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Describing (pre)linguistic oral productions in 3- to 5-year-old autistic children: A cluster analysis

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Abstract

In many autistic children, speech onset is delayed and expressive language emerges after 3 years of age. We qualitatively and quantitatively describe oral productions of autistic preschoolers, including many non- or minimally speaking, recorded during interactions with a caregiver and with an experimenter. Data clustering on manually coded oral production samples indicates five validated linguistic profiles of oral production in this diverse and inclusive sample ($n=59$) of 3- to 5-year-old autistic children with highly variable expressive language abilities. These profiles are then compared on a series of demographic (age, socioeconomic status) and psychometric (autism severity, nonverbal and verbal IQ) measures, as well as on additional measures of language (expressive vocabulary, phonetic inventories). Two clusters are composed of speaking autistic children, while the three others comprise non- or minimally speaking children with qualitatively different patterns of vocal productions. The five-profile division suggests that traditional binary division of speaking vs nonspeaking children does not do justice to the complexity of early expressive language in autism.

Lay abstract

For most autistic children, spoken language emergence and development happen after the age of 3. Once they start developing and using spoken language, some eventually manage to reach typical levels of language abilities, while others remain minimally speaking into adulthood. It is therefore difficult to consider young autistic preschoolers as a homogeneous group in terms of spoken language levels. In our study, we breakdown a representative and inclusive group of children on the spectrum aged from 3 to 5 into five subgroups that correspond to different linguistic profiles. To do so, we qualitatively described children's (pre)verbal productions elicited during interactions with a parent and with an experimenter. We then used a type of statistical analysis called cluster analysis to group together the children that had a similar expressive (pre)linguistic behavior. Using this analysis, we were able to delineate five linguistic profiles with qualitatively different patterns of vocal production. Two of these profiles are composed of speaking children; the three others are composed of non- or minimally speaking children. Our findings show that traditional binary division of speaking versus nonspeaking autistic children is not precise enough to describe the heterogeneity of early spoken language in young autistic children. They also support the use of qualitative descriptions of vocal productions and speech to accurately document children's level of language, which could, in turn, help design very finely tailored language intervention specific to each child.

Keywords

autism spectrum disorder, cluster analysis, expressive language, minimally speaking

Introduction

Two central characteristics of spoken language in autism are delays in the onset of speech and heterogeneity of linguistic profiles. First, in comparison to their typically developing (TD) peers, most autistic children display significant delays in reaching well-identified milestones of typical language acquisition, such as canonical babbling

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(Patten et al., 2014) or first words (Howlin, 2003). Second, expressive language skills in autistic children range from a total absence of spoken language to structural language abilities within the typical range (Kim et al., 2014). Around 30% of individuals diagnosed with autism remain nonspeaking into adulthood, and among those children who do develop spoken language, there is substantial variability both in the time of speech onset and in the rate of language growth (Anderson et al., 2007; Ellis Weismer & Kover, 2015; Pickles et al., 2014; Thurm et al., 2015; Wodka et al., 2013).

In autism, divergences from typical language acquisition trajectories become already apparent in early vocal prelinguistic behaviors (Yankowitz et al., 2019). During their first 3 years of life, and in comparison to their TD peers, young children who would later receive a diagnosis of autism have been described as producing lower rates of directed (Apicella et al., 2013; Garrido et al., 2017; Ozonoff et al., 2010; Plumb & Wetherby, 2012) and speech-like (Chenausky et al., 2017; Garrido et al., 2017; Plumb & Wetherby, 2012; Warlaumont et al., 2014; Warren et al., 2010) vocalizations, as well as higher rates of nonspeech-like vocalizations (Plumb & Wetherby, 2012; Schoen et al., 2011). In the same vein, autistic children have been found to start babbling later (Patten et al., 2014), and to produce less canonical babbling (i.e. the repetition or reduplication of one consonant-vowel combination such as “dadada”) (Garrido et al., 2017; Patten et al., 2014; Werner & Dawson, 2005) or syllabic vocalizations (Tenenbaum et al., 2020). In addition, autistic children display reduced consonant inventories in comparison to TD children as early as 14 months of age (Landa et al., 2007, 2013; Schoen et al., 2011; Wetherby et al., 2007), namely, they use fewer different consonant types in their productions. Accordingly, they have a consonant production that is closer to that of younger, verbal age-matched TD children (McCleery et al., 2006; Schoen et al., 2011). These early differences in prelinguistic behavior obviously have repercussions on the onset and development of more mature forms of spoken language, and autistic children’s early preverbal vocalizations have been reported to correlate with concurrent and later language abilities (McDaniel et al., 2018, 2020).

Autistic children with language delays produce their first words, on average, at around 38 months, and their first phrases at around 52 months (Howlin, 2003). (Expected milestones for TD children are between 11 and 14 months for first words and around 36 months for adultlike constructions (Clark, 2009).) Studies on early word production in autism have confirmed that young autistic children (age 3 and younger) tend to produce lower rates of word approximations and full words in comparison to TD peers (Bacon et al., 2019; Chericoni et al., 2016; Tenenbaum et al., 2020; Werner & Dawson, 2005) and children with language delay (Bacon et al., 2019); young autistic children also have lower productive vocabulary (Landa et al., 2007; Mitchell et al., 2006; Wetherby et al., 2007).

In sum, young autistic children appear to be delayed in the acquisition of all early milestones of language production. Most studies on early (pre)linguistic productions in autism have focused on autistic children younger than 3. Yet, in autism, a lion’s share of language development occurs after age 3 (Gagnon et al., 2021; Wodka et al., 2013). That is, spoken language emergence is unlikely to happen during the first 3 years of the life of most autistic children. However, there have been no studies on the quality and quantity of (pre)linguistic productions of autistic preschoolers, even though this is precisely the period when speech is likely to emerge. It is therefore pressing to better characterize oral productions of autistic children older than 3, especially because, like in younger children (McDaniel et al., 2018, 2020), such productions could be manifestations of dynamic language acquisition processes rather than fixed characteristics of nonspeaking children’s speech.

The fact that early expressive (pre)linguistic development is significantly delayed in autism is largely documented in the literature. However, classic paradigms of group comparisons of early spoken language between autistic and TD children, which often entail approaching autistic children as a uniform group, may obliterate different linguistic profiles that may co-exist within the autism spectrum. An important step toward a better understanding of autistic spoken language development would be to qualitatively map the linguistic heterogeneity among autistic children aged from 3 to 5, that is, at the age range when spoken language is most likely to emerge.

The present study

The goal of the present study is threefold. First, we aim at qualitatively describing the (pre)linguistic productions of autistic children including many with no or minimal language. Second, we target children aged from 3 to 5, which is the critical window for spoken language emergence in autism. Third, we focus on potential differences in (pre)linguistic productions within the autism spectrum rather than looking for group differences with TD children. The overarching objective of this exploratory study is to delineate different linguistic profiles present in a sample of young autistic preschoolers, based on their oral productions obtained during interactions with a caregiver and an experimenter.

Methods

Comprehensive descriptions of several methodological aspects (data collection and preparation, coding procedure, interrater agreement, data clustering and clustering validation, phonetic inventories construction) are available on the Open Science Framework (OSF; https://osf.io/9my7v/?view_only=640108b528fb45fe8c2a186745db9af5).

Table 1. Descriptive statistics of participants' characteristics.

