Published in final edited form as:

J Child Psychol Psychiatry. 2013 July ; 54(7): 745–753. doi:10.1111/jcpp.12073.

Children with ASD can use gaze in support of word recognition and learning

Karla K. McGregor¹, Gwyneth Rost^{1,2}, Rick Arenas¹, Ashley Farris-Trimble¹, and Derek Stiles^{1,3}

¹The University of Iowa, Iowa City, IA, USA

Abstract

Background—Many children with autism spectrum disorders (ASD) struggle to understand familiar words and learn unfamiliar words. We explored the extent to which these problems reflect deficient use of probabilistic gaze in the extra-linguistic context.

Method—Thirty children with ASD and 43 with typical development (TD) participated in a spoken word recognition and mapping task. They viewed photographs of a woman behind three objects and simultaneously heard a word. For word recognition, the objects and words were familiar and the woman gazed ahead (neutral), toward the named object (facilitative), or toward an un-named object (contradictory). For word mapping, the objects and words were unfamiliar and only the neutral and facilitative conditions were employed. The children clicked on the named object, registering accuracy and reaction time.

Results—Speed of word recognition did not differ between groups but varied with gaze such that responses were fastest in the facilitative condition and slowest in the contradictory condition. Only the ASD group responded slower to low frequency than high-frequency words. Accuracy of word mapping did not differ between groups, but accuracy varied with gaze with higher performance in the facilitative than neutral condition. Both groups scored above single-trial chance levels in the neutral condition by tracking cross-situational information. Only in the ASD group did mapping vary with receptive vocabulary.

Conclusions—Under laboratory conditions, children with ASD can monitor gaze and judge its reliability as a cue to word meaning as well as typical peers. The use of cross-situational statistics to support word learning may be problematic for those who have weak language abilities.

Keywords

Autistic disorder; language

© 2013 The Authors.

Correspondence Karla K. McGregor, University of Iowa, 303 Speech and Hearing Center, Iowa City, IA 52242, USA; karla-mcgregor@uiowa.edu.

²Present address: Gwyneth Rost University of Massachusetts, Amherst, MA, USA

³Present address: Derek Stiles Rush University, Chicago, IL, USA

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Stimuli.

Introduction

When listening to spoken language, we seek meaning from a noisy, probabilistic signal (Nusbaum & Margoliash, 2009). We retrieve the meanings of familiar words and assign probable meanings to unfamiliar words. In both cases, we are aided in the quest for meaning by multiple cues from the linguistic and extra-linguistic contexts in which the word is used (Hollich, Hirsh-Pasek & Golinkoff, 2000; Seidenberg & MacDonald, 1999). In this sense, the distinction between understanding familiar words and learning unfamiliar words is blurred; both are supported by a desire for meaning.

However, not everyone shares the ability to satisfy this desire to the same extent. People with autism spectrum disorders (ASD) have problems comprehending the meanings of spoken (Henderson, Clarke & Snowling, 2011; Norbury, 2005) and written words (Nation, Clarke, Wright & Williams, 2006; Norbury & Nation, 2011). They also seem less able to learn word meanings than word forms (the opposite of typical peers) and less able than typical peers to retain newly learned word meanings (Norbury, Griffiths & Nation, 2010). In this study, we investigated whether the problem that people with ASD have in attaching meaning to words reflects a deficit in use of eye gaze information in the extra-linguistic context.

Gaze as a support for meaning

Typically the ability to use the gaze of a social partner develops early. Three-to 6-month olds monitor and follow the gaze and head turn of their social partners (D'Entremont, Hains & Muir, 1997). Two-year olds check the gaze of a speaker after hearing a novel word even when not directly addressed (Akhtar, Jipson & Callanan, 2001). Such behaviors grow more sophisticated as children shift from using information to cue attention to using the same information to cue intention (Hollich et al., 2000).

Children must come to judge the reliability of their partners' gaze. In naturalistic settings, gaze sometimes supports the extraction of meaning, but at other times, it is irrelevant or contradictory to that goal. In fact, other cues to meaning are probabilistic as well. For example, learners can infer word mappings by tracking co-occurrences of words and referents as they accrue over time (Yu & Smith, 2007). But words co-occur with their referents in probabilistic ways. Even words for concrete objects are only sometimes uttered in the context of those objects. In the Competition Model, MacWhinney (1987, (2008) describes the probabilistic nature of cues in terms of reliability, availability, and validity. *Reliability* is the proportion of times the cue is correct over the total number of occurrences of the cue. *Cue availability* is the proportion of times the cue is available over the times it is needed. The product of cue reliability and cue availability is overall *cue validity*. The higher the cue validity, the more useful it will be. Cues to word meaning must be stored, evaluated for their usefulness, and then applied (or ignored) across multiple encounters.

