Published in final edited form as:
Autism Res. 2013 October ; 6(5): . doi:10.1002/aur.1304.

Individual Differences in the Real-Time Comprehension of Children with ASD

Courtney E. Venker, **Elizabeth R. Eernisse**, **Jenny R. Saffran**, and **Susan Ellis Weismer**
University of Wisconsin, Waisman Center, 1500 Highland Avenue Room 475, Madison, WI 53705

Abstract

Lay Abstract—Spoken language processing is related to language and cognitive skills in typically developing children, but very little is known about how children with autism spectrum disorders (ASD) comprehend words in real time. Studying this area is important because it may help us understand why many children with autism have delayed language comprehension. Thirty-four children with ASD (3–6 years old) participated in this study. They took part in a language comprehension task that involved looking at pictures on a screen and listening to questions about familiar nouns (e.g., *Where's the shoe?*). Children as a group understood the familiar words, but accuracy and processing speed varied considerably across children. The children who were more accurate were also faster to process the familiar words. Children's language processing accuracy was related to processing speed and language comprehension on a standardized test; nonverbal cognition did not explain additional information after accounting for these factors. Additionally, lexical processing accuracy at age 5½ was related to children's vocabulary comprehension three years earlier, at age 2½. Autism severity and years of maternal education were unrelated to language processing. Words typically acquired earlier in life were processed more quickly than words acquired later. These findings point to similarities in patterns of language development in typically developing children and children with ASD. Studying real-time comprehension in children with ASD may help us better understand mechanisms of language comprehension in this population. Future work may help explain why some children with ASD develop age-appropriate language skills, whereas others experience lasting deficits.

Scientific Abstract—Many children with autism spectrum disorders (ASD) demonstrate deficits in language comprehension, but little is known about how they process spoken language as it unfolds. Real-time lexical comprehension is associated with language and cognition in children without ASD, suggesting that this may also be the case for children with ASD. This study adopted an individual differences approach to characterizing real-time comprehension of familiar words in a group of 34 three- to six-year-olds with ASD. The looking-while-listening paradigm was employed; it measures online accuracy and latency through language-mediated eye movements and has limited task demands. On average, children demonstrated comprehension of the familiar words, but considerable variability emerged. Children with better accuracy were faster to process the familiar words. In combination, processing speed and comprehension on a standardized language assessment explained 63% of the variance in online accuracy. Online accuracy was not correlated with autism severity or maternal education, and nonverbal cognition did not explain unique variance. Notably, online accuracy at age 5½ was related to vocabulary comprehension three years earlier. The words typically learned earliest in life were processed most quickly. Consistent with a dimensional view of language abilities, these findings point to similarities in patterns of language acquisition in typically developing children and those with ASD. Overall, our results emphasize the value of examining individual differences in real-time language comprehension in this population. We propose that the looking-while-listening paradigm

---

Corresponding Author: Courtney E. Venker, Phone: 608-890-4826, General Fax: 608-263-0529, cgerickson@wisc.edu.

is a sensitive and valuable methodological tool that can be applied across many areas of autism research.

Keywords

autism; comprehension; language processing; receptive vocabulary; eye-gaze methodology; individual differences

Introduction

Language comprehension is markedly delayed in many children with autism spectrum disorders (ASD), but the nature and extent of these deficits are not well understood. Notably, very little is known about how quickly and accurately children with ASD make sense of spoken language as it unfolds—knowledge that is central to a more complete understanding of comprehension processes in this population. This study adopted an individual differences approach to investigating real-time comprehension in children with ASD using a well-known methodology from developmental psychology—the looking-while-listening (LWL) paradigm (Fernald, Zangl, Portillo, & Marchman, 2008).

The study objectives were to characterize online comprehension of familiar nouns in a heterogeneous group of children with ASD and to identify relationships between online lexical processing, and child-level and word-level factors. A final objective was to evaluate the utility of the LWL method for use with children with ASD.

Language Comprehension in Children with ASD

Spoken language deficits in children with autism are clearly detrimental and immediately recognizable, but several recent studies have suggested that language comprehension may be even more severely delayed than language production in children with ASD early in development (Charman, Drew, Baird, & Baird, 2003; Ellis Weismer, Lord, & Esler, 2010; Hudry et al., 2010). These findings point to the importance of investigating early language comprehension in children with ASD, since it appears to be the source of marked deficits in this population. Although most children with ASD experience early language delays, their language skills become increasingly variable over the course of development (Charman et al., 2003; Charman, et al., 2005; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, Paul, & Lord, 2005). Indeed, some children with ASD eventually attain age-appropriate or even precocious language abilities, whereas others experience lasting impairments.

One empirical approach to characterizing this variability in language skills has been to examine associations with factors that are hypothesized to support successful language learning—including nonverbal cognition, imitation, joint attention, gesture use, and play. For example, a large literature has demonstrated that joint attention supports language development in children with ASD (e.g., Charman, 2003; Mundy, Sigman, & Kasari, 1990). Nonverbal cognitive abilities have also emerged as a robust predictor of language comprehension in children with ASD both concurrently (Ellis Weismer et al., 2010; Luyster, Kadlec, Carter, & Tager-Flusberg, 2008) and longitudinally (Charman et al., 2005; Thurm, Lord, Lee, & Newschaffer, 2007), leading to our interest in examining cognition in the current study.

Researchers have also begun to explore how the severity of children’s autism symptoms relates to their language abilities—a remarkably complex issue, given the array of skills that represent ‘language,’ and the array of behaviors that represent ‘autism.’ Prior to the development of a standardized metric, raw totals from the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2002) were sometimes used as a proxy for autism severity. This practice was imperfect not only because raw totals were not designed to measure severity, but also because they were often correlated with language (Gotham, Risi, Pickles, & Lord, 2007; Joseph, Tager-Flusberg, & Lord, 2002). Calibrated ADOS severity scores (Gotham, Pickles, & Lord, 2009), which are used in the current study, address both issues. Although some degree of association remains, language as measured by standardized assessments and parent report is more weakly associated with ADOS calibrated severity scores than with raw totals (Gotham et al., 2009; Shumway et al., 2012).

In sum, previous studies have investigated how language outcomes in children with ASD are related to factors such as nonverbal cognition and autism severity; the current study extended this approach to the study of lexical processing. This allowed us to determine whether the skills that support broader language outcomes are also associated with a specific aspect of language: comprehension of familiar vocabulary words in real time.

Measuring Language Comprehension in Real Time

To date, most studies of language comprehension in children with ASD have utilized parent report or standardized behavioral assessments. Although these measures are valuable methodological tools, they capture comprehension offline, after it has occurred—meaning they provide no information about language processing in real time. Additionally, these measures incorporate relatively high task demands because they are socially mediated and require children to produce purposeful responses (e.g., pointing to pictures) as an indication of comprehension. For these reasons, we turned to an alternative method for measuring language comprehension: eye-gaze paradigms.

In contrast to traditional assessments, eye-gaze paradigms measure language comprehension in real time through language-mediated eye movements. Eye-gaze paradigms also have relatively limited task demands—namely, sitting reasonably still and looking at visual stimuli on a screen—which is particularly advantageous for children with ASD because their limited social reciprocity, attentional deficits, and other challenging behaviors often interfere in the administration of standardized language assessments (Charman et al., 2003; Kjelgaard & Tager-Flusberg, 2001). Nevertheless, it is important to acknowledge that some children with ASD have difficulty even with the limited requirements of eye-gaze paradigms; for example, three children were excluded from the eye-gaze analyses in this study because of limited attention to the screen (see Methods).

The LWL paradigm (Fernald et al., 2008) is a well-established methodology for measuring the accuracy and speed of real-time lexical comprehension in young children. In a typical trial, children see two images on a screen and hear speech describing one of the images. The critical assumption is that children's eye movements will be guided by the auditory signal—if they understand the target word, they will look at the named image (Fernald et al., 2008). Eye-gaze is recorded and coded offline, and subsequent analyses provide measures of real-time lexical processing accuracy and latency. Following the procedures outlined by Fernald and colleagues, accuracy is defined as the relative amount of time spent looking at the target image as compared to the distracter image, and latency is defined as the speed with which children initiate a gaze shift toward the target image, calculated from the onset of the target word (see Methods for full details).

Studies using the LWL paradigm have revealed a great deal about the time course of vocabulary comprehension in young children. Most relevant to the current study is evidence that individual differences in real-time lexical processing relate to vocabulary levels in young typically developing children (Fernald, Perfors, & Marchman, 2006; Fernald, Swingley, & Pinto, 2001; Marchman & Fernald, 2008), children with cochlear implants (Grieco-Calub, Saffran, & Litovsky, 2009) and late-talking toddlers (Eernisse, Ellis

Weismer, & Saffran, 2011; Fernald & Marchman, 2012). Interestingly, these relationships appear to be quite robust, as lexical and grammatical skills in 12-month-old infants are associated with their real-time comprehension at 25 months of age (Fernald et al., 2006). Even more striking is the finding that lexical processing speed in toddlerhood is associated with working memory and expressive language at eight years of age in typically developing children, over and above the effects of early vocabulary (Marchman & Fernald, 2008). Studies have also identified associations between accuracy and processing speed in both typically developing children (Fernald et al., 2006) and late talkers (Eernisse et al., 2011), meaning that the children with more accurate lexical processing were also more efficient.