	N	*M* (*SD*)	Range
Chronological age (months)	59	56.08 (9.9)	39–71
Socioeconomic status (from 0 to 19)	55	9.39 (2.51)	5.5–16.5
ADOS-2 comparison score (from 0 to 10)	58	7.02 (1.8)	2–10
ADOS-2 Social Affect calibrated severity score (from 0 to 10)	58	7.59 (1.93)	3–10
ADOS-2 Restricted and Repetitive Behaviors calibrated severity score (from 0 to 10)	58	6.22 (1.88)	1–10
Nonverbal IQ (from 30 to 170)	43	86.42 (17.04)	47–115
Verbal IQ (from 40 to 160)	28	77.71 (16.79)	56–130
CDI raw expressive vocabulary at T1 (from 0 to 680)	45	170.07 (195.46)	0–577
CDI raw expressive vocabulary at T2 (from 0 to 680)	40	213.12 (213.02)	0–623

ADOS-2: Autism Diagnostic Observation Schedule; CDI: Communicative Development Inventory.
Sample size varies from one measure to another and is therefore systematically specified. Nonverbal IQ is measured by Leiter-3, verbal IQ by PPVT-R, and raw expressive vocabulary by CDI. Socioeconomic status is based on parents' economic and educational background. Specific data on race/ethnicity were not recorded.

Participants

Sixty-seven autistic children between the ages of 3 and 5 were initially recruited for this study. Participants were recruited through flyers posted on social media and networks of parents' associations, through special education preschools and daycares, and through our internal lab database. Inclusion criteria were to have received a formal clinical diagnosis of autism spectrum disorder (ASD) and to be exposed to French at home and/or school.

Spoken language samples were obtained from recordings of a parent–child interaction and an experimenter–child interaction. Data from six children could not be used because the child was already 6 years old when entering the study ($n=2$), because the family moved abroad before completing the study ($n=1$), or because the child showed reluctance toward participating in the experiment ($n=3$). In addition, two children were excluded because data from both the parent–child interaction and the experimenter–child interaction were unusable. For one of these children, the parent–child interaction did not yield usable data because the mother could not get the child to play with her and the experimenter–child interaction was stopped because the child was crying. For the other child, the parent–child interaction was not usable because the mother did not understand the instructions and the experimenter–child interaction was disrupted by constant interruptions from the child's brother.

The final sample included in this study is composed of 59 autistic children (49 boys, 10 girls). The recruitment strategy was designed to build an inclusive and diverse sample of children on the spectrum between the ages of 3 and 5. The sample of autistic children who took part in this study is therefore heterogeneous on many clinical and descriptive features, including autistic symptomatology severity, levels of intelligence, and expressive and receptive language abilities (see Table 1). All participants had previously received or were in the process of receiving a formal clinical diagnosis of ASD from a multi-disciplinary team. The Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2012) was administered by the lab neuropsychologist with an official ADOS-2 certification to assess autistic symptomatology severity and to confirm the participants' diagnosis. Two autistic children scored below cutoffs for autistic spectrum on the ADOS-2. We decided not to exclude those children from the study as they had previously received a formal diagnosis of autism. Statistical analyses will be conducted with and without those children and any changes in the results will be duly reported. The inclusion of autistic children with minimal speaking skills also implies that verbal IQ scores, as measured by the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 2007), and nonverbal IQ scores, as measured by the Leiter International Performance Scale-Third Edition (Leiter-3; Roid et al., 2009), may fall below the typical range (i.e. <70). Several autistic children scored below typical range on measures of verbal ($n=11$) and nonverbal ($n=5$) IQ; additionally, for many autistic children, it was impossible to administer the Leiter-3 ($n=16$) or the PPVT-R ($n=31$) in a meaningful way. IQ tests are notoriously difficult to administer to young non- or minimally speaking children (Courchesne et al., 2019; Tager-Flusberg et al., 2017). The PPVT-R, in particular, involves additional challenges as it requires children to have acquired the ability to use pointing gestures, which many autistic children may find difficult (American Psychiatric Association, 2013). Autistic participants who did not score within the typical range or who did not have reliable scores on those measures were not excluded from the study.

Children's expressive vocabulary was measured by summing all vocabulary items that the child both understood and used as reported by their parents on the Words and Gestures or Words and Utterances version of the MacArthur Bates Communicative Development Inventory (CDI; Fenson et al., 2007). Investigation into children's

Table 2. Final corpus description (recordings ready for subsequent analyses).

	Parent–child interaction corpus			ADOS-2 corpus		
Number of recordings	43			56		
	Tascam DR-05		Retrieved from video	Tascam DR-05		Retrieved from video
	36		7	38		18
	Parent–child interaction corpus			ADOS-2 corpus		
Recording length (mm:ss)	*M*	Min	Max	*M*	Min	Max
	17:41	6:31	27:22	18:6	5:47	39:49
	Total (hh:mm:ss) 12:40:54			Total (hh:mm:ss) 16:53:43		

ADOS-2: Autism Diagnostic Observation Schedule.

CDI reports confirmed that the participants' language skills were highly heterogeneous, ranging from an absence of spoken language to use of full sentences structures. CDI reports were collected at the study onset (T1) and 1 year later (T2).

Data collection

Oral productions were elicited from the participants in two different elicitation contexts: a parent–child interaction that took form as a free play, and an experimenter–child interaction during the administration of the ADOS-2. To engage in the free play with their child, parents were given a set of pre-selected age-adequate toys. Toys included a Mr. Potato Head©, small toy cars and animals, a cooking set, a doctor and nurse set, and a tool belt. Parents were told that they could bring in other toys if they knew that would help maintain the child's attention or elicit speech. Instructions were to play freely and try to interact with the child as they would normally do in a regular play session at home. Free play lasted around 20 min unless the child showed signs of unrest, distress, or fatigue, in which case it was immediately stopped. In most cases, the mother played with the child. Nine children engaged in the free play with their father. The ADOS-2 was always administered by the same experimenter, namely, the lab neuropsychologist.

In both contexts, oral productions were collected using a Tascam DR-05 recorder located approximately 30 cm away from the child. In cases of technical misfunctions with the recorder, audio recordings were exported from video recordings of the interactions filmed with a Sony FDR-AX33 camera. Additional data loss across both contexts included foreign language use during the parent–child interaction ($n=4$), lack of cooperation from the child and/or the parent ($n=13$), and poor recording quality due to a noisy environment ($n=2$).

Out of the 59 included children, 40 children provided usable data for both elicitation contexts. Nineteen children were included in the analysis even though their oral productions could only be retrieved from one context (either the parent–child interaction or the ADOS-2). The final corpus included in subsequent analyses is composed of 43 audio recordings of parent–child interactions and 56 audio recordings of ADOS-2 assessments (see Table 2).

Additional information about the two contexts of elicitation, the recording material, and the editing of both audio and video recordings for data extraction is available on OSF.

Coding procedure

All audio recordings included in the final corpus were segmented, annotated, and transcribed for oral production behaviors using Praat (Boersma & Weenink, 2013). The segmentation, annotation, and transcription of the audio recordings followed a coding scheme designed jointly by the first and second authors, a linguist and an experienced developmental speech-language pathologist, respectively.

A TextGrid was created for each audio recording and divided into four tiers (see Figure 1). Tier 1 was used to locate target oral productions, namely, all stretches of the audio where the child was producing a sound, and to identify whether that production was overlapping with other noises or not. All audible (overlapping or not) non-physiological productions identified in Tier 1 were segmented in more detail in Tier 2. In Tier 2, each production was assigned one of seven "type of production" codes that were designed to cover all steps of spoken language acquisition, spanning from prelinguistic vocalizations to full-structured sentences. These codes were identified by the first and second authors as being essential steps of language acquisition based on existing literature on typical first language development (Clark, 2009; Vihman, 2014). Table 3 provides definitions for each of the seven "type of production" codes.