Gaze and ASD

Early symptoms of ASD include infrequent looking at others' faces and infrequent use of gaze to share interests with others (Osterling & Dawson, 1994). Children with ASD are slow

to orient to visual stimuli (Townsend, Harris & Courchesne, 1996), especially if those stimuli involve people (Leekam & Moore, 2001). They demonstrate impairment in the perception of gaze direction (Howard et al., 2000) and immature neural responses to changes in gaze direction (Grice et al., 2005). Even as adolescents, high-functioning children with ASD are poorer than peers at determining the gaze of people in still photographs (Campbell et al., 2006). For these reasons, listeners who have ASD may derive less benefit from gaze cues to meaning than other listeners.

In fact, it has been demonstrated that children with ASD are less likely than typical peers to use another's gaze to determine the referent of a new word in an ambiguous context. However, the strength of the finding varies across studies. In some, group differences are robust (Baron-Cohen, Baldwin & Crowson, 1997; Preissler & Carey, 2005); in others they are not (Luyster & Lord, 2009). Perhaps, only a subset of children with ASD – those with concomitant deficits in overall intellectual functioning or concomitant weaknesses in language – find it difficult to use gaze in service of word learning. This is a popular hypothesis but one that is not yet fully addressed. Moreover, previous studies have concentrated on the role of gaze during single encounters with new words. Whether children with ASD can exploit probabilistic gaze information across encounters, as one would need to do in natural settings, has not been determined.

Our understanding of how children with ASD process familiar words is less complete still, but two studies are informative. Loucas et al. (2011) used gating to compare word recognition in adolescents with ASD and concomitant syntactic language impairments to that of typical peers matched on nonverbal IQ or language impairment. The words were concrete nouns and verbs of either high or low frequency. The deficit among the ASD group was revealed only in the most difficult condition: they needed more information than typical peers with or without language impairment to recognize low-frequency words. Because this study was limited to children with ASD who had language impairments, we do not know whether word recognition is problematic for those with ASD broadly defined.

Whereas Loucas et al. (2011) used a highly decontextualized task to tap word recognition, Brock, Norbury, Einav and Nation (2008) used a less decontextualized task that varied linguistic context such that competitors (e.g., hamster and hammer) were or were not constrained by a biasing sentence (e.g., Jon stroked the hamster). The children with ASD were as sensitive to linguistic contexts as their typical peers; however, within both groups, children with lower language abilities were less sensitive. Both Loucas et al. (2011) and Brock et al. (2008) leave unanswered the question of whether children with ASD can make use of cues in the *extralinguistic* context to support the quest for meaning.

We, therefore, examined the ability of children with ASD to use gaze in the extra-linguistic context to support word recognition and learning. There were two main questions: do they monitor gaze and do they accurately judge the reliability of the gaze as a cue to meaning. We also made an initial exploration of their ability to use other probabilistic cues, namely, cross-trial word-object co-occurrences.

Two diagnostic groups participated: children with ASD and their unaffected age-mates who were typically developing (TD). To isolate ASD symptomology from broader intellectual deficits, we included only high-functioning children. To determine whether problems with word recognition and learning reflect weak language abilities rather than ASD *per se*, we allowed language abilities to vary in both groups and explored individual differences in performance related to this variability.

The task tapped familiar word recognition and unfamiliar word-to-referent mapping given probabilistic cues of gaze and word-object co-occurrences. On some word recognition and mapping trials the gaze cue was absent (neutral); in others it was present. When present, a woman either gazed toward the target (facilitative) or toward a competitor (contradictory) during word recognition trials. Only facilitative gaze was presented during word mapping trials. The presence of contradictory gaze required the children to judge the reliability of the cue to use it effectively. Because the gaze was sometimes absent, the children needed to rely on cross-trial information when attempting to map new words.

Word recognition

For recognition of familiar words, we determined reaction times (RT) because accuracy would likely be at ceiling. The familiar word stimuli were of two types, high and low frequency. Compared with high-frequency words, low-frequency words tend to be acquired later (Roodenrys, Hulme, Alban, Ellis & Brown, 1994) and they have more phonemes and rarer phonotactics (Landauer & Streeter, 1973). Therefore, any problems that children with ASD experience with word recognition might be more noticeable for low frequency than high-frequency words.

We predicted that both groups would be quicker to recognize words given a facilitative than a neutral cue and, in turn, that recognition would be quicker in response to a neutral than a contradictory cue. We predicted the ASD group to show smaller differences between cue conditions because they would not make use of gaze cues to the same extent as the TD group. We predicted that both groups would be quicker to recognize high-frequency words than low-frequency words. Following Loucas et al. (2011), we predicted the ASD group to show larger differences between frequency conditions.