Real-Time Language Comprehension in Children with ASD

Recent findings have suggested that eye-gaze paradigms hold promise as a more implicit measure of comprehension in children with ASD (Edelson, Fine, & Tager-Flusberg, 2008; Swensen, Kelley, Fein, & Naigles, 2007). For example, eye-gaze paradigms have been used to investigate aspects of language learning in children with ASD, including attention to social cues (Norbury, Griffiths, & Nation, 2010), noun-learning biases (Swensen et al., 2007; Tek, Jaffery, Fein, & Naigles, 2008), and syntactic bootstrapping (Naigles, Kelty, Jaffery, & Fein, 2011).

A recent eye-gaze study by Goodwin, Fein, and Naigles (2012) demonstrated that real-time comprehension of wh- questions was associated with vocabulary and adaptive behavior skills in young children with ASD, but not with nonverbal cognition. This finding is relevant to the current study because it confirms variability in real-time language processing in children with ASD—variability that is related to some, but not all, child-level abilities. Additionally, Naigles et al. (2011) identified a longitudinal effect of real-time language processing in ASD that led to the retrospective investigation of early language abilities in the current study. Specifically, Naigles and colleagues found that children with ASD who demonstrated higher vocabulary skills and faster real-time processing of subject-verb-object word order early in life were more accurate on a processing measure of syntactic bootstrapping 8 months later.

What remains unknown is how children with ASD process familiar nouns in real time and whether patterns of lexical processing in children with ASD are similar to those identified in other groups of children—issues investigated by the current study. We propose that determining whether patterns of language processing in ASD are qualitatively similar to those in other populations invites discussion of two contrasting theoretical viewpoints regarding language abilities in ASD: the dimensional account and the distinct category account.

The dimensional account was originally proposed to characterize language abilities in children with language delay and/or language disorders relative to typically developing children (e.g., Dollaghan, 2004; Leonard, 1991; Rescorla, 2009). This view asserts that language abilities fall on a continuum and that some children simply show more language facility than others; emphasis is placed on qualitative similarities in patterns of language development, while acknowledging the potential for quantitative differences in the level of ability. Applied to individuals with ASD, the dimensional account suggests that language abilities in ASD may be quantitatively delayed but qualitatively similar to those seen in other populations (Ellis Weismer et al., 2011; Gernsbacher, Geye, & Ellis Weismer, 2005; Tager-Flusberg, Calkins, Nolin, Anderson, & Chadwick-Dias, 1990). A contrasting view is the distinct category account (Gernsbacher et al., 2005), which posits that children with language disorders—or, in this case, children with ASD—have language deficits that comprise a qualitatively different category of phenomena than those seen in other groups of children.

In support of the dimensional view, a study by Tager-Flusberg and colleagues (1990) found that a small sample of children with ASD showed patterns of lexical and grammatical development in spoken language that were qualitatively similar to those that would be expected in typical language development. Ellis Weismer and colleagues (2011) found that toddlers with ASD and non-spectrum toddlers with language delay who were matched on productive vocabulary produced words that fell into similar semantic categories, despite the more severe delay in the ASD group; additionally, the groups were indistinguishable on the basis of the grammatical complexity of their spoken language. If the findings had indicated that toddlers with ASD produced different categories of words than the late talking toddlers or displayed a unique profile of association between vocabulary and grammatical abilities, the distinct category view would have been supported. A study by Rescorla and Safyer (2013) produced very similar findings—namely, that children with ASD had spoken language delays, but the lexical composition of their expressive vocabularies was similar to that seen in typically developing children and late talking toddlers.

Consistent with a dimensional account of language abilities in ASD, we hypothesized that patterns of real-time lexical comprehension in the current study would be similar to those identified in children without ASD. Specifically, we predicted that children with ASD who were more accurate at processing language would also be faster; that real-time processing would be supported by language ability and nonverbal cognition, both concurrently and retrospectively; and that words typically learned earlier in life would be processed more accurately or efficiently than words acquired later in life. On the other hand, it was entirely possible that our results might point to qualitatively *different* patterns than those seen in typical development, or might reveal that typical patterns of real-time language processing were simply absent in this population—findings more consistent with a distinct category account of language processing in ASD.

The Current Study

We propose that a comprehensive understanding of real-time lexical processing in children with ASD is critical for three primary reasons. First, comprehension is often severely delayed in children with ASD, and it is essential to understand how these striking deficits manifest in real time. Second, language skills in ASD are remarkably variable, and it is unlikely that real-time language processing is an exception. Third, early lexical processing relates to language and cognitive abilities in other groups of children, suggesting that this may also be the case for children with ASD. Understanding individual differences in real-time vocabulary comprehension has the potential to shed light on the underlying mechanisms of language and cognitive development in autism and to inform theories of language acquisition in this population. Importantly, the LWL paradigm may prove to be a valuable methodology that can be applied to many areas of autism research.

The current study investigated individual differences in the time course of vocabulary comprehension in a heterogeneous group of 3- to 6-year-old children with ASD using the LWL paradigm, a method for measuring subtle differences in real-time accuracy and processing efficiency without requiring explicit behavioral responses. We hypothesized that our results would point to patterns of lexical processing that are qualitatively similar to those seen in children without ASD, consistent with a dimensional view of language development. The first objective was to characterize real-time comprehension of familiar words in young children with ASD. Specifically, we were interested in analyzing comprehension at the group level, examining individual differences in online processing, and determining whether faster and more accurate processing were associated. Although the target words were familiar and early emerging, we anticipated that some children would be quite adept at processing familiar words, whereas others would do poorly. Based on previous work, we hypothesized a negative association between online accuracy and latency.

The second objective was to specify the relationship between individual differences in lexical processing and child-level characteristics, to better understand the skills that support real-time comprehension in this population. In order to address this question both concurrently and retrospectively, we examined children's abilities at the same time they completed the LWL task, as well as three years earlier. Based on the findings of Fernald and colleagues, we hypothesized that children's online processing would relate to their language abilities both concurrently and retrospectively. Based on findings regarding predictors of language outcomes in children with ASD, we also expected to identify associations between real-time processing and cognition and autism severity—most likely because both of these factors capture information about children's more general attentional abilities, which could relate directly to their performance on the LWL task.

Our third objective was to determine whether differences in real-time lexical processing were related to a characteristic of the words themselves. Specifically, we examined the relationship between real-time accuracy and latency, and an index of age-of-acquisition specific to each target noun, which was based on the proportion of typically developing 8-month-old infants reported to understand each word (see Methods). We expected that words typically learned earlier in life would be processed more accurately and efficiently than words typically learned later in life.

Our final objective was to establish whether the LWL paradigm is a feasible method for measuring language comprehension in children with ASD, drawing on our findings from the previous three objectives.

Method

Participants

Participants were thirty-four children with ASD (3–6 years of age) from a broader longitudinal investigation of early language development in children with ASD. In the broader study, children were evaluated annually from age 2½ to 5½. Evaluations involved two sessions, each lasting approximately three hours. Parents provided written consent, and procedures were approved by the institutional review board. Initial DSM-IV best estimate diagnoses were determined by an experienced clinician through integration of information from the ADOS (Lord et al., 2002) or the Autism Diagnostic Observation Schedule-Toddler Module (ADOS-T; Luyster et al., 2009); the Autism Diagnostic Interview-Revised (Rutter, Le Couteur, & Lord, 2003); and clinical expertise. Children with known chromosomal abnormalities, cerebral palsy, seizure disorder, uncorrected vision or hearing impairments, or frank neurological insult were excluded. All children were from monolingual English speaking homes. The LWL task took place at children's second, third, or fourth visit for the longitudinal study, when they were, on average, 3½, 4½, or 5½ years old. The timing of children's participation in the LWL task was dependent on the schedule dictated by the broader longitudinal study; any families coming into the lab during the time when the LWL study was taking place were offered the chance to participate (see Table 1). The retrospective analysis focused on children's language and cognitive abilities at their initial visit to the lab, when they were 2½ years old. To account for differences in timing, only children who participated in the LWL task at their final visit (age 5½) were included in this retrospective analysis; children who participated at age 3½ or 4½ were excluded because relatively less time had elapsed since their initial visit. Thirty children were Caucasian; one child was African American, and three identified with multiple races or ethnicities. Thirty-one children were male.

