Phonology and Vocal Behavior in Toddlers with Autism Spectrum Disorders

Elizabeth Schoen[1], **Rhea Paul**, and **Katyrzyna Chawarska**
Yale Child Study Center, Yale University, 230 South Frontage Road, New Haven, CT 06519

Scientific Abstract

The purpose of this study is to examine the phonological and other vocal productions of children, 18-36 months, with autism spectrum disorder (ASD) and to compare these productions to those of age-matched and language-matched controls. Speech samples were obtained from 30 toddlers with ASD, 11 age-matched toddlers and 23 language-matched toddlers during either parent-child or clinician-child play sessions. Samples were coded for a variety of speech-like and non-speech vocalization productions. Toddlers with ASD produced speech-like vocalizations similar to those of language-matched peers, but produced significantly more atypical non-speech vocalizations when compared to both control groups.Toddlers with ASD show speech-like sound production that is linked to their language level, in a manner similar to that seen in typical development. The main area of difference in vocal development in this population is in the production of atypical vocalizations. Findings suggest that toddlers with autism spectrum disorders might not tune into the language model of their environment. Failure to attend to the ambient language environment negatively impacts the ability to acquire spoken language.

Keywords

Autism; phonology; autism spectrum disorders; atypical; vocalizations

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Autism is a complex neurodevelopmental disorder characterized by severe impairments in social interaction and communication and accompanied by a range of repetitive behaviors and restricted interests (American Psychiatric Association, 2000). Along with its less severe variants, Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS) and Asperger syndrome, it makes up what is currently referred to in the literature as Autism Spectrum Disorder (ASD). Until recently children with ASD were rarely diagnosed before the age of 3 to 4 years (Chakrabarti & Fombonne, 2001; Charman & Baird, 2002; Filipek, et al., 1999; Fombonne, 2005), but a major thrust of current research has been to lower the age of identification, due in part to evidence supporting the effectiveness of early intervention (Rogers, 2006; Stahmer & Ingersoll, 2004). Recent research suggests that the clinical diagnosis of autism can be reliably assigned in the second year of life, and is stable when conferred by a multidisciplinary team of experienced clinicians (Chawarska, Klin, Paul, & Volkmar, 2007; Chawarska, Paul, Klin, Hannigan, Dichtel, & Volkmar, 2007; Cox, et al., 1999; Klin et al., 2004).

Several studies (Paul, Chawarska, Cicchetti, & Volkmar, 2008; Wetherby, Watt, Morgan, & Shumway, 2007) have described the communicative characteristics of children in the second

[1]Address for Correspondence: Yale Child Study Center, 40 Temple St. #7D, New Haven, CT 06510, Phone: 203 7371267, Facsimile: 203 764 4373, elizabeth.schoen@yale.edu.

and third year of life who are identified with ASD. Chawarska and Volkmar (2005) summarized the findings of these studies to include:

- Abnormal gaze patterns;

- Limited social referencing and sharing of affect;

- Low frequency of joint attention, showing, or commenting;

- Inconsistent response to name;

- Low frequency of nonverbal communication;

- Failure to respond to or use conventional gestures;

- Limited pretend pay;

- Limited motor or vocal imitation;

- Limited interest in people and interactive games;

- Delayed onset and development of spoken language;

- Unusual vocalizations

Although these studies have amply demonstrated that, among other communication difficulties, children with ASD are almost universally delayed in their acquisition of spoken language (Tager-Flusberg, Paul, & Lord, 2005; Wetherby et al., 2004), little research has focused on the phonological and other vocal characteristics of these toddlers. An emerging body of literature suggests deviancies in vocal development in this population. Ricks and Wing (1976) studied parents' identification of the meaning of prelinguistic vocalizations of preverbal preschoolers with ASD and found that their parents were unable to understand the intentions behind the vocalizations of other parents' children with ASD, even though they could understand their own child's messages. In contrast, parents of typically developing children could understand vocalizations of typical children who were not their own, as well as those of their own child. These findings, however, were not replicated in a study by Elliott (1993). Anecdotally, children with ASD have been described as babbling less frequently than other infants. However, Elliott found no difference in the average frequency with which preverbal, developmentally delayed two-year-olds, preverbal typically developing 10- to 12-month-olds, and two-year-olds with autism produced vocalizations in free play situations. It is noteworthy, however, that a greater number of children in the group with ASD produced no vocalizations. Moreover, the vocalizations of children with ASD were less likely than those of children in the other groups to be paired with nonverbal communication, such as shifts in gaze, gestures, or changes in facial expression, as has frequently been reported (e.g., Chawarska & Volkmar, 2005; Wetherby et al., 2004; Wetherby et al., 2007)).

Sheinkopf, Mundy, Oller and Steffens (2000) conducted a detailed examination of the vocal behavior of preverbal young children with ASD at 3-4 years and a group of slightly younger comparison children with developmental delays. They showed that the preschoolers with ASD did not have difficulty with the expression of well-formed syllables (i.e., canonical babbling), but produced a greater proportion of syllables with atypical phonation than did comparison children. Wallace et al. (2008) performed acoustic analysis on the vocalizations of preschool children with ASD, comparing them to those of children with other developmental delays, and reported no differences in the vibratory quality (e.g., regular harmonic intervals, widely spaced harmonics, closely spaced harmonics) of the sound production. They did, however, see trends toward differences in the perceptual quality of phonation (e.g., breathy, tremors).