Each utterance from Tier 2 was transcribed in Tier 3 in a broad phonetic transcription using symbols of the Speech Assessment Methods Phonetic Alphabet (SAMPA) (Wells, 1997). If an utterance could not be confidently

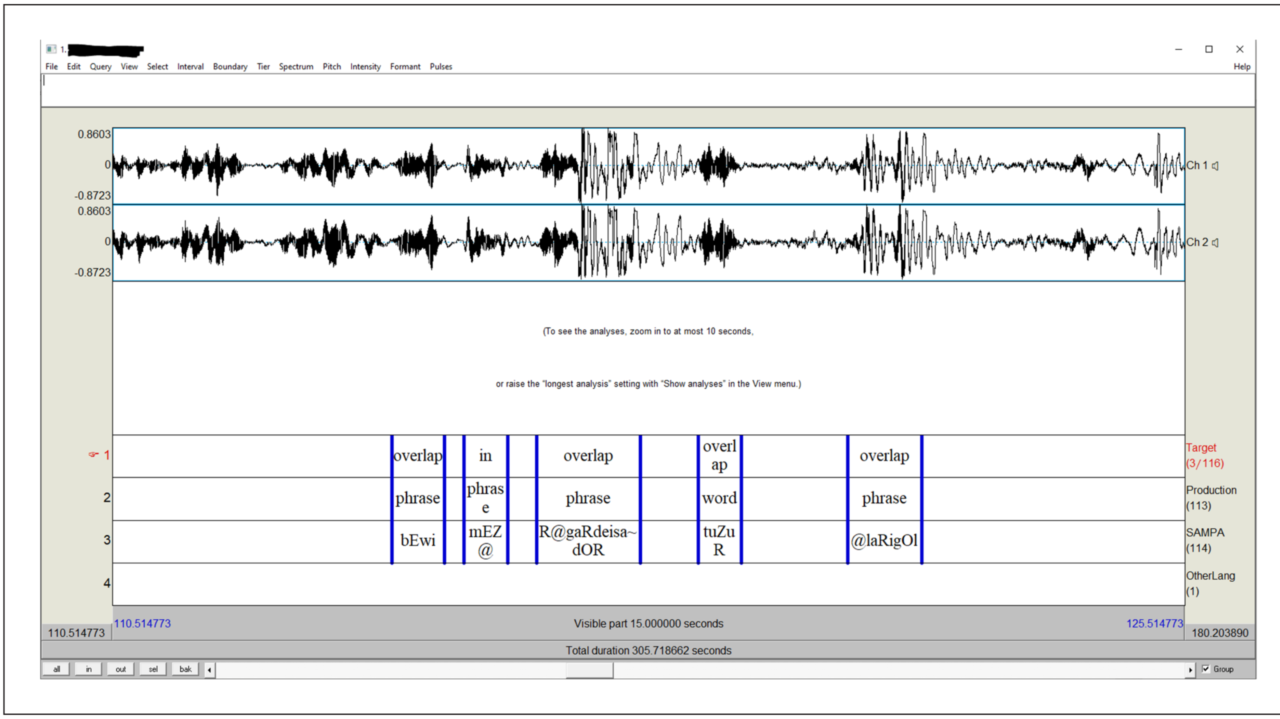

Figure 1. Fifteen seconds of a coded audio recording in Praat.

Table 3. Definition of the seven "type of production" codes of Tier 2.

Vocalic preverbal production	Consonant-less, periodic productions varying in intensity and loudness
Nonvocalic preverbal production	Consonant-like sounds produced with articulators of the vocal tract (including grunting, humming, raspberries, snorting, etc.)
Syllabic production	Productions composed of at least one syllable formed by at least one consonant and one vowel in any order of appearance
Proto-word	Word approximations that can unequivocally be recognized as targeting a French word
Isolated word	Identifiable French words that are not accompanied by a determiner and come in their mature shape
Word combination	Sequences of two words (or proto-words) that do not necessarily bear syntactic markers of gender, tense, plural, etc., or function words such as conjunctions, prepositions, determiners, etc.
Phrase	Noun, verb, adjectival, adverbial, or prepositional phrases formed by a combination of minimum two words, up to full-structured sentences

transcribed into SAMPA after four consecutive listening, it was labeled as "non-transcribable" (Paul et al., 2011). Finally, Tier 4 was used to specify if a proto-word, an isolated word, a word combination, or a phrase was produced by the child using another language than French. The tier remained empty if the child only used French.

A comprehensive description and a pre-registered version of the coding procedure are available on OSF.

Interrater agreement

To assess coding reliability, 10% of the participants of each corpus were randomly selected to undergo double-coding by the second author. The audio recordings of six and four autistic participants were selected for the ADOS-2 corpus and the parent–child interaction corpus, respectively. For Tier 2, the overall weighted Cohen's κ with linear weights was computed. The levels of the factor were ordered as follows: (1) vocalic preverbal production, (2) nonvocalic preverbal production, (3) syllabic production, (4) proto-word, (5) isolated word, (6) word combination, and (7) phrase. The overall weighted Cohen's κ for all categories of Tier 2 was .78 which indicates excellent agreement between the two coders. To measure coders' agreement for phonetic transcriptions (Tier 3), we compared the phonetic (vowels and consonants combined), vowel, and consonant inventories obtained for each double-coded recording by the two coders using intraclass correlation coefficients (ICCs) based on single-measurement, absolute-agreement, two-way mixed-effects models. ICC estimates for the phonetic (vowels and consonants) inventories (ICC = .99; 95% confidence interval (CI) (.95, .99)), the vowel inventories (ICC = .99; 95% CI (.95, .99)), and the consonant inventories (ICC = .98; 95% CI (.94, .99)) indicated excellent reliability between the two coders.

The coding of the primary coder (first author) was kept in all analyses.

Additional information about the way interrater agreement was measured for each of the first three tiers is available on OSF.

Procedure

Participants' parents signed a written informed consent form for their child to be enrolled in this study. When possible, children were asked for oral assent.

The study reported in this article is part of a broader four-session experiment on early linguistic development in autism. During the first session, parents received all questionnaires and took part in the free play with their child. During the second session, children took part in the ADOS-2 with the lab neuropsychologist. During the third and fourth session, they were administered the Leiter-3 and the PPVT-R, respectively. All sessions also included eye-tracking experiments unrelated to this article.

Testing of the participants took place in our lab, at the children's home, or at the children's school. Participants were individually tested by the first author or by the lab neuropsychologist, sometimes in the presence of a parent. When the testing conditions enabled it, the experimenter left the room during the parent–child free play.

Data preparation for statistical analyses

Nineteen children were included in the analyses even though their oral productions could only be retrieved from one elicitation context. To prepare for the subsequent cluster analysis (see below), "type of production" data from Tier 2 were merged across elicitation contexts (i.e. across the parent–child interaction and the ADOS-2) and counted for each participant. Contexts had to be merged because a cluster analysis cannot be conducted if there are missing data as the similarity between two data points cannot be measured if one is missing. Raw counts of each type of productions, as well as the total production count, were transformed into ratios of production by dividing, for each child, the number of productions of each type by the total recording length in seconds to account for between-participant variations in recording length. The data from Tier 2 used in subsequent analyses contained, for each participant (both elicitation contexts merged), a production ratio for each type of production, as well as for the total number of productions.

Phonetic transcriptions from Tier 3 were used to build the phonetic inventories of each child. Full phonetic inventory corresponded to the percentage of phonemes represented in the child's productions over the total number of phonemes in the French sound system (based on Fougeron & Smith, 1993). Consonant inventory corresponded to the percentage of consonants represented in the child's productions over the total number of consonants in the French sound system. Vowel inventory corresponded to the percentage of vowels represented in the child's productions over the total number of vowels in the French sound system. For a phoneme to be included within a child's inventory, it had to be produced at least more than once by the child, in any position of a verbal or preverbal production. There is a lack of consensus on the number of times a phoneme has to be uttered to be included within an inventory (at least three times in Chenausky et al., 2017; more than one instance of use in Wolk & Brennan, 2013; at least once in Wolk & Edwards, 1993). On one hand, a stricter criterium would have been too conservative for children with shorter recording length, but, on the other hand, producing a sound only once may result from an "articulatory accident" and does not necessarily reflect the child's true competence. Finally, phonemes that were produced as substitutions for other phonemes in (proto-)words were also included. Additional information about the procedure used to build the phonetic inventories is available on OSF.

