Published in final edited form as:

J Speech Lang Hear Res. 2014 August 1; 57(4): 1428–1441. doi:10.1044/2014_JSLHR-L-13-0006.

Lexical Characteristics of Expressive Vocabulary in Toddlers with Autism Spectrum Disorder

Sara T. Kover and Susan Ellis Weismer

Waisman Center and Department of Communication Sciences and Disorders University of Wisconsin-Madison

Abstract

Purpose—Vocabulary is a domain of particular challenge for many children with autism spectrum disorder (ASD). Recent research has drawn attention to ways in which lexical characteristics relate to vocabulary acquisition. The current study tested the hypothesis that lexical characteristics account for variability in vocabulary size of young children with ASD, applying the Extended Statistical Learning theory of vocabulary delay in late talkers (Stokes, Kern, & dos Santos, 2012) to toddlers with ASD.

Method—Parents reported the words produced by toddlers with ASD ($n=57$; ages 21–37 months) or toddlers without ASD ($n=41$; ages 22–26 months) on the MacArthur-Bates Communicative Development Inventories. The average phonological neighborhood density, word frequency, and word length of each toddler's lexicon was calculated. These lexical characteristics served as predictors of vocabulary size.

Results—Findings differed for toddlers with and without ASD and according to subsamples. Vocabulary size was predicted by word length for toddlers with ASD and by phonological neighborhood density for toddlers without ASD.

Conclusions—Distinct relationships between lexical characteristics and vocabulary size were observed for toddlers with and without ASD. Experimental studies on distributional cues to vocabulary acquisition are needed to inform what is known about mechanisms of learning in neurodevelopmental disorders.

Keywords

autism; statistical learning; vocabulary; language development; production

---

Statistical learning—a type of implicit learning that proceeds incidentally through the use of distributional cues or regularities to discern patterns among units—is a pivotal mechanism for language acquisition in typical development (see review by Arciuli & Torkildsen, 2012). The term statistical learning is most widely known to refer to the process of tracking transitional probabilities between syllables for the purpose of word segmentation (Saffran,

---

Corresponding Author: Sara T. Kover, Waisman Center, Room 475, University of Wisconsin-Madison, 1500 Highland Avenue, Madison, WI 53705, kover@wisc.edu, Phone: (608) 890-4826.

A portion of these data was presented at the 2013 Biennial Meeting of the Society for Research in Child Development in Seattle, Washington.

Aslin, & Newport, 1996), but taken broadly, statistical learning processes are thought to contribute to the development of phonological, lexical, and syntactic skills during infancy and into the early childhood years (Gomez & Gerken, 1999; Graf Estes, Evans, Alibali, & Saffran, 2007; Saffran & Thiessen, 2003; Thompson & Newport, 2007). In these contexts, distributional information might include the probability of one syllable following another, the phonological structure of syllables in nonwords, the positions of words in strings of an artificial language, or the likelihood that words from particular word classes follow each other within or between phrases. Of particular interest is recent evidence that statistical learning can directly support word learning, even in natural language, lending ecological validity to the theoretical emphasis on this learning mechanism as an explanatory account of successful language acquisition in typical development (Hay, Pelucchi, Graf Estes, & Saffran, 2011). Furthermore, empirical studies have demonstrated links between statistical learning and aspects of language ability in individuals with typical development and individuals with language impairment (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Evans, Saffran, & Robe-Torres, 2009; Kidd, 2012; Torkildsen, Dailey, Aguilar, Gomez, & Plante, 2013). The current study was designed as a first step in examining the relationship between distributional properties of language and lexical development in toddlers with autism spectrum disorder (ASD), a neurodevelopmental disorder associated with significant language impairments.

Relationships between Distributional Cues and Vocabulary Development

The role of distributional cues in lexical development has been investigated on primarily two fronts in typical language learners: using experimental tasks testing novel word learning and through correlational studies of children's lexicons. Experimental word learning studies have demonstrated that even before the age of two years, several types of distributional cues, including phonological cues (e.g., the phonotactic legality of sound combinations) and co-occurrence cues (e.g., transitional probabilities between syllable boundaries that allow segmentation) may signal the presence of candidate words to which meanings can be mapped (Graf Estes, Edwards, & Saffran, 2011; Graf Estes et al., 2007). However, different cues are likely to become more or less salient and provide more or less support for word learning at different times during development or for language learners with different levels of ability. For example, 22-month-olds with smaller vocabularies make use of phonological cues (e.g., the number of syllables a novel label has), whereas those with larger vocabularies make use of co-occurrence cues (e.g., phrase context) to support word learning (Lany & Saffran, 2011). These studies demonstrate that, even very early in development, typical language learners attend to multiple distributional features of language and rely on the variability and complexity of the input that support lexical acquisition in dynamic ways (Alt, Meyers, & Ancharski, 2012).

Research on preschool children has led to similar conclusions, but with a focus on different distributional features of language input. Such studies have demonstrated that characteristics of novel labels, such as phonotactic probability and phonological neighborhood density, can facilitate word learning as indexed by both comprehension and production (Gray, Brinkley, & Svetina, 2012; Hoover, Storkel, & Hogan, 2010; McKean, Letts, & Howard, 2012). Phonotactic probability refers to the probability of the co-occurrence of sounds in a word.

High phonotactic probability (i.e., having a common sound sequence) has been found to facilitate word learning early in the preschool years, whereas low phonotactic probability (i.e., having a rare sound sequence) facilitates word learning later in the preschool years (McKean et al., 2012). Phonological neighborhood density (hereafter, neighborhood density) is a distributional lexical characteristic that refers to the number of other words in the input that sound similar to a given word, such that they differ by only a single phoneme. For 3- to 5- year-old children, there may be an advantage for learning words with low neighborhood density (e.g., ‘give’, as opposed to ‘bat’) as demonstrated by comprehension (McKean et al., 2012), although the effects of neighborhood density may also vary depending upon the learning task or the aspect of lexical acquisition that is examined (Storkel & Lee, 2011). In some cases, cues such as neighborhood density and phonotactic probability may combine to facilitate learning; however, the interactions among cues to word learning are likely to hinge on the developmental level of the child and the specifics of the learning context (Hoover et al., 2010). Taken together, these studies suggest that many aspects of a word, including characteristics of its occurrence and sound structure relative to the input in which it occurs, may affect the ease with which it is acquired.

Recent research has examined children’s existing vocabularies to further establish the connection between typical lexical development and lexical characteristics, such as word frequency (i.e., a general index of the extent to which a child might be exposed to particular lexical units) and word length (i.e., number of phonemes), as well as neighborhood density. For example, more frequent words in parents’ usage are produced by children later, probably due to the high frequency of closed class words (e.g., articles, determiners) relative to specific nouns; however, within lexical categories, more frequent words are produced earlier (Goodman, Dale, & Li, 2008). This study showed that word frequency is likely to impact vocabulary, although the nature of the impact is not straightforward because of variable effects across lexical categories, as well as modality and development. Examining multiple predictors, Storkel (2004) found that age of acquisition (i.e., the age at which at least half of toddlers are reported to produce a given word), was related to neighborhood density, word frequency, and word length among nouns from the MacArthur-Bates Communicative Development Inventories (CDI; Fenson et al., 1993). This study provided evidence that nouns from dense neighborhoods are acquired first in typical development, as are words higher in frequency and words that are shorter in length. Similarly, Storkel (2009) tested the relationship between the percentage of toddlers that could produce a given noun according to parent report and the characteristics of that word. She concluded that, in contrast to phonological characteristics (i.e., positional segment average, biphone average—two measures of phonotactic probability) that influence learning with a consistent pattern from 16 to 30 months of age, lexical characteristics (i.e., neighborhood density, word length) influence the nouns infants learn with potentially lesser impact after 20 months.

In the current study, we chose to focus on lexical, as opposed to phonological, characteristics because they are thought to relate to fundamental aspects of word learning, including engagement, the process by which new representations are integrated with existing representations (Leach & Samuel, 2007; Storkel & Lee, 2011). Lexical characteristics, such as neighborhood density, word frequency, and word length, are correlated (Storkel, 2009). Investigating these related, yet distinct lexical characteristics could serve to link mechanisms

of learning to observed language profiles of children with typical and atypical language development. Given the role of distributional lexical cues related to the occurrence and sound structure of words relative to the input in typical development, the current study examined neighborhood density, word frequency, and word length as predictors of variability in vocabulary size of toddlers with ASD.