In terms of phonological development, articulation is often reported to be normal or even precocious in children with ASD who speak (Kjelgaard & Tager-Flusberg, 2001; Pierce & Bartolucci, 1977), although Rapin, Dunn, Allen, Stevens and Fein (2009) and Cleland, Gibbon, Peppé, O'Hare and Rutherford (2010) showed a range of patterns of speech and language behavior to be present in school-aged children with ASD.

In comparing speech development in children with ASD to those with non-autistic developmental disorders, Bartak and colleagues (Bartak, Rutter, & Cox, 1975) found articulation development to be somewhat slower than normal and that these delays were more transient in a group of high-functioning boys with autism than in language-level matched nonautistic boys with severe receptive-expressive delays in middle childhood (Rutter, Mawhood, & Howlin, 1992). Articulation delays were interpreted in this study to be related to later onset of language milestones. Bartolucci, Pierce, Streiner, and Tolkin-Eppel (1976) showed that phoneme frequency distribution and the distribution of phonological error types in a small group of children with autism was similar to that of intellectually disabled and typical children matched for nonverbal mental age. The less frequent the phoneme's occurrence in their language, the greater the number of errors. Wetherby, Yonclas, and Bryan (1989), in an examination of a small sample of preschool children with developmental disabilities, reported the children with specific language impairment (SLI) and ASD, unlike those with Down syndrome, showed a reduced frequency of vocal productions that contained a consonant, relative to children with TD at similar levels of language development.

More recently, McCleery, Tully, Slevc, and Schreibman (2006) reported that minimally verbal 2-3 year old children with ASD also showed a normal sequence of phonological acquisition in an elicited imitation task. However, Wolk and Edwards (1993) and Wolk and Giesen (2000) have reported both delayed and atypical patterns of phonological production in a single case study and in a case series of four siblings with ASD. They observed some degree of chronologic mismatch in speech sound development, such that early-developing sounds were absent whereas later developing sounds were present. Additional literature on school-age children with ASD has reported that one-third of speakers with high functioning autism retained residual speech distortion errors on sounds such as /r/, /l/, and /s/ into adulthood, whereas the rate of these errors in the general population is 2 to 3 percent (Kirkpatrick & Ward, 1984; Shriberg et al., 2001). Gibbon, McCann, Peppe, O'Hare, and Rutherford (2004) reported similar findings. An update of Gibbon and colleagues (2004) study found that approximately 41% of the school-aged participants with ASD in their study produced speech errors (Cleland et al., 2010). Thus, there remains some disagreement in the literature about the status of phonological development in this population.

In the present report, we examine vocal production in a group of toddlers who were referred between 18 and 36 months of age for suspicion of ASD, and received an ASD diagnosis from a multidisciplinary team of experienced clinicians. Vocalization samples were derived from semi-structured interactions with these toddlers and were analyzed for the consonant content of babbling and early word approximations (e.g., distribution of consonants, syllable structure types) as well as for the quality of other vocal productions that were less speech-like. Vocalizations from the toddlers with ASD were compared to those of typically developing (TD) children at the same age, as well as to a group of younger children with typical development whose language level was on par with the toddlers with ASD. The aims of this investigation are to describe the vocal production of toddlers with ASD, to determine whether sound production in ASD is, like their acquisition of words and word combinations, delayed relative to TD age-mates. Moreover, we aim to examine whether differences in vocal production in the group with ASD are greater than would be expected, given their

delayed language development, by comparing them to a group of younger toddlers at the same level of language acquisition.

Methods

Participants

Participants in the current study represent a subset of those seen as part of multiple, ongoing research studies on early identification of ASD at the Yale Child Study Center. This project received approval from the Yale University School of Medicine's Human Investigation Committee (i.e., the university's Institutional Review Board).

ASD Group—Each participant was seen by a multidisciplinary team consisting of a clinical child psychologist, speech-language pathologist, and social worker. Children in the group with ASD were referred by parents or professionals for a differential diagnosis between 2001 and 2006. Consecutive referrals that met the inclusion and exclusion criteria were invited to participate. Inclusion criteria were a diagnosis of ASD and chronological age ranging from 18 – 36 months. Exclusion criteria included history of hearing loss, exposure to more than one language in the child's home and presence of genetic syndromes (e.g. Fragile X). Parental age and ethnic composition of participants are reported in Table 1.

TD Groups—Participants in the two control groups were recruited by means of flyers distributed to local childcare centers and pediatric practices. The typically developing age-matched (TDA) group was chosen to match chronological age of the ASD group. Inclusion criteria for this group included absence of developmental delays and chronological age ranging from 18 – 36 months. Exclusionary criteria included a history of hearing loss and exposure to more than one language in the child's home.

The second control group was chosen to match the language level of the ASD group. The typically developing language-matched (TDL) group ages ranged from 11 – 13 months. Inclusion criteria for this group were similar to that of the TDA group and included the absence of developmental delays and expressive language levels matched to the ASD group as measured by the *Vineland Adaptive Behavior Scales* (VABS; Sparrow, Balla, & Cicchetti, 1984). Exclusion criteria included a family history of autism spectrum disorder, a history of hearing loss or exposure to more than one language in the child's home. Table 1 reports ethnic composition of participants, parental age and education.

