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## Proportion and Profile of Autistic Children Not Acquiring Spoken Language Despite Receiving Evidence-Based Early Interventions

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### ABSTRACT

**Objective:** To determine the proportion and profile of preschoolers on the autism spectrum who do not acquire spoken language despite receiving evidence-supported interventions that target spoken language.

**Methods:** We examined an aggregate dataset comprising 707 preschoolers on the autism spectrum who had received evidence-supported interventions to determine the proportion and profile of those who experienced limited progress in spoken language. Interventions were delivered through programs affiliated with university research settings and ranged in duration from 6 to 24 months. Spoken language outcomes were determined from parent-report measures, which were validated against direct assessments and natural language samples.

**Results:** Approximately two-thirds of children who were non-speaking at baseline were using single words or more complex spoken language by intervention exit. Those who remained non-speaking had lower baseline motor imitation scores, derived mainly from parent reports. Approximately half of the children who were minimally speaking (i.e. had single words or no words) at baseline were combining words by intervention exit. Those who did not acquire word combinations had lower baseline scores in cognitive, social, adaptive and motor imitation measures, and shorter intervention duration. Age at intervention start influenced spoken language advancement differently depending on the initial spoken language level. The odds of acquiring spoken language did not differ based on the intervention received.

**Conclusions:** Approximately one-third of children who had limited or no spoken language at baseline did not advance to spoken language stages following intervention. Development of spoken language was associated with modifiable factors at the child and intervention level.

Approximately one in three school-aged children diagnosed with autism spectrum disorder (hereafter “autism”) do not communicate using spoken language (Bacon et al., 2019; Hughes et al., 2024; Schaeffer et al., 2023). Although spoken language differences in autism are manifested as a continuum and may vary in response to different contexts in some individuals (e.g., preference for using non-verbal communication under specific circumstances), children with limited spoken language by school-age may represent a distinct,

clinically meaningful subgroup (Jack & Pelphrey, 2017; Tager-Flusberg & Kasari, 2013). As children who do not acquire spoken language beyond a minimal level during preschool years are at an increased risk for lifelong disabilities (DiRezze et al., 2019; Zaidman-Zait et al., 2021), spoken language has been included as a key target in autism intervention since pioneering work in the field (Lovaas et al., 1966; Rutter & Schopler, 1978).

Although positive effects on spoken language have been documented in response to various autism early

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interventions (Fuller & Kaiser, 2020; Sandbank et al., 2020), a sizable minority of children do not appear to experience gains in this domain despite receiving intervention (Barber et al., 2020; Frazier et al., 2021; Trembath et al., 2023). However, to our knowledge, no large-scale study has investigated this phenomenon. Further, estimates for the proportion of children who continue to have limited or no spoken language after receiving early intervention vary widely across the few well-controlled studies in this area (Bal et al., 2020; Rose et al., 2016; Trembath et al., 2023). Similarly, knowledge of the characteristics of children who do not acquire spoken language following early intervention is limited, although there is preliminary indication of developmental impairments in pre-linguistic skills including non-verbal and verbal cognition, social reciprocity, and imitation for those remaining minimally speaking (Hampton & Kaiser, 2016; Latrèche et al., 2024; Tager-Flusberg, 2018). Limited knowledge of the proportion and profile of children who do not acquire spoken language despite receiving targeted interventions is a major barrier to progress in the field, as understanding variability in spoken language advancement is critical for individualizing interventions and optimizing outcomes (McGrew et al., 2016; Vivanti, 2017).

The current study was designed to address these gaps in the literature through a retrospective large-scale examination of the proportion and profiles of autistic children who did not acquire spoken language despite receiving evidence-based interventions that included spoken language as a key target. To this end, we assembled an aggregate dataset comprising child-level data for 707 preschoolers on the autism spectrum who had received approximately 11 months of well-characterized, evidence-based early interventions connected to university-affiliated programs and/or funded research projects. Data were examined (1) to determine the proportion of children who had either limited or no spoken language at baseline and continued to show limited or no spoken language at exit and (2) to identify empirically derived profiles of “advancers” and “non-advancers” in the spoken language domain through the examination of child and intervention factors predicting spoken language acquisition and progress.

