competitor) acted as a possible target until the additional information in the prepositional phrase was presented (e.g., for the target *blue square with dots* the competitor was a blue square without dots). With the information from the prepositional phrase, this item could be eliminated as the intended target. The other two items of the same type were distractors. These contrasted with the target and competitor in size or in colour (e.g., for the target *big monkey with a banana*, the two distractors were small monkeys and for the target: *little girl with a flower*, the two distractors were pictures of big girls). The children would be expected to look away from the two distractors once they had processed the adjective and noun (e.g., *big monkey*).

The four pictures were evenly distributed in the four corners of the Tobii T120 Eye Tracker V 2.2.8 monitor, and the arrangement varied so that the target and competitor appeared in different locations for different items.

Nine filler items, sentences with different structures and different visual stimuli, were used. All sentences were pre-recorded in a soundproof studio by a female native speaker of Australian English, using typical prosody. Prosody was not manipulated since we were not contrasting different possible interpretations. For each item, the audio stimuli started 1 s after the four pictures appeared on the monitor. The presentation of pictures prior to the auditory stimuli allowed participants to examine them briefly before listening to the sentence. Half the participants heard the sentences in the reverse order. Participants were semi-randomly assigned to one of the two orders so that gender and ages were distributed fairly

Table 1. Means and standard deviations (SD) for the dependent variables for the two groups

	TD			HFA		
	n	Mean	SD	*n*	Mean	SD
Age	56 (28 male)	6.62	1.00	48 (34 male)	6.68	1.01
ADOS Severity Raw Score	–	–	–	45	16.00	5.74
Language						
Receptive	56	98.41	13.60	47	96.98	17.35
Expressive	56	104.59	10.86	47	94.89	18.77
Total	56	103.00	11.54	47	94.00	18.97
Intelligence						
NV-IQ[a]	56	10.44	2.24	44	11.11	2.38
V-IQ[b]	56	10.22	1.74	43	9.28	2.50
FSIQ[c]	56	100.21	10.74	44	98.50	12.31
Auditory attention	56	10.93	2.77	42	10.45	3.47
SCQ	51	3.80	3.15	46	19.0	6.79

Notes: *n* is reduced for a variable if some children did not complete the task.
[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).

evenly. Preliminary analyses did not show version to be significant and so the data from the two versions were collapsed.

Analyses

The proportion of looking times to the four pictures or away were calculated per 200-ms interval from the onset of the adjective. As is common practice in eye-tracking studies, trials were omitted if a child looked away for more than 67% of the time. Omitted trials by group for Phase 1 of the analysis (see the Analysis section) were: ASD = 9.5%, TD = 8.3%; and for Phase 2: ASD = 8.9%, TD = 5.1%. For Phase 2, we conducted a sensitivity analysis to determine if the elimination of these trials affected the findings. Inclusion of these trials made no difference to the overall results, as discussed in the Results section.

For each 200-ms interval, the eye tracker provides 12 ordered-by-time observations indicating the item looked at, which can be converted to a proportion of looking time at each item type (e.g. at target, at competitor and at distractors) or proportion of time looking away (i.e. looking at no item). Given that each child completed more than one item, within each interval generalized estimating equations (GEEs) (e.g., Hardin 2005) were used to carry out a repeated-measures analysis. We examined the data in two phases. Phase 1 was from the onset of the adjective (e.g., the onset of *blue* in the phrase *the blue square* and *little* in the phrase *the little girl*) up to the time interval of 800–1000 ms following that onset. We were interested in whether the children looked more at the target and competitor than at the two distractors. If so, this would indicate that they had processed the adjective and noun (e.g., blue and square) and their attention was drawn to the two appropriate possibilities. Phase 2 started at the onset of the disambiguating noun in the modifying preposition phrase (e.g., *flower* in the phrase *with the flower*). The disambiguating information started at approximately 700 ms following the onset of the first noun; from then on, Phase 1 overlapped with Phase 2.

In the first analysis in Phase 2 we used proportion of looking time to the target as the dependent variable; in the second analysis, fixation to target was the dependent variable. Since the proportion of looking time can neither be assumed normal nor a binomial proportion (due to lack of independence between observations within each child), we followed the procedure adopted by Bavin *et al.* (2014): proportions within each time interval were converted to a three-level ordered factor variable with levels 0 (< 20%), 1 (≥ 20% but < 80%) or 2 (≥ 80%). For the fixation analyses, fixation in an interval was taken to be that a child had looked at the target for more than 80% of the time either in that interval, or in any preceding interval (e.g. had fixated at least once by the end of the interval concerned). R version 2.13.1 (R Core Team 2013) was used for the analysis and R package 'geepack' (Højsgaard *et al.* 2006) was used to model the repeated measures data for both the ordered factor response (for proportion of looking time) and the binary response (for fixation). For Phase 2, we also ran analyses on the proportion of looking to target data and on the fixation data using the SCQ scores in place of diagnosis status.