Standardized Measures

The ADOS informed ASD diagnosis and provided a measure of autism severity. Following Gotham et al. (2009), raw algorithm totals were converted to calibrated autism severity scores. The calibrated scores indicate classifications of non-spectrum (1–3), ASD (4–5), and autism (6–10). The Visual Reception scale of the Mullen Scales of Early Learning (Mullen; Mullen, 1995) measured nonverbal cognition. Items include sorting objects, remembering pictures, and matching shapes. The Preschool Language Scale, 4th Edition (PLS-4; Zimmerman, Steiner, & Pond, 2002) is an omnibus measure of lexical, grammatical, and conceptual aspects of language. The PLS-4 Auditory Comprehension and Expressive Communication subscales assessed comprehension and production, respectively. The MacArthur-Bates Communicative Development Inventory-Infant Form (CDI; Fenson et al., 1993) assessed parent report of vocabulary comprehension (number of words understood) at the initial visit; this variable was used in the retrospective analysis.

Mullen, PLS-4, and CDI raw scores were used in the analyses because we were interested in children's absolute cognitive and language abilities, not their extent of delay relative to age-matched peers. This decision was further supported because T-scores could not be derived for children who were older than the age range for which the Mullen manual provides normative data. Additionally, PLS-4 standard scores were positively skewed and did not appear to capture variability at the lower end of the scale. (The lowest possible standard score on the PLS-4 is 50, and over one-third of the sample achieved standard scores of 52 or lower on either subscale.) Sample characteristics are presented in Table 2.

LWL Task

Procedure—Children sat in a chair approximately 1.5 meters in front of a 58" wall-mounted LCD screen in a sound-attenuated booth with draped black walls. A research assistant sat on the floor behind the child's chair. Children were told that they were going to watch a 'movie' and that their job was to watch and listen; no other instructions were given. Children viewed two familiar images on the screen and heard speech describing one image. Auditory stimuli were presented at 65 dB SPL from a central speaker. A video camera below the screen recorded children's eye movements.

Stimuli—The eight target words (*ball, baby, car, doggie, cup, spoon, shoe,* and *book)* are among the earliest words learned by young children (Dale & Fenson, 1996). Because many participants had language deficits, we asked parents to complete a questionnaire indicating whether their child understood each target word. Due to a change in study protocol, the parent questionnaire was unavailable for four participants; in these cases, assessments from previous years were examined at the item level (e.g., the child had demonstrated understanding of *ball* on the PLS-4 at the first visit). Based on these criteria, four trials were eliminated for four participants because there was no evidence available that the words were familiar.

Each word was depicted by two prototypical images. Auditory stimuli were recorded in an infant directed register by a female native English speaker. Target words were presented within a carrier phrase (*Where's the ___?)*, followed by a tag question (*Do you see it?* or *Do you like it?*). Mean target word duration was 590 ms (range = 440 ms to 760 ms).

Pictures of two familiar objects appeared at the start of each trial. Trials lasted seven seconds, and the target noun was presented four seconds into the trial. Each word was presented twice, for a total of 16 trials. The task lasted approximately two minutes and 15 seconds. Words were presented in yoked pairs (e.g., *doggie* with *baby*) to control for potential salience effects. Words served an equal number of times as target and distracter, and order and side of presentation were counterbalanced. Four short animated movies were interspersed to maintain attention.

Two versions of the task with different trial orders were created; approximately half of the sample (n = 19 vs. n = 15) received each version. Data were collapsed across the two versions because t-tests identified no significant differences in mean accuracy, $t(df = 29) = -1.34$, $p = .19$, or latency, $t(df = 25) = -.48$, $p = .64$.

Eye-gaze coding—

Eye movements were coded offline at a rate of 30 frames per second. No auditory or visual information about trial content was available during coding. Looks were coded as left, right, shifting, or away from the screen. Six randomly selected video files (18% of the total sample) were independently re-coded by the first author. Inter-coder frame agreement (the proportion of all frames on which the two coders agreed) was 98.0%. Inter-coder shift agreement (the proportion of shift frames on which the two coders agreed) was 98.1%.

Measuring online accuracy and latency—

Two measures of online language processing were obtained: accuracy and latency. These measures were calculated following the standard procedures outlined by Fernald and colleagues (2008). *Accuracy* was defined as the proportion of looking to the target image during the target window, 300 ms to 2000 ms after noun onset. Specifically, accuracy was the amount of time a child looked at the target image, divided by the amount of time a child looked at the target and distracter images, during the target window. Following Fernald and colleagues, shifts between images and looks away from the screen did not directly affect children’s accuracy; in cases of extreme inattention, trials were eliminated (see below). Eye movements earlier than 300 ms after noun onset were considered too rapid to be related to the auditory information, given the time required to plan and execute an eye movement (Fernald et al., 2008; Fernald & Marchman, 2012). Eye movements longer than 2000 ms after noun onset were no longer assumed to be related to the auditory signal (Fernald et al.; Grieco-Calub et al., 2009). Trials were excluded if the child looked away from the screen for more than half of the target window. Participants were eliminated if they contributed data for fewer than 8 of the 16 trials. Adoption of this criterion resulted in the exclusion of data from three participants.

Latency was calculated for the subset of trials in which the child was looking at the distracter image at word onset (i.e., distracter-initial trials). *Latency* was defined as the time to initiate a shift toward the target image in distracter-initial trials, calculated from noun onset. As with accuracy, trials with latencies of less than 300 ms or more than 2000 ms were eliminated. A minimum criterion of two latency trials was imposed, which resulted in the exclusion of data from an additional four children from latency analyses.

Index of age-of-acquisition—

The proportion of 8-month-old infants reported to understand each target word in the CDI normative database (Dale & Fenson, 1996) was used as an index of age-of-acquisition. Data from 8-month-olds were used because of limited variability (i.e., ceiling effects) for comprehension of these words at older ages.

Results

Characterizing Real-Time Comprehension

The first objective of this study was to characterize real-time comprehension of familiar words in children with ASD using the LWL paradigm. Recall that accuracy was measured as the relative proportion of looking to the target image, 300 ms to 2000 ms after noun onset. The proportion of looking to target was also calculated at baseline—the two seconds prior to noun onset—when children were expected to spend a similar amount of time looking at each image. Each child (*n* = 31) contributed between 9 and16 accuracy trials (*M* = 13.32, *SD* = 2.09), for a total of 413 trials.

Time course data are presented in Figure 1. Relative looking to target was significantly higher after noun onset (*M* = 78.73%, *SD* = 9.72) than at baseline (*M* = 52.51%, *SD* = 8.16; *t(df* = 30) = −10.72, *p* < .001, *d* = 1.93), meaning that children's eye movements provided evidence of comprehension. Consistent with our predictions, mean accuracy varied considerably across children (55.09% to 97.38%). This means that one child looked at the target image nearly exclusively after hearing it named, whereas another child spent nearly the same amount of time fixating the target and the distracter.

Interestingly, accuracy also varied a great deal across the trials contributed by individual children. Several children had accuracy values of 0 on at least one trial, meaning that they never looked at the target image during the target window; all children had accuracy values of 1 on at least one trial, indicating that they looked exclusively at the target image. To further illustrate, one child had an accuracy of 0 on one trial for the word *ball* and an accuracy of 1 on the other *ball* trial. This demonstrates the variability in children's attention across trials, the challenge of interpreting children's performance on individual trials, and the impetus behind calculating mean accuracy values by child.

Recall that latency was the time to initiate a shift toward the target image in distracter-initial trials, calculated from noun onset. Each child (*n* = 27) contributed between 2 and 8 latency trials (*M* = 4.0 trials, *SD* = 1.49), for a total of 108 trials. On average, the first shift away from the distracter image was initiated 561.19 ms after word onset (*SD* = 183.12 ms). As with online accuracy, variability in mean latency across children was substantial (333.50 ms to 1000.00 ms). Latency also varied considerably at the trial level. Similar to accuracy, children's latency values on individual trials ranged from 300 ms (the minimum) to 2000 ms (the maximum). Because latency was calculated only for the subset of distracter-initial trials, some children contributed very few trials to this variable, which may have produced an undesirable degree of noise. If possible, future studies using the LWL method with children with ASD should incorporate more trials to increase the likelihood of capturing meaningful information about their processing speed.

In addition to calculating mean latency for distracter-initial trials, which is the standard measure of latency used by Fernald and colleagues (2008), we also calculated latency for target-initial trials. As in the original latency analyses, trials with latencies outside of the target window were eliminated. Latency of the target-initial trials indicated the amount of time it took children to initiate the first shift from the target (correct) to the distracter (incorrect) picture, calculated from noun onset. Because children already happened to be looking at the target picture when the target word was presented, we predicted that mean latencies in target-initial trials would be longer than mean latencies in the distracter-initial trials.