## Method

The use of the deidentified database used for the study was approved by the institutional review board of Drexel University (protocol #1901006930). The institutional review board granted a waiver of informed consent.

## Study Design and Procedures

Our research aims were addressed through an international consortium-sharing agreement which resulted in the creation of an aggregate dataset that retrospectively combined child-level data meeting these inclusion criteria: (1) child age at baseline between 15 and 68 months; (2) established diagnosis of autism; (3) use of standardized tests measuring spoken language at pre- and post-intervention; (4) participant received a manualized, evidence-based intervention for at least 6 months and no longer than 24 months; (5) all interventions were comprehensive in scope and included spoken language as an intervention target; (6) all interventions were implemented by trained clinicians or educators who provided direct intervention delivery for 10+ hours per week. Details related to each site, original dataset, and intervention program received by participants in the aggregate dataset are reported in Supplementary Materials Table S1.

## Interventions

For parsimony and analytic purposes, the interventions received by participants in the aggregate dataset (listed in Supplementary Materials Table S1) were classified according to four overarching categories. The first category ( $n = 216$ ) included participants who had received the Early Start Denver Model (ESDM; Rogers & Dawson, 2010), a comprehensive early intervention designed to facilitate the development of new skills across multiple domains (including spoken language) through the child’s engagement in joint activity routines that build on the child’s initiative and preferences. The “other Naturalistic Developmental Behavioral Interventions [NDBIs]” category ( $n = 208$ ) included other approaches that similarly target developmental milestones by blending teaching episodes (e.g., instructing/reinforcing the child’s use of a pointing gesture to choose desired item) within naturalistic contexts (e.g., when the child shows a desire to access the item; Schreibman et al., 2015). The Early Intensive Behavioral Intervention [EIBI] category ( $n = 197$ ) referred to interventions that use a more structured, adult-directed, didactic format to promote skill acquisition, such as Discrete Trial Training (T. Smith et al., 2015). The final category included participants who received TEACCH ( $n = 86$ ), an approach focused on environmental accommodations to address the learning differences and preferences of autistic individuals, including visual supports to create predictability and facilitate attention to and interpretation of relevant information (Schopler et al., 1995).

These approaches share important features, such as: the use of manualized educational/psychosocial strategies to target assessment-derived individualized goals pertaining to the acquisition/mastery of new skills; and data collection systems to measure progress. Instructional strategies, however, differ across intervention approaches, reflecting differences in underlying theoretical frameworks (Vivanti & Messinger, 2021). Of particular note for the current study is the operant-learning approach used in EIBI, which is based on Skinner's (1957) analysis of verbal behavior. The approach posits that spoken language acquisition is governed, like all learned behaviors, by three-step contingencies involving antecedents, verbal acts, and positive consequences for this behavior. Conversely, NDBI strategies are informed by developmental research findings that interactive partners, rather than merely reinforcing and shaping the child's utterances, scaffold child use of spoken language to communicate various intents during dyadic exchanges and daily routines (Bruner, 1975). NDBI interventions thus emphasize the child and partner's shared social/communicative engagement in adult-supported (rather than adult-directed) routines as a key element of spoken language development (Vivanti & Zhong, 2020). In the TEACCH program, the emphasis is on individualized visual supports like picture schedules and visual instructions to facilitate understanding and production of communication in context. Additional information on the interventions' areas of overlap and distinction, as well as the rationale for the current categorization, is reported in Supplementary Materials I.

## Participants

De-identified participant data from the contributing sites were provided by research staff at each site using a study-specific template and merged into an aggregate database

located at Drexel University. An extensive data quality assurance process was conducted, including checking for inclusion criteria, impossible data entries, and missing values. Information available for all children across sites included sex assigned at birth, age at pre- and post-intervention, intervention type, intervention duration, and intervention intensity. Information on race/ethnicity was available for approximately half of the sample, due to variations in demographic data collection for different sites/countries. After removal of 73 participants at baseline and 309 participants at post-intervention due to missing data on expressive language at pre- or post-intervention that would preclude the characterization of their spoken language benchmark (see Measures section), our analyses included a final sample of 707 participants with complete data on our main variable of interest, i.e., child spoken language benchmark at pre- and post-intervention. Characteristics for this final sample are detailed in Table 1.