Alternatively, following Brock et al. (2008), if word recognition problems stem from language deficits, we would not find the interactions predicted above. Instead there would be correlations between speed of word recognition and language ability within participant groups.

Word mapping

For the mapping of unfamiliar words to novel referents, accuracy of target selection was the dependent variable. We predicted that both groups would use gaze when available so that performance on facilitative trials would be higher than on neutral trials; however, the difference between gaze conditions would be smaller for the ASD group than the TD group because they would not make use of gaze to the same extent.

Alternatively, if problems with use of gaze are limited to the subset of children with ASD who also have concomitant language deficits then we might not obtain the predicted interaction, but there would be correlations between accuracy of word-to-referent mapping and language ability within the participant groups.

We predicted that, on neutral trials, the TD group would use information gleaned on earlier trials (gaze cues and word-to-object co-occurrences) to support mapping inferences. We did not make any prediction about the ASD group as little is known about their cross-situational statistical learning.

Method

Participants

Participants were 73 children, 30 with diagnosed ASD, and 43 without who were treated according to ethics approved by the University of Iowa IRB. These were a subset of participants in a study of vocabulary depth (McGregor et al., 2012). The groups were selected to be similar in age, nonverbal IQ, and maternal education (Table 1). A wide range of language ability was permitted to allow exploration of the contribution of language ability to performance via regression. On the most comprehensive standardized test of language administered, the core battery of the Clinical Evaluation of Language Fundamentals-4 (Semel, Wiig & Secord, 2003), there were children who scored more than one standard deviation above the mean and others who scored more than two standard deviations below the mean in both ASD and TD groups. Scores on the tests of language were highly intercorrelated; therefore, we selected the Peabody Picture Vocabulary Test-III (PPVT-III, Dunn & Dunn, 1997) scores as a proxy for language ability in the regression analysis. As a measure of receptive vocabulary knowledge, it was the most closely related to the aspects of language under investigation.

All participants had normal hearing acuity and nonverbal intelligence as determined by passing scores on a pure-tone hearing screening (ASHA, 1990) and standard scores above 84 on the matrices subtest of the Kaufman Brief Intelligence Test-2 (Kaufman & Kaufman, 2004), respectively. An assistant trained in reliable administration for research purposes verified the diagnosis of ASD via scores on Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore & Risi, 1999) and the Social Communication Questionnaire (SCQ, Rutter, Bailey, Berument, Lord & Pickles, 2003) that met cutoffs for ASD/autism. All members of the TD group scored outside the range of ASD (lower than 11) on the SCQ.

Stimuli

Thirty-six easily identifiable objects were selected as familiar targets for word recognition. These were named by concrete nouns of high (>30 per million words) or low frequency (<1 per million words) (Carroll, Davies & Richman, 1971). All were 1-to-3 syllables long. Age-of-acquisition for the high-frequency words averaged 4.6 years with a range of 3.33–6.11, whereas age-of-acquisition for the low-frequency words averaged 6.3 years with a range of 4.05–12.16 (Kuperman, Stadthagen-Gonzalez & Brysbaert, 2012). Eighteen difficult-to-identify objects were selected as unfamiliar targets for word-to-referent mapping. Novel

words of 1-to-3 syllables with English-appropriate phonotactics were created as their names. Real and novel target words appear in the Appendix S1.

The words were recorded by a female native speaker of American English on a Kay CSL device using Multi-speech software and were normalized for volume using PRAAT. Words ranged from 390 to 510 ms with no difference between familiar and novel words, $p = .40$.

The objects were presented in photographs on a computer screen. Each showed a woman seated at a table behind three clear 12" × 12" × 12" cubes each containing a single object (Figure 1). Each familiar object was the target once in each of the three gaze conditions and a competitor in six other photographs. Thus, each familiar object appeared in nine photographs, paired with other objects of similar name frequency. The nine photographs represented three object contexts. For example, *elf* appeared with *cucumber* and *teacup* on three trials, with *tricycle* and *visor* on three trials, and with *bleach* and *cookbook* on three trials.

To the target trials, we added 36 foil trials, eight at the beginning and approximately one every 10 trials thereafter. To ensure that the gaze cue was reliable, that is, facilitative more often than contradictory, foils involved repetition of familiar targets with facilitative gaze cues. Given 36 targets and 36 foils with facilitative gaze cues and 36 targets with contradictory gaze cues, the reliability of the gaze cue for word recognition, when available, was 66.7%. Cues were available on 75% of all trials; therefore, cue validity was 50% ($66.7\% \times 75\%$).