Consistent with our expectations, mean latency in target-initial trials was 1023.95 ms (*SD* = 330.64), nearly 500 ms longer than mean latency in distracter-initial trials (561.19 ms). Of the 21 children who contributed data for both latency variables, 19 (90.5%) had a longer latency on the target-initial trials. This demonstrates that children took a longer time to initiate a shift toward the incorrect image than they did to initiate a shift toward the correct image, confirming that the latency measure is capturing meaningful information about children's processing speed. (Note that the standard measure of latency based on distracter-initial trials was used in all subsequent analyses.)

To determine whether children's online accuracy and processing speed were related, a Pearson correlation was calculated for the subset of children who contributed accuracy and latency data ($n = 27$). A significant negative correlation was identified, $r = -.51$, $p = .01$, meaning that the children who were more accurate were also faster. Additionally, the partial correlation between accuracy and latency remained significant when chronological age was statistically controlled, $r = -.47$, $p = .015$, demonstrating that age did not fully account for the relationship between online accuracy and processing speed.

Next, we felt it necessary to ensure that accuracy and latency were not inherently correlated due to a potential measurement confound. Because the length of the target window was fixed (300 ms to 2000 ms after noun onset), trials in which children had long latencies to initially shift to the target image may have inherently had lower accuracy. To address this issue, we conducted a complementary analysis that rested on the creation of an alternative accuracy variable containing only those trials that were *not* included in the latency analyses. This ensured that the accuracy and latency variables relied on entirely independent subsets of trials, thus precluding an inherent correlation. Although the standard accuracy variable required each child to contribute at least 8 trials, some children contributed as few as 6 trials to the alternative accuracy variable because all latency trials had been eliminated; the minimum criterion was not applied in order to retain all 31 children in this analysis.

The correlation between the standard and alternative accuracy variables was $r = .95$, $p < .001$, indicating that both accuracy variables were capturing very similar information. Individual children's mean accuracies changed very little between the two variables, as 84% of the sample differed by only 0 to 3 percentage points. Next, we examined the correlation between the alternative accuracy variable and the standard latency variable; a one-tailed test was adopted because there was a clear expected direction of effect (i.e., that children who were more accurate would also be faster). The correlation between the alternative accuracy variable and latency was weakened but remained significant: $r = -.36$, one-tailed $p = .03$.

This analysis therefore provides convincing evidence that online accuracy and processing speed are associated in children with ASD. The new accuracy variable contained primarily of trials in which the child was already looking at the correct picture when they heard it named, which may represent a qualitatively different experience than distracter-initial trials. For this reason, the standard accuracy variable was retained in all subsequent analyses unless indicated otherwise.

Online Processing and Child-Level Characteristics

Our second objective was to examine the relationship between individual differences in online lexical processing (i.e., accuracy and latency) and several child-level characteristics, both concurrently and retrospectively. To provide a meaningful context for interpreting our results, we also examined the concurrent relationship between *offline* language comprehension (PLS-4 Auditory Comprehension raw score) and these same characteristics. Analyzing online *and* offline language comprehension in this way allowed us to identify similarities and differences in the factors that were most strongly related to the online and offline constructs of language comprehension.

Concurrent analyses—Correlational analyses were conducted prior to the concurrent analyses to affirm our selection of independent variables for the regression models. Given our limited sample size, it was imperative to limit the number of predictors entered into the models; our correlational analyses ensured selection of the most powerful predictors. Bivariate Pearson correlations were conducted between online accuracy and latency, offline comprehension, and several child-level characteristics (see Table 3). Age was not significantly correlated with any variables tested, including language and cognitive raw scores (*p*s > .12). Significance levels were unchanged and correlation strengths were nearly identical when age was statistically controlled through partial correlations for analyses involving raw scores. Only bivariate correlations are presented for the sake of clarity.

With the exception of online accuracy (described above), online latency was not significantly associated with any child-level variable. Online accuracy was strongly correlated with offline language comprehension, offline language production (PLS-4 Expressive Communication raw score), and nonverbal cognition (Mullen Visual Reception raw score), but not with maternal education or autism severity. In contrast, offline language comprehension was strongly correlated with online accuracy, offline language production, nonverbal cognition, and autism severity, and moderately correlated with maternal education.

Next, regression analyses were conducted to identify concurrent predictors of online accuracy and offline comprehension. Unlike the bivariate correlational analyses, the regression analyses allowed us to determine whether certain variables explained *unique* variance in online and offline language comprehension, controlling for other correlated variables. Stepwise regression analyses were conducted because although we hypothesized that several factors would relate to online lexical processing, we did not have strong *a priori* hypotheses about the factors that would uniquely predict online accuracy. The stepwise regression approach statistically identifies the most predictive independent variable and enters that variable into the model first, followed by the second most predictive, and so on. If a predictor does not account for unique variance in the dependent variable, it is automatically excluded from the model.

Two separate regression analyses of the concurrent predictors were conducted—one with online accuracy as the dependent variable, and one with offline comprehension as the dependent variable (see Table 4). Three-predictor models were used. The three concurrent variables that were most strongly correlated with each dependent variable were entered as the independent variables, with one exception: offline production was excluded because it was highly associated with offline comprehension ($r = .94$).

Offline comprehension, nonverbal cognition, and online latency were entered as concurrent predictors of online accuracy. The final model included offline comprehension and online latency and accounted for 62.9% of the variance in online accuracy. Partial regression plots are presented in Figures 2 and 3. Offline comprehension was the strongest predictor of online accuracy, followed by online latency. Nonverbal cognition was statistically removed from the stepwise regression model because it did not explain unique variance in online accuracy. This regression analysis was also conducted using the alternative accuracy variable that contained only the non-latency trials. This step was taken to ensure that the measurement confound was not responsible for the variance that online latency explained in online accuracy. Results of this analysis were consistent with the previous analysis, such that offline comprehension and online latency were both significant predictors of online accuracy; again, nonverbal cognition was not a unique predictor and was thus removed from the model.

Online accuracy, nonverbal cognition, and autism severity were entered as concurrent predictors of offline comprehension. Maternal education was not included because it was more weakly correlated with offline comprehension than the other predictors. The final model contained all three predictors and accounted for 70.1% of the variance in offline comprehension. Nonverbal cognition was the strongest predictor of offline comprehension, followed by online accuracy and autism severity.

Retrospective analyses—Finally, we examined whether online accuracy was related to children's early vocabulary comprehension as measured by parent report of words understood on the CDI at approximately age 2½. Only the children who participated in the LWL task during their final visit in the broader longitudinal study (at age 5½) were included in this analysis ($n = 26$), because it had been approximately 3 years since the CDI had been completed at the start of the broader study. On average, 37 months (range = 33 to 42 months) had lapsed between the CDI completion date and the date of the LWL task; an 'age difference' variable was created to account for this time lapse. Consistent with the concurrent analyses, the dependent variable of interest in the regression analyses was online accuracy; online latency was not explored because it was not significantly correlated with children's early abilities. The predictor variables of interest at age 2½ were number of words understood on the CDI and nonverbal cognition (Mullen Visual Reception raw score); the age difference variable was also included to control for the amount of time between visits.

The final model included only vocabulary comprehension and accounted for 34.2% of the variance in later online accuracy (see Table 5). Interestingly, despite the 3-year time lapse, the amount of variance accounted for in online accuracy was similar to that explained by concurrent offline language comprehension alone (39.7%). Nonverbal cognition and the age difference variable were automatically excluded from the model because they did not explain significant unique variance in online accuracy. Thus, the findings of the retrospective regression analyses were similar to the findings for the concurrent analyses.

Online Processing and a Word-Level Characteristic

The final objective was to determine whether a feature of the target words—an index of age-of-acquisition—was associated with online lexical processing. Spearman correlations were conducted because histograms of accuracy and latency for the eight target words suggested a non-normal distribution. A significant correlation was identified between the index of age-of-acquisition and online latency, $\rho = -.72$, $p = .04$, meaning that the words typically acquired earlier in life were processed more quickly. The correlation with online accuracy was non-significant, $\rho = .43$, $p = .28$.

Discussion

Patterns of Real-Time Lexical Processing in Children with ASD

This study found that the eye-gaze patterns of 3- to 6-year-old children with ASD provided evidence of their comprehension of familiar words in real time. Specifically, children looked relatively longer at the target picture after hearing it named (79%) than at baseline (53%). Despite the significant group effect, there was a great deal of variability in mean online accuracy (55% to 97%) and online latency (334 ms to 1000 ms) across children. This variability is consistent with our initial hypotheses and provides evidence that heterogeneity in language skills in young children with ASD extends to real-time lexical comprehension.

Child-level individual differences in online accuracy were best explained by only two concurrent factors: offline language comprehension (PLS-4 Auditory Comprehension raw score) and online processing speed (i.e., latency). Offline comprehension and online latency each explained unique variance in online accuracy when the other factor was controlled, revealing their independent contributions; in combination, they accounted for 63% of the variance in online accuracy. Contrary to our expectations, nonverbal cognition did not explain unique variance in online accuracy. Notably, online lexical processing at age 5½ was also related retrospectively to vocabulary comprehension three years earlier, at age 2½ —though it was not uniquely related to early nonverbal cognition. Lastly, faster online processing was associated with an index of age-of-acquisition of the target words, such that words typically learned earlier in life were processed more quickly.