Analytic plan

All statistical analyses were implemented in R (R Core Development Team, 2019). To find different profiles of oral production behaviors in autistic preschoolers, agglomerative hierarchical clustering was conducted using the *hclust* function from the *stats* package on the following set of variables: ratio of vocalic preverbal productions, ratio of nonvocalic preverbal productions, ratio of syllabic productions, ratio of proto-words, ratio of isolated words, ratio of word combinations, ratio of phrases, and ratio of total number of productions. Additional information about the clustering analysis and the clusters validation procedure can be found on OSF. Next, between-cluster differences on a series of demographic and psychometric measures and on phonetic inventories were investigated with simple linear regression models using the *lm* function from the *stats* package. Cluster (cluster A vs cluster B vs cluster C vs cluster D vs cluster E), Type of production (vocalic vs nonvocalic vs syllabic vs proto-word vs isolated word vs word combination vs phrase), and Inventory type (consonant vs vowel) were used as independent variables. Post hoc pairwise comparisons were implemented with Tukey

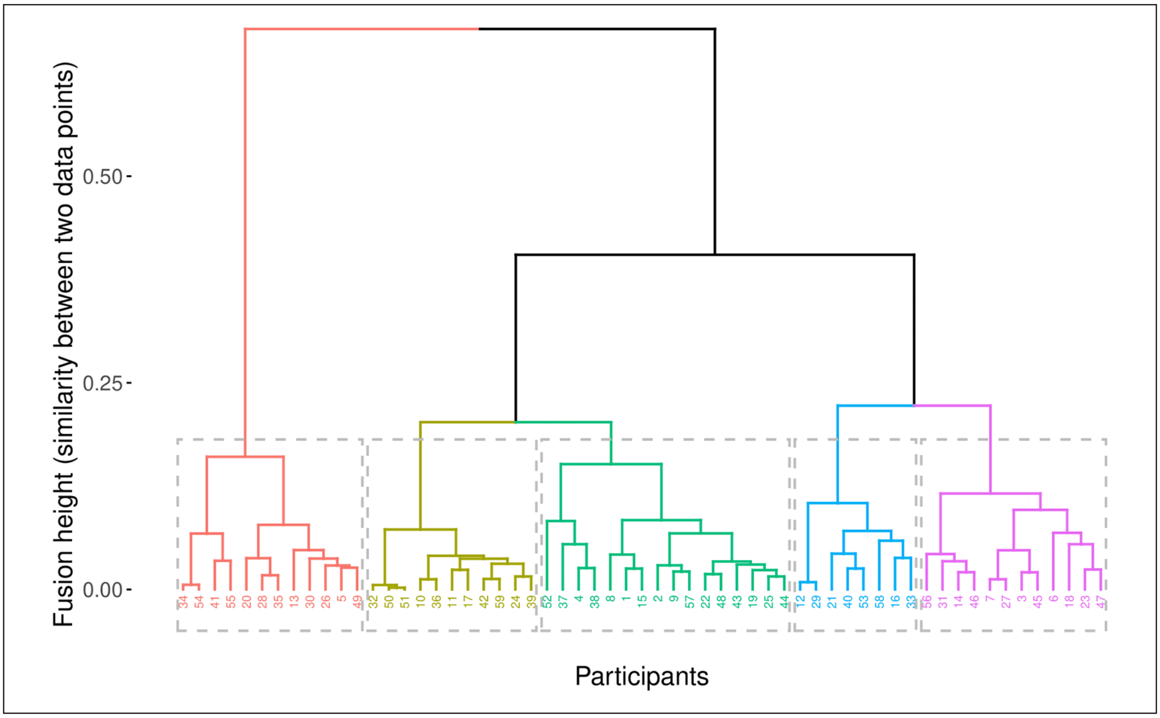

Figure 2. Resulting dendrogram of agglomerative hierarchical clustering with Ward's method cut into five clusters. The higher the fusion between two branches, the less similar the observations.

adjustment using the *emmeans* function from the *emmeans* package (Lenth et al., 2020).

Community involvement

No community members were involved in the design, analyses, or results interpretation of this study.

Results

Data clustering

Agglomerative hierarchical clustering with Ward's method found a solution of five clusters, each corresponding to a different production style (see Figure 2).

The output of the hierarchical clustering remained identical when we excluded the two children who did not meet cutoffs for autistic spectrum on the ADOS-2. As a result, all subsequent between-cluster analyses were conducted using the clusters obtained from the complete sample of 59 children.

As a result of the hierarchical clustering, each autistic child has been assigned to a cluster shared with other autistic children with a similar linguistic profile. While the cluster analysis' output reveals the composition of each cluster, it does not specify the characteristics of each cluster and how they are different from one another. As a result, further analyses were performed to investigate between-cluster differences on the different ratios of type of production. First, visual inspection of Figure 3 suggests that cluster A ($n=12$) is composed of the most speaking children: high producers whose productions were mainly phrases and words. Children in cluster D ($n=8$) are relatively high producers, but they produced mainly isolated words and fewer phrases. Children in cluster E ($n=12$) are also relatively high producers, but their productions were mainly preverbal, and especially syllabic, suggesting an elevated use of jargon. Children in cluster C ($n=16$) are fair producers and their productions were essentially vocalic, nonvocalic, and syllabic. Finally, children in cluster B ($n=11$) made few oral productions and the few they did produce were mainly preverbal.

Between-cluster differences on the ratios of production were investigated using simple linear regression with the Cluster × Type of production interaction as fixed effect. The model reached significance, $F(39, 432)=119.4$, $p<.001$, $R^2=.91$, and the significant interaction was further analyzed with post hoc pairwise comparisons for each Type of production independently (see Supplemental Table 1 for a summary of all pairwise comparisons).

As evidenced in Figure 3, there were no between-cluster differences in children's productions of proto-words and word combinations (all $p>.9$). This lack of difference was essentially explained by the fact that children in all clusters did not seem to produce proto-words or word combinations. All other production ratios allowed to distinguish between the clusters (see Figure 3 and