Each unfamiliar object appeared as a target twice, once each in facilitative and neutral conditions, and as a competitor four times, for a total of six photographs per object. Because unfamiliar objects never appeared in the contradictory condition, the reliability of the gaze cue for word-to-referent matching was 100% when available. The cue was available on 50% of all trials; therefore, cue validity was 50% ($100\% \times 50\%$). By repeating each of the items and varying their roles as targets or competitors across trials, the effect of any extra attention paid to particularly salient objects would be washed out and word-object co-occurrences could be used to support performance.

Procedure

Participants were instructed to click on a cross-mark to begin each trial and then to click on one of the three pictured objects as soon as it was named. No instruction or explanation regarding the woman standing behind the objects was provided. After practicing with familiar object trials (not in the experiment proper), the participants were told, 'Now that you've learned how to do this, it's going to get a little harder. You will not recognize some of the pictures and will not know all of the words you hear. Just make your best guess.' The experiment then began. For each trial, the photograph appeared as soon as the child clicked the cross-mark and, 100 ms later, a single spoken word named the target object. The 180 items were presented in a fixed random order with E-Prime collection of response accuracy and RT from the onset of the spoken word to the child's click.

Results

Word recognition

Accuracy of word recognition ranged from 95% to 100% across groups and conditions. Median RT for accurate responses was the dependent variable in a mixed model ANOVA with word frequency (high, low) and gaze cue type (facilitative, neutral, and contradictory) as within-subject variables and diagnostic group (ASD, TD) as the between-subjects variable. The median was used to minimize the effect of positive skew in the data.

There was no main effect of diagnostic group, $F(1,71) = 2.09, p = .15$. There was a main effect of frequency, $F(1,71) = 6.21, p = .02, \eta^2_{\text{partial}} = .08$, with RT to low-frequency words slower than for high-frequency words. However, this effect was qualified by a Frequency $\times$ Diagnostic group interaction, $F(1,71) = 5.15, p = .03, \eta^2_{\text{partial}} = .07$. Only the children with ASD responded more slowly to lower frequency words, $p = .01$; the children in the TD group did not, $p = .99$, (Figure 2). The ASD group was not significantly different from the TD group in RT to low- or high-frequency words, $ps > .32$.

There was a main effect of cue, $F(2,142) = 229.71, p < .0001, \eta^2_{\text{partial}} = .76$, such that responses were faster for facilitative cues than neutral cues which, in turn, were faster than responses for contradictory cues, all $ps < .0001$. This effect was qualified by a Cue $\times$ Frequency interaction, $F(2,142) = 15.56, p < .0001, \eta^2_{\text{partial}} = .18$. Compared with low-frequency words, high-frequency words elicited faster responses in the facilitative ($p = .05$) and contradictory conditions ($p = .0002$), but slower responses in the neutral condition ($p = .05$) (Figure 3). Contrary to prediction, there was no interaction between diagnostic group and cue condition, $F(2,142) = 1.49, p = .23$.

Knowing that frequency, age-of-acquisition, and word length are confounded, we further explored the Cue $\times$ Frequency interaction by correlating RT per cue condition and diagnostic group with age-of-acquisition and word length. There were no significant relationships with age-of-acquisition, all $ps > .19$, nor were there significant relationships with word length in the facilitative or contradictory cue conditions, all $ps > .22$. In the neutral cue condition, there were significant negative correlations between RT and word length for the ASD group, $r = -.36, p = .03$, and the TD group, $r = -.43, p = .009$. Longer words elicited faster responses.

To explore individual differences within the groups, we regressed age and PPVT-III raw scores on word recognition RT averaged across conditions. For the ASD group, age and vocabulary together accounted for 26% of the variance in RT, adjusted $R^2 = .26, p = .007$. Neither age nor vocabulary bore a significant independent correlation with RT, $ps = .14$. For the TD group, age and vocabulary together accounted for 23% of the variance in RT, adjusted $R^2 = .23, p = .002$. Neither age nor vocabulary bore a significant independent correlation with RT, $ps > .07$.

Word mapping

The dependent variable for word-to-referent mapping was mean accuracy, defined as the proportion of trials in which the participant clicked on the target. A mixed model ANOVA

with gaze cue as a within-subject variable and diagnostic group as the between-subjects variable revealed no main effect of diagnostic group, $F(1,71) < 1$. There was a main effect of gaze cue, $F(1,71) = 123.48, p < .0001, r^2_{\text{partial}} = .63$, with accuracy in the facilitative condition ($M = 0.73, SD = 0.17$) higher than in the neutral condition ($M = 0.42, SD = 0.17$) (Figure 4). Contrary to prediction, there was no interaction between diagnostic group and condition, $F(1,71) < 1$. Mean accuracy in the facilitative condition was 74% ($SD = 20$) for the ASD group and 73% ($SD = 20$) for the TD group. In the neutral condition, chance on a single trial was 33%, but mean accuracy in the neutral condition was 42% ($SD = 14$) for both groups. Therefore, both groups scored significantly above chance, ASD: $t = 3.55, df = 29, p = .001$; TD: $t = 4.38, df = 42, p < .0001$.