In combination, these findings provide support for a dimensional view of language abilities in ASD in a previously unexplored area of language development: processing of familiar nouns in real time using the LWL paradigm. Specifically, the patterns of online language processing that emerged in this sample of children with ASD mirror those seen in previous work with typically developing children and children with language delays. This finding suggests that, although children with ASD may show more severe delays in language comprehension, there are more qualitative similarities than differences in their patterns of real-time lexical processing.

Even when a more conservative analysis was used, children with higher online accuracy were also faster to process the familiar nouns. Additionally, latency and offline language ability were *both* unique predictors of online accuracy (also see Naigles et al., 2011). Previous studies have identified parallel relationships in younger children without ASD (Eernisse et al., 2011; Fernald et al., 2006; Fernald & Marchman, 2012), suggesting that language knowledge, online accuracy, and online processing speed are closely linked in young children, regardless of diagnostic status. In combination, these findings contribute to a growing body of literature suggesting that some patterns of typical language acquisition are also evident in children with ASD (Goodwin et al., 2012; Luyster et al., 2008; Swensen et al., 2007; but see Tek et al., 2008).

It was also interesting that children’s lexical processing speed was related to the index of age-of-acquisition for each of the target words. To our knowledge, previous studies investigating real-time lexical processing in young children have not specifically investigated this issue; however, results from previous studies point to a prominent role of age-of-acquisition in many language processing tasks—for example, word recognition, picture naming, and lexical decision tasks—in both children and adults (e.g., Garlock, Walley, & Metsala, 2001; Juhasz, 2005). Our finding that children with ASD processed earlier-learned words more quickly suggests that they may be sensitive to the same factors that allow typically developing infants to learn some words more quickly and easily than others. This finding is particularly interesting in the context of statistical learning theories of language acquisition (Romberg & Saffran, 2010), which emphasize the impact of linguistic structure on language learning. Future studies may identify similar effects based on features such as word frequency or sound or syllable phonotactics.

This study is not the first to identify continuity in patterns of language development across populations of children with and without ASD that are consistent with a dimensional view of language abilities. Several studies (Ellis Weismer et al., 2011; Rescorla & Safyer, 2013; Tager-Flusberg et al., 1990) have identified similar patterns of lexical and grammatical development in toddlers with ASD and non-spectrum toddlers with language delay or developmental delay. Naigles et al. (2011) found that young children with ASD were capable of learning novel transitive verbs through syntactic bootstrapping, leading the authors to conclude that syntactic bootstrapping is a robust language-learning mechanism in children with and without ASD. Brock, Norbury, Einav, and Nation (2008) found that adolescents with poorer language skills—regardless of ASD diagnosis—were less sensitive to sentence context in an online sentence processing task, even when nonverbal IQ was controlled. This finding points to similarities in the processing skills of children with language deficits, regardless of etiology—which supports the possibility that language impairments in ASD do not represent a qualitatively distinct category.

Understanding Variability in Real-Time Lexical Processing in ASD

Although it is clear that some children had a more difficult time in the LWL task than others, it is not immediately clear why this is the case. The target words were early emerging—indeed, all the children had certainly heard words like *ball, cup,* and *shoe* thousands of times during their three to six years of life—and all words were reported to be familiar. Why did such variability in online lexical processing emerge?

We believe that the answer to this question lies in our interpretation of the construct of language processing itself. One interpretation—supported by the robust concurrent and retrospective relationships between online accuracy and offline language abilities—is that some children simply had a better understanding of the target words. As discussed by Fernald and colleagues (2006), vocabulary acquisition is not a black and white process; the LWL paradigm captures subtle differences not only in what words children understand, but also in how well they understand them. From this perspective, the root of variability in lexical processing might be seen as originating in the richness or connectedness of children's lexical representations. However, it is clear that factors other than language knowledge—namely, processing speed—also affected performance.

What does it mean that children's lexical processing accuracy was explained by processing speed and offline language comprehension? Although this study does not speak directly to causality, it is likely that language knowledge and real-time lexical processing interact in complex ways during development. For example, knowing certain words may allow them to be processed more quickly; faster processing may free resources for learning new words; and learning new words may facilitate faster processing of even more words (Fernald & Marchman, 2012). This cascading effect is one mechanism through which language interventions may impact both current lexical knowledge and sustained language learning in children with ASD.

It is also noteworthy that our study identified a relationship between children's online accuracy for word recognition at age 5½ and their vocabulary comprehension three years earlier, at age 2½. This finding, along with the finding of Naigles et al. (2011) that early language processing was predictive of later verb learning in young children with ASD, suggests that language processing may indeed play an important role throughout development in this population. An important next step is understanding how slowed and less accurate processing manifests over developmental time in children with ASD. For example, early language processing may have prognostic value for later vocabulary growth in young children with ASD, as it does for late talking toddlers (Fernald & Marchman, 2012). It is crucial to identify the children with ASD who are most likely to exhibit persistent language challenges and to ensure that these children begin to receive the intervention as early as possible; knowing about their online language processing may inform this prognosis.

Interestingly, online accuracy was not significantly associated with autism severity, maternal education, or age, and nonverbal cognition was not uniquely predictive (also see Goodwin et al., 2012). Together, these findings suggest that the LWL paradigm provides a measure of language processing in individuals with ASD that is relatively less affected by factors such as cognition and autism symptomatology. This argument is further strengthened by our finding that offline language comprehension on the PLS-4 *was* associated with autism severity and maternal education, and that nonverbal cognition *was* uniquely predictive—precisely the opposite of the findings for online accuracy.

The finding that nonverbal cognition was not a unique predictor of online accuracy deserves further attention. One potential reason that nonverbal cognition did not explain unique variance in online accuracy is that the skills measured by the Mullen Visual Reception Scale —the measure of nonverbal cognition adopted in this study—do not directly align with the skills required for online lexical processing accuracy as measured by the LWL paradigm. The majority of items on the Mullen Visual Reception scale between 21 and 45+ months measure matching (e.g., of pictures or words) or memory (e.g., of one or three pictures). Although matching and memory are certainly critical developmental skills, their relationship with real-time processing of familiar nouns may be indirect.

For example, although successful performance in the LWL task requires children to 'remember' that the noun *cup* goes with the picture of the drinking receptacle with the handle, the task itself has limited memory requirements because the auditory label must be retained for only a few seconds, and the two object images are visible throughout the trial. Although nonverbal cognition is certainly an important foundation for language acquisition, there may be a tighter link between real-time lexical comprehension and cumulative language knowledge (as measured by the PLS-4 or the CDI) than general nonverbal cognition in children with ASD. In fact, the language processing abilities captured by the LWL paradigm may be what allows children to accumulate the language knowledge that they demonstrate on measures like the PLS-4.

Although the LWL paradigm is a relatively implicit measure of vocabulary comprehension, it is important to acknowledge that successful performance relies on more than vocabulary knowledge alone (Fernald et al., 2006). For example, fast and accurate recognition of a target word in the LWL paradigm requires that children segment nouns from continuous speech, integrate auditory and visual modalities, and disengage and shift their visual attention (see Fernald and Marchman, 2012). While these skills do not generally pose a challenge for typically developing children, children with ASD may have difficulty integrating multi-modal sensory input (Iarocci & McDonald, 2006) and disengaging visual attention (i.e., sticky attention; Landry & Bryson, 2004).

It is therefore possible that future studies may uncover specific visual attentional factors— perhaps those more broadly related to nonverbal cognition or autism severity—that impact online language processing in children with ASD. For example, although the static images used in the current study are unlikely to have elicited sticky attention, such problems may occur when children are exposed to more complex and dynamic visual stimuli. In these situations, it is possible that the latency variable would measure not only the speed with which children process verbal language, but also their tendency to disengage their visual attention. It is important to acknowledge, however, that one attentional factor *not* required by LWL or similar eye-gaze paradigms (e.g., IPL; see discussion below) is joint attention, which is an area of deficit in many children with ASD. Thus, poor language processing skills in the LWL task cannot be directly explained by poor joint attention skills—which is not the case for many other assessments of early language ability.

Interestingly, Fernald et al. (2006) found no relationship between children's speed of oculomotor response during a non-linguistic visual orienting task, and their processing speed for familiar nouns, prompting them to emphasize the language-specific nature of the LWL task. Additionally, Kelly, Walker, and Norbury (2012) found that children with ASD and language impairment (8–14 years of age) demonstrated no deficits in basic oculomotor control; instead, deficits emerged only when higher-order inhibition was required. Because it does not incorporate specific instructions, the LWL task does not specifically require inhibition of this type, but future work is needed to address this issue.