Procedures

Provisional diagnoses of ASD—For children in the ASD group, a consensus clinical diagnosis was assigned by at least two experienced clinicians who participated directly in the assessment. Considering findings that experienced clinicians' judgment of children at the age of 2 is a better predictor of later diagnosis than scores on the ADOS-G (Chawarska et al., 2007; Lord et al., 2006), clinical consensus was the primary diagnostic method used. Provisional diagnosis of ASD (*n* = 30) was based on the DSM-IV-TR criteria modified for children under the age of 3 (Chawarska & Volkmar, 2005) with emphasis on the absence of early emerging dyadic and triadic interaction skills, extremely limited nonverbal communication skills, and lesser emphasis on the presence of restricted and repetitive behaviors.

A comprehensive evaluation was completed utilizing the *Mullen Scales of Early Learning* (MSEL; Mullen, 1995), *Vineland Adaptive Behavior Scales* (VABS; Sparrow et al., 1984), the *Autism Diagnostic Observation Schedule – Module G* (ADOS; Lord et al., 2000), and the *Communication and Symbolic Behavior Scales – Developmental Profile* (CSBS-DP;

Wetherby & Prizant, 1993). In addition to clinical diagnosis conferred by the multidisciplinary team, all but one toddler in the ASD group met criteria for ASD on the ADOS – Module G algorithm. Approximately 30% of the ASD sample was between the ages of 18 – 24 months with the remainder of the sample older than 24 months. This cohort of participants were re-assessed at age 3 as part of the larger study evaluating ASD. All participants received a confirmatory diagnosis at their re-evaluation. In addition to the aforementioned behavioral assessments, genetic testing and screening for dysmorphology were completed to rule out underlying genetic syndromes.

Control Group Characterization—Two control groups were employed. The first was selected to match the group with ASD on chronologic age, the Typically Developing Age-Matched group (TDA, $n = 11$) (See Table 1). The second, the Typically Developing Language-Matched (TDL, $n = 23$) group, was selected to match the group with ASD on expressive language level as measured by the VABS. Although a one-way ANOVA revealed differences among the three groups on the VABS Expressive Language subdomain ($F(2, 65) = 23.46$, $p = .05$), post-hoc analysis utilizing Bonferroni correction revealed that while the TDA group scored higher than the other two groups, there was no significant difference between the ASD and TDL groups in terms of expressive language performance on the VABS ($p = .55$).

Both control groups received the comprehensive evaluation that included the MSEL and VABS to ensure global development was within normal limits. The TDA group also received a CSBS-DP. The TDL group was administered the *Autism Diagnostic Observation Schedule – Toddler Module* (ADOS – T; Luyster et al.) All control participants in both control groups received a *t*-score greater than 45 on the Visual Reception subdomain of the MSEL, indicating normal nonverbal ability and a standard score of 90 or greater on the Communication subdomain of the VABS, indicating typical language ability for age.

The ASD group was comprised of more males than females given the higher prevalence of the disorder in males. Similarly, the TDA and TDL groups had a greater number of males than females. However, the gender distribution was not precisely balanced across groups.

Vocalization Sample Collection—Vocalizations were collected through two different means. Collection methods were chosen based on the participant's chronological age. For younger participants in the TDL group, a parent-child interaction was used to obtain vocalizations. A clinician-child interaction was used for the older participants in the ASD and TDA groups.

Vocalization samples were collected for the ASD and TDA groups from clinician-child structured play during the CSBS-DP Behavior Sample, collected as part of the evaluation process for the older two groups. Each CSBS-DP Behavior Sample was video-recorded onto digital media by a trained research assistant. A timed, 15-minute segment from the CSBS-DP interaction was analyzed from each participant in the ASD and TDA groups. The first 50 speech-like utterances produced by the child within the first 15-minutes of the interaction were used in transcription. The same timed segment was used for coding non-speech vocalizations.

The TDL group did not receive a CSBS-DP as part of their developmental evaluation as it was not part of the research protocol for this age group. Instead, vocalization samples were collected from a timed 5-minute parent-child interaction. A set of developmentally appropriate toys (e.g., soft blocks, bubbles, cars) was provided for the child. The parent was instructed to interact with the child as they would at home. Vocalizations were recorded using a Shure SM58 omni-directional microphone placed in a stand on the floor next to the

child and parent. A Marantz CDR300 compact disc recorder captured the vocalizations onto digital media.

Transcription—Vocalizations produced by each participant were separated into two categories -- speech-like or non-speech -- by the first author. The first author was blind to participants' group status to prevent transcriber bias. The recording methodology differed for the TDL group; however, the transcriber was nonetheless blind to diagnostic status. That is, participants from the TDL group were part of another research study examining baby siblings of children with ASD. For that project, two different participant groups were recruited: high-risk siblings (e.g. babies with a sibling with ASD) and a low-risk contrast group (e.g. babies with no family history of ASD). The transcriber coded both the high-risk and low-risk babies. The transcriber was blind to their group status, again minimizing transcriber bias.

The speech-like vocalizations were characterized by the production of consonants and/or vowels that could be represented by phonetic symbols and contained speech-like resonance. These productions were transcribed using broad phonemic transcription. The non-speech category included vocalizations characterized by non-speech resonance (e.g. screams, laughter, crying) without recognizable consonants. These productions were coded and tallied. Any vocalization that occurred simultaneously with any other sound on the recording was not transcribed. Such cotemporaneous sounds included parental or clinician speech, sound of toys, rustling of supplies and adult coughing.