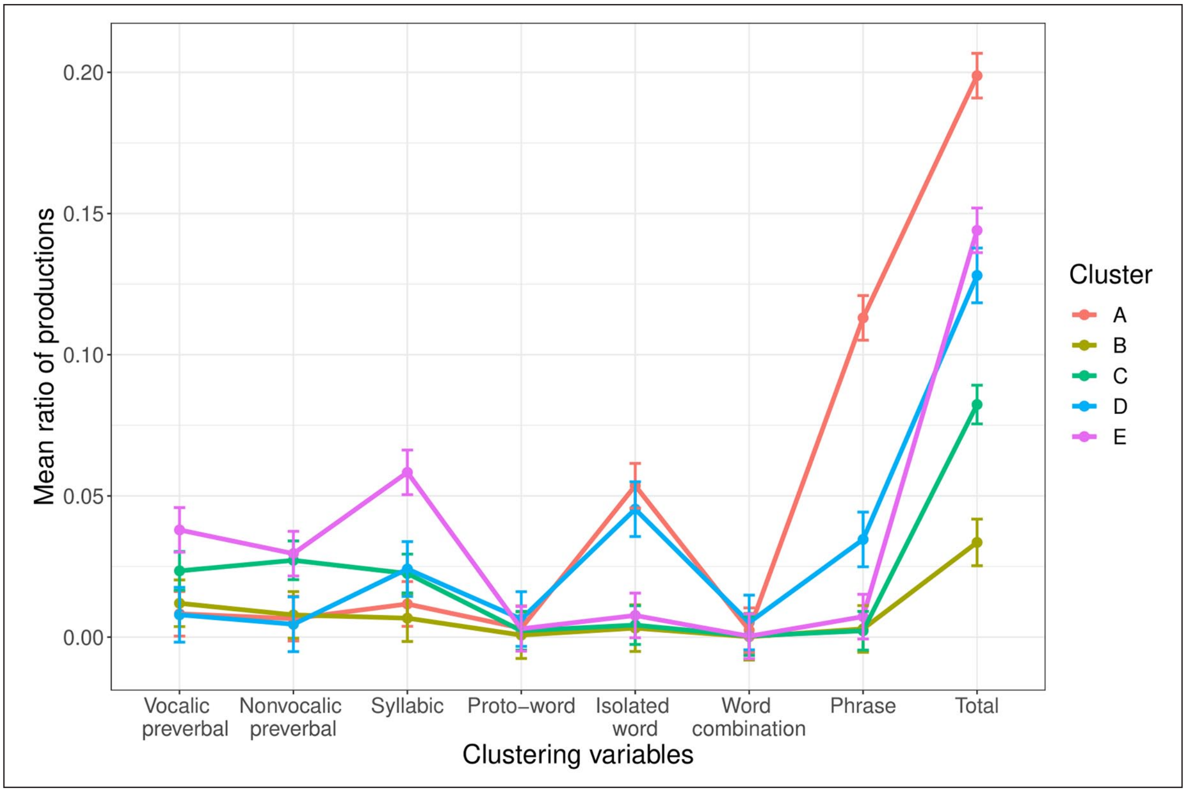

Figure 3. Mean ratios of each type of production per cluster (both elicitation contexts merged). Error bars represent fitted 95% confidence intervals.

Supplemental Table 1). Of particular interest are the variables that allow to distinguish between speaking clusters (A and D), on one hand, and non- or minimally speaking clusters (B, C, and E), on the other hand.

The children in the two speaking clusters differed from each other in that, even though they produced equal ratios of isolated word (p = .68), children in cluster A produced at significantly higher rates (β = .07, SE = .006, p < .001) and used more phrase speech (β = .08, SE = .006, p < .001) than those in cluster D (see Figure 4).

The children in non- or minimally speaking clusters (i.e. clusters B, C, and E) essentially differed from each other in their ratios of total production and their patterns of preverbal and syllabic productions. Overall, children in cluster E were the highest producers, followed by those in cluster C and, finally, those in cluster B (see Fig. 5). Children in cluster B were very low producers. As a result, they used less vocalic preverbal productions than children in cluster E (β = −.03, SE = .006, p < .001) and less nonvocalic preverbal and syllabic productions than those in clusters C (nonvocalic: β = −.02, SE = .005, p = .004; syllabic: β = −.02, SE = .005, p = .03) and E (nonvocalic: β = −.02, SE = .006, p = .002; syllabic: β = −.05, SE = .006, p < .001). Children in cluster E stood out from children in cluster C in that they used a higher ratio of syllabic productions (β = −.04, SE = .005, p < .001).

Finally, children in clusters D and E did not differ in their ratios of total production (p = .09). However, they did differ from each other in that children in cluster D produced higher ratios of isolated words (β = .04, SE = .006, p < .001), and children in cluster E produced higher ratios of syllabic productions (β = −.03, SE = .006, p < .001) (see Figure 6).

Additional analyses of between-context (parent–child interaction vs ADOS-2) differences in oral productions are available in Supplemental material.

Between-cluster differences on demographic and psychometric measures

Between-cluster differences on each demographic (age, socioeconomic status) and psychometric (ADOS-2 comparison scores, nonverbal and verbal IQs, raw expressive vocabulary at T1 and T2) measure were assessed independently using simple linear regression with Cluster as fixed effect. Tables summarizing the descriptive statistics and regression models outputs for each measure as well as Tukey post hoc pairwise comparisons of the significant main effects of Cluster are available in Supplemental material.

There was no significant main effect of Cluster on age or socioeconomic status (both p > .1). Overall, children

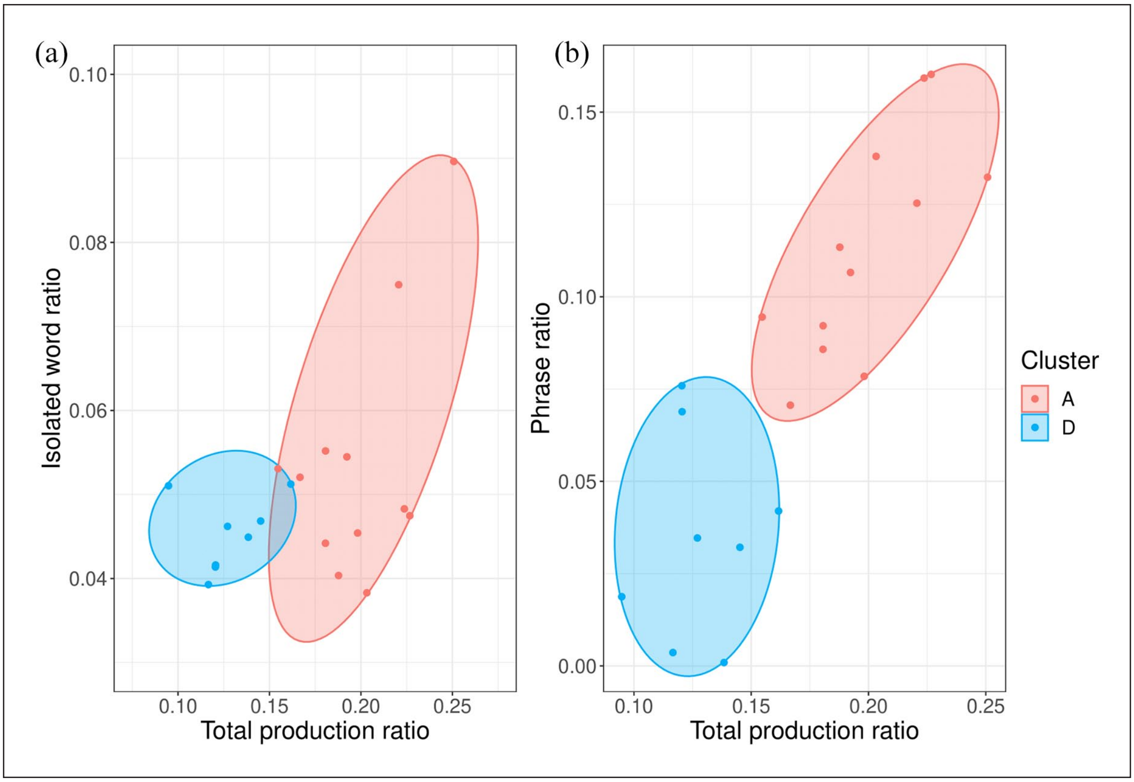

Figure 4. Scatter plots of mean ratios of isolated words and total production (a), and phrases and total production (b) per participant from clusters A and D.