Methodological Implications

Our final objective was to evaluate the utility of the LWL method with children with ASD. Broadly, this study adds to the growing evidence that eye-gaze paradigms are a feasible method for investigating language processing in children with ASD, as over 90% of participants provided adequate data for analysis. Importantly, the results of this study suggest that the LWL paradigm is appropriate for children with ASD who demonstrate a wide range of language and cognitive abilities.

More specifically, this study makes an important methodological contribution by validating the LWL paradigm for investigating of familiar language processing in ASD. The LWL methodology has not been previously used with children with ASD, but we argue that the LWL paradigm represents a valuable tool that can be applied across many areas of research pertinent to individuals with ASD. The LWL paradigm is beneficial because it offers a window into real-time comprehension processes, while offering the practical advantage of limited task demands. The use of this method is also important because its focus on the *time course* of comprehension more closely parallels children's language comprehension during every day learning opportunities. These conclusions are consistent with findings from studies using the intermodal preferential looking (IPL) paradigm (Goodwin et al., 2012; Naigles et al., 2011; Swensen et al., 2007; Tek et al., 2008), a similar eye-gaze method using offline coding, which supports the broader implication that implicit eye-gaze methods provide insight into the language processing abilities of children with ASD.

Although the LWL paradigm is similar to automatic eye tracking, and can accomplish similar objectives, it differs in several aspects that may be particularly important when working with young children with ASD. First, eye-gaze data are hand-coded, offline, by trained coders. Training and coding are time-intensive, but it is extremely valuable to have the flexibility to determine the location of children's eye gaze without requiring them to remain in the relatively small tracking range of an automatic eye tracker. Our experience with automatic eye tracking has revealed that some children with ASD frequently move forward and back or side to side in their chair, or squint their eyes, which can result in data loss. Despite the challenging behaviors exhibited by several children in this study, hand coding of the data resulted in the exclusion of only three of 34 children due to excessive inattention. Another possible reason for the limited data loss may have been that children's visual attention was captured and maintained by the 58″ screen, which is much larger than most automatic eye-tracking screens.

Second, the LWL approach to measuring and analyzing the constructs of online accuracy and processing speed differs from approaches taken in other types of eye-tracking studies—even those that are also designed to measure language comprehension. For example, the manner in which accuracy is calculated in the LWL paradigm differs from measurements of accuracy using first looks to target; we believe it offers a useful alternative because it allows children to switch their attention between the two images, which may capture meaningful uncertainty about the target words. Another difference associated with the LWL method is the emphasis on processing of familiar words. Although the LWL method is easily adapted to measure word *learning*, many studies—including the current study—have revealed a meaningful relationship between lexical processing of familiar words and extant language skills, both concurrently and across several years.

The sensitivity of the LWL method is clear: despite the fact that children were reported to know the target words, striking individual differences emerged. Measuring real-time lexical processing abilities in children with ASD using the LWL paradigm could have important implications for individually identifying optimally effective interventions, for designing treatment strategies, and for measuring intervention outcomes. Importantly, measuring real-time language processing may help us to understand the changes that occur during the course of intervention that lead to positive—or, even more importantly, negative—outcomes. If future studies are to realistically adopt this method, however, it is critical to first understand the construct of language processing captured by the LWL paradigm in children with ASD; this study is a vital first step in that direction.

Conclusions and Future Directions

This study adopted an individual differences approach to characterizing real-time lexical processing in a heterogeneous group of children with ASD using the LWL paradigm. Children with higher online accuracy processed the target words more quickly, and individual differences in online accuracy were concurrently and retrospectively related to offline language abilities. Additionally, the target words typically acquired earlier in life were processed more quickly. The findings support a dimensional account of language abilities in ASD and point to avenues of future research that will further inform theories of language processing in this population. Building on our specific findings, we propose that the LWL methodology is a valuable and sensitive tool that can be adapted to answer many questions about language development and attention in this population.

Because the current study was focused on individual differences in children with ASD, a comparison group was not included; studies that examine lexical processing in children with typical development or other neurodevelopmental disorders, as well as children with ASD, will inform theories of language development across these populations. Future studies that test multiple exemplars of target objects may also be capable of exploring the extent to which children with ASD flexibly generalize word labels, though the limited number of trials used in the current study precluded us from addressing this question.

Future work is also needed to determine how language interventions impact real-time language processing. Expressive language is often the primary target of language intervention (Tager-Flusberg et al., 2005), but researchers have begun to stress the importance of targeting language comprehension in clinical settings (Charman et al., 2003; Hudry et al., 2010; Ellis Weismer et al., 2010). Our finding that some children had a difficult time accurately and efficiently comprehending even familiar words in real time supports the suggestion that language comprehension should continue to be an important intervention target for many children with ASD.

Acknowledgments

Grant Sponsors: National Institute on Deafness & Other Communication Disorders, National Institute of Child Health & Human Development

Grant Numbers: R01DC007223-05, F31DC009142-02, T32DC005359-10, R37HD037466-12, P30HD003352-46

First and foremost, we would like to thank the children and families who participated in this study. We appreciate their generosity and their commitment to this research. We would also like to thank Anna Dorrance, Taryn Stricker, and Meghan Davidson for their assistance with eye-gaze coding. Thanks also to Chris Potter, Casey Lew-Williams, Sara Kover, Brianna McMillan, and Erica Wojcik for helpful discussions about the looking-while-listening paradigm. Funding for this study was provided by the National Institute on Deafness & Other Communication Disorders (R01DC007223, T32DC005359, F31DC009142) and the National Institute of Child Health & Human Development (R37HD037466, P30HD003352).

Literature Cited

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]

Charman T. Why is joint attention a pivotal skill in autism? Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences. 2003; 358(1430):315–324.

Charman T, Drew A, Baird C, Baird G. Measuring early language development in preschool children with autism spectrum disorder using the MacArthur Communicative Development Inventory (Infant Form). Journal of Child Language. 2003; 30:213–236. [PubMed: 12718299]

Charman T, Taylor E, Drew A, Cockerill H, Brown J, Baird G. Outcome at 7 years of children diagnosed with autism at age 2: Predictive validity of assessments conducted at 2 and 3 years of age and pattern of symptom change over time. Journal of Child Psychology and Psychiatry. 2005; 46:500–513. [PubMed: 15845130]

Dale PS, Fenson L. Lexical developmental norms for young children. Behavioral Research Methods, Instruments, & Computers. 1996; 28:125–127.

Dollaghan CA. Taxonometric analyses of specific language impairment in 3- and 4-year-old children. Journal of Speech, Language, and Hearing Research. 2004; 47(2):464–475.

Edelson, L.; Fine, A.; Tager-Flusberg, H. Comprehension of nouns and verbs in toddlers with autism: An eye-tracking study. Paper presented at the International Meeting for Autism Research; London. 2008 May.

Eernisse, E.; Ellis Weismer, S.; Saffran, J. Vocabulary comprehension and fast mapping in late-talking toddlers. Poster presented at the Symposium on Research in Child Language Disorders; Madison, WI. 2011 Jun.

Ellis Weismer S, Gernsbacher MA, Stronach S, Karasinski C, Eernisse ER, Venker C, Sindberg H. Lexical and grammatical skills in toddlers on the autism spectrum compared to late talking toddlers. Journal of Autism and Developmental Disorders. 2011; 41(8):1065–1075. [PubMed: 21061053]

Ellis Weismer S, Lord C, Esler A. early language patterns of toddlers on the autism spectrum compared to toddlers with developmental delay. Journal of Autism and Developmental Disorders. 2010; 40:1259–1273. [PubMed: 20195735]

Fenson, L.; Dale, P.; Reznick, S.; Thal, D.; Bates, E.; Hartung, J.; Pethick, S.; Reilly, J. MacArthur Communicative Development Inventories: User's guide and technical manual. San Diego, CA: Singular Publishing; 1993.

Fernald A, Marchman VA. Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. Child Development. 2012; 83:203–222. [PubMed: 22172209]

Fernald A, Perfors A, Marchman VA. Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. Developmental Psychology. 2006; 42:98–116. [PubMed: 16420121]

Fernald A, Swingley D, Pinto JP. When half a word is enough: infants can recognize spoken words using partial phonetic information. Child Development. 2001; 72:1003–1015. [PubMed: 11480931]

Fernald, A.; Zangl, R.; Portillo, AL.; Marchman, VA. Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In: Sekerina, IA.; Fernandez, E.; Clahsen, H., editors. Developmental Psycholinguistics: On-line methods in children's language processing. Amsterdam: John Benjamins; 2008. p. 97-135.

Gernsbacher, MA.; Geye, HM.; Ellis Weismer, S. The role of language and communication impairments within autism. In: Fletcher, P.; Miller, JF., editors. Language disorders and developmental theory. Philadelphia: John Benjamins; 2005. p. 73-93.

Garlock VM, Walley AC, Metsala JL. Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by children and adults. Journal of Memory and Language. 2001; 45(3):468–492.