Rules for transcription of speech-like vocalizations were adapted from Olswang, Stoel-Gammon, Coggins and Carpenter (1987). The first 50 speech-like vocalizations (i.e., word approximations and babble) produced were transcribed using International Phonetic Alphabet (IPA) symbols. For sounds that appeared to be distortions of English phonemes (e.g., lateral fricatives) the production was assigned to the phoneme category to which it was perceptually closest. Non-English phonemes, such as clicks, pharyngeal fricatives, or ingressive sounds were not coded; however, these were exceedingly rare. If the participant produced more than 50 speech-like utterances, these were tallied, but not transcribed. Approximately 56% of participants in the ASD group, 69% of participants in the TDL group and 10% of participants in the TDA group did not produce 50 vocalizations within the timed segment. In these instances, all utterances produced by the participant were transcribed. Both word approximations and babbled productions were included in the speech-like transcription. Any cries, screams and other non-speech vocalizations produced by the participant were analyzed separately. Vegetative sounds including coughing or burping were discarded from all transcription.

The same five or 15- minute samples transcribed for speech-like vocalizations were also coded for non-speech vocalizations. All non-speech vocalizations occurring within the same time period as the speech-like vocalizations were coded using rules adapted from Sheinkopf et al. (2000). Non-speech vocalizations were separated into productions based on breath groups or a pause of greater than one second. The first 50 non-speech productions that occurred during the timed period were coded. Again, if the participant did not produce 50 non-speech productions, all were coded. The type and mean number of vocalizations analyzed for each participant group is described in Table 2. There was no significant difference among the three groups in the mean number of vocalizations analyzed, despite the fact that the sampling conditions for the TDL group differed from those of the other two groups. Differences were observed in the number of speech-like and non-speech vocalizations analyzed. The TDA group produced significantly more vocalizations for analyses compared to the TDL group. The ASD group produced significantly more non-

speech vocalizations for analyses compared to the TDA group. One-way ANOVAs with Bonferroni corrections were used to determine differences between groups (see Table 3).

Coding—Transcription and coding was completed on the transcribed speech-like vocalizations and tallied non-speech productions produced by each participant by the first author and a trained research assistant. Data from each participant in each of the three groups were analyzed for both speech-like vocalizations and non-speech productions.

Non-speech coding: The categories of non-speech vocalizations were identified from Sheinkopf et al. (2000). Each non-speech production was assigned to one of the following perceptual categories:

1. Laughter: Vocal production expressing pleasure.

2. Atypical:

    a. Squealing High-pitch vocal production.

    b. Growl: Low-pitch vocal production.

    c. Yell: Loud, high-intensity vocal production.

3. Distress: Crying, whining or fussing

Speech-like coding: All speech-like vocalizations produced by each participant were transcribed using broad phonemic transcription. Any utterance that could not be confidently transcribed after four playbacks was eliminated. These transcriptions formed the basis for the speech analyses, which included singleton consonant inventory and Syllable Structure Level (SSL; Olswang et al., 1987). For participants in the ASD and TDA groups a consonant blend inventory, word production inventory, and Percent Consonants Correct (PCC; Shriberg & Kwiatkowski, 1982) were also computed. Consonant blends were defined as a cluster of consonants occurring within a given syllable (e.g., blow, balloons). While the word production inventory was a tally of the number of different word or word approximations produced by each participant. These variables were recorded only for toddlers in the two older groups as these vocal behaviors are not often observed at the developmental level of the TDL group.

Consonant inventory: Inventories of singleton consonants (ASD, TDA and TDL groups) and of consonant blends (ASD and TDA groups) were assembled for each participant. Consonants were then divided into three categories as outlined by Shriberg (1993) (See Table 4). These categories reflect relative order of acquisition of consonants in young children with typical development (Shriberg, Gruber, & Kwiatkowski, 1994). Consonant inventories were collected from word approximations, babble (e.g., /baba/, /bada/ and jargon (e.g., babble with speech-like inflection) produced by each participant.

Syllable structure complexity: A mean syllable structure level (SSL; Olswang et al., 1987) was computed for each participant to examine syllable complexity. Syllable structure levels were assigned to each utterance transcribed, following Paul and Jennings (1992). That is, each utterance was assigned to one of the following levels, based on Olswang et al.

Level 1 utterances were comprised of vowels or continuant single consonants (i.e., /mmm/).

Level 2 utterances were comprised of a single consonant plus vowel, which might be reduplicated (i.e., /pa/ or /papa/), with voicing differences disregarded.

Level 3 utterances were comprised of two or more different consonants (excluding syllables in which consonants differed only in voicing) plus vowels (i.e., /pati/).

The scores for each utterance were then averaged for each participant to derive that participant's SSL.

Consonants in words: Participants who produced ≥ 10 interpretable words or word approximations were classified as having meaningful speech (MS), following Thal, Oroz, and McCaw (1995). Participants who produced fewer than 10 words or word approximations were classified as having premeaningful speech (PS) (See Table 5). All participants in the TDA group produced more than ten meaningful words; none in the TDL group did. In the group with ASD, 30% were in the MS group; 70% in the PS. For all participants with MS, in both the ASD and TDA groups, PCC was calculated by counting the number of consonants that matched the target sounds in the adult words produced, and dividing by the total number of consonants in the adult words attempted (Shriberg, 1993).

Table 6 outlines the coding variables examined for each diagnostic group.