In the facilitative condition, we regressed age and PPVT-III raw scores on word mapping accuracy and found no significant associations, whether considered in combination or alone, for either group, $ps > .13$. In the neutral condition, vocabulary, but not age, was correlated with accuracy in the ASD group: age $r_{\text{partial}} = -.35, p = .14$; PPVT-III $r_{\text{partial}} = .56, p = .02$. For the TD group, neither age nor vocabulary, in combination or alone, bore a significant association with accuracy in the neutral condition, $ps > .66$. This difference in predictive relationships between groups occurred despite their being similar in range of raw vocabulary scores (TD = 101–182; ASD = 101–193) and mapping performance in the neutral condition (TD = 0.11–0.72; ASD = 0.25–0.75).

Discussion

Children with ASD and typical peers recognized familiar words and made decisions about the referents of unfamiliar words in response to probabilistic gaze cues and word-object co-occurrences. Because children with ASD have deficient perception and interpretation of gaze, we predicted they would not exploit gaze cues to the same extent as other children, but we were wrong. The two groups presented with remarkably similar patterns of gaze usage. Below we explore the evidence that children with ASD can use gaze as a cue to meaning.

Children with ASD can use gaze in support of word meaning

The speed of word recognition was influenced by gaze in predictable ways. Facilitative gaze produced faster response times than neutral gaze, which in turn was faster than contradictory gaze. This effect was equally large for both the ASD and TD groups; therefore, children with ASD did monitor gaze direction. In their laboratory study, Brock et al. (2008) also failed to find differences between high-functioning children with ASD and their typical peers on a word recognition task. Recall that they manipulated the linguistic context rather than the extra-linguistic context. This is likely relevant to understanding why, despite no group-level effects, they found that individuals with lower language abilities within the groups had more difficulty using contextual information to support word recognition. We found a weaker relationship. Language scores and age together accounted for roughly one-quarter of the variance in each group such that older children with stronger receptive vocabularies were faster at word recognition but, alone, neither was predictive. Thus, high-functioning children with ASD, even those with lower language abilities, monitor gaze in the extra-linguistic context. Facilitative gaze speeds their word recognition.

As predicted, high-frequency words elicited faster responses than low-frequency words in the facilitative and contradictory conditions (but, unexpectedly, not in the neutral condition¹), but this was true only of the ASD group. This finding is consistent with Loucas et al. (2011) who found adolescents with ASD to be more challenged by low than high-frequency words relative to their unaffected peers during a gated word recognition task. By definition, the word learner experiences low-frequency words less often than high-frequency words. Thus, the Group $\times$ Frequency interaction suggests that learners with ASD require a higher threshold of exposures than unaffected peers to represent words robustly. This could reflect lower level deficits in speech processing or higher level deficits in the formation of mental representations (Loucas et al., 2011). However, to put this difference in perspective, recall that, although the children with ASD were slower to respond to low-frequency words than high-frequency words, in neither case were their response times significantly different from those of their unaffected peers. Therefore, the functional impact of this difference in profile appears to be minimal.

Accuracy of word recognition was always at ceiling, even in the contradictory gaze condition. This is not surprising given that the words were selected to be familiar; however, this means that the word recognition data cannot reveal the children's judgments of gaze cue reliability. For that, we must consider word-to-referent mapping. If, based on their experience across word recognition trials, children took the woman as a perfectly reliable source of information, they would have scored at ceiling when mapping words to referents in the facilitative condition. Instead, the children with ASD averaged 74% accuracy and those in the TD group averaged 73%. These values are close to the reliability of the gaze cues in the word recognition trials (67%), suggesting that both groups of children had accurately determined the reliability of the woman's gaze cues. They paid attention to information across situations.

Therefore, neither gaze *per se* nor the probabilistic manner in which gaze was offered across trials presented problems for these high-functioning children with ASD. However, we must qualify this conclusion by pointing out that this laboratory experience was simpler than a real-world experience. The visual stimuli were still photographs requiring no movement tracking or social interaction. Moreover, the woman depicted in the photographs oriented toward the objects with both her eyes and head, thereby increasing the salience of the cue (Leekam, Hunnisett & Moore, 1998). The familiar word stimuli were concrete nouns, most of which are early acquired. Thus, it was likely trivial for the children to realize that gaze was not a completely reliable cue. In this sense, the findings present a baseline against which to compare gaze usage in face-to-face interactions where social, linguistic, and statistical demands are higher and cues may be more subtle.