Goodwin A, Fein D, Naigles LR. Comprehension of wh-questions precedes their production in typical development and autism spectrum disorders. Autism Research. 2012; 5:109–123. [PubMed: 22359403]

Gotham K, Pickles A, Lord C. Standardizing ADOS scores for a measure of severity in autism spectrum disorders. Journal of Autism and Developmental Disorders. 2009; 39:693–705. [PubMed: 19082876]

Gotham K, Risi S, Pickles A, Lord C. The autism diagnostic observation schedule: Revised algorithms for improved diagnostic validity. Journal of Autism and Developmental Disorders. 2007; 37:613–627. [PubMed: 17180459]

Grieco-Calub TM, Saffran JR, Litovsky RY. Spoken word recognition in toddlers who use cochlear implants. Journal of Speech, Language, and Hearing Research. 2009; 52:1390–1400.

Hudry K, Leadbitter K, Temple K, Slonims V, McConachie H, Aldred C, Charman T. Preschoolers with autism show greater impairment in receptive compared with expressive language abilities. International Journal of Language & Communication Disorders. 2010; 45:681–690. [PubMed: 20102259]

Iarocci G, McDonald J. Sensory integration and the perceptual experience of persons with autism. Journal of Autism and Developmental Disorders. 2006; 36:77–90. [PubMed: 16395537]

Joseph RM, Tager-Flusberg H, Lord C. Cognitive profiles and social-communicative functioning in children with autism spectrum disorder. Journal of Child Psychology and Psychiatry. 2002; 43:807–821. [PubMed: 12236615]

Juhasz BJ. Age-of-acquisition effects in word and picture identification. Psychological Bulletin. 2005; 131(5):684–712. [PubMed: 16187854]

Kjelgaard MM, Tager-Flusberg H. An Investigation of Language Impairment in Autism: Implications for Genetic Subgroups. Language and Cognitive Processes. 2001; 16:287–308. [PubMed: 16703115]

Landry R, Bryson SE. Impaired disengagement of attention in young children with autism. Journal of Child Psychology and Psychiatry. 2004; 45:1115–1122. [PubMed: 15257668]

Leonard LB. Specific language impairment as a clinical category. Language, Speech, and Hearing Services in Schools. 1991; 22(2):66.

Lord, C.; Rutter, M.; DiLavore, PC.; Risi, S. Autism Diagnostic Observation Schedule Manual. Los Angeles: Western Psychological Services; 2002.

Luyster RJ, Kadlec MB, Carter A, Tager-Flusberg H. Language assessment and development in toddlers with autism spectrum disorders. Journal of Autism and Developmental Disorders. 2008; 38:1426–38. [PubMed: 18188685]

Luyster R, Gotham K, Guthrie W, Coffing M, Petrak R, Pierce K, Lord C. The autism diagnostic observation schedule – toddler module: A new module of a standardized diagnostic measure for ASD. Journal of Autism and Developmental Disorders. 2009; 39:1305–1320. [PubMed: 19415479]

Marchman VA, Fernald A. Speed of Word Recognition and Vocabulary Knowledge Predict Cognitive and Language Outcomes in Later Childhood. Developmental Science. 2008; 11:F9–F116. [PubMed: 18466367]

Mullen, EM. Mullen Scales of Early Learning Manual. Minneapolis, MN: Pearson; 1995. AGS edition ed

Mundy P, Sigman M, Kasari C. A longitudinal study of joint attention and language development in autistic children. Journal of Autism and developmental Disorders. 1990; 20(1):115–128. [PubMed: 2324051]

Naigles LR, Kelty E, Jaffery R, Fein D. Abstractness and continuity in the syntactic development of young children with autism. Autism Research. 2011; 4:422–437. [PubMed: 22012625]

Norbury CF, Griffiths H, Nation K. Sound before meaning: word learning in autistic disorders. Neuropsychologia. 2010; 48:4012–9. [PubMed: 20951710]

Rescorla L. Age 17 language and reading outcomes in late-talking toddlers: Support for a dimensional perspective on language delay. Journal of Speech, Language, and Hearing Research. 2009; 52:16–30.

Rescorla L, Safyer P. Lexical composition in children with autism spectrum disorder (ASD). Journal of Child Language. 2013; 40:47–68. [PubMed: 23217291]

Romberg AR, Saffran JR. Statistical learning and language acquisition. Wiley Interdisciplinary Reviews: Cognitive Science. 2010; 1(6):906–914. [PubMed: 21666883]

Rutter, M.; Le Couteur, A.; Lord, C. ADI-R: Autism Diagnostic Interview-Revised. Los Angeles, CA: Western Psychological Services; 2003.

Shumway S, Farmer C, Thurm A, Joseph L, Black D, Golden C. The ADOS calibrated severity score: Relationship to phenotypic variables and stability over time. Autism Research. 2012; 5:267–276. [PubMed: 22628087]

Swensen LD, Kelley E, Fein D, Naigles LR. Processes of language acquisition in children with autism: evidence from preferential looking. Child Development. 2007; 78:542–57. [PubMed: 17381789]

Tager-Flusberg H, Calkins S, Nolin T, Baumberger T, Anderson M, Chadwick-Dias A. A longitudinal study of language acquisition in autistic and Down syndrome children. Journal of Autism and Developmental Disorders. 1990; 20:1–21. [PubMed: 2139024]

Tager-Flusberg, H.; Paul, R.; Lord, C. Language and Communication in Autism. In: Volkmar, FR.; Paul, R.; Klin, A.; Cohen, D., editors. Handbook of autism and pervasive developmental disorders. 3. Hoboken, NJ: Wiley and Sons; 2005. p. 335-364.

Tek S, Jaffery G, Fein D, Naigles LR. Do Children with Autism Spectrum Disorders Show a Shape Bias in Word Learning? Autism Research. 2008; 1:208–222. [PubMed: 19360671]

Thurm A, Lord C, Lee LC, Newschaffer C. Predictors of language acquisition in preschool children with autism spectrum disorders. Journal of Autism and Developmental Disorders. 2007; 37:1721–1734. [PubMed: 17180717]

Zimmerman, I.; Steiner, V.; Pond, R. Preschool Language Scale. 4. San Antonio, TX: The Psychological Corporation; 2002.

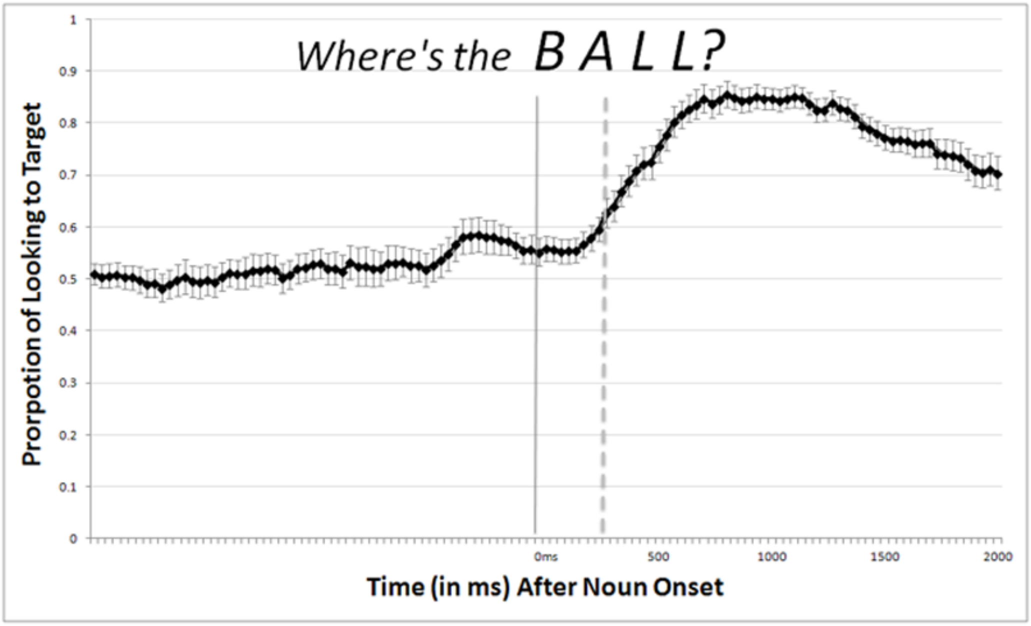

Figure 1.
Time course of lexical comprehension.