Reliability—Interrater reliability was computed by having a second trained rater independently transcribe and code data from a randomly selected 10% sample of the participants. Point-to-point reliability was used for both speech-like and non-speech coding. There was 91.8% agreement in assigning vocalizations to the speech-like category. For specific speech-like codes, there was 87.0% agreement for consonant production, 91.5% agreement for SSL, and 89.6% agreement for PCC. There was 84.3% agreement in assigning vocalizations to the non-speech category. For specific non-speech productions there was 96.3% agreement within the Distress category, 97.7% agreement within the Laugh category, and 91.8% agreement within the Atypical category.

Data Analysis—Data were initially analyzed descriptively for each variable through reporting of means, standard deviations and ranges. Inferential statistics were then completed to compare performance across the three groups.

One-way analyses of variance (ANOVAs) were completed to measure group differences (ASD; TDA; TDL) on speech-like and non-speech variables. Levene's test of homogeneity of variance was completed for each variable to ensure variances among groups were not significantly different. For variables with no significant difference in variance, Bonferroni adjustment was used for post hoc analysis. Dunnett's T3 correction was used for variables with significantly different variances using SPSS 16.0 software.

Results

Non-speech Vocalizations

Non-speech productions were tallied for each of the participant groups. Means and standard deviations for frequency of each non-speech production type for each group appear in Table 7. All participants produced at least one non-speech vocalization. Laugh was the most commonly produced non-speech vocalization produced by the ASD and TDA groups. Distress was the most commonly produced vocalization for the TDL group.

One-way ANOVA results indicate no significant differences among groups on Laugh and Distress categories. A significant difference among the three groups was found on the Atypical vocalization variable. To examine the Atypical category more in depth, each non-speech variable comprising this category (i.e., squeal, growl, yell) was analyzed separately. No significant differences were found among groups on the Growl and Yell variables. The

ASD group did produce a significantly greater number of high-pitched 'Squeal' vocalizations compared to both the TDA and TDL groups. See Table 7 for post hoc comparisons.

Use of Meaningful Speech

Table 5 depicts the number of different words produced by the ASD and TDA groups. PCC was tabulated for the MS groups only. The TDA-MS group produced significantly more words than the ASD-MS group (t[18] = 2.52, p = .02 [two-tailed], d = *1.14*). PCC was computed only for participants with MS. There was no significant difference in PCC between the ASD-MS and TDA-MS groups (t[18] = 1.54, p = .14 [two-tailed]).

Inventories of speech production

Consonant inventories were tallied and organized into the three developmental levels identified by Shriberg (1993). Mean number of different consonant types in each of these levels produced by each participant group is presented in Table 8. Specific consonant types produced and the percentage of participants using each appear in Figure 1.

No participants in the ASD group produced the /ŋ/, /r/ or /ʒ/ phonemes. The TDA group produced a significantly greater number of consonants from Early, Middle and Late levels and a significantly greater number of total consonants compared to the ASD participants. No differences between the ASD and TDL groups achieved significance. See Table 9 for post hoc analysis of speech variables.

Consonant blend inventories were also tallied for the ASD and TDA groups. Forty-eight percent of participants in the ASD group produced consonant blends while 100% of participants in the TDA group produced blends. Non-English blends including /gh/, /hm/, /vw/, /tj/ and /θs/ where produced by 40% of ASD participants. No non-English blends were recorded for TDA participants. Consonant blends were not coded for the TDL group.

Syllable structure complexity. Means and standard deviations computed for syllable structure level for each group are displayed in Table 9. Participants in the TDA group produced a mean SSL of greater than 2, indicating the majority of their utterances contained at least a single consonant-vowel (CV) combination and some included more complex syllables. The ASD and TDL groups produced mean SSLs less than 2, indicating a minority of CV syllables and few complex syllable productions. There was no significant difference on SSL between the ASD and TDL groups as revealed by post-hoc analysis displayed in Table 9.

Discussion

This study aimed to investigate the foundation in phone production that young children with ASD bring to the task of learning to talk. That is, speech and language production are very closely tied in typical development (Stoel-Gammon, 1998), but the relationship between these two aspects of communication had not previously been explored in ASD. What this study suggests is that toddlers with ASD have phonological systems that function much like those of children at similar levels of language development, when broad phonemic categories are analyzed. The toddlers with ASD in our sample with some meaningful speech were not significantly different from age-mates with typical development in terms of their percentage of correct consonants in words, even though they produced fewer words than their peers. In terms consonant production, the ASD group was similar to language-matched controls relative to consonant distribution and order of emergence of consonants. Syllable complexity analysis presented an analogous picture, with the ASD group producing SSLs similar to those of language-matched controls, though different from those of more

linguistically advanced age-mates. The only difference in speech-like vocalizations seen in the group with ASD was the presence of non-English consonant combinations.

Toddlers with ASD were more different from both age- and language-matched peers, however, in the production of non-speech sounds, particularly atypical vocalizations. Toddlers with ASD produced significantly more of these atypical vocalizations than age- or language-matched peers, with high-pitched 'squeals' primarily accounting for this difference.