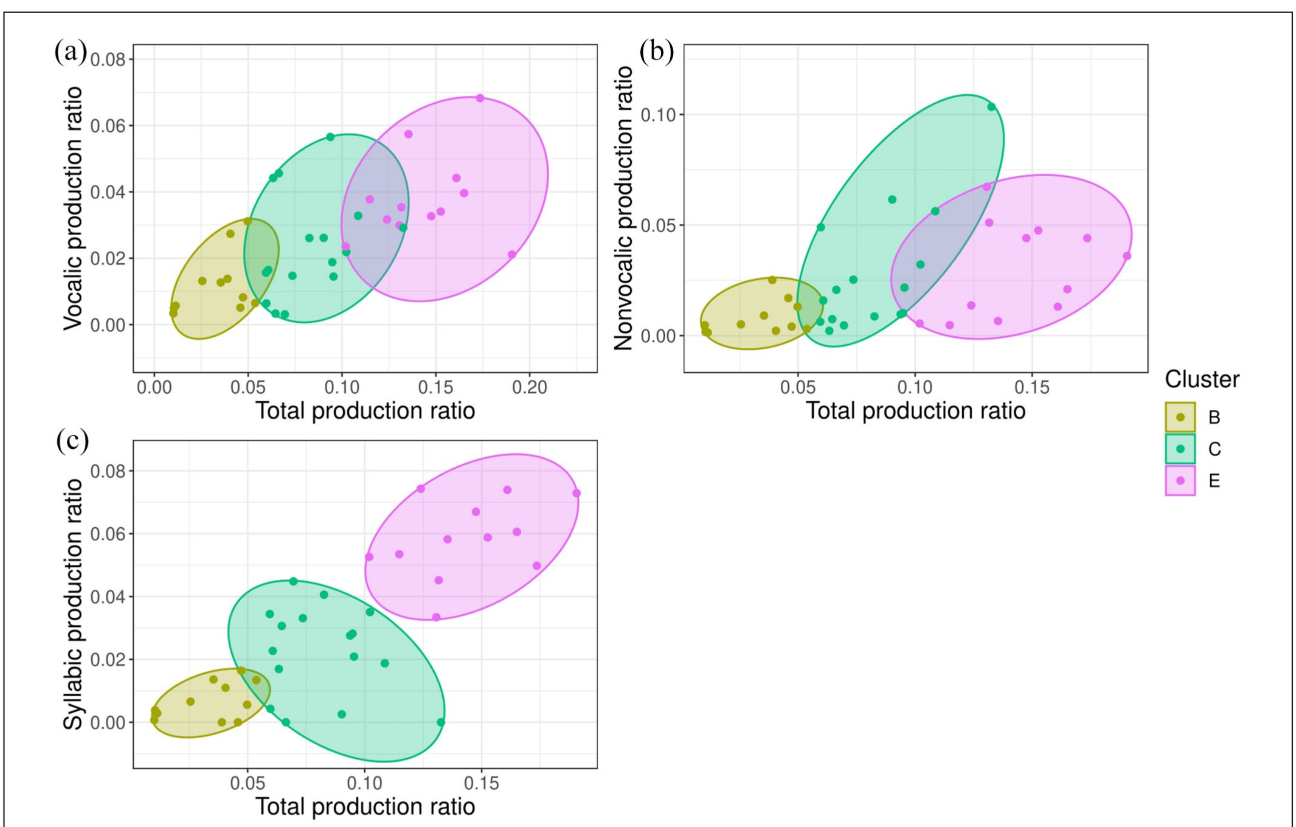

Figure 5. Scatter plots of mean ratios of vocalic production and total production (a), nonvocalic production and total production (b), and syllabic production and total production (c) per participant from clusters B, C, and E.

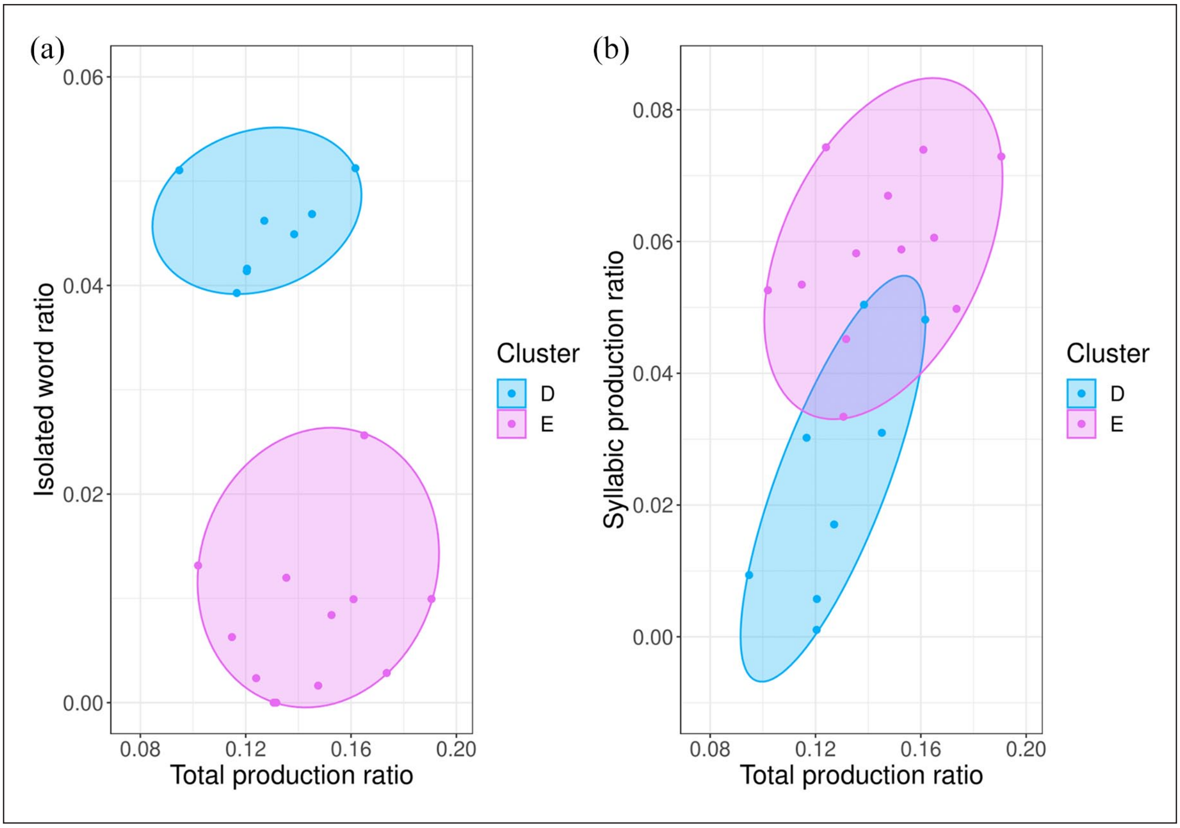

Figure 6. Scatter plots of mean ratios of syllabic production and total production (a), and isolated word and total production (b) per participant from clusters D and E.

from the five clusters were the same age and had similar socioeconomic backgrounds.

The simple linear regression models revealed a significant main effect of Cluster on ADOS-2 Total comparison scores, ADOS-2 Social Affect (SA) comparison scores, nonverbal IQ, and verbal IQ (see Supplemental Table 2). Overall, children in speaking clusters (A and D) had lower ADOS-2 Total comparison scores, lower ADOS-2 SA comparison scores, higher nonverbal IQs, and higher verbal IQs than those in non- or minimally speaking clusters (B, C, and E) (see Supplemental Table 3). Interestingly though, the simple main effect of Cluster on ADOS-2 Restricted and Repetitive Behaviors (RRB) comparison scores proved nonsignificant, indicating that there were no between-cluster differences on RRB comparison scores.

Finally, the simple main effect of Cluster on raw expressive vocabulary at T1 and at T2 also proved significant (see Supplemental Table 2). At T1, children in cluster A had higher expressive vocabularies than those in clusters B, C, D, and E who, in their turn, did not differ between each other. At T2, however, children in cluster A and in cluster D had higher expressive vocabularies than those in clusters B, C, and E. Thus, by T2, children in clusters A and D did not differ between each other in expressive vocabulary, suggesting that children in cluster D made a significant gain in expressive vocabulary over a year. Pairwise comparisons of a simple linear regression on raw expressive vocabulary with the Cluster × Time (T1 vs T2) interaction as fixed effect confirmed that only children in cluster D had significantly higher expressive vocabularies at T2 than T1 ($\beta = -182.29$, $p = .007$) in comparison with all other clusters (all other $p > .2$).