Moreover, although both the ASD and TD groups exploited gaze in service of meaning, we do not assume a common mechanistic basis for this shared behavior. Our thinking here is

¹There are confounds between word frequency, length, and phonotactics such that low-frequency words tend to be longer and have rarer phonotactics than high-frequency words (Landauer & Streeter, 1973); therefore, low-frequency words will tend to have fewer lexical neighbors. Older children and adults are more efficient at recognizing words with fewer neighbors (Garlock, Walley & Metsala, 2001) so, in the absence of cues, the benefit of low-frequency words may be better attributed to neighborhood density than frequency *per se*.

influenced by Senju, Tojo, Dairoku and Hasegawa (2004). They compared children with ASD and typical age-mates on the ability to locate a target on a computer screen when preceded by a neutral cue or a directional cue, either an arrow or a photograph of a woman with her gaze shifted. The children were similar to those studied here in age and, although no nonverbal IQs were available, they were also high functioning in that they had age-expected academic achievement. In one experiment, the cue was four times more likely to indicate the wrong than the right direction. The children were told to ignore this misleading cue. The typical children ignored the arrow but reflexively oriented to gaze. The children with ASD reflexively oriented to both cues, that is, they failed to privilege eye gaze. Their use of another's gaze was not social as it was for other children (Senju et al., 2004). It could be that the participants with ASD in this study treated gaze much as they would an arrow. This hypothesis gains support given reports of weaker word learning among children with ASD in tasks that require the reading of a social partner's intentions than in those that can be accomplished by surface perceptions alone (Parish-Morris, Hennon, Hirsch-Pasek, Golinkoff & Tager-Flusberg, 2007). Thus, to amend the conclusion further: Children with ASD can use probabilistic gaze in simplified contexts in support of word recognition and learning but they may arrive at this solution via different mechanisms than other children.

Finally, there was evidence that using gaze, or other probabilistic cues, across trials to support word learning in ambiguous contexts may be problematic for some individuals with ASD. Recall that, like their peers, the children with ASD performed above 33% accuracy on word-to-referent mapping in the neutral condition. Therefore, as a group, they stored, evaluated, and applied information gleaned on previous trials to support their inferences about word-to-referent maps on neutral trials (Yu & Smith, 2007). However, within the ASD group, and that group alone, language ability was strongly predictive of performance in the neutral condition, accounting for over 50% of variance in mapping accuracy. The lack of association between language scores and mapping accuracy in the TD group was neither a problem of power, as the sample size was larger than in the ASD group, nor of variability, as the range of their scores was similar. We therefore posit a new hypothesis: cross-situational statistical learning is problematic for a subgroup of children with ASD, those who present with weaker (potentially clinically significant) language abilities. As the evidence here is preliminary, this hypothesis awaits further study. In the meantime, it is useful to note that statistical learning is deficient in children affected by specific language impairment (e.g., Hedenius et al., 2011).

Conclusions and future directions

In conclusion, the ASD and TD groups were equally able to use gaze in support of word recognition and mapping and they were similar in judgments of cue reliability. This strength could be exploited in interventions designed to remediate vocabulary deficits in affected individuals. Specifically, reliable gestures that support word-to-referent mappings should be accessible to children with ASD, at least those who are high functioning. Future studies may reveal whether the ability to use gestural cues is reduced in face-to-face social contexts and whether compromised cross-situational statistical learning contributes to the deficits in word recognition and mapping that are characteristic of some individuals with ASD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank Amanda Berns for ADOS testing, Amanda Nematbash for stimuli, and the participants for their generosity. This study was funded by NIH-NIDCD 2 R01 DC003698 and an augmentation award from Autism Speaks.