Extended Statistical Learning

A series of studies has shown that lexical characteristics of the words in a toddler's lexicon might be meaningful predictors of expressive vocabulary size. Among British English-speaking toddlers (24 - 30 months of age), neighborhood density accounted for 47% of unique variance in vocabulary size, and word frequency accounted for an additional 14% of unique variance in vocabulary size (Stokes, 2010). After dichotomizing her sample, Stokes found that British English-speaking toddlers with smaller vocabularies produced words that were from denser neighborhoods and were of lower frequency than toddlers with larger vocabularies. Differences between toddlers with smaller and larger vocabularies in terms of higher neighborhood density and different word frequency have been replicated in other languages, including a study of French toddlers (Stokes, Kern, & Dos Santos, 2012) and a study of Danish-speaking toddlers (Stokes, Bleses, Basboll, & Lambertsen, 2012). In the study of Danish-speaking children, word length was also considered as a predictor of vocabulary size. Although it accounted for only 2% of the variance, children with smaller vocabularies produced words that were shorter than those with larger vocabularies. In addition, the direction of effect for word frequency for Danish (higher frequency associated with smaller vocabulary), accounting for 3% of the variance, was opposite that for English and French (lower frequency associated with smaller vocabulary). Stokes, Bleses, et al. (2012) suggested that the direction of the effect for word frequency differed among studies because most of the Danish words analyzed were nouns, whereas there was more variability in word class for British English. Overall, this research suggests that smaller and larger vocabularies are distinguished not only in size, but also in the lexical characteristics of the words they contain.

Stokes, Kern, et al. (2012) proposed a theory of Extended Statistical Learning (ExSL) to account for the slowed vocabulary development of toddlers who are late to talk based on the observation that those children with smaller vocabularies produce words that sound like many other ambient words (i.e., differ from many other words by only a single phoneme; Stokes, 2010; Stokes, Kern, et al., 2012). That is, ExSL was proposed to account for findings related to neighborhood density. The average neighborhood density score of a child's expressive vocabulary can be taken as representing a distributional property of the child's lexicon, estimated relative to the ambient language input. According to ExSL, the increased neighborhood density associated with smaller vocabularies results from the high likelihood of learning words from dense neighborhoods during early lexical development and perhaps, overreliance on common phonological features of lexical items (Stokes, Kern, et al., 2012). Words from such dense neighborhoods might be easier to acquire because they are familiar in form and demand less processing capacity, particularly in terms of phonological memory (Swingley, 2005; Thomson, Richardson, & Goswami, 2005). Indeed, statistical learning might be useful for identifying a set of word forms that would both serve

as a platform for attaching meaning and lead to the availability of other, perhaps more developmentally demanding, cues that support learning (Swingley, 2005; Thiessen & Saffran, 2003).

Thus, the general argument put forth by Stokes, Kern, et al. (2012) was that children with smaller vocabularies are slow to acquire the distributional regularities of language input that support lexical learning. They suggested that it is these children who are also slow to relax the constraints on lexical learning afforded by statistical learning strategies. This delay in grasping onto distributional regularities, followed by the delay in adapting that learning mechanism to account for more variability in lexical items, results in smaller vocabularies with a signature of higher neighborhood density values than children with larger vocabularies, who have presumably more quickly acquired, and then updated, statistical learning strategies.

In summary, the ExSL account suggests that late talkers use dense labels as cues for word learning even when their peers with larger expressive vocabularies have shifted to learning words with sparse labels, resulting in increased average neighborhood density of the lexicons of children with smaller vocabularies. Although there is recent evidence that other explanations may better account for delayed vocabulary in late talkers (Stokes, in press), it remains to be seen whether the distributional characteristics of lexicons and the ExSL framework have utility for explaining variability in expressive vocabulary development in young children with ASD.

Vocabulary Delays in Children with ASD

Impairments in structural language development (i.e., vocabulary, syntax) are frequently apparent in children with ASD (Eigsti, de Marchena, Schuh, & Kelley, 2011). These delays begin early in language acquisition with weaknesses in vocabulary during the toddler and preschool years in both the receptive and expressive modalities (Ellis Weismer, Lord, & Esler, 2010; Luyster, Lopez, & Lord, 2007; Volden et al., 2011). For example, Charman et al. (2003) reported an overall delay in vocabulary comprehension and production in 134 preschool children with ASD (ages 18 to 88 months), with wide variability in language skills among children.

Although vocabulary development is often impaired in children with ASD, the exact nature of the delay and its sources remain to be defined (Kover, McDuffie, Hagerman, & Abbeduto, 2013). It has been suggested that some learning mechanisms for vocabulary acquisition (e.g., syntactic bootstrapping, noun bias) are intact (Naigles, Kelty, Jaffery, & Fein, 2011; Tek, Jaffery, Fein, & Naigles, 2008), while others (e.g., shape bias) may not be available to young children with ASD (Tek et al., 2008). Regarding the contents of their lexicons, some children with ASD may have a higher proportion of nouns than do children from other populations (e.g., Down syndrome), although this finding is based on an extremely small sample (Tager-Flusberg et al., 1990). Despite clear evidence for the use of distributional cues for lexical learning in typical development, lexical characteristics, including those with distributional properties, have not been examined as potential predictors of variability in the vocabulary ability of toddlers with ASD.

Distributional lexical characteristics, in particular, are compelling to test with respect to the ASD linguistic phenotype. First, the evidence regarding whether or not statistical learning is an available mechanism for language acquisition in children with ASD is inconclusive. Some studies have reported intact statistical learning, but only in high-functioning school-age children or adolescents with ASD (Brown, Aczel, Jimenez, Kaufman, & Grant, 2010; Mayo & Eigsti, 2012). Mayo and Eigsti (2012) examined statistical learning in children and adolescents with high functioning autism, testing their ability to segment words using transitional probabilities alone. They found that these individuals, who had a history of language delay but whose current language abilities were age-appropriate, performed no differently than those with typical development of similar age and full scale IQ. In contrast, one study reported that individuals with ASD failed to show neural evidence of learning based on statistical cues (in combination with prosody—a speech cue to segmentation) relative to verbal IQ-matched typically developing individuals (Scott-Van Zeeland et al., 2010). Second, there is some evidence of impaired cognitive flexibility in individuals with ASD, although it may be better characterized as a nonspecific weakness in executive function (Geurts, Corbett, & Solomon, 2009). The failure to switch between learning mechanisms or to adjust word-learning biases across the course of development could be downstream effects of such a cognitive profile.

As such, applying the ExSL theory of delayed vocabulary to toddlers with ASD has significant implications because (1) an understanding of the impact of distributional regularities on the lexicons of children with ASD could inform more general theories about learning and memory in the ASD phenotype, (2) evidence that vocabulary development is delayed by overreliance on a protollexicon, as proposed by Swingley (2005) and ExSL, could inform future research on the impacts of cognitive processing on development, and (3) identifying the relationship between distributional cues and expressive vocabulary in toddlers with ASD could provide the groundwork for future empirical studies of statistical learning in ASD.

The Current Study

The purpose of the present study was to provide a preliminary test of ExSL in young American English-speaking children with ASD as an account of delayed vocabulary development. Our goal was to draw conclusions about the extent to which the lexicons of toddlers with ASD reflect the distributional regularities of language input. Following previous research (Stokes, Blases, et al., 2012; Stokes, Kern, et al., 2012), we asked: **(1)** Do neighborhood density, word frequency, and word length account for unique variance in the vocabulary size of toddlers with ASD? and, **(2)** Do toddlers with ASD with smaller and larger vocabularies differ in neighborhood density, word frequency, and word length? We expected that all lexical characteristics, but particularly neighborhood density, would predict individual differences in expressive vocabulary and that children with smaller and larger vocabularies would be differentiated by these characteristics. Because no previous study has tested the relationship between these variables and vocabulary size in American English and due to inconsistent findings in other languages (e.g., Stokes, Kern, et al. [2012] and Stokes, Blases, et al. [2012]), our hypotheses for the direction of effect for neighborhood density, word frequency, and word length were bidirectional. We also tested these hypotheses in a

sample of American English-speaking toddlers without ASD, who were matched on expressive vocabulary size to the toddlers with ASD, to provide a point of comparison for the expected relationships between lexical characteristics and vocabulary size in American English, as well as to establish whether a different pattern of performance (i.e., different lexical characteristic scores or different relationships between lexical characteristics and vocabulary size) would emerge between toddlers with and without ASD.