Within the sample, participants were classified based on their spoken language use at baseline (prior to intervention start) according to discrete spoken language benchmarks. Irrespective of chronological age, participants were defined as "minimally speaking" if they were not combining words to form short phrases (66.4% of the sample). This "minimally speaking" subsample included a subset of children who did not use single words, defined as "non-speaking" (41.4%) as well as children who used single words but did not combine words (25%).

We addressed our research questions by examining the characteristics of children who remained "minimally speaking" or "non-speaking" despite receiving targeted interventions and reaching a chronological age at which more advanced spoken language use is expected. Given that operational definitions of "minimally verbal"/"minimally speaking" in the autism field vary (Koegel et al., 2020), spoken language profiles and progress (or lack thereof) in our sample were defined through the fine-

**Table 1.** Participant characteristics ( $n = 707$ ).

	Mean (SD)	Range	Missing data %
Baseline Chronological Age (months)	38.23 (12.55)	15–68	–
Post-Intervention Chronological Age (months)	48.94 (11.83)	25–80	–
Intervention Duration (months)	10.72 (3.23)	6–24	–
Intervention Intensity (weekly hours)	17.97 (9.29)	4–35	–
Baseline Verbal DQ	52.31 (27.03)	5–187	12.8%
Baseline Non-Verbal DQ	70.21 (22.80)	12–171	17.7%
Baseline VABS ABC	72.89 (13.01)	31–116	14.3%
Sex	82% male		1.2%
Race	36.2% White; 6.5% Black; 3.2% Asian; 3.8% Multiracial; 0.8% Other;		49.5%
Baseline APPL Phase	41.4% Preverbal/Non-Speaking; 25.1% Single Words; 22.9% Word Combination; 6.9% Sentences; 3.7% Complex Language		–
Intervention received (broad category)	30.5% ESDM; 29.4% other NDBI; 27.8% EIBI; 12.3% TEACCH		–

Legend – DQ: Developmental Quotient; VABS ABC: Vineland Adaptive Behavior Scales Adaptive Behavior Composite; APPL: Assessment of Phase of Preschool Language (see Table 2); ESDM: Early Start Denver Model; NDBI: Naturalistic Developmental Behavioral interventions; EIBI: Early Intensive Behavioral Intervention.

grained characterization of spoken language benchmarks at baseline and post-intervention detailed below.

### Characterization of Spoken Language Benchmarks

Discrete categories of spoken language benchmarks were derived from the Assessment of Phase of Preschool Language (APPL; Flanagan et al., 2019) which provides a parsimonious and clinically interpretable indication of spoken language status. This coding system operationalizes development stages of spoken language outlined by Tager-Flusberg et al. (2009) according to the definitions in Table 2, and aligns with operationalizations and recommendations in the field of language development, the autism field (Chenausky et al., 2023; Hus et al., 2014; Bal et al., 2016) and the literature on “late talking” children (Desmarais et al., 2008; Morgan et al., 2020). All 707 participants in the final sample were characterized using the APPL spoken language benchmarks at baseline and post-intervention based on their spoken language at the time, irrespective of their chronological age. The APPL allows assessors to determine spoken language phase using either natural language samples or standardized measures, including parent rating forms or clinician-delivered assessments. Because the Vineland Adaptive Behavior Scales (VABS; Sparrow et al., 2016) were available for 77% participants at baseline and post-intervention, we used the age-equivalent scores from its Expressive Communication subscale to complete the APPL. For children for whom the VABS was unavailable at pre- or post-intervention, the Mullen Scales of Early Learning (Mullen, 1995) Expressive Language subscale was used to derive APPL spoken language benchmarks. Additionally, we obtained natural language samples for 95 participants for whom audio- or video- segments were available, and we validated the APPL classification derived from standardized assessments against the classification derived from natural language samples. Procedures for standardization, transcription, and coding of natural language samples to derive spoken language classification on the APPL are reported in Supplementary Materials III. An intraclass correlation coefficient of .73 ( $p < .01$ ) was

found between these two data sources. We also examined the APPL phase classification based on the VABS against the classification based on the assessor-rated MSEL Expressive Language age-equivalent scores for the children who had both measures ( $n = 551$ , 78% of the sample) and found an intraclass correlation coefficient of .91 ( $p < .01$ ).