References

- Akhtar N, Jipson J, Callanan MA. Learning words through overhearing. *Child Development*. 2001; 72:416–430. [PubMed: 11333075]
- ASHA. Guidelines for screening for hearing impairments and middle ear disorders. ASHA. 1990; 32:17–24.
- Baron-Cohen S, Baldwin DA, Crowson M. Do children with autism use the speaker's direction of gaze strategy to crack the code of language? *Child Development*. 1997; 68:48–57. [PubMed: 9084124]
- Brock J, Norbury C, Einav S, Nation K. Do individuals with autism process words in context? Evidence from language-mediated eye-movements. *Cognition*. 2008; 108:896–904. [PubMed: 18692181]
- Campbell R, Lawrence K, Mandy W, Mitra C, Jeyakuma L, Skuse D. Meanings in motion and faces: Developmental associations between the processing of intention from geometrical animations and gaze detection accuracy. *Development and Psychopathology*. 2006; 18:99–118. [PubMed: 16478554]
- Carrol, JB.; Davies, P.; Richman, B. *The American heritage word frequency book*. New York: Houghton Mifflin; 1971.
- D'Entremont B, Hains SMJ, Muir DW. A demonstration of gaze following in 3- to 6-month-olds. *Infant Behavior and Development*. 1997; 20:569–572.
- Dunn, LM.; Dunn, LM. *Peabody picture vocabulary test*. 3. Circle Pines, MN: American Guidance Service; 1997.
- Garlock VM, Walley AC, Metsala JL. Age-of-acquisition, word frequency, neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language*. 2001; 45:468–492.
- Grice SJ, Halit H, Farroni T, Baron-Cohen S, Bolton P, Johnson MH. Neural correlates of eye-gaze detection in young children with autism. *Cortex*. 2005; 41:342–353. [PubMed: 15871599]
- Hedenius M, Persson J, Tremblay A, Adi-Japha E, Verissimo J, Dye CD, Ullman MT, et al. Grammar predicts procedural learning and consolidation deficits in children with specific language impairment. *Research in Developmental Disabilities*. 2011; 32:2362–2375. [PubMed: 21840165]
- Henderson LM, Clarke PJ, Snowling MJ. Accessing and selecting word meaning in autism spectrum disorder. *Journal of Child Psychology and Psychiatry*. 2011; 52:964–973. [PubMed: 21401594]
- Hollich GJ, Hirsh-Pasek K, Golinkoff RM. Breaking the language barrier: An emergentist coalition model for the origins of word learning. *Monographs of the Society for Research in Child Development*. 2000; 65(3, Serial No. 262):1–123.
- Howard MA, Cowell PE, Boucher J, Broks P, Mayes A, Farrant A, Roberts N. Convergent neuroanatomical and behavioural evidence of an amygdala hypothesis of autism. *Neuro Report*. 2000; 11:2931–2935.
- Kaufman, AS.; Kaufman, NL. *The Kaufman brief intelligence test-2*. Circle Pines, MN: AGS; 2004.
- Kuperman V, Stadthagen-Gonzalez H, Brysbaert M. Age-of-acquisition ratings for 30 thousand English words. *Behavior Research Methods*. 2012 Advance online publication. 10.3758/s13428-012-0210-4
- Landauer T, Streeter L. Structural differences between common and rare words: Failure of equivalence assumptions for theories of word recognition. *Journal of Verbal Learning and Verbal Behavior*. 1973; 12:119–131.

- Leekam SR, Hunnisett E, Moore C. Targets and cues: Gaze following in children with autism. *Journal of Child Psychology and Psychiatry*. 1998; 39:951–962. [PubMed: 9804028]
- Leekam, S.; Moore, C. The development of attention and joint attention in children with autism. In: Burack, JA.; Charman, T.; Yirmiya, N.; Zelazo, PR., editors. *The development of autism: Perspectives from theory and research*. Hillsdale, NJ: Lawrence Erlbaum Associates; 2001. p. 105-129.
- Lord, C.; Rutter, M.; DiLavore, P.; Risi, S. *Autism diagnostic observation schedule – WPS edition*. Los Angeles, CA: Western Psychological Services; 1999.
- Loucas T, Riches N, Baird G, Pickles A, Simonoff E, Chandler S, Charman T. Spoken word recognition in adolescents with autism spectrum disorders and specific language impairment. *Applied Psycholinguistics*. 2011; 1:1–22.
- Luyster R, Lord C. Word learning in children with autism spectrum disorders. *Developmental Psychology*. 2009; 45:1774–1786. [PubMed: 19899931]
- MacWhinney, B. The competition model. In: MacWhinney, B., editor. *Mechanisms of language acquisition*. Hillsdale, NJ: Lawrence Erlbaum; 1987. p. 249-308.
- MacWhinney, B. A unified model. In: Robinson, P.; Ellis, N., editors. *Handbook of cognitive linguistics and second language acquisition*. Mahwah, NJ: Lawrence Erlbaum Associates; 2008.
- McGregor KK, Berns A, Owen AJ, Michels S, Duff D, Bahnsen AJ, Lloyd M. Associations between syntax and the lexicon among children with or without ASD and language impairment. *Journal of Autism and Developmental Disorders*. 2012; 42:35–47. [PubMed: 21365354]
- Nation K, Clarke P, Wright B, Williams C. Patterns of reading ability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*. 2006; 36:911–919. [PubMed: 16897396]
- Norbury CF. Barking up the wrong tree? Lexical ambiguity resolution in children with language impairments and autistic spectrum disorders. *Journal of Experimental Child Psychology*. 2005; 90:142–171. [PubMed: 15683860]
- Norbury CF, Griffiths H, Nation K. Sound before meaning: Word learning in autistic disorders. *Neuropsychologia*. 2010; 48:4012–4019. [PubMed: 20951710]
- Norbury CF, Nation K. Understanding variability in reading comprehension in adolescents with autism spectrum disorders: Interactions with language status and decoding skill. *Scientific Studies of Reading*. 2011; 15:191–210.
- Nusbaum, HC.; Margoliash, D. Language processes. In: Berntson, GG.; Cacioppo, JT., editors. *Handbook of neuroscience for the behavioral sciences*. Vol. 2. Hoboken, NJ: John Wiley; 2009. p. 879-904.
- Osterling J, Dawson G. Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism and Developmental Disorders*. 1994; 24:247–257. [PubMed: 8050980]
- Parish-Morris J, Hennon EA, Hirsch-Pasek K, Golinkoff RM, Tager-Flusberg H. Children with autism illuminate the role of social intention in word learning. *Child Development*. 2007; 78:1265–1287. [PubMed: 17650138]
- Preissler MA, Carey S. The role of inferences about referential intent in word learning: Evidence from autism. *Cognition*. 2005; 97:B13–B23. [PubMed: 15925356]
- Roodenrys S, Hulme C, Alban J, Ellis AW, Brown GD. Effects of word frequency and age of acquisition on short-term memory span. *Memory and Cognition*. 1994; 22:695–701. [PubMed: 7808278]
- Rutter, M.; Bailey, A.; Berument, SK.; Lord, C.; Pickles, A. *Social communication questionnaire (SCQ)*. Los Angeles: Western Psychological Services; 2003.
- Seidenberg MS, MacDonald MC. A probabilistic constraints approach to language acquisition and processing. *Cognitive Science: A Multidisciplinary Journal*. 1999; 23:569–588.
- Semel, E.; Wiig, EH.; Secord, WA. *Clinical evaluation of language fundamentals – Fourth edition (CELF-4)*. San Antonio, TX: The Psychological Corporation; 2003.
- Senju A, Tojo Y, Dairoku H, Hasegawa T. Reflexive orienting in response to eye gaze and an arrow in children with and without autism. *Journal of Child Psychology and Psychiatry*. 2004; 45:445–458. [PubMed: 15055365]