Method

Participants

Participants were 57 toddlers with ASD (51 males; ages 21 – 37 months) and 41 toddlers without ASD (27 males; ages 22 – 26 months) drawn from larger longitudinal studies on language development, respectively, in ASD and in toddlers with the full range of expressive language abilities, including those who might be considered late talkers. The selection of participants from the larger longitudinal studies is described in detail below.

All participants were monolingual English speakers. The participants with ASD in the current study overlap with those reported by Ellis Weismer et al. (2011), Ray-Subramanian, Huai, and Ellis Weismer (2011), Ray-Subramanian and Ellis Weismer (2012), and Venker, Eernisse, Saffran, and Ellis Weismer (2013); the participants without ASD overlap with those reported by Ellis Weismer et al. (2011) and Ellis Weismer, Venker, Evans, and Moyle (2013). This research was approved by the appropriate University of Wisconsin-Madison Institutional Review Board.

Materials

Autism diagnosis—For toddlers with ASD, clinical best estimates based on DSM-IV TR criteria confirmed diagnoses. Assessments included the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2002) or the ADOS-Toddler Module (ADOS-T; Luyster et al., 2009) and the Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003). Autism severity scores, shown in Table 1, were calculated based on ADOS algorithm scores (Gotham, Pickles, & Lord, 2009). Toddlers without ASD did not score above the screening cut-off of the Social Communication Questionnaire (Rutter, Bailey, & Lord, 2003) at 66 months of age.

Nonverbal cognition—For toddlers with ASD, cognitive ability was assessed with the Cognitive subscale of the Bayley Scales of Infant and Toddler Development, Third Edition (Bayley-III; Bayley, 2006) and, for descriptive purposes, the Visual Reception subtest of the Mullen Scales of Early Learning (MSEL; Mullen, 1995). All toddlers without ASD scored within normal range on the Denver Screening Test II (Frankenburg et al., 1990) to rule out general developmental delay.

Vocabulary ability—For all participants, a parent completed the CDI Words and Sentences form (Fenson et al., 2007) either at home or during the initial visit. Parent responses, indicating the words spoken by the toddler, were coded as described below.

Procedure

Following Stokes (2010), we coded only monosyllabic words and excluded the following categories: sound effects and animal sounds, people, games and routines, words about time, pronouns, question words, prepositions and locations, quantifiers and articles, helping verbs, and connecting words. Consequently, words from the following CDI categories were examined: action, animals, descriptive, food, household items, furniture, outside, places, body, clothing, toys, and vehicles. We combined duplicate phonological forms ($n = 9$ pairs). Thus, 287 unique monosyllabic words were coded and analyzed. To avoid further exclusion of words, we coded several pluralized CDI items as the singular ($n = 14$; e.g., *boots* as *boot*).

We coded lexical characteristics (i.e., neighborhood density, word frequency, and word length) using Storkel and Hoover's (2010) online calculator's adult corpus, the Hoosier Mental Lexicon, which is described in greater detail by Pisoni and colleagues (Large & Pisoni, 1998; Nusbaum, Pisoni, & Davis, 1984). The Hoosier Mental Lexicon was based on 19,750 words drawn from the Merriam-Webster Dictionary (1964), of which 11,750 overlapped with the text corpus of Kucera and Francis (1967). Neighborhood density was defined by the online calculator as the number of words in the corpus differing from the target word by one phoneme, including substitution, deletion, and addition. Word frequency was calculated by the calculator by taking the log base 10 of the raw frequency of the word and adding 1, so as to avoid values of zero when the raw frequency is 1. Word length was defined as the number of phonemes. Only neighborhood density and word length (not word frequency), were coded for the few words ($n = 3$) that could not be found in the adult database. See Table 1 for average values for each child's lexicon for these adult-referenced lexical characteristics.

Although both adult and child corpora were available from the online calculator for the computation of lexical characteristics, we chose to use the adult corpus because it more closely reflects the ambient input (Storkel, 2009). In addition, Storkel and Hoover (2010) report very high correlations between adult and child corpus results (e.g., $r = .94$ for neighborhood density). In the current study, for the 57 participants with ASD, adult- and child-referenced neighborhood density values were highly positively correlated, $r = .82$, $p < .001$; adult- and child-referenced word frequency values were also highly positively correlated, $r = .87$, $p < .001$. For the 41 participants without ASD, adult and child neighborhood density values were also highly positively correlated, $r = .86$, $p < .001$; adult and child word frequency values were highly positively correlated, as well, $r = .92$, $p < .001$.

Selection of Subsamples and Establishment of Equivalence

Participants were drawn from larger pools of toddlers with ASD ($N = 129$) or without ASD ($N = 80$), as described above. Item-level expressive vocabulary data were not available for five toddlers with ASD. Two more participants with ASD were excluded because they were outside of the age range of interest (i.e., were older than 40 months of age) at the time of CDI administration. Participants were further selected based on (1) sufficient expressive vocabulary and (2) subsequent matching on coded vocabulary size.

Before performing group matching, participants were restricted to those who were reported to produce at least 5 of the 287 coded words on the CDI. We chose 5 coded words as an initial cut-off so as to err on the side of including more toddlers by requiring fewer spoken words, such that our findings would represent a greater range of the ASD phenotype. However, lexical characteristic estimates based on as few as 5 coded words might be less informative or representative for participants with very few words and may lead to violation of some statistical assumptions (Stokes, in press). To mitigate this, we repeated analyses for subsamples of toddlers who produced at least 20 coded words, replicating the Stokes, Bleses, et al. (2012) cut-off. Both subsets of participants (i.e., 5 coded words, 20 coded words) are described below.

After imposing the 5- and 20-word lower limit cut-offs, group matching on coded vocabulary size was achieved by restricting the upper limit of the range of coded words simultaneously for toddlers with and without ASD. To establish equivalence between groups, we followed Kover and Atwood (2013), thereby seeking an effect size near zero and variance ratio near 1, in addition to a large p -value, in comparing the groups on coded vocabulary size.

For toddlers who produced 5 or more coded vocabulary words, the initial (maximum) samples of toddlers with ASD ($n = 64$) and toddlers without ASD ($n = 71$) were not matched. They significantly differed in terms of coded vocabulary size, $t(133) = 3.98$, $p < .001$, with an unacceptably large effect size, $d = 0.56$, and an unacceptably small variance ratio, 0.47. These unmatched groups differed with respect to average word frequency, $t(133) = -2.19$, $p = .030$, $d = 0.41$, and average word length, $t(133) = 2.29$, $p = .024$, $d = -0.38$, but not average neighborhood density, $t(133) = -0.53$, $p = .599$, $d = 0.09$.

Larger matched subsamples—When limiting the maximum number of coded words to 140, the resulting subsamples ($n = 57$ with ASD; $n = 41$ without ASD) were sufficiently equivalent on coded vocabulary words in terms of (1) an effect size near zero for the mean difference between groups, $d = 0.05$, and (2) a variance ratio near one, variance ratio = 0.98 (Kover & Atwood, 2013). As expected based on the observed effect size, these groups did not differ in coded vocabulary size, $t(96) = 0.25$, $p = .801$. Complete descriptive statistics for the larger matched subsamples are shown in Table 1.

Smaller matched subsamples—When further limiting the larger subsamples to those toddlers who produced 20 or more coded vocabulary words, the resulting 20-coded-word subsamples ($n = 31$ with ASD; $n = 24$ without ASD) were sufficiently equivalent. These subsamples, whose range of coded vocabulary words was restricted to 20 - 140, had (1) an effect size near zero for the mean difference between groups, $d = 0.08$, and (2) a variance ratio near one, variance ratio = 0.81. As expected based on the observed effect size, these subsamples did not differ in coded vocabulary size, $t(53) = -0.29$, $p = .773$. Descriptive statistics for the smaller subsamples are shown in Table 2.

Results

Given our focus on individual differences, we tested our research questions separately in toddlers with and without ASD for the larger ($n = 57$ with ASD; $n = 41$ without ASD) and smaller ($n = 31$ with ASD; $n = 24$ without ASD) matched subsamples.

Preliminary Analyses

Differences in lexical characteristics between toddlers with and without ASD

—In the larger matched subsamples, toddlers with and without ASD did not differ with respect to neighborhood density, $t(96) = 1.62, p = .109, d = -0.33$, word frequency, $t(96) = -0.88, p = .380, d = 0.15$, or word length, $t(96) = 0.14, p = .891, d < 0.01$. The 20-coded-word matched subsamples did not differ with respect to word frequency, $t(53) = 0.18, p = .859, d < 0.01$, but did differ in terms of neighborhood density, $t(53) = 2.48, p = .016, d = -0.67$, and average word length, $t(53) = -2.29, p = .026, d = 0.70$.