### Clinical Measures and Data Harmonization

As different tests were used by the consortium sites to measure autism diagnostic characteristics, adaptive functioning, and non-verbal and verbal developmental level, data across measures were harmonized to derive common metrics. These were used both to characterize the sample and as putative predictors of spoken language outcomes, given their theoretical and empirical associations with spoken language (Thomas et al., 2023; Trembath et al., 2021).

### Autism Characteristics

A metric of autism characteristics was derived from the Autism Diagnostic Observation Schedule (ADOS), which is widely accepted as the gold standard to support autism diagnosis. The first edition of the ADOS (ADOS-G; Lord et al., 2000) was used for 2.4% of participants, and the second edition (ADOS-2; Lord et al., 2012) was available for 60.1%; the remaining 37.5% had no ADOS data. ADOS-G scores were first converted to ADOS-2 scores using the ADOS-2 algorithm. The calibrated severity score (CSS) was then derived as a metric of autism characteristics according to the ADOS conversion tables in Hus et al. (2014), Esler et al. (2015), and Gotham et al. (2009) with higher scores indicating more autism characteristics. See Supplementary Materials I for information on diagnostic tools used to support diagnoses in participants for whom the ADOS was not completed.

### Adaptive Functioning

As a metric of adaptive functioning, we used the Adaptive Behavior Composite standard score from the VABS II (Sparrow et al., 2005) which was available for

**Table 2.** Operationalization of spoken language benchmarks in the assessment of Phase of Preschool Language (APPL).

Phase	Expressive Language Age Equivalent <sup>a</sup>	Vocabulary and Grammar <sup>b</sup>
1 - Preverbal/Non-Speaking	0–14 months	<5 different words or <20 words used in 20 min.
2 - First Words	15–23 months	5+ different words and 20+ words used in 20 min.
3 - Word Combination	24–35 months	30+ different words in 20 min. MLU $\geq$ 1.8
4 - Sentences	36–47 months	70+ word roots in 50 utterances. MLU $\geq$ 3.0
5 - Complex language	48+ months	105+ word roots in 50 utterances. MLU $\geq$ 4.0

Legend – MLU = Mean Length of Utterance.

<sup>a</sup>derived for all participants from standardized assessments.

<sup>b</sup>derived for a subset of participants ( $n = 95$ ) from natural language samples.

72.3% children, or from the first edition of the VABS (Sparrow et al., 1984), which was available for 13.4% of the sample.

### **Verbal and Non-Verbal Developmental Level**

Comparable metrics were derived from the measures of verbal and non-verbal developmental level used by the sites, which included the Mullen Scales of Early Learning, used for 76% of the sample, the Bayley Scales of Infant Development – Third Edition (BSID-III; Bayley, 1993), used for 6% of the sample, the Wechsler Preschool and Primary Scale of Intelligence-Fourth Edition (WPPSI-IV; Wechsler, 2012) used for 1.5% of the sample, the Stanford-Binet Intelligence Scale: Fourth Edition (SB-IV; Thorndike et al., 1986), used for 1.5% of the sample and the Preschool Language Scales 4th Edition (PLS-4; Zimmerman, Steiner, & Pond, 2011) used for 11.5% of the sample. For the MSEL, verbal and non-verbal Developmental Quotient (DQ) scores were calculated according to the formula:  $DQ = (\text{average of age equivalent subscale scores} / \text{chronological age}) * 100$ , with verbal DQ encompassing the receptive and expressive language subscales, and non-verbal DQ encompassing the visual reception and fine motor subscales. For the BSID-III, Verbal DQ was derived from the Receptive and Expressive Communication subscales and non-verbal DQ from the Cognition subscale. For participants who had received the PLS-5, a Verbal DQ score was derived from the Expressive Communication and Auditory Comprehension subscales. No non-verbal DQ was generated for these participants as no test of non-verbal cognition is included in the PLS-5.

### **Motor Imitation**

Data on motor imitative skills based on direct assessments were available for 20.6% children through different protocols/tasks, which were harmonized to compute a commensurate variable using percentage scores, whereby a 100% score indicated errorless imitation performance. For the children for whom specific motor imitation assessments were not conducted, imitation scores were derived from the sum of items 9, 12, and 16 of the VABS Interpersonal Relationships subscale, which include information on motor imitation, which was then converted to a percentage score. Imitation batteries and metrics are described in Supplementary Materials II.