These data suggest that, first, the language delays seen almost universally in toddlers with ASD cannot be attributed to a failure of development of basic speech skills. For this sample of toddlers, two-thirds of whom are not producing meaningful language, prelinguistic speech production, in terms of consonant inventory, order of sound acquisition, and syllable complexity, is not different from that of typically developing peers at comparable levels of language acquisition. While speech skills in many of these toddlers with ASD are less advanced than those of age-mates, they are no less sophisticated in phonological development than younger typical children who function at similar language levels. This finding could be interpreted to suggest that in this population, it is language development that drives speech production. That is, toddlers with ASD may marshal the speech skills they need to express the language they have in mind. While some have argued (Gernsbacher et al., 2008; Prizant, 1996; Szypulski, 2003; Velleman, 1996; Velleman et al., 2009) that apraxic difficulties in motor planning may underlie spoken language delays in children with ASD, the present data suggest that, on the contrary, most toddlers with ASD follow the normal trajectory of phonological development, which is closely tied to their level of language, as it is in typical peers.

What does appear aberrant in the sound production of toddlers with ASD is their production of non-speech vocalization. Children with ASD in this sample produced more non-speech, particularly the high-pitched type, than either age- or language-matched peers, as others have reported (Sheinkopf et al., 2000; Wetherby, et al., 2004). We recently reported, also, that these atypical productions were the primary aspect of prelinguistic vocalization that differentiated 9-12 month olds at high risk for ASD (those with a sibling diagnosed with ASD) from low risk peers (Paul, Fuerst, Ramsay, Chawarska, & Klin, in press). In addition, we have reported elsewhere on the acoustic character of the vocalizations of this cohort. Schoen, Paul, and Chawarska (2009) showed that toddlers with ASD did not, in general, produce vocalizations that were significantly different in terms of highest pitch, lowest pitch, average pitch range or duration of utterances from those of peers with typical development. However, a difference was found in the proportion of longer-than-average vocalizations produced by the ASD group when compared to the group with TD. Toddlers with ASD also produced a significantly greater number of pitch points above the group median pitch of 400Hz, when compared to participants in the TD cohort, supporting the perceptual reports here of the presence of an excess of high pitched vocal behaviors in these young children. In addition, analysis of pitch contours within utterances, following Kent and Murray (1982), showed that although the range of pitch contours produced was similar across the two diagnostic groups, complex pitch patterns -- in which pitch fluctuated irregularly within a breath group -- were used significantly more frequently by the group with ASD.

Taken together, the findings of the present and our earlier studies could be interpreted to suggest that vocalizations of toddlers with ASD are not being aligned to the duration, pitch, and phonotactic properties of the ambient language. The majority of differences found in vocal production in toddlers with ASD, then, tend to be those more closely related to suprasegmental, rather than segmental aspects of production. In spite of their generally

typical relation of phonology to language level, and the normal sequence of phonological development seen in these toddlers with ASD, their retention of aberrant pitch, timing and phonotactic patterns leads to the suggestion that these children may not experience so great a difficulty in the development of basic sound production, as they show, rather, a failure to shape their production toward the sound parameters of the ambient language.

The present data suggest toddlers with ASD have the capacity to generate a range of vocal productions both similar to and different from the speech in their environment. Typically developing children, tend, toward the end of the first year of life, to match their productions more closely to ambient speech models. Toddlers with ASD, on the other hand, even though they develop speech sounds in a typical sequence, show less winnowing of the other kinds of sounds that are not produced by the speech models in their environment. This reduced tendency to "tune in and tune up" (Shriberg, Paul, Black, & Van Santen, in press) to ambient speech models, even when speech production capacities are being acquired, is reminiscent of findings in the listening behavior of toddlers with ASD, as well. As we reported earlier (Paul et al., 2007), toddlers with ASD show reduced time spent attending to child-directed speech in an auditory preference paradigm, again suggesting a failure to "tune in" to facilitative language input and to show a less-than-typically marked preference for it over other kinds of auditory stimuli.

In sum, the present findings can be taken to support a view of speech development in children with ASD that is constrained less by motor planning difficulty than by the slow development of target language forms as an engine for increasing phonological accuracy and complexity, as well as by a reduced tendency to hone sound production increasingly closely to models produced by others in the environment.

There could, of course, be other interpretations of these findings. It is conceivable that children with ASD may produce more high-pitched 'squeals,' which listeners generally perceive as unpleasant, in order to deter others from interacting with them or imposing on their activities. Without experimental manipulation of listener responses to child production, we are unable to resolve this question. Moreover, without a contrast group of non-autistic developmentally delayed toddlers, it cannot be established whether or not the atypical productions observed here would also be seen in a group of delayed children without social disability. In addition, the use of broad phonemic transcription and the decision to class speech-like productions into perceptually defined categories of primarily English language sounds limited our ability to ask questions about whether children with ASD produced higher levels of distorted or less prototypical sounds. The use of narrow phonetic transcription in future studies would serve to address the question of accuracy and prototypicality of sound acquisition. Finally, the decision not to code non-English sounds such as clicks or ingressive sounds made it impossible to ask whether children with ASD produced more of these sounds, as they produced more non-English clusters, and whether the same children produced both kinds of abnormal output. Further study of the phonetic and phonemic character of early production of toddlers with ASD, as well as contrast groups with other developmental disabilities is needed to resolve these questions.

Finally, the gender distribution between the three diagnostic groups was not equally matched. While the ASD and TDA groups were similar in their gender composition, the ASD and TDL groups were less similar with the TDL group comprised of a greater percentage of girls than boys. While research suggests that the age of consonant acquisition in typical developmental is quite broad (Prather, Hedrick, & Kern, 1975; Templin, 1957) with little difference between gender (Smit, Hand, Freilinger, Bernthal, & Bird, 1990), it is possible that a greater percentage of females than males in the TDL group could have impacted the speech-like variables collected.