Associations among lexical characteristics—Before proceeding to hierarchical regression analyses, we examined the correlations among neighborhood density, word frequency, word length, cognitive ability, and age. Tables 3 and 4 summarize these bivariate correlations for both the larger and smaller subsamples of participants, respectively. Age was not significantly correlated with other variables, but was included in regression analyses to control for length of exposure to ambient linguistic input. For toddlers with ASD, vocabulary size was negatively correlated with neighborhood density and word frequency and positively correlated with word length. For toddlers without ASD, correlations between vocabulary size and lexical characteristics were in the expected direction, but only significant for neighborhood density and word length and only in the smaller subsample. For all toddlers, neighborhood density was positively correlated with word frequency and negatively correlated with word length. Bayley-III cognitive composite raw scores were positively correlated with total and coded vocabulary size for the larger subsample of toddlers with ASD. Third order correlations among lexical characteristics and vocabulary size controlling for age and cognitive composite raw scores for toddlers with ASD are presented in Table 5 for the larger and smaller subsamples. Almost all bivariate and third order correlations with vocabulary size were significant for toddlers with ASD; as such, all lexical predictors were included in regression analyses.

Predictors of Vocabulary Size

Following Stokes, Bleses, et al. (2012), we predicted coded vocabulary size from age, neighborhood density, word frequency, and word length. We entered variables into hierarchical regression models in that order because of their theoretical relevance to vocabulary size. We estimated models separately for toddlers with and without ASD. Results are shown in Tables 6 and 7 for larger and smaller subsamples, respectively. Two-tailed p -values are reported. Age was not a significant predictor in any model.

Larger matched subsamples—For the larger subsample of toddlers without ASD, no significant predictors emerged at any step. For the larger subsample of toddlers with ASD, neighborhood density significantly and negatively predicted vocabulary size, controlling for

age (Step 2). In Step 3, only word frequency negatively predicted vocabulary size for toddlers with ASD, controlling for age and neighborhood density. In Step 4, word length was a significant positive predictor of vocabulary size and the effect of word frequency remained significant. Because of the known role of cognitive ability in language development for children with ASD and the significant bivariate correlations, we repeated these regression analyses with Bayley-III cognitive composite raw scores in addition to age as the initial predictors of coded vocabulary. Results remained the same, with Bayley-III scores significant at each step.

Smaller matched subsamples—For the smaller subsample of toddlers without ASD, neighborhood density significantly and negatively predicted vocabulary size at Steps 2, 3, and 4. No other predictors were significant. For the smaller subsample of toddlers with ASD, neighborhood density negatively predicted vocabulary size at Steps 2 and 3 (that is, controlling for age and word frequency), but only word length was a significant predictor of vocabulary size when all three lexical characteristics were included. For the toddlers with ASD, with age and Bayley-III cognitive raw scores as initial predictors, again, word length was the only significant predictor of coded vocabulary size; however, neighborhood density remained a significant negative predictor when word frequency was the only other lexical characteristic in the model.

In summary, results differed when subsamples were restricted to different ranges of coded vocabulary size (see Supplementary Figures 1 and 2). In the larger subsample, word frequency and word length were unique predictors of vocabulary size for toddlers with ASD, even after controlling for cognitive ability. In the smaller subsamples, neighborhood density was a predictor of vocabulary size for toddlers with and without ASD; however, when including all lexical characteristics, only word length accounted for variance in vocabulary size for those with ASD.

Differences between Toddlers with Smaller and Larger Vocabularies

We tested group differences in lexical characteristics separately for the larger and smaller subsamples of participants with or without ASD to establish whether toddlers with smaller or larger vocabularies were distinguished by the lexical characteristics of the words comprising those vocabularies. In each case, toddlers were categorized within subsamples as having smaller or larger vocabulary size based on z-scores. We report parametric results for group differences to allow for easily interpretable effect sizes, but we also analyzed group differences using Mann-Whitney *U* tests due to the smaller sample sizes and indication from Q-Q plots of some nonnormality. Unless noted, nonparametric tests for significance of group differences were consistent with the results of the parametric analyses.

Larger matched subsamples—For the larger subsample, toddlers with ASD with positive z-scores ($n = 22$; coded vocabulary size: $M = 81.05$; $SD = 27.92$) were considered to have relatively large vocabularies; participants with negative z-scores ($n = 35$; coded vocabulary size: $M = 14.17$; $SD = 9.58$) were considered to have relatively small vocabularies. Relative to those with larger vocabularies, toddlers with ASD with smaller vocabularies did not have significantly higher neighborhood density averages, $t(55) = -1.78$,

$p = .080$, $d = -0.49$ ($U = 261.50$, $p = .043$), but had significantly higher word frequency averages, $t(55) = -3.27$, $p = .002$, $d = -0.86$, and significantly lower word length averages, $t(55) = 3.87$, $p < .001$, $d = 1.09$. Toddlers without ASD with larger vocabularies were those with positive z-scores ($n = 13$; coded vocabulary size: $M = 90.69$; $SD = 29.49$); participants with smaller vocabularies were those with negative z-scores ($n = 28$; coded vocabulary size: $M = 19.32$; $SD = 10.11$). Relative to those with larger vocabularies, toddlers without ASD with smaller vocabularies did not have higher neighborhood density averages, $t(39) = -1.82$, $p = .076$, $d = -0.61$ ($U = 106.00$, $p = .033$), or significantly higher word frequency averages, $t(39) = -1.79$, $p = .081$, $d = -0.67$ ($U = 102.00$, $p = .025$), but did have lower word length averages, $t(39) = 2.25$, $p = .030$, $d = 0.72$ ($U = 112.00$, $p = .051$).

Smaller matched subsamples—For the smaller subsample, toddlers with ASD with positive z-scores ($n = 13$; coded vocabulary size: $M = 100.92$; $SD = 16.60$) were considered to have relatively large vocabularies; participants with negative z-scores ($n = 18$; coded vocabulary size: $M = 40.11$; $SD = 14.54$) were considered to have relatively small vocabularies. Relative to those with larger vocabularies, toddlers with ASD with smaller vocabularies had significantly higher neighborhood density averages, $t(29) = -4.25$, $p < .001$, $d = -1.56$, significantly higher word frequency averages, $t(29) = -2.14$, $p = .041$, $d = -0.86$, and significantly lower word length averages, $t(29) = 4.77$, $p < .001$, $d = 1.66$. Toddlers without ASD ($n = 24$) were categorized into those with larger (positive z-scores; $n = 10$; coded vocabulary size: $M = 102.10$; $SD = 22.85$) and smaller vocabularies (negative z-scores; $n = 14$; coded vocabulary size: $M = 34.71$; $SD = 11.68$). Relative to those with larger vocabularies, toddlers without ASD with smaller vocabularies had significantly higher neighborhood density averages, $t(22) = -5.32$, $p < .001$, $d = -2.22$, and significantly lower word length averages, $t(22) = 4.26$, $p < .001$, $d = 1.85$, but not higher word frequency averages, $t(22) = -1.36$, $p = .19$, $d = -0.62$.

Discussion

The purpose of the present study was to establish whether lexical characteristics account for expressive vocabulary size in toddlers with ASD. We identified relationships between lexical characteristics and vocabulary size for both toddlers with ASD and toddlers without ASD; however, the pattern of results differed between these groups. For toddlers with ASD, we found that neighborhood density and word length accounted for variability in vocabulary size; however, word length was the only unique lexical characteristic that consistently predicted vocabulary size when all lexical characteristics were included. For toddlers without ASD, neighborhood density was the only significant predictor of vocabulary size and only in the smaller matched subsample of participants, who produced at least 20 coded words. When toddlers with ASD were dichotomized according to vocabulary size, they differed in average neighborhood density, word frequency, and word length; toddlers without ASD dichotomized by vocabulary size differed only in neighborhood density and word length.