### **Statistical Approach**

To determine the proportion and profile of children with limited or no spoken language who did not move

to more advanced spoken language phases after intervention, we examined changes in the APPL-defined benchmarks of spoken language from baseline to post-intervention and factors associated with spoken language advancement status. Our main analyses focused on children classified as “minimally speaking” at baseline who did not advance from “first words” stage (APPL Phase 2) or below to “word combination” or more advanced stages (APPL Phase 3 or above) during their intervention. These cutoffs were based on the spoken language development stage outlined in Tager-Flusberg et al. (2009) as operationalized by the APPL.

We then conducted additional analyses on two subsets of the main sample. The first focused on children classified as “non-speaking” at baseline (i.e., not using any spoken language) who did not advance to “first words” or more advanced stages of language development during their intervention – i.e., not advancing from APPL Phase 1 (expressive language age equivalent < 15 months) to APPL Phase 2 or more advanced phase. The rationale for the focus on this subset was based on the notion that children not using single words (i.e., non-speaking) might constitute a distinctive subgroup among minimally speaking children (Keen et al., 2016; Pizzano et al., 2024).

The second subset included participants who were 48 months or younger at intervention start. Like for the main analysis, in this subset we examined the proportion of children classified as “minimally speaking” at baseline who did not advance to “word combination” or more advanced stages. In the context of our sample’s age range (15–68 months), a distinctive focus on this younger subset was predicated on the idea that change in spoken language status might be affected by developmental period, with more openness to change for children younger than 48 months (DiStefano & Kasari, 2016).

For all analyses, we first identified the proportion of children who moved from their initial APPL spoken language phase to a more advanced phase (“advancers”) versus those who did not (“non-advancers”), and modeled “advancer status” as the dependent variable in a mixed effect logistic regression model that included both theoretically and empirically motivated putative predictors. These putative predictors – the fixed effect independent variables in the model – were sex at birth, intervention type, intervention duration, intervention intensity, age at intervention start, and baseline measures of imitation, verbal and nonverbal DQ, ADOS CSS, and VABS ABC. The mixed effect logistic regression model was implemented using the *glmer* function in the *lme4* R library. Variability due to the originating site/dataset was accounted for in the model as a random

effect modeled with random intercepts. All continuous variables were first scaled to a mean of 0 and standard deviation of 1 to standardize variables before modeling.

Due to the correlated nature of several independent variables in the model (see Figures 1(a) and 2(a)), we utilized Principal Component Analysis (PCA; Greenacre et al., 2022) to first orthogonalize (i.e., separate) the predictors inserted into the model in order to remove collinearity and enhance interpretability. PCA was selected over alternative approaches because it is optimally suited for analyzing datasets with many inter-correlated variables due to its ability to reduce dimensionality while retaining information. This is achieved by transforming the original correlated variables into a new set of uncorrelated variables called principal components. These components are linear combinations of the original variables that retain most of the variance in the data. Additionally, PCA eliminates redundancy (i.e., overlapping information) from correlated variables by summarizing the information into fewer, orthogonal (i.e., independent) components, thus avoiding multicollinearity, which can distort analyses like regression or classification and lead to spurious interpretations about the importance of specific variables over others. Because PCA combines correlated variables into orthogonal variables that are weighted linear combinations of the original variables, these can later be interpreted as latent variables by examining their loadings or weights on specific principal components.

The first five principal components (PCs) from the PCA were included in the model as they accounted for >90% of the variance in the originating continuous variables (Supplementary Figure S1). Variables in the model were deemed significant if they passed FDR  $q < 0.05$  for multiple comparison correction. All post hoc pairwise comparisons between intervention types were implemented with the *emmeans* R function and were deemed statistically significant if they passed Tukey-corrected  $p < .05$ . To interpret PCs as linear combinations of multiple independent variables, we visualized the PC loadings as heatmaps (Figures 1(b) and 2(b)). To interpret statistically significant PCs as projections back into the originating variables, we back-projected statistically significant PCs using matrix multiplication of significant PC scores with their coefficients. This procedure allows for plotting the originating variables to see variation due to the significant PCs and the directionality of differences with respect to advancer status. Plotting the data from significant PCs back onto their original space is important for interpreting the directionality of group differences, due to arbitrary rotations decisions that can be made under different PCA implementations in different software packages. Standardized effect sizes (Cohen's  $d$ ) were

used to describe the size of differences between advancers and non-advancers on the PC-reconstructed data. Reproducible analysis code can be found at [https://github.com/IIT-LAND/mira\\_lang](https://github.com/IIT-LAND/mira_lang).