Phonetic investigation

A linear regression model on the full phonetic inventory with Cluster as fixed effect and total recording length as controlling covariate reached significance, $F(5, 53) = 21.04$, $p < .001$, $R^2 = .63$. As can be seen in Figure 7 and Supplemental Table 4, children in cluster A and D came closer to a full phonetic inventory than those in clusters B and C. Children in cluster B also had significantly lower phonetic inventories than those in cluster E. Other between-cluster differences did not reach significance. Turning to vowel and consonant inventories, a linear regression with the Cluster × Inventory type interaction as fixed effect and total recording length as controlling covariate reached significance, $F(10, 107) = 21.74$, $p < .001$, $R^2 = 0.67$. Post hoc pairwise comparisons (see Supplemental Table 4) showed that for both inventory types separately,

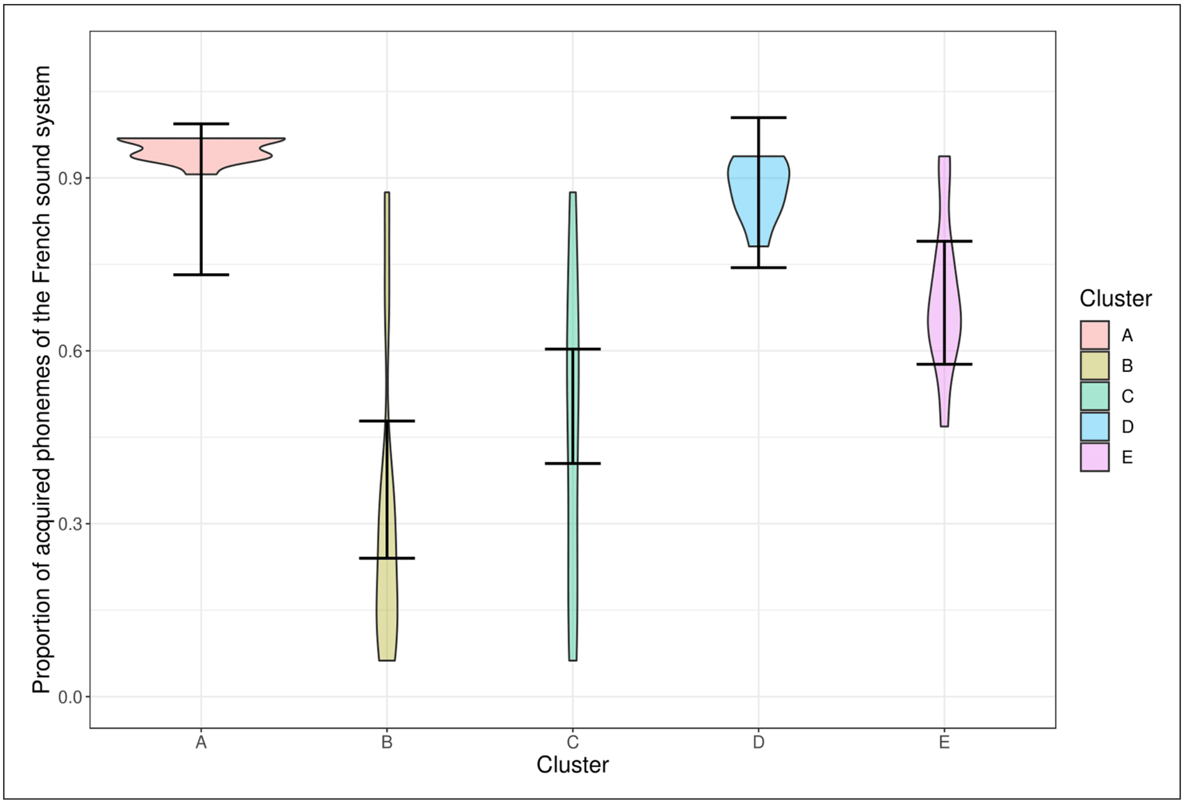

Figure 7. Proportion of represented phonemes of the French sound system per cluster. Error bars represent fitted 95% confidence intervals.

between-cluster differences mirrored those of the previous analysis with the full phonetic inventory.

Interestingly, post hoc pairwise comparisons also showed that the proportion of represented vowels was higher than the proportion of represented consonants in clusters B, C, and E (i.e. the non- or minimally speaking clusters) (cluster B: $\beta = -0.21$, $p = .009$; cluster C: $\beta = -0.2$, $p = .003$; cluster E: $\beta = -0.16$, $p = .03$). On the other hand, speaking clusters A and D have a similar proportion of represented vowels and consonants (both $p > .1$).

Finally, we investigated the details of the consonant production of each cluster, based on manner and place of articulation; the idea being that a poorer phonetic proficiency should come along with an overrepresentation of less developmentally advanced sounds in the child's production such as plosives or labials. The proportion of total produced consonants per manner (plosive, fricative, nasal, trill, glide or lateral approximant) and per place of articulation (bilabial, dental, velar, labiodental, alveolar, palato-alveolar, palatal, uvular, labiovelar or labiopalatal) was computed for each child.

A simple linear regression model on the proportion of produced consonants with the Cluster × Manner interaction as fixed effect reached significance, $F(29, 306) = 21.81$, $p < .001$, $R^2 = .67$. Further examination of this interaction showed that in clusters B, C, and E, the production of plosives was significantly greater than the production of all other consonants, while in clusters A and D, the rate of production of plosives was higher than the production of all other consonants except fricatives (see Supplemental Table 5 for the output of the pairwise comparisons).

Similarly, a simple linear regression model on the proportion of produced consonants with the Cluster × Place interaction as fixed effect reached significance, $F(49, 510) = 13.71$, $p = < .001$, $R^2 = .57$. Post hoc pairwise comparisons indicated that children in clusters B and C produced a greater proportion of bilabials than those in cluster D (B–D: $\beta = 0.13$, $p = .01$; C–D: $\beta = 0.13$, $p = .007$). However, they did not differ from cluster A on the proportion of bilabials (both $p > .07$). Cluster E did not differ significantly from clusters A and D on this measure (both $p > .9$) but did produce a smaller proportion of bilabials than clusters B and C (B–E: $\beta = 0.11$, $p = .02$; C–E: $\beta = 0.11$, $p = .009$).

Discussion

Using manually coded naturalistic language samples and cluster analysis, we found five different expressive language profiles within an inclusive and diverse group of autistic children between the ages of 3 and 5.

Each subgroup that has been delineated thanks to this cluster analysis corresponds to a different profile of expressive language in terms of the types of oral productions used by the children during interactions with a caregiver and with an experimenter. Taken together, the results from the cluster analysis and the phonetic investigation suggest that two profiles (cluster A, "phrase speech," and cluster D, "word speech") correspond to speaking children, while three other distinct profiles (cluster B, "least speaking," cluster C, "preverbal," and cluster E, "nonspeaking high producers") correspond to non- or minimally speaking children. The fact that there are different profiles of speaking children, on one hand, and non- or minimally speaking children, on the other hand, is a very interesting observation. It is fair to assume that the causes for the success or failure to develop language by that point may differ between profiles. In other words, speaking children from different profiles have probably not followed the same language acquisition trajectories and may not end up reaching comparable language levels. Likewise, it is unlikely that non- or minimally speaking children from different profiles are experiencing the same struggles in their path toward language acquisition. For example, a child may fail to acquire language because of speech articulation disabilities while another may struggle with gathering relevant linguistic information from socio-communicative cues. More broadly, this five-profile clustering output strongly support the idea that simple binary divisions between speaking and nonspeaking autistic children cannot do justice to the complexity and heterogeneity of language abilities and acquisition styles in autism (Arunachalam et al., 2021). A complete understanding of an autistic child's spoken language both from clinical or scientific perspectives should thus include a qualitative description of their productions.