Based on larger subsamples of participants, who produced a minimum of only 5 coded words, results differed. Most notably, no lexical characteristic was a significant predictor of vocabulary size for toddlers without ASD in the larger subsample. For toddlers with ASD in

the larger subsample, word frequency, in addition to word length, was a unique predictor of vocabulary size. These differences could be due to less accurate estimates of lexical characteristics because of the small number of words in each child's coded lexicon or undesirable statistical properties of lexical characteristics based on such a small numbers of words, as suggested by Stokes (in press). In the remainder of our comments, we emphasize the findings for the smaller matched subsamples, containing participants who produced at least 20 coded words, following Stokes and colleagues (2012; in press) to allow direct comparison to existing studies.

Lexical Characteristics

In line with previous research, neighborhood density and expressive vocabulary size were negatively related in the current sample of toddlers without ASD (Stokes, 2010; Stokes, Bleses, et al., 2012; Stokes, Kern, et al., 2012). That is, children with larger vocabularies tended to have lower average neighborhood density scores, indicating greater diversity in the lexical items they acquired relative to the linguistic input, whereas children with smaller vocabularies may first learn words from dense neighborhoods, taking advantage of phonological characteristics of the ambient input. In contrast with the studies by Stokes and colleagues, not all of the examined lexical characteristics were unique predictors of vocabulary size, which could be due to our modest sample sizes. Nonetheless, neighborhood density was the best lexical predictor of vocabulary size for toddlers without ASD in the current study.

For toddlers with ASD, our results suggest that although those with smaller vocabularies may acquire words that sound like many other words in the ambient input, word length may be a more critical constraint on expressive vocabulary: toddlers with ASD with smaller vocabularies tended to produce words with shorter length, controlling for neighborhood density and word frequency. It should also be noted that, despite having similar coded vocabulary sizes, on average, toddlers with ASD had lexicons with longer word length (and lower neighborhood density) than toddlers without ASD. Unlike toddlers without ASD, it is possible that word length plays a primary role in vocabulary acquisition for toddlers with ASD. In the context of the broader word learning literature, it is not unexpected that high density, short words would be produced first (Storkel, 2004, 2009). Our findings hint that this pattern might extend to toddlers with ASD during some periods of development, at least in terms of word length.

Hoover et al. (2010) found that, given common sound sequences, dense neighborhood labels were acquired more easily than sparse neighborhood labels. They interpreted this finding to indicate that words with high neighborhood density facilitate word learning because dense words provide a working memory advantage (Thomson et al., 2005). Shorter words would also be expected to provide a memory advantage. Memory limitations may relate to the fact that toddlers with ASD with smaller vocabularies tend to produce words that are shorter; however, research on memory in children with ASD has yielded mixed findings. Some studies have identified deficits in some aspects of working memory (e.g., in the verbal domain in school-age children), but not others (e.g., nonsocial stimuli in infant siblings of children with ASD) and profiles of memory ability have yet to be linked to trajectories of

vocabulary acquisition (Gabig, 2008; Noland, Reznick, Stone, Walden, & Sheridan, 2010). Only one experimental study of word learning has examined task processing demands (i.e., increased delay between presentation of the novel label and comprehension probe), but failed to find an impact of those demands in school-age children with ASD; however, this study examined much older children and did not manipulate lexical characteristics of the novel labels (McDuffie, Kover, Hagerman, & Abbeduto, 2013). Future research is needed to determine whether the effects of lexical characteristics on vocabulary acquisition can be attributed to developing cognitive skills, such as phonological or short-term memory, and why those skills would result in an effect of word length for toddlers with ASD, but an effect of neighborhood density for toddlers without ASD.

Extended Statistical Learning?

As a type of implicit learning, statistical learning is a theoretically motivated and empirically convincing mechanism for typical language acquisition. As such, it is a productive perspective from which to examine potential sources of language delay in children with neurodevelopmental disorders. The ExSL position leans strongly on evidence that phonological forms with many neighbors are easier to acquire because of their reduced memory load (Swingley, 2005; Thomson et al., 2005). Swingley (2005) proposed that statistical learning might be useful for identifying a set of word forms, using frequency and co-occurrence probabilities, that would both serve as a platform for attaching meaning and highlighting other cues to word segmentation, such as stress. Thiessen and Saffran (2003) also suggest that early attention to statistical regularities might give rise to the availability of other cues that are generalized from the outcomes of that initial learning. The extent to which flexibility in cue use— and the role of memory or executive function in supporting a shift between learning mechanisms— accounts for patterns of vocabulary development in children with ASD will be an important topic of future research.

Applying the theory of ExSL to toddlers with ASD allowed the test of the hypothesis that, similar to late talkers, the lexicons of children with ASD have characteristics indicative of a vocabulary-learning process that is overly sensitive to, or constrained by, statistical properties of lexical items in the language input. Although we identified relationships between some of the lexical characteristics examined by Stokes and colleagues and vocabulary size, the observed relationship between neighborhood density and vocabulary size was far weaker for toddlers with ASD than predicted by ExSL or observed in the smaller subsample of toddlers without ASD in the current study. Ultimately, word length was the best predictor of expressive vocabulary size for toddlers with ASD. Thus, the current findings lend minimal support to the ExSL theory (Stokes, Kern, et al., 2012) as an account for vocabulary delays in toddlers with ASD.

One explanation for the current findings is that toddlers with ASD are not limited by the use of distributional cues for developing expressive vocabulary. This interpretation falls in line with the suggestion that implicit learning, as a whole, is intact in individuals with ASD (Boucher et al., 2008). That is, vocabulary acquisition might be limited neither by the failure to extract statistical patterns nor to loosen statistical constraints on lexical items. However, the possibility that we have simply missed the developmental window during which

neighborhood density is a defining characteristic of expressive vocabulary for toddlers with ASD cannot be ignored. Impossible to test in the current study was whether some toddlers with ASD have lexicons with characteristics indicative of a vocabulary-learning process that is uninformed by statistical properties of vocabulary—perhaps including those who are not yet producing words. Stokes, Kern, et al. (2012) noted that some toddlers with smaller vocabularies had neighborhood densities that were average relative to their larger-vocabulary peers. They suggested that those children might be the ones who have yet to master statistical learning as a mechanism for vocabulary acquisition. Future studies will need to address this possibility in toddlers with ASD.

It might also be the case that the lexical characteristics we assessed may be more predictive of lexical acquisition for toddlers with ASD later (or earlier) in development. Storkel (2009) found that lexical characteristics, such as neighborhood density, might have weakening impact for noun learning after 20 months of age in typical development. This suggests that in typical development, high neighborhood density supports vocabulary acquisition, but that it does so only to a lesser extent as development continues and vocabulary size increases. In contrast, children with delayed vocabulary development continue to have lexicons that are defined by high neighborhood density, perhaps indicating overreliance on distributional cues (Stokes, 2010; Stokes, Kern, et al., 2012). In extending ExSL to children with neurodevelopmental disorders, it will be important to consider the developmental timing of the benefits of statistical regularities in the ambient input for lexical acquisition.

There are additional alternative explanations for the pattern of results obtained. It has recently been suggested that ExSL is suitable to explain variability in only the expressive, and not receptive, vocabularies of late talkers (Stokes, in press). Stokes (in press) found that neighborhood densities were higher in expressive than receptive vocabularies for late talkers and typically developing toddlers combined, but with a greater difference in neighborhood density between modalities for late talkers than typically developing toddlers, such that neighborhood density distinguished between large and small expressive, but not receptive, vocabularies. Stokes (in press) posited that dense words move quickly from being understood to also produced and that it is inadequate depth of phonological representations that results in high neighborhood density values in the expressive vocabularies of late talkers. This hypothesis must be tested in toddlers with ASD to distinguish between ExSL and a phonological representation account of vocabulary delay in this population. In addition, we can only speculate as to whether results for toddlers with ASD differ from those reported for late talkers in previous studies because of their older age (i.e., 30 months), the high rate of males in the sample (i.e., 90%), lower neighborhood density values, or more restricted variability relative to results from British English (Stokes, 2010; Stokes, in press).

Limitations

The conclusions drawn must be tempered by the observational and correlational nature of this cross-sectional study. We analyzed the lexicons of only children with at least 5 or 20 coded vocabulary words, meaning that those with very small expressive vocabularies or no spoken language were not represented. In addition, the comparison group of toddlers without ASD is likely to over-represent late talkers, given that the groups were matched on

expressive vocabulary. Further, this study used only parent report, rather than spontaneous language samples, and examined only expressive vocabulary. Future research should investigate receptive vocabulary, which would allow the inclusion of children with ASD with very little or no spoken language (see Stokes, in press). Finally, an important extension of this research will be to examine how semantic neighborhood density interacts with the lexical characteristics examined here, given the putative difficulties individuals with ASD have with meaning per se. Any of these research questions would lend themselves to large consortium databases, in which much larger sample sizes could be attained.