Acknowledgments

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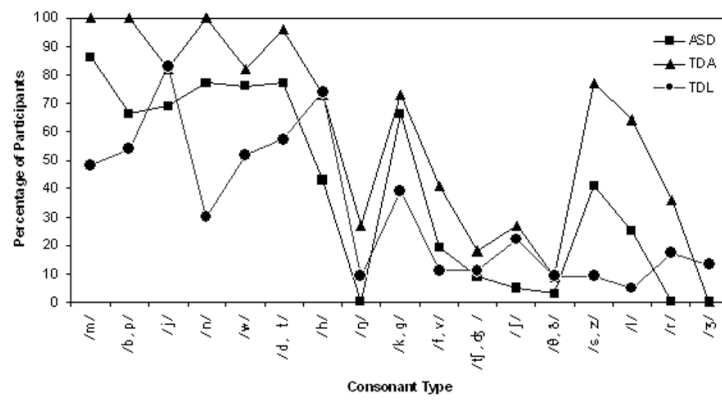
Figure 1.
Percentage of participants producing different consonant types by diagnostic group.

Table 1

Parental Age and Participant Ethnic Composition

	Parental Age in Years		Parental Education (% completed 4 year college)		Ethnicity				
Group (*n*)	Mean Maternal Age (*SD*)	Mean Paternal Age (*SD*)	Maternal College Education	Paternal College Education	Caucasian	African-American	More than One Race	Did not report	Hispanic
ASD (30)	34 (5)	36 (5)	70%	77%	86.6%	3.3%	n/a	10.1%	3.3%
TDA (11)	30 (5)	32 (6)	67%	33%	80%	6.7%	6.7%	6.7%	13.3%
TDL (23)	34 (6)	36 (7)	83%	83%	91.3%	4.3%	4.3%	n/a	8.7%

Note. ASD = autism spectrum disorder. TDA = typically developing – age matched.

TDL = typically developing – language matched.

Table 2

Participant Information

Group (*n*)	Average Age in Months (SD)	Sex		*Vineland Adaptive Behavior Scale* (Sparrow et al., 1984) Communication Domain Scores		
		M	F	Communication Domain Mean Standard Score* (*SD*)	Expressive Language Subdomain Mean Age-Equivalent in Months (*SD*)	Receptive Language Subdomain Mean Age-Equivalent in Months (*SD*)
ASD (30)	28.33 (5.08)	23	7	71.73 (8.27)	13.93 (4.93)	17.20 (5.92)
TDA (11)	27.73 (5.50)	8	3	104.27 (10.18)	27.91 (10.61)	30.18 (8.16)
TDL (23)	12.27 (0.50)	13	10	105.96 (7.51)	11.65 (1.64)	14.26 (2.94)

Note.

*
Mean = 100, SD = 15. ASD = autism spectrum disorder. TDA = typically developing – age matched.

TDL = typically developing – language matched.

Table 3

Mean Number of Vocalizations Analyzed by each Participant Group

	ASD (*n* = 30)	TDA (*n* = 11)	TDL (*n* = 23)
Mean Total Vocalizations (*SD*)	51.13 (22.94)	51.00 (8.32)	41.70 (18.48)
Mean Speech-like Vocalizations (*SD*)	37.33 (15.22)	47.45 (8.44)	33.87 (16.11)
Mean number of word approximations produced (*SD*)	17.27 (14.90)	36.55 (9.75)	-
Mean number of babbled vocalizations produced (*SD*)	32.77 (14.82)	13.45 (9.75)	33.87 (16.11)
Mean Non-Speech Vocalizations (*SD*)	13.80 (14.81)	3.55 (3.42)	7.83 (6.69)

Note. Dash denotes variable not computed. ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched.

Table 4

Post hoc comparisons from one way ANOVAs of Mean Number of Vocalizations Analyzed

Vocalization Type	Difference (*M*)	Significance	*d*[*] (effect size)
Speech-like			
ASD vs. TDA	-10.12	.165	-
ASD vs. TDL	3.46	1.00	-
TDA vs. TDL	13.59	.043[**]	1.05
Non-speech			
ASD vs. TDA	10.26	.032[**]	0.95
ASD vs. TDL	5.79	.167	-
TDA vs. TDL	-4.28	.885	-
Total Number of Vocalizations (Speech-like + Non Speech)			
ASD vs. TDA	0.13	1.00	-
ASD vs. TDL	9.44	.263	-
TDA vs. TDL	9.30	.602	-

Note.

[*] Cohen's (1988) effect size metric (.20–.49 = small effect; .50–.79 = medium effect; >.80 = large effect).

[**] $p < .05$, one-tailed.

ASD = autism spectrum disorder. TDA = typically developing – age matched.

TDL = typically developing – language matched.