## Results

### **Main Analysis – Proportions and Profiles of Minimally-Speaking Children Who Did Not Advance to Word Combinations**

Our main set of analyses focused on the 470 children who met APPL-defined spoken language Phase 1 (expressive language age equivalent <15 months;  $n = 293$ ) or Phase 2 (expressive language age equivalent between 15 and 24 months;  $n = 177$ ) at baseline. Characteristics of this subsample are reported in Supplementary Table S3a. Of these 470 children, 233 (49.56%) advanced to “word combination” or more advanced phases, and the remaining 237 (50.42%) did not. Among the 233 “advancers,” at baseline 123 children (52.78%) were using single words (APPL Phase 2), and 110 (47.21%) were non-speaking (APPL Phase 1).

To test whether the spoken language advancement was more prevalent within a specific intervention type, we used a chi-square test on the contingency table of advancer – non-advancer status by intervention type. This analysis found that the counts of advancers versus non-advancers in each intervention type did not statistically differ from each other ( $\chi^2(3) = 1.90, p = .59$ ) (Figure 1(c)). This indicates that intervention type did not influence advancer versus non-advancer status. To further test whether other intervention-related variables or child baseline characteristics would predict advancer versus non-advancer status, we used a mixed effect logistic regression with “advancer/non-advancer” status as the binary dependent variable. Putative independent variables examined were (a) intervention type received (ESDM, NDBIs, EIBI, and TEACCH); (b) intervention intensity (average number of weekly hours) (c) intervention duration (in months), (d) age at intervention start, (e) sex, (f) baseline ADOS CSS, (g) baseline VABS ABC, (h) Verbal DQ, (i) Nonverbal DQ, and (l) motor imitation. Before running the regression, we first examined how independent variables may be correlated with each other. Figure 1(a) shows a strong degree of correlation between individual characteristics of the child and intervention-related characteristics. Thus, inserting such variables into a regression would lead to a high degree of multicollinearity.

To manage this issue, we utilized Principal Component Analysis to decorrelate the correlated predictors (Figure 1(a)) into a set of orthogonal latent variables (see Methods



section). The loadings or weights for each PC are shown in [Figure 1\(b\)](#) and can be used to interpret how each of the original variables contributes to each PC. For example, PC1 captures the strong correlations between baseline child characteristics and some intervention characteristics (e.g., age at start, VABS, DQ, intervention duration, and intensity). The first five PCs accounted for 90% of the variance in the original variables. Thus, for the mixed effect logistic regression, we inserted sex, intervention type, and the first five PCs as fixed effects and included site as a random effect modeled with random intercepts. Sex was not a significant predictor of advancer status (sex  $\beta = 0.20$ ,  $p = .69$ ). Congruent with the previous chi-square analysis testing the effect of intervention type, the regression and follow-up pairwise comparisons between intervention types showed that type of intervention did not predict advancer status (all intervention pairwise comparisons  $p > .25$ ; see [Table 3](#); [Figure 1\(c\)](#) and Supplementary Table S4 for full statistics). As for the continuous variables summarized by PCs in the model, we identified PC1 and PC2 as statistically significant after FDR correction (PC1:  $\beta = -0.94$ ,  $p = 2.32e-4$ ; PC2:  $\beta = 0.91$ ,  $p = 1.49e-3$ ) ([Figure 1\(b\)](#); see [Table 3](#) for full set of statistics for all PCs). PC1 accounted for ~43.71% of the variance in continuous predictors (Supplementary Materials V) and heavily loaded onto most of the continuous variables aside from baseline imitation and ADOS CSS scores ([Figure 1\(b\)](#)). PC2 picked up on an additional factor orthogonal to PC1 accounting for ~17.73% of the variance in continuous predictors, with strong contributions from all variables except nonverbal DQ and VABS ABC scores ([Figure 1\(b\)](#)). Descriptively plotting the data reconstructed from variation from PC1 and PC2 showed that the differences between advancers and non-advancers