Conclusions and Clinical Implications

Despite limitations, the current findings have implications for theories on language development in children with ASD, including the role of lexical characteristics and statistical learning for vocabulary acquisition. The observed relationships between lexical characteristics and vocabulary size suggest that, beyond age and general cognitive ability, cognitive processes brought to the vocabulary-learning task by a child interact with ambient linguistic input in systematic ways that might overlap or differ between populations of children with similar language outcomes (Leonard, 1991). We suggest that the underlying processes of vocabulary acquisition are shared between toddlers with and without ASD, but that the timing, duration, or precedence of learning mechanisms may be shifted or prolonged in children with language difficulties. It will be the task of future research to further define these learning mechanisms and to characterize their role in language learning across development.

Regardless of whether ExSL proves to be a source of vocabulary delay in young children with ASD, the current results suggest that processing demands should also be considered in relation to trajectories of vocabulary acquisition. Rather than examining statistical properties of linguistic input in isolation, cognitive processing skills (e.g., phonological memory) will be an important point of investigation for experimental studies of novel word learning in young children with ASD. Such word learning studies and longitudinal research on lexical acquisition will be essential to understanding the developmental effects of distributional properties of language and cognitive development on the vocabulary of typically developing children, children with ASD, and children with other neurodevelopmental disorders (Arciuli & Torkildsen, 2012). In particular, directly testing memory and statistical learning abilities of toddlers with ASD and those who are late talkers would be informative. Only with such research will it be possible to conclude whether a failure to extend lexical learning to a wider variety of phonological forms or longer phonological forms is a source of delay in children with ASD. Pending this future research, successful strategies for intervention might include acknowledging that high neighborhood density words could serve as a platform for learning before gradually introducing words from sparser neighborhoods (Stokes, in press); however, attention to the memory and cognitive demands of word learning may also be important for toddlers with ASD. While it seems premature to posit specific clinical recommendations, one might speculate, given their well-established difficulties with executive functioning (particularly shifting skills and updating working memory) and with central coherence (see Pellicano, 2010), that children with ASD might be more likely to learn words with shorter phonological forms in which multiple cues need not be integrated.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by NIH grants R01 DC07223, R01 DC03731, T32 DC05359 (Ellis-Weismer, PI), and P30 HD03352 (Mailick, PI). We offer sincere appreciation to the families who participated in this study.

References

- Alt M, Meyers C, Ancharski A. Using principles of learning to inform language therapy design for children with specific language impairment. *International Journal of Language and Communication Disorders*. 2012; 47(5):487–498. [PubMed: 22938060]
- Arciuli J, Torkildsen JK. Advancing Our Understanding of the Link between Statistical Learning and Language Acquisition: The Need for Longitudinal Data. *Frontiers in Psychology*. 2012; 3:324. [PubMed: 22969746]
- Bayley, N. Bayley Scales of Infant and Toddler Development. Third Edition. Psychological Corporation; San Antonio, Texas: 2006.
- Brown J, Aczel B, Jimenez L, Kaufman SB, Grant KP. Intact implicit learning in autism spectrum conditions. *Quarterly Journal of Experimental Psychology (Hove)*. 2010; 63(9):1789–1812.
- 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(1):213–236. [PubMed: 12718299]
- Conway CM, Bauernschmidt A, Huang SS, Pisoni DB. Implicit statistical learning in language processing: word predictability is the key. *Cognition*. 2010; 114(3):356–371. [PubMed: 19922909]
- Eigsti IM, de Marchena AB, Schuh JM, Kelley E. Language acquisition in autism spectrum disorders: A developmental review. *Research in Autism Spectrum Disorders*. 2011; 5(2):681–691.
- Ellis Weismer S, Gernsbacher MA, Stronach S, Karasinski C, Eernisse ER, Venker CE, 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.
- 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(10):1259–1273.
- Ellis Weismer S, Venker CE, Evans JL, Moyle MJ. Fast mapping in late-talking toddlers. *Applied Psycholinguistics*. 2013; 34(1):69–89. [PubMed: 23898218]
- Evans JL, Saffran JR, Robe-Torres K. Statistical learning in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*. 2009; 52(2):321–335.
- Fenson, L.; Dale, P.; Reznick, JS.; Thal, D.; Bates, E.; Hartung, J.; Reilly, J. The MacArthur Communicative Development Inventory: User's Guide and Technical Manual. Singular Publishing Group; San Diego, CA: 1993.
- Fenson, L.; Marchman, VA.; Thal, DJ.; Dale, PS.; Reznick, JS.; Bates, E. MacArthur-Bates Communicative Development Inventories: User's Guide and Technical Manual. Second Edition ed.. Paul H. Brookes Publishing Co.; Baltimore: 2007.
- Frankenburg, W.; Dodds, J.; Archer, P.; Bresnick, BM.; P.; Edelman, N.; Shapiro, H. Denver Screening Test II. Denver Developmental Materials; Denver, CO: 1990.
- Gabig CS. Verbal working memory and story retelling in school-age children with autism. *Language, Speech, and Hearing Services in Schools*. 2008; 39(4):498–511.
- Geurts HM, Corbett B, Solomon M. The paradox of cognitive flexibility in autism. *Trends in Cognitive Sciences*. 2009; 13(2):74–82. [PubMed: 19138551]
- Gomez RL, Gerken L. Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition*. 1999; 70:109–135. [PubMed: 10349760]

- Goodman JC, Dale PS, Li P. Does frequency count? Parental input and the acquisition of vocabulary. *Journal of Child Language*. 2008; 35(3):515–531. [PubMed: 18588713]
- 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(5):693–705. [PubMed: 19082876]
- Graf Estes K, Edwards J, Saffran JR. Phonotactic Constraints on Infant Word Learning. *Infancy*. 2011; 16(2):180–197. [PubMed: 21297877]
- Graf Estes K, Evans JL, Alibali MW, Saffran JR. Can infants map meaning to newly segmented words? Statistical segmentation and word learning. *Psychological Science*. 2007; 18(3):254–260. [PubMed: 17444923]
- Gray S, Brinkley S, Svetina D. Word learning by preschoolers With SLI: Effect of phonotactic probability and object familiarity. *Journal of Speech, Language, and Hearing Research*. 2012; 55(5):1289–1300.
- Hay JF, Pelucchi B, Graf Estes K, Saffran JR. Linking sounds to meanings: Infant statistical learning in a natural language. *Cognitive Psychology*. 2011; 63(2):93–106. [PubMed: 21762650]
- Hoover JR, Storkel HL, Hogan TP. A cross-sectional comparison of the effects of phonotactic probability and neighborhood density on word learning by preschool children. *Journal of Memory and Language*. 2010; 63(1):100–116. [PubMed: 20563243]
- Kidd E. Implicit statistical learning is directly associated with the acquisition of syntax. *Developmental Psychology*. 2012; 48(1):171–184. [PubMed: 21967562]
- Kover ST, Atwood AK. Establishing equivalence: Methodological progress in group-matching design and analysis. *American Journal on Intellectual and Developmental Disabilities*. 2013; 118(1):3–15. [PubMed: 23301899]
- Kover ST, McDuffie A, Hagerman R, Abbeduto L. Receptive vocabulary in boys with autism spectrum disorder: Cross-sectional developmental trajectories. *Journal of Autism and Developmental Disorders*. 2013; 43:2696–2709.
- Kucera, H.; Francis, WN. *Computational Analysis of Present-day American English*. Brown University Press; Providence, RI: 1967.
- Lany J, Saffran JR. Interactions between statistical and semantic information in infant language development. *Developmental Science*. 2011; 14(5):1207–1219. [PubMed: 21884336]
- Large, NR.; Pisoni, DB. *Subjective Familiarity of Words: Analysis of the Hoosier Mental Lexicon*. Speech Research Laboratory, Indiana University; Bloomington, IN: 1998. Vol. Research on Spoken Language Processing Progress Report No. 22
- Leach L, Samuel AG. Lexical configuration and lexical engagement: when adults learn new words. *Cognitive Psychology*. 2007; 55(4):306–353. [PubMed: 17367775]
- Leonard LB. Specific language impairment as a clinical category. *Language, Speech, and Hearing Services in Schools*. 1991; 22(2):66–68.
- Lord, C.; Rutter, M.; DiLavore, P.; Risi, S. *Autism Diagnostic Observation Schedule*. Western Psychological Services; Los Angeles, CA: 2002.
- 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 autism spectrum disorders. *Journal of Autism and Developmental Disorders*. 2009; 39(9):1305–1320.
- Luyster R, Lopez K, Lord C. Characterizing communicative development in children referred for autism spectrum disorders using the MacArthur-Bates Communicative Development Inventory (CDI). *Journal of Child Language*. 2007; 34(3):623–654. [PubMed: 17822142]
- Mayo J, Eigsti IM. Brief Report: A Comparison of Statistical Learning in School-Aged Children with High Functioning Autism and Typically Developing Peers. *Journal of Autism and Developmental Disorders*. 2012
- McDuffie A, Kover ST, Hagerman R, Abbeduto L. Investigating word learning in fragile x syndrome: A fast-mapping study. *Journal of Autism and Developmental Disorders*. 2013; 43(7):1676–1691.
- McKean C, Letts C, Howard D. Functional reorganization in the developing lexicon: separable and changing influences of lexical and phonological variables on children's fast-mapping. *Journal of Child Language*. 2012:1–29. [PubMed: 21418730]