While the difference between the non- or minimally speaking clusters resides mainly in production styles, the two speaking clusters seem to differ in terms of spoken language skills, with the "phrase speech" cluster (cluster A) being more proficient at combining words into phrases. This observation is in line with the fact that both speech onset and spoken language growth are highly heterogenous in autism (Anderson et al., 2007; Ellis Weismer & Kover, 2015; Pickles et al., 2014; Thurm et al., 2015; Wodka et al., 2013). However, children in the "word speech" cluster (cluster D) managed to close the gap in expressive vocabulary between them and children in the "phrase speech" cluster in 1 year. A straightforward interpretation of this finding is that the "word speech" children made significant gains in spoken language while the "phrase speech" children experienced a plateau with limited progress (see Gagnon et al., 2021). (Note that the latter, or at least some of them ($M = 520.86$, range = 317-613), may also have reached ceiling expressive vocabulary scores at T2.) In any case, identifying the expressive language profile of a child may help better support their language development: a "word speech" child likely needs support for the acquisition of morphosyntactic combination rules, while a "phrase speech" child seems to have an age-expected production style but may need support to extend their use of language to more complex situations than play-based interactions in which the conversation revolves around the here and now.

In addition, several findings reported above point at the idea that typical spoken language acquisition processes may not suffice to explain all processes of spoken language acquisition at play in autism. The following interpretation of our findings, and more generally all reported between-cluster differences, should however be regarded with caution as the cluster analysis significantly reduced the initial knowledgeable sample size to subgroups of maximum 16 children. In other words, the following null results could also be due to small sample size and not a lack of relationship between production style and the predictor variables. Nonetheless, while we did not target specific spoken language acquisition processes or use a longitudinal design, our study did target a window identified as critical for speech emergence and development in autism. Accordingly, several results could have been expected if at least some of the autistic children in our sample were actually in the process of developing spoken language and if this development followed a strictly typical, but delayed, trajectory.

First, it would have been fair to hope that younger autistic children would be more represented in non- or minimally speaking clusters as they could have been at earlier stages of language development. However, cluster membership was not related to age and younger children were not more represented in non- or minimally speaking clusters or older children in speaking clusters.

Second, socioeconomic status is, in the general population, a robust predictor of language outcome, and thus individuals from lower socioeconomic backgrounds could have been expected to display lower language abilities (Ginsborg, 2006). However, consistent with previous reports (Anderson et al., 2007; Stone & Yoder, 2016), our results suggest that socioeconomic status does not predict spoken language proficiency in autism. The fact that age and socioeconomic status do not predict linguistic profiles membership in our study suggests that there are other stronger predictors of spoken language proficiency that supplant age or socioeconomic status in autism.

Third, based on what is known about typical and autistic language acquisition, one should have expected a significant proportion of our sample to be in the process of acquiring language and to, therefore, display proto-words or two-word combinations—well-attested productions in transitional stages of typical language trajectories (Clark, 2009). A potential explanation for the absence of proto-words and two-word combinations in the productions of our sample (other than due to the fact that not enough children in our sample were at that stage of spoken language development) could be owe to the central role echolalia plays in the emergence of speech in autism. If a child starts acquiring functional spoken language by echoing and then decomposing long strings of speech instead of combining single words, they could skip the typical "two-word combination" milestone of typical language acquisition trajectories. Likewise, echolalic productions are often composed of mature forms of language and children may therefore be skipping the step of proto-words productions, as their first word productions may be embedded in larger echoed utterances. It therefore makes sense to speculate that autistic language acquisition and development differs from typical trajectories in that autistic children may be displaying a more fruitful and persistent use of echolalia as a bridge toward self-generated speech (Stiegler, 2015).

Finally, the phonetic behavior of children in the "nonspeaking high producers" profile (cluster E) is intriguing; unlike the phonetic inventories of the children in other clusters, it did not strictly reflect typical early or advanced stages of phonological development. On some measures, the phonetic patterns of "nonspeaking high producers" approached those found in early language development (like children in the other nonspeaking clusters): they acquired a greater proportion of vowels than consonants and used a greater proportion of plosives relative to fricatives. On other measures, however, their phonetic inventories resembled those found in more advanced stages of phonological development (like children in the speaking clusters): they had quite large phonetic inventories and did not have an overrepresentation of bilabial consonants. In that sense, children in the "nonspeaking high producers" cluster could be seen as transitioning from a preverbal to a verbal stage of language development. However, this assumption was not supported by the data on expressive vocabulary as these children did not increase their vocabulary over a year. Interestingly though, consonant and phonetic inventories have previously been found to predict expressive language growth in minimally speaking autistic children (Saul & Norbury, 2020; Yoder et al., 2015). Our results, however, suggest that this may not be the case for all profiles of minimally speaking autistic children. More generally, phonological development is said to play a massive role in the development of further spoken language skills, like the lexicon, in typical development (McGillion et al., 2017). It is likely that "nonspeaking high producers" are very idiosyncratic in terms of phonetic (and syllabic) productions, in aspects that cannot be directly transposed to identified stages of spoken language development.

Our study is also a demonstration of the strengths and value of manually coded language samples analyses. Despite being costly and time-consuming, detailed qualitative descriptions of children's productions, which go beyond purely quantitative summaries of volubility, provide a window on the (pre)linguistic profiles of autistic children. More so, such qualitative characterizations allow to delineate profiles that are unlikely to be distinguished by using standardized assessments or parental reports. Taking the time to document and count each production of the children allowed us to breakdown two subgroups (speaking vs nonspeaking) that can sometimes be regarded as homogeneous and that may have clinical value in other domains (see results from the ADOS-2 and IQ scores) into five validated spoken language subgroups. This has great implications for both clinicians and researchers on which tools they use to characterize autistic children as speaking or minimally speaking.

Limitations and future directions

The results of our cluster analysis should be interpreted in the context of several important limitations. Despite 59 participants being a fair sample size for studies using manual qualitative transcriptions of language samples, the between-cluster differences reported in our study are based on clusters' sample size ranging from 8 to 16 participants. These small clusters' sample sizes significantly limit the interpretations of our findings as they increase the risk for both type I and type II errors. It is also unclear whether those results would generalize to profiles found in larger populations of autistic children. As a result, our findings should be interpreted with caution and regarded as being strictly exploratory and should be replicated in other and larger samples of children.

Another limitation to our study is that definitions of speaking and nonspeaking linguistic profiles are only based on one source of language output (i.e. naturalistic speech sample obtained from short interactions). It is possible that children in our sample would have been more proficient if they had a need to communicate or to request something, situations which may not have arisen in short periods of play. Moreover, the non- or minimally speaking children in our sample may be able to communicate using other modalities (gestures, Augmentative and Alternative Communication, signs, written language, etc.) or through their non- or preverbal vocalizations. Despite not being the primary focus of the present study, future analyses of our annotated corpus or of any naturalistic language samples could investigate the communicative intent behind the children's oral productions. Finally, the fact that the preschool-aged children in clusters B, C, and E were identified as non- or minimally speaking based on their oral productions at one time point of their early linguistic development does not entail that they will not develop functional spoken language in the future. In line with this reasoning is the fact that 66% of the children in our sample were identified as being non- or minimally speaking, which is slightly higher than rates of nonspeaking children in other studies (e.g. 52% at 2.5 years old in Ellis Weismer & Kover, 2015).

We hope that our study shows that a promising direction to better understand language trajectories in autism is to systematically add detailed and qualitative analyses of naturalistic speech samples to parental reports and standardized assessments. However, future research should seek to determine the number and type of sessions and number of coders necessary to produce replicable and accurate estimates of children's oral productions (see Bottema-Beutel et al., 2019, for an example on caregiver–child joint engagement states). In addition, research should also be done to assess the impact of the talkativeness of the child's partner during the interaction on the child's oral production to adequately account for it in the future.

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Ethical approval

Ethical approval for the study was obtained from the ULB-Erasme Ethics committee in accordance with the declaration of Helsinki (approval code: P2018/499/B406201837514).

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Supplemental material

Supplemental material for this article is available online.

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