were medium in effect size for age at start, intervention intensity and duration (Cohen's  $d$  0.44 to 0.55). Non-advancers experienced intervention at a later age and for shorter durations, but at higher intensity compared to advancers. In contrast, much larger effect sizes (Cohen's  $d > 0.76$ ) were observed for baseline imitation, ADOS CSS, verbal and nonverbal DQ, and VABS ABC. Non-advancers had higher ADOS CSS, lower VABS ABC and verbal and nonverbal DQ, and lower motor imitation scores at baseline than did advancers ([Figure 1\(d\)](#)).

### Subset 1 Analyses – Proportion and Profile of Non-Speaking Children Who Did Not Acquire Single Words

Of the 707 children in the sample, 293 were non-speaking at baseline, corresponding to the APPL Phase 1 classification (i.e., expressive language age equivalent <15 months; [Table 2](#)). Characteristics of this subset are reported in Supplementary Table S3b. Of this subset, 195 children (66.55%) advanced to “single words” or more advanced phases, whereas 98 (33.45%) did not (i.e., remained non-speaking).

Similar to our previous analyses, we used a chi-square test on the contingency table of advancer status by intervention type. This analysis also found that the counts of advancers versus non-advancers in each intervention type did not statistically differ from each other ( $\chi^2(3) = 2.72$ ,  $p = .43$ ) ([Figure 2\(c\)](#)). We next used logistic regression to predict “advancer” status from a range of intervention-related and child baseline characteristics. Similar to previous analyses, we found that continuous predictors were highly

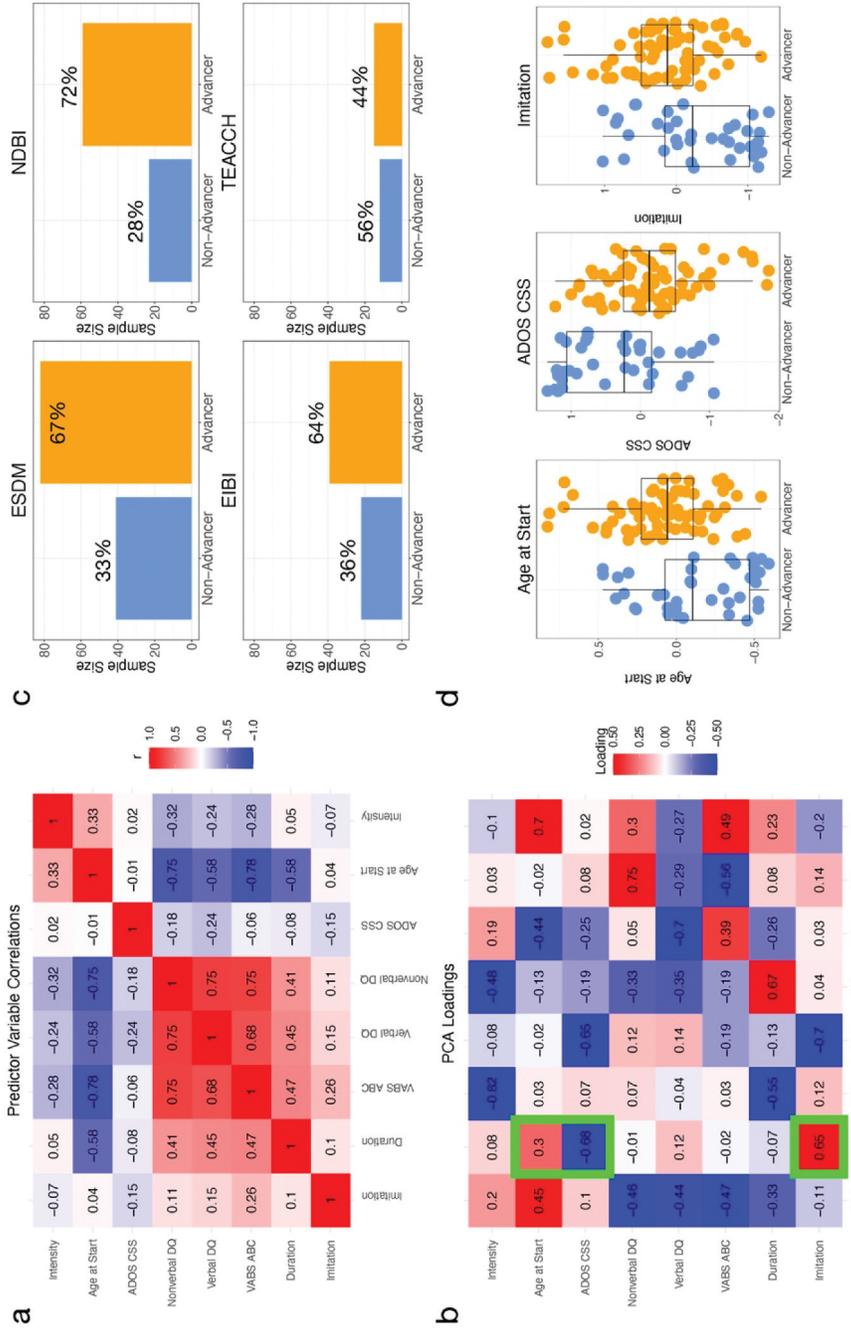
**Table 3.** Statistics for mixed effect logistic regression model using “advancer” status from single words (APPL Phase 2) or less advanced phase to word combination (APPL Phase 3) or more advanced phases as the binary dependent variable (i.e., did/did not advance) (advancer  $n = 80$ ; non-advancer  $n = 85$ )<sup>†</sup> including fixed effect independent variables (“sex assigned at birth,” using male as the reference, and “intervention type” using TEACCH as the reference) and all principal components comprising the continuous variables.