- Mullen, EM. Mullen Scales of Early Learning: AGS Edition. American Guidance Service; Circle Pines, MN: 1995.
- Naigles L, Keltz E, Jaffery R, Fein D. Abstractness and continuity in the syntactic development of young children with autism. *Autism Research*. 2011; 4(6):422–437. [PubMed: 22012625]
- Noland JS, Reznick JS, Stone WL, Walden T, Sheridan EH. Better working memory for non-social targets in infant siblings of children with Autism Spectrum Disorder. *Developmental Science*. 2010; 13(1):244–251. [PubMed: 20121880]
- Nusbaum, HC.; Pisoni, DB.; Davis, CK. Sizing up the Hoosier Mental Lexicon: Measuring the Familiarity of 20,000 Words. Speech Research Laboratory, Indiana University; Bloomington, IN: 1984. Vol. Research on Speech Perception Progress Report No. 10
- Ray-Subramanian CE, Ellis Weismer S. Receptive and Expressive Language as Predictors of Restricted and Repetitive Behaviors in Young Children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*. 2012; 42:2113–2120.
- Ray-Subramanian CE, Huai N, Ellis Weismer S. Brief report: Adaptive behavior and cognitive skills for toddlers on the autism spectrum. *Journal of Autism and Developmental Disorders*. 2011; 41(5): 679–684.
- Rutter, M.; Bailey, A.; Lord, C. The Social Communication Questionnaire: Manual. Western Psychological Services; Los Angeles: 2003.
- Rutter, M.; Le Couteur, A.; Lord, C. Autism Diagnostic Interview - Revised. Western Psychological Services; Los Angeles: 2003.
- Saffran JR, Aslin RN, Newport EL. Statistical learning by 8-month-old infants. *Science*. 1996; 274:1926–1928. [PubMed: 8943209]
- Saffran JR, Thiessen ED. Pattern induction by infant language learners. *Developmental Psychology*. 2003; 39(3):484–494. [PubMed: 12760517]
- Scott-Van Zeeland AA, McNealy K, Wang AT, Sigman M, Bookheimer SY, Dapretto M. No neural evidence of statistical learning during exposure to artificial languages in children with autism spectrum disorders. *Biological Psychology*. 2010; 68(4):345–351.
- Stokes SF. Neighborhood density and word frequency predict vocabulary size in toddlers. *Journal of Speech, Language, and Hearing Research*. 2010; 53(3):670–683.
- Stokes SF. The impact of phonological neighborhood density on typical and atypical emerging lexicons. *Journal of Child Language*. in press.
- Stokes SF, Bleses D, Basboll H, Lambertsen C. Statistical learning in emerging lexicons: The case of Danish. *Journal of Speech, Language, and Hearing Research*. 2012; 55(5):1265–1273.
- Stokes SF, Kern S, Dos Santos C. Extended Statistical Learning as an account for slow vocabulary growth. *Journal of Child Language*. 2012; 39(1):105–129. [PubMed: 21729369]
- Storkel HL. Do children acquire dense neighborhoods? An investigation of similarity neighborhoods in lexical acquisition. *Applied Psycholinguistics*. 2004; 25(2):201–221.
- Storkel HL. Developmental differences in the effects of phonological, lexical and semantic variables on word learning by infants. *Journal of Child Language*. 2009; 36(2):291–321. [PubMed: 18761757]
- Storkel HL, Hoover JR. An online calculator to compute phonotactic probability and neighborhood density on the basis of child corpora of spoken American English. *Behavior Research Methods*. 2010; 42(2):497–506. [PubMed: 20479181]
- Storkel HL, Lee SY. The independent effects of phonotactic probability and neighborhood density on lexical acquisition by preschool children. *Language and Cognitive Processes*. 2011; 26(2):191–211. [PubMed: 21643455]
- Swingle D. Statistical clustering and the contents of the infant vocabulary. *Cognitive Psychology*. 2005; 50(1):86–132. [PubMed: 15556130]
- 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):1–21.
- Tek S, Jaffery G, Fein D, Naigles LR. Do children with autism spectrum disorders show a shape bias in word learning? *Autism Res*. 2008; 1(4):208–222. [PubMed: 19360671]

- Thiessen ED, Saffran JR. When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Developmental Psychology*. 2003; 39(4):706–716. [PubMed: 12859124]
- Thompson SP, Newport EL. Statistical learning of syntax: The role of transitional probability. *Language Learning and Development*. 2007; 3(1):1–42.
- Thomson JM, Richardson U, Goswami U. Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia. *Memory and Cognition*. 2005; 33(7):1210–1219. [PubMed: 16532854]
- Torkildsen JK, Dailey NS, Aguilar JM, Gomez R, Plante E. Exemplar variability facilitates rapid learning of an otherwise unlearnable grammar by individuals with language-based learning disability. *Journal of Speech, Language, and Hearing Research*. 2013; 56(2):618–629.
- Volden J, Smith IM, Szatmari P, Bryson S, Fombonne E, Mirenda P, Thompson A. Using the preschool language scale, fourth edition to characterize language in preschoolers with autism spectrum disorders. *American Journal of Speech-Language Pathology*. 2011; 20(3):200–208. [PubMed: 21478278]

Table 1
Participant Characteristics, Vocabulary Ability, and Lexical Characteristics for Larger Matched Subsamples of Toddlers with ASD and Toddlers without ASD

Variable	Toddlers with ASD (<i>n</i> = 57)			Toddlers without ASD (<i>n</i> = 41)		
	Mean	(SD)	Range	Mean	(SD)	Range
Chronological age	30.35	(3.88)	21 - 37	23.88	(1.23)	22 - 26
CDI total words produced	90.82	(79.77)	10 - 299	96.41	(76.07)	26 - 301
Coded vocabulary size	39.98	(37.77)	5 - 132	41.95	(38.22)	6 - 138
Neighborhood density	19.20	(1.90)	15 - 23	19.77	(1.48)	16 - 23
Word frequency	2.80	(0.19)	2.37 - 3.30	2.77	(0.20)	2.36 - 3.52
Word length	3.03	(0.20)	2.56 - 3.33	3.03	(0.16)	2.62 - 3.38
Bayley-III Cognitive						
Raw	64.93	(4.90)	52 - 74	-	-	-
Age-equivalent	25.60	(3.50)	18 - 33			
Composite	87.19	(9.36)	65 - 115	-	-	-
MSEL ^a						
Age-equivalent	26.45	(4.81)	16 - 40	-	-	-
T-Score	36.45	(12.27)	20 - 58	-	-	-
Autism symptom severity	7.18	(1.99)	1 - 10	-	-	-
Maternal education in years	14.53	(2.22)	11 - 19	-	-	-

Note. Age and age-equivalent scores are given in months. CDI = MacArthur-Bates Communicative Development Inventories: Words and Sentences (Fenson et al., 2007); MSEL = Mullen Scales of Early Learning Visual Reception subtest (Mullen, 1995). Coded vocabulary ability reflects the number of words produced from the CDI that were included in the analysis subset of 287 words. Lexical characteristics were calculated using the adult-referenced database from Storkel and Hoover (2010).

^aScores were available only for the 49 participants who received the MSEL in addition to the Bayley-III.