Results

Phase 1

Proportion of looking time to target or competitor

Greater proportional looking time to the target and competitor in comparison with the distractors in Phase 1 indicates that children can restrict reference based on the initial disambiguating information (e.g., *Look at the blue square* . . . .). The average proportion of looking time (per 200-ms interval from the onset of the noun) to the target or competitor (TC) versus the two distractors (DD) indicated that *in the first interval* (0–200 ms) children in both the TD and ASD groups looked more at the distractors (TD: 0.4598 at TC and 0.5253 at DD; ASD: 0.4288 at TC and 0.5677 at DD). In the *second interval* (200–400 ms), the TD group looked more at the TC (0.5759) than the distractors (0.3884). This pattern continued for the TD group in the subsequent intervals. In the 800–1000-ms interval the average proportion of looking at TC was 0.7887 versus 0.1875 at DD. However, for the ASD group a greater proportion of looking at TC versus DD did not occur until *about 400 ms after the TD*, that is, in the 600–800-ms interval (0.5660 at TC and 0.3958 at DD). In the next interval (800–1000 ms) for the ASD group, the proportion of looking to TC was 0.6736 and to DD 0.2656.

Age, Attention, IQ and Language were also included as variables in the GEE analysis for Phase 1. Both Age and Attention were significant in the 400–600-ms interval (Age: $p = .028$, Attention: $p = .048$) and 600–800-ms interval (Age: $p = .003$, Attention: $p = .009$) following the onset of the noun, with the older children looking significantly more at the target or competitor than the younger children, and the children with higher attention scores looking more at the target or competitor than those with lower attention scores. IQ and Language[1] were only significant in the 600–800-ms interval: $p = .027$ and .016 respectively; they did not have a major effect on looking patterns in Phase 1. Diagnosis only contributed significantly in the 800–1000-ms interval ($p = .020$), with lower proportions of looking time to TC for the ASD group. This interval followed the onset of the disambiguating information which, as stated above, came at approximately 700 ms after the first noun onset.

Phase 2

More looking time to the target in comparison with the competitor and distractors in Phase 2 indicates that children can further restrict reference to the target picture (i.e., *the blue square* *with dots*). Figure 1 includes plots by group for: (A) the proportion of looking time to the target, (B) the proportion of looking time to the competitor, (C) the proportion of looking time to the distractors, and (D) time to fixation.

Proportion of looking time to target

The results for the first GEE analysis in Phase 2, on the proportion of looking time to target, are summarized

Table 2. GEE analyses results for proportion of looking time: Phase 2

	200–400			400–600			600–800			800–1000			1000–1200		
	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*
Diagnosis	1.346	0.971–1.867	.958	1.431	1.005–2.037	.047	1.662	1.13–2.43	.009	1.579	1.062–2.347	.024	1.59	0.894–2.828	.115
Age	0.958	0.827–1.109	.563	1.162	0.993–1.359	.061	1.397	1.159–1.684	< .0001	1.375	1.12–1.684	.002	1.313	1.025–1.681	.031
Attention	1.029	0.968–1.094	.359	1.058	0.998–1.123	.059	1.084	1.025–1.14	.005	1.038	0.973–1.106	.258	1.041	0.963–1.125	.314
FSIQ	0.997	0.979–1.016	.756	0.99	0.97–1.011	.337	0.995	0.975–1.016	.659	1.006	0.985–1.028	.559	1.004	0.98–1.029	.724
Language	1.005	0.991–1.02	.463	1.006	0.992–1.0	.428	0.991	0.976–1.006	.245	0.996	0.979–1.013	.626	1.005	.982–1.028	.685

Note: OR: odds ratio, CI: confidence interval.

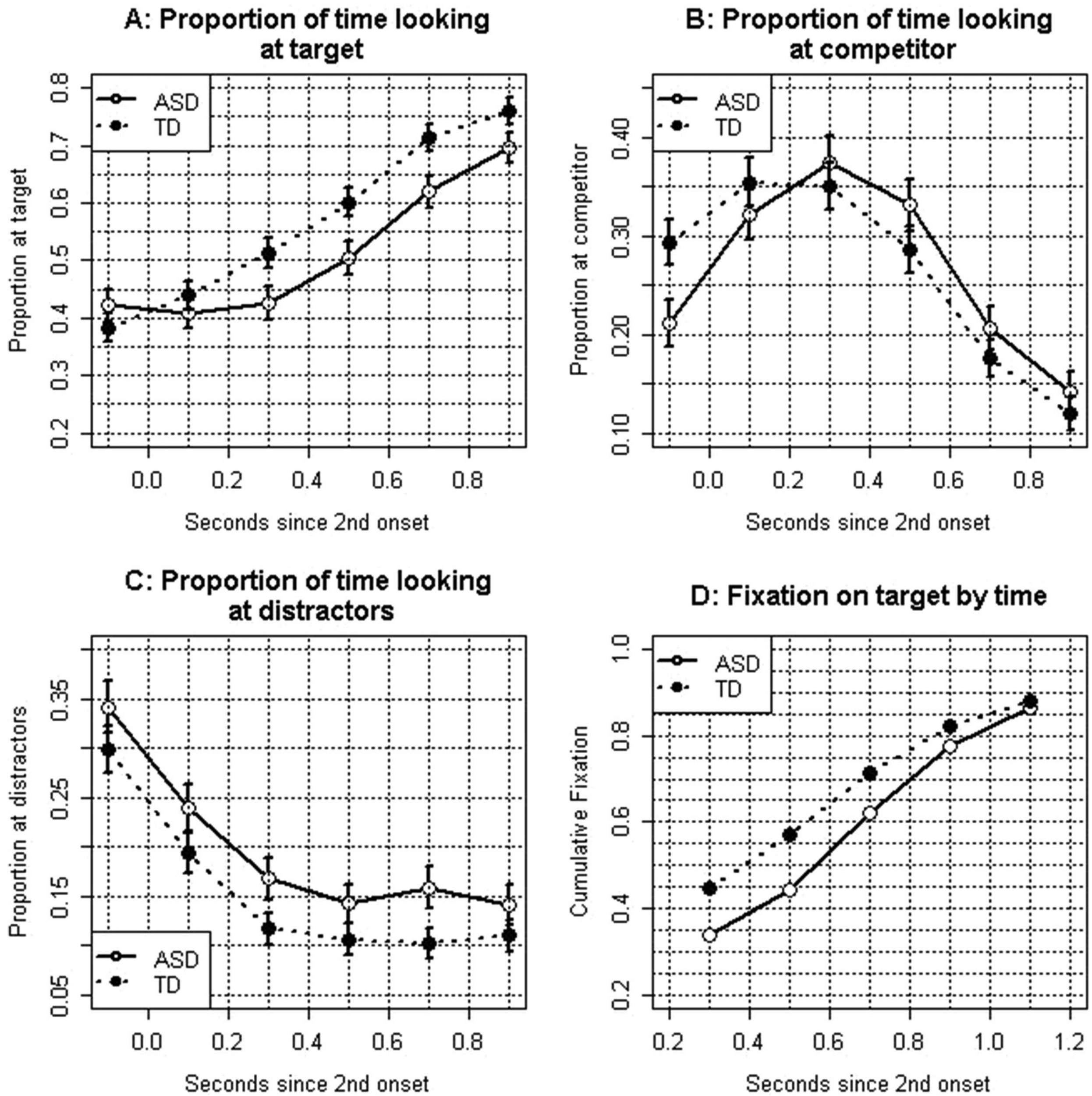

Figure 1. Phase 2: proportion of looking time at (A) target, (B) competitor and (C) distractors, and in (D) time to fixate on target.

in table 2. A clear trend for Diagnosis as an influencing factor started at the 200–400-ms interval and continued as statistically significant through the 800–1000-ms interval. At that stage, the ASD group caught up with the TD group in terms of proportion of looking time to target. In addition, a trend for Age as an influencing factor was clear from the 400–600 interval, continuing as a statistically significant variable through to the end of Phase 2, with the older children looking significantly more at target than the younger children. A trend was apparent for Attention as an influencing variable starting in the 400–600-ms interval, continuing through the 600–800-ms interval. No other variables affected the results. Interaction between Age and Diagnosis was also considered in the GEE; however, there was no evidence in any time period of a significant difference between groups with respect to improvements with age.

Although the percentage of data omitted was small, a sensitivity analysis was conducted for Phase 2. In order to determine if our findings resulted from omitting data when a child looked away for more than 67% of the time, we included those trials; inclusion of these data did not change the overall pattern of results. That is, as found in the previous analysis, Diagnosis was an influencing factor in looking times from the 200–400-ms interval through the 800–1000-ms interval, Age was an influencing factor from the 400–600 interval and Attention in both the 400–600 and 600–800-ms intervals. Thus, the results were not adversely biased due to omission of children looking away.

Fixation to target

The second analysis in Phase 2 was on fixation time to target. As shown in table 3, a trend for Diagnosis was evident from the 200–400-ms interval; this continued to be significant through the 600–800-ms interval, with the children in the TD group more likely to fixate to target than those in the HFA group. Age had a significant impact from the 600–800-ms interval through the 1000–1200-ms interval, with older children more likely than the younger children to fixate to target. Attention also contributed to the variance from the 800–1000-ms interval, trailing off in the final interval of Phase 2; the children with higher attention scores were more likely to fixate on the target. No other variables were significant. As with the proportion of looking data analysis, there was no evidence of a significant difference between groups with respect to improvements with age in any time interval.

Analyses using SCQ scores

We conducted two further analyses, one on the proportion of looking time to target and one analysis on fixation to target—but replacing the dichotomous variable of Diagnosis with the continuous SCQ scores. In the proportion of looking to target analysis, results were very similar to those using Diagnosis: a trend for Age as an influencing factor started in the 400–600-ms interval and continued through to the end of the phase, with the older children looking more. For Attention there was a significant effect only in one interval, 600–800 ms. SCQ score was significant in the 400–600 and 600–800-ms intervals with higher scores, that is, more severe behaviours associated with autism were associated with less looking to target. No other variables were significant.

In the analysis of fixation data using the SCQ scores instead of Diagnosis, the results were similar to those for the analysis using Diagnosis, with SCQ significant for the 400–600 and 600–800-ms intervals but not the later ones. As with the Diagnosis analysis, Age was significant from the 600–800-ms interval through the end of Phase 2. Attention was significant in the 800–1000-ms interval. Neither Language nor IQ had a significant impact on the results.

Table 3. GEE analyses results for fixation: Phase 2

	200–400			400–600			600–800			800–1000			1000–1200		
	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*	OR	CI	*p*
Diagnosis	1.422	0.975–2.075	.067	1.48	1.033–2.119	.033	1.478	1.03–2.109	.031	1.363	0.842–2.207	.208	1.467	0.687–3.136	.322
Age	0.93	0.81–1.122	.566	1.081	0.923–1.265	.333	1.287	1.06–1.563	.011	1.453	1.071–1.97	.016	1.518	1.016–2.267	.041
Attention	1.015	0.95–1.084	.656	1.048	0.987–1.112	.125	1.036	0.97–1.097	.222	1.081	1.009–1.159	.026	1.092	0.997–1.196	.058
FSIQ	0.994	0.975–1.013	.545	0.989	.969–1.01	.306	.986	0.96–1.007	.194	0.99	0.964–1.016	.432	0.997	0.962–1.032	.85
Language	1.005	0.989–1.022	.524	1.008	0.993–1.023	.279	1.005	0.99–1.019	.441	0.993	.973–1.013	.492	0.985	0.954–1.016	.336

Note: OR: odds ratio, CI: confidence interval.

Discussion

We used an eye-tracking task to examine whether the processing involved in integrating a noun with post-nominal modifying information would be similar for young school-age children with HFA and children with TD. The results showed that both groups initially accessed the two possible items that matched the description (that is, the target and competitor) before hearing a modifying phrase that restricted these two items to one, and they looked more at these two items than at the two distractors. That is, children in both groups were able to process the auditory information in the noun phrase and link this to the two appropriate pictures. However, the children with HFA were slower to focus on the two matching items. In previous research using a contrastive context, 5–6-year-olds with TD have shown sensitivity to the presence of two possible referents before settling on the target (Nadig *et al.* 2003). In our study, we provided two additional items of the same type as the target and competitor, and so the children needed to focus on the adjective in the noun phrase to eliminate those additional two items. The fact that the ASD group were slower to link the information required to select the two possible candidates might suggest they are less sensitive to referential conventions.

After hearing the prepositional phrase which provided disambiguating information to reduce two possibilities to one, the looking patterns in Phase 2 (as shown in figure 1) indicated that children in both groups focused more on the target than the competitor (or distractors). However, there were differences between the groups: the mean proportion of looking time to target was higher for the TD group, who also fixated on the target more quickly. It is possible that the ASD group was not as aware as the TD group that disambiguating information would follow and so did not anticipate, which would add to processing time. However, other research has shown slower processing for individuals with autism (e.g., Kourkoulou *et al.* 2013), and deficits in the integration of information have been discussed in previous research that has not been concerned with referential contexts (e.g., Minshew *et al.* 1997). In the current study, differences between the two groups might be associated with speed of integration of the auditory stimuli over the course of the sentence, style of visual processing, or problems integrating the auditory and visual information. Clearly slower processing of auditory input can have an impact on education achievement. In classroom settings the child would be at a disadvantage since most instructions are oral and in real time. Speech is fast and communication will be negatively affected if the listener cannot keep up.

An important finding was the effect of age on how much children looked at the target or competitor in Phase 1 and the target in Phase 2, and how fast they fixated on the target. However, no interaction of age with diagnosis was found; thus, regardless of diagnosis, the older children in the study performed better than the younger children. The implication is that although language processing skills of the children with HFA were less mature than those of children with TD, they will improve, at least in using modifying information in order to identify an intended referent. The other variable that had an impact on the results was attention; how well the children, regardless of group, attended to the stimuli was influenced by their scores on the sustained auditory attention task. This result was not unexpected, given that the task required the children to attend to which adjectives were used with the noun, and keep the initial noun phrase active while attending to the rest of the sentence in order to process the target description and find the target in the display. The results indicate the importance of controlling for these variables in eye-tracking studies.

The results also showed that Language and IQ scores were not significant contributors to how much the children looked at the target or how fast they fixated. Norbury (2005) and Brock *et al.* (2008) found that language scores on a standardized assessment influenced the processing of lexical ambiguity, independent of diagnosis. In both of those studies participants with low language scores were included; for example, in Brock *et al.*, a significant proportion of the comparison group was children with language impairment. Clearly sentence processing draws on language knowledge but it also involves attention, memory, world knowledge and knowledge of the conventions of communication. That the speed of processing was slower for the ASD group may be related to efficiency in visual or auditory processing, and their integration over the course of the sentence. Further research with large samples would be of value to provide a clearer understanding of factors that influence speed of processing in children with ASD.

Of note is that similar results were obtained when we included the SCQ variable instead of Diagnosis; those children who were reported to have more behavioural characteristics typically associated with ASD showed poorer integration of information. This finding complements that of Bavin *et al.* (2014). Severity of autistic behaviours influences the speed in which linguistic and visual information is integrated.

A focus of previous ASD research has been the influence of context in resolving lexical or syntactic ambiguity (e.g., Norbury 2005). In the current study we did not manipulate the verb, nor did we manipulate the nonverbal context; a referential contrast in the visual display was provided for all items. Unlike previous research with individuals with TD, we included four items of the same kind in the display, two of which could be identified by the adjective included with the noun. The first step in identifying the target was to narrow down the choice to these two possibilities. The second step was to use the information from a modifying phrase presented later in the sentence in order to identify the intended referent. If children have an understanding of referential conventions—for example, that when there is more than one of the same kind, speakers can be expected to provide additional information—they might anticipate that if a phrase does not provide a unique description, more information might follow, to provide a unique description of one of the items. Both the TD and HFA groups were able to use the information provided to restrict reference. However, the ASD group was slower, suggesting they may be less advanced than the TD in learning referential conventions.

In conclusion, the current eye-tracking study, with a larger sample of children with HFA than is typical, adds to current knowledge about how children with HFA of primary school age process modifying information in the course of listening to a sentence. It also adds to previous research on how children with TD restrict reference (e.g., Nadig *et al.* 2003). The participants were recruited from mainstream schools and therefore all would be expected to be able to function in the classroom. In primary school, oral instruction plays a major role; based on our results, we can anticipate that the children with HFA would not be as efficient in processing the information addressed to them as the children with TD. Thus, education programs might include training in using available contextual clues and in understanding conversation conventions in order to avoid misunderstanding; for example, training on how items can be identified using different linguistic structures and how information is integrated to provide meaning. The context may help disambiguate when there are two items of the same kind, but speakers often include additional information to clarify which was intended. Such training may be useful in assisting children with HFA to understand more of what others are saying. It is also important that children with ASD are provided with time to process the information that is addressed to them.

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Notes

1. We initially used the scores for V-IQ and NV-IQ separately and those for Receptive language and Expressive language separately. None of these had a significant impact on the results and so we included the total language score and FSIQ score.

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