	beta	95% Confidence Intervals (CI)		<i>p</i>
Intercept	-0.6941149	-2.8615414	1.4733117	0.75744157
Sex	0.20670262	-0.817781	1.2311862	0.85639092
EIBI	1.02184734	-1.2915637	3.3352584	0.67290639
NDBI	-0.4496794	-3.4743771	2.5750184	0.85639092
ESDM	0.98914318	-1.332807	3.3110933	0.67290639
PC1	-0.9429445	-1.4450199	-0.4408692	0.00232263*
PC2	0.91564865	0.3505801	1.4807172	0.00746542*
PC3	-0.4293682	-1.140208	0.2814716	0.67290639
PC4	-0.0076477	-0.4856596	0.4703643	0.9749841
PC5	-0.3904357	-1.1089403	0.3280689	0.67290639

Legend ESDM: Early Start Denver Model; NDBI: Naturalistic Developmental Behavioral interventions; EIBI: Early Intensive Behavioral Intervention; PC: Principal Component.

The asterisks next to specific *p*-values indicate statistical significance after FDR multiple comparison correction at  $q < 0.05$ .

<sup>†</sup>Sample sizes are smaller in the logistic regressions as all data for all participants need to be completed for inclusion in the regression analyses.



**Figure 2.** Factors differentiating initially non-speaking children (based on APPL Phase 1 classification) who do/do not advance to acquire single words. Panel a shows a correlation matrix of all continuous predictor variables utilized in the statistical model predicting advancer status. Due to the highly correlated nature of these predictors, principal components analysis (PCA) was used to decorrelate predictors into a set of orthogonal latent variables (panel b). How each variable contributes to the resulting latent principal component (PC) variables can be seen in panel B showing a heatmap of PCA loadings. PC2 was statistically significant in predicting advancer status and specific variables with loadings >0.2 are highlighted in green outlines as the primary variables contributed most to those PCs. Panel C shows sample sizes and relative proportions of individuals in each intervention type that were either advancers (orange; total n = 195) or non-advancers (light blue; total n = 98). Panel D shows scores on the predictor variables contributing to PC2 when only the variance from the statistically significant PC is retained. Effect size is  $d = 0.69$  for the variables in panel d.

**Table 4.** Statistics for a mixed effect logistic regression model using “advancer” status from APPL Phase 1 (preverbal/non-speaking) to verbal phases