Table 2
Participant Characteristics, Vocabulary Ability, and Lexical Characteristics for Smaller Matched Subsamples of Toddlers with ASD and Toddlers without ASD

Variable	Toddlers with ASD (<i>n</i> = 31)			Toddlers without ASD (<i>n</i> = 24)		
	Mean	(SD)	Range	Mean	(SD)	Range
Chronological age	30.70	(3.93)	21 - 37	24.04	(1.20)	22 - 26
CDI total words produced	144.10	(72.95)	43 - 299	135.79	(77.79)	59 - 301
Coded vocabulary size	65.61	(34.07)	20 - 132	62.79	(37.85)	21 - 138
Neighborhood density	19.19	(1.29)	17 - 21	20.00	(1.10)	18 - 22
Word frequency	2.72	(0.12)	2.37 - 3.01	2.73	(0.09)	2.48 - 2.91
Word length	3.09	(0.11)	2.84 - 3.27	3.01	(0.14)	2.62 - 3.16
Bayley-III Cognitive						
Raw	66.35	(4.42)	56 - 74	-	-	-
Age-equivalent	26.55	(3.33)	20 - 33			
Composite	89.35	(9.38)	75 - 115	-	-	-
MSEL ^a						
Age-equivalent	27.27	(4.94)	16 - 36	-	-	-
T-Score	37.77	(12.71)	20 - 58	-	-	-
Autism symptom severity	6.97	(2.07)	1 - 10	-	-	-
Maternal education in years	14.87	(2.26)	12 - 19	-	-	-

Note. Age and age-equivalent scores are given in months. CDI = MacArthur-Bates Communicative Development Inventories: Words and Sentences (Fenson et al., 2007); MSEL = Mullen Scales of Early Learning Visual Reception subtest (Mullen, 1995). Coded vocabulary ability reflects the number of words produced from the CDI that were included in the analysis subset of 287 words. Lexical characteristics were calculated using the adult-referenced database from Storkel and Hoover (2010).

^a Scores were available only for the 26 participants who received the MSEL in addition to the Bayley-III.

Table 3
Bivariate Correlations Among Vocabulary Size, Age, Cognitive Ability, and Lexical Characteristics for the Larger Matched Subsamples of Toddlers with ASD (n = 57) and Toddlers without ASD (n = 41)

Variable	1	2	3	4	5	6	7
1. Age	—	.153	.126	.117	.083	-.010	-.044
2. Bayley-III cognitive raw	-	—	.359*	.381*	-.007	-.158	.098
3. CDI total words	.061	-	—	.990*	-.279*	-.459*	.512*
4. Coded vocabulary	.030	-	.979*	—	-.256	-.455*	.516*
5. Neighborhood density	.091	-	-.240	-.220	—	.328*	-.584*
6. Word frequency	.236	-	-.246	-.249	.422*	—	-.433*
7. Word length	-.190	-	.304	.284	-.690*	-.495*	—

Note. Correlations for toddlers with ASD are presented above the diagonal; correlations for toddlers without ASD are presented below the diagonal.

* $p < .05$ (2-tailed).

Table 4
Bivariate Correlations Among Vocabulary Size, Age, Cognitive Ability, and Lexical Characteristics for the Smaller Matched Subsamples of Toddlers with ASD (n = 31) and Toddlers without ASD (n = 24)

Variable	1	2	3	4	5	6	7
1. Age	—	.056	.106	.087	-.041	.103	.009
2. Bayley-III cognitive raw	-	—	.239	.277	-.161	-.106	.204
3. CDI total words	-.063	-	—	.980*	-.801*	-.411*	.813*
4. Coded vocabulary	-.103	-	.970*	—	-.754*	-.402*	.806*
5. Neighborhood density	.073	-	-.801*	-.793*	—	.406*	-.808*
6. Word frequency	.029	-	-.329	-.310	.608*	—	-.520*
7. Word length	-.208	-	.668*	.683*	-.846*	-.467*	—

Note. Correlations for toddlers with ASD are presented above the diagonal; correlations for toddlers without ASD are presented below the diagonal.

* $p < .05$ (2-tailed).

Table 5
Third Order Correlations Among Vocabulary Size and Lexical Characteristics
Controlling for Age and Bayley-III Cognitive Raw Scores for Larger (n = 57) and Smaller
(n = 31) Subsamples of Toddlers with ASD

Variable	1	2	3	4	5
1. CDI total words	—	.988*	-.305*	-.439*	.520*
2. Coded vocabulary	.980*	—	-.281*	-.434*	.526*
3. Neighborhood density	-.796*	-.748*	—	.331*	-.584*
4. Word frequency	-.415*	-.402*	.403*	—	-.425*
5. Word length	.808*	.799*	-.802*	-.515*	—

Note. Correlations for toddlers with ASD who produced at least 5 coded words are presented above the diagonal; correlations for toddlers with ASD who produced at least 20 coded words are presented below the diagonal.

* $p < .05$ (2-tailed).

Table 6
Hierarchical Regressions Predicting Coded Vocabulary with Lexical Characteristics for Larger Matched Subsamples

Predictor	Toddlers with ASD ($n = 57$)				Toddlers without ASD ($n = 41$)					
	R^2	b	95% CI	t	Semi-partial r	R^2	b	95% CI	t	Semi-partial r
Step 1	.01					.01				
Age		1.14	-1.48, 3.75	0.87	.12		.92	-9.15, 10.99	0.19	.03
Step 2	.07*					.05				
Age		1.36	-1.20, 3.91	1.06	.14		1.56	-8.44, 11.55	0.32	.05
Neighborhood density		-5.30	-10.50, -0.11	-2.05*	-.27		-5.81	-14.14, 2.51	-1.41	-.22
Step 3	.15*					.04				
Age		1.21	-1.15, 3.57	1.03	.12		2.87	-7.33, 13.06	0.57	.09
Neighborhood density		-2.61	-7.69, 2.47	-1.03	-.12		-3.59	-12.70, 5.51	-0.80	-.13
Word frequency		-80.95	-131.29, -30.62	-3.23*	-.39		-40.80	-110.11, 28.51	-1.19	-.19
Step 4	.12*					.02				
Age		1.23	-0.96, 3.42	1.13	.13		3.43	-6.86, 13.72	0.68	.11
Neighborhood density		1.81	-3.69, 7.32	0.66	.07		-0.30	-11.86, 11.26	-0.05	-.01
Word frequency		-56.94	-106.11, -7.77	-2.32*	-.26		-31.28	-103.73, 41.16	-0.88	-.14
Word length		86.38	30.73, 142.03	3.12*	.35		52.24	-60.30, 164.79	0.94	.15
Total R^2	.36					.11				

*
 $p < .05$.

Table 7
Hierarchical Regressions Predicting Coded Vocabulary Ability with Lexical Characteristics for Smaller Matched Subsamples

Predictor	Toddlers with ASD (<i>n</i> = 31)					Toddlers without ASD (<i>n</i> = 24)				
	<i>R</i> ²	<i>b</i>	95% CI	<i>t</i>	Semi-partial <i>r</i>	<i>R</i> ²	<i>b</i>	95% CI	<i>t</i>	Semi-partial <i>r</i>
Step 1	.01					.01				
Age		0.75	-2.53, 4.04	0.47	.09		-3.27	-17.18, 10.64	-0.49	-.10
Step 2	.57*					.62*				
Age		0.48	-1.72, 2.68	0.45	.06		-1.45	-10.19, 7.30	-0.34	-.05
Neighborhood density		-19.85	-26.54, -13.16	-6.08*	-.75		-27.72	-37.44, -18.01	-5.94*	-.79
Step 3	.01					.05				
Age		0.61	-1.62, 2.84	0.56	.07		-1.31	-9.72, 7.09	-.33	-.04
Neighborhood density		-18.50	-25.88, -11.12	-5.14*	-.64		-33.55	-45.30, -21.80	-5.96*	-.76
Word frequency		-34.24	-111.49, 43.01	-0.91	-.11		120.14	-27.05, 267.33	1.70	.22
Step 4	.10*					.01				
Age		0.60	-1.39, 2.58	0.62	.07		-1.42	-10.42, 7.54	-0.33	-.04
Neighborhood density		-7.68	-17.82, 2.47	-1.56	-.17		-34.26	-54.72, -13.80	-3.51*	-.46
Word frequency		2.13	-71.32, 75.58	0.06	.01		120.87	-31.56, 273.29	1.66	.22
Word length		170.28	48.57, 291.99	2.88*	.32		-6.03	-145.91, 133.84	-0.09	-.01
Total <i>R</i> ²	.69					.68				

* *p* < .05.