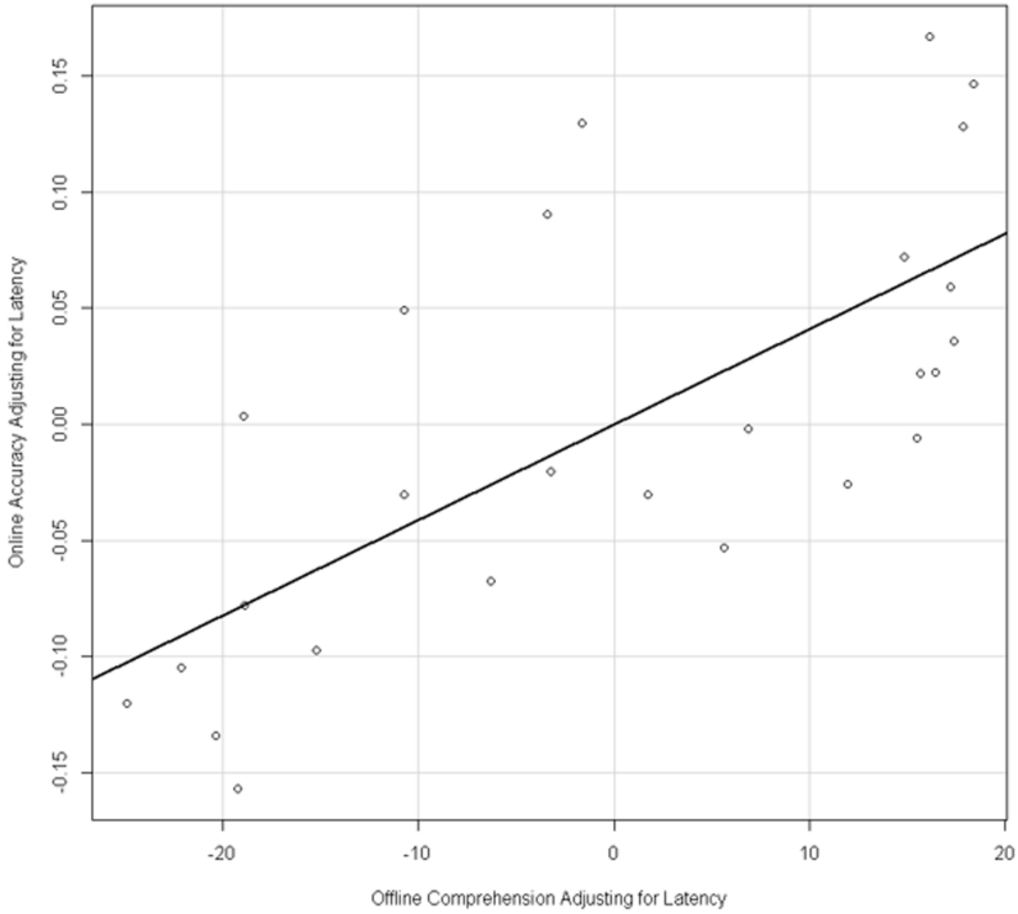

Figure 2.
Partial relationship between online accuracy and offline comprehension, adjusting for online latency.

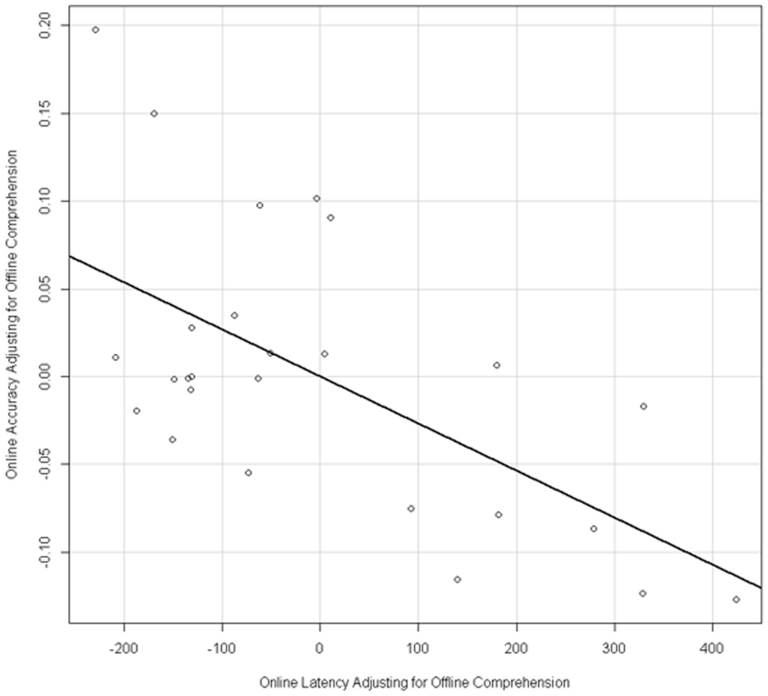

Figure 3.
Partial relationship between online accuracy and online latency, adjusting for offline comprehension.

Table 1

Number of Children Participating in the LWL Task at Each Visit in the Broader Study

	Number of Children	**Percentage of Total Sample**
Visit 2 (Age 3½)	2	5.9
Visit 3 (Age 4½)	3	8.8
Visit 4 (Age 5½)	29	85.3

Table 2

Participant Characteristics

Characteristic	***n***	***M (SD)***	**Range**
Chronological age	34	65.32 (7.56)	44–79
Maternal education	34	14.15 (1.88)	12–18
Calibrated autism severity score	34	7.15 (1.84)	3–10
Mullen Visual Reception			
Raw score	34	43.62 (7.82)	24–50
Age equivalent	34	53.56 (15.31)	21–69
PLS-4 Comprehension			
Raw score	33	43.58 (16.34)	17–62
Age equivalent	33	48.24 (25.50)	10–81
Standard score	33	79.73 (29.27)	50–129
PLS-4 Production			
Raw score	33	45.36 (15.96)	18–67
Age equivalent	30	42.87 (21.31)	12–81
Standard score	33	76.15 (26.75)	50–133

Note. Maternal education is presented in years. The calibrated autism severity scores were derived from the ADOS. Visual Reception scores were obtained from the Mullen Scales of Early Learning. Language scores were obtained from the Preschool Language Scale, 4th edition, Auditory Comprehension (Comprehension) and Expressive Communication (Production) subscales. One child did not complete the PLS-4, and three children had Production age equivalents of > 6 years, 11 months, which are omitted.

Table 3

Bivariate Correlations Between Online Processing and Child Characteristics

	Online accuracy	**Online latency**	**Age**	**Maternal education**	**Autism severity**	**Nonverbal cognition**	**PLS-4 Comprehension**
Online latency	$-.51^{**}$						
Age	−.22	.30					
Maternal education	.13	.17	.07				
Autism severity	−.26	−.21	−.19	−.21			
Nonverbal cognition	$.51^{**}$	−.10	.27	.18	$-.47^{**}$		
PLS-4 Comprehension	$.62^{**}$	−.04	.28	$.45^{*}$	$-.58^{**}$	$.74^{**}$	
PLS-4 Production	$.57^{**}$	−.001	.24	$.42^{*}$	$-.58^{**}$	$.74^{**}$	$.94^{**}$

Note. Autism severity was measured by calibrated ADOS severity scores. Nonverbal cognition was measured by Mullen Visual Reception raw score. PLS-4 Comprehension was measured by Auditory Comprehension subscale raw score. PLS-4 Production was measured by Expressive Communication subscale raw score.

$^{*}p < .05$.

$^{**}p < .01$.

Table 4

Results of Concurrent Stepwise Regression Analyses Predicting Online Accuracy and Offline Language Comprehension

	R^2	F	*df*	*b*	*SE b*	*b**	*p*
Online Accuracy							
Step 1	.40	15.80	25				
Constant				0.59	0.05		<.001
PLS-4 Comprehension				0.004	0.001	0.63	.001
Step 2	.63	19.51	25				
Constant				0.75	0.06		<.001
PLS-4 Comp				0.004	0.001	0.61	<.001
Online Latency				0.000	0.000	−0.48	.001
Offline Comprehension							
Step 1	.55	33.94	29				
Constant				−27.87	12.83		.04
Nonverbal Cognition				1.65	0.28	0.74	<.001
Step 2	.63	23.28	29				
Constant				−51.26	15.04		.002
Nonverbal Cognition				1.27	0.30	0.57	<.001
Online Accuracy				51.14	20.45	0.34	.02
Step 3	.70	20.36	29				
Constant				−19.70	18.93		.31
Nonverbal Cognition				0.98	0.30	0.44	.003
Online Accuracy				50.46	18.80	0.33	.01
Autism Severity				−2.54	1.04	−0.30	.02

Note. PLS-4 Comprehension was measured by Auditory Comprehension subscale raw score. Nonverbal Cognition was measured by Visual Reception raw score on the Mullen. Autism severity was measured by calibrated ADOS severity

Table 5

Results of Retrospective Stepwise Regression Analysis Predicting Online Accuracy

	R^2	F	*df*	*b*	*SE b*	*b**	*p*
Online Accuracy							
Step 1	.34	12.47	25				
Constant				.69	.03		<.001
CDI Words Understood				.00	.00	.59	.002

Note. CDI Words Understood was the raw number of words understood on the Communicative Development Inventory—Infant Form. Non-significant predictors were nonverbal cognition, as measured by Visual Reception raw score on the Mullen; and age difference in months between when the CDI was completed and when the LWL task was completed.