Table 5
Sounds Based on Developmental Acquisition

Early-8	/m/	/b/	/j/	/n/	/w/	/d/	/p/	/h/
Middle-8	/t/	/ŋ/	/k/	/g/	/f/	/v/	/tʃ/	/dʒ/
Late-8	/ʃ/	/θ/	/s/	/z/	/ð/	/l/	/r/	/ʒ/

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Table 6

Expressive Language Characteristics for Participants in PS and MS Stages

Group (*n*)	Number of Different Words Produced		PCC
	Range	*M (SD)*	*M (SD)*
ASD (30)			
ASD PS (21)	0-8	3.52 (2.73)	-
ASD MS (9)	10-30	15.89 (6.47)	58.72 (9.34)
TDA MS (11)	10-62	30.36 (16.13)	65.84 (10.99)
TDL PS (23)	0	0	-

Note. PCC was only calculated for the MS groups who produced 10 or more words. ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched. PS = premeaningful speech. MS = meaningful speech.

Table 7

Variables Examined by Diagnostic Group

	Speech-like					Non-speech		
Group (*n*)	Consonant inventory	Consonant Blend Inventory	Word Production Inventory	Percent Consonants Correct	Syllable Structure Level	Laughter	Atypical	Distress
ASD (30)	+	+	+		+	+	+	+
ASD PS (21)	+	+	+	-	+	+	+	+
ASD MS (9)	+	+	+	+	+	+	+	+
TDA (11)	+	+	+	+	+	+	+	+
TDL (23)	+	-	-	-	+	+	+	+

Note. Dash denotes variable not examined. ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched. PS = premeaningful speech. MS = meaningful speech.

Table 8

Non-speech Productions produced by ASD, TDA and TDL Groups

	Group					
	ASD (n = 30)	TDA (n = 11)	TDL (n = 23)			
Production Type	M (SD)	M (SD)	M (SD)	F (2, 61)	Significance	d (effect size)**
Laugh	4.73 (8.82)[1]	1.73 (2.10)[1]	0.65 (1.34)[1]	3.01	NS	
Atypical	5.07 (5.70)[1]	1.09 (1.92)[2]	0.61 (1.34)[2]	8.89*	p < .02	ASD v. TDL: 1.08 ASD v. TDA: 0.94
Squeal	3.37 (4.53)[1]	0.18 (0.60)[2]	0.26 (0.86)[2]	7.75*	p <.003	ASD v. TDL: 0.96 ASD v. TDA: 0.99
Growl	1.27 (2.32)[1]	0.91 (1.81)[1]	0.35 (0.94)[1]	1.61	NS	
Yell	0.27 (0.69)	-	-	2.49		
Distress	3.07 (7.57)[1]	0.36 (0.67)[1]	3.57 (5.93)[1]	1.01	NS	

Note. Dash indicates no vocalizations produced. Matching superscripts indicate NSD. Differing superscripts are significantly different.

*
Comparison with the same superscript are NSD; those with differing superscripts differ at *p*<.05, one-tailed.

**
All reported effect sizes are large (Cohen, 1988).

ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched. PS = premeaningful speech. MS = meaningful speech.

Table 9

Comparison of Consonant and Syllable Shape Variables in ASD, TDA and TDL Groups

	Group										
	ASD (*n* = 30)			TDA (*n*=11)			TDL (*n* = 23)			F (2,61)
	M	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range	
Consonant Inventories										
Different Consonants	6.73	3.16	2-12	13.82	2.93	8-18	7.52	4.13	0-15	17.14 *
Number of Early-8 Consonants	5.50	2.13	1-8	7.36	0.92	5-8	4.57	2.39	0-8	6.69 *
Number of Middle-8 Consonants	2.27	136	0-5	4.18	1.78	1-8	1.83	1.44	0-4	10.01 *
Number of Late-8 Consonants	0.87	1.07	0-3	3.09	1.51	0-6	1.09	1.20	0-4	14.49 *
Different Consonant Blends	0.97	1.47	0-5	3.00	3.72	0-10	-	-	-	-
Syllable Structure										
Syllable Structure Level	1.69	0.41	1.0-2.4	2.28	0.26	1.9-2.7	1.36	.027	1.0-2.0	25.94 *

Note. Dash denotes variables not collected.

*
statistically significant p<.001, 1-tailed.

ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched.

Table 10
Post hoc comparisons from one-way ANOVAs of speech-like variables

Speech Variable	Difference (*M*)	Significance	d^* (effect size)
Number of Different Consonants			
ASD vs. TDA	-7.09	>.001	2.33 (Large)
ASD vs. TDL	-0.79	NS	_
TDA vs. TDL	6.30	>.001	1.80 (Large)
Early-8 Consonants[**]			
ASD vs. TDA	-1.86	.001	1.06 (Large)
ASD vs. TDL	0.94	NS	_
TDA vs. TDL	2.80	>.001	1.54 (Large)
Middle-8 Consonants			
ASD vs. TDA	-1.91	.001	1.21 (Large)
ASD vs. TDL	0.44	NS	_
TDA vs. TDL	1.92	.001	1.46 (Large)
Late-8 Consonants			
ASD vs. TDA	-2.22	>.001	1.70 (Large)
ASD vs. TDL	-0.22	NS	_
TDA vs. TDL	2.00	>.001	1.47 (Large)
SSL[**]			
ASD vs. TDA	-0.59	>.001	1.77 (Large)
ASD vs. TDL	-0.32	NS	0.92 (Large)
TDA vs. TDL	0.91	>.001	3.47 (Large)

[*] Cohen's (1988) effect size metric (.20-.49=small effect; .50-.79=medium effect; >.80=large effect).

[**] Dunnett's T3 test used due to unequal variance.

ASD = autism spectrum disorder. TDA = typically developing – age matched. TDL = typically developing – language matched.