- Townsend J, Harris NS, Courchesne E. Visual attention abnormalities in autism: Delayed orienting to location. *Journal of the International Neuropsychological Society*. 1996; 2:541–550. [PubMed: 9375158]
- Williams, KT. Expressive vocabulary test. 2. Circle Pines, MN: AGS; 2007.
- Yu C, Smith L. Rapid word learning under uncertainty via cross-situational statistics. *Psychological Science*. 2007; 18:414–420. [PubMed: 17576281]

Key points

- Little is known about the bases of deficits in word recognition and mapping that are characteristic of ASD.
- We compared the performance of high-functioning children with and without ASD on a task that required the recognition of familiar words and the mapping of unfamiliar words in response to probabilistic gaze cues and word-object co-occurrences.
- As a group, children with ASD showed intact abilities to monitor gaze, determine its reliability, and apply it in service of word recognition and mapping.
- The ability of children with ASD to use cross-situational statistical information to support word-to-referent mapping may be compromised in those who have lower levels of language development.

Figure 1.
Example stimuli by word frequency and gaze cue condition

Figure 2. Response times (RT) for recognition of familiar words by diagnostic group and word frequency. ** $p = .01$

Figure 3.

Response times (RT) for recognition of familiar words by gaze cue and word frequency. * $p < .05$, ** $p < .01$, *** $p < .001$, **** $p < .0001$

Figure 4.

Accuracy of word-to-referent mapping by gaze cue. **** $p < .0001$

Table 1

Age, maternal education, and test scores expressed as means and standard deviations (within parenthesis) by diagnostic group

	ASD <i>n</i> = 30	TD <i>n</i> = 43	<i>p</i> level	Effect size <i>d</i>
Age in months	134 (25)	131 (19)	.47	
ME in years	16 (3)	16 (2)	.70	
KBIT	108 (11)	106 (12)	.64	
CELF4 Core	98 (20)	106 (19)	.08	
CELF4 Rec	101 (17)	108 (17)	.08	
CELF4 Exp	95 (21)	106 (20)	.03	0.52
EVT	99 (20)	102 (18)	.55	
PPVT-III	109 (16)	113 (13)	.26	
SCQ-Raw score	20 (8)	4 (3)	<.001	2.0

ME, maternal education; KBIT, matrices subtest of the Kaufman Brief Intelligence Test-2; CELF4, Clinical Evaluation of Language Fundamentals-4 (Semel et al., 2003) with Core, Receptive, and Expressive composites reported; EVT, Expressive Vocabulary Test (Williams, 2007); PPVT-III, Peabody Picture Vocabulary Test-III; SCQ, Social Communication Questionnaire.

Except where noted, all test scores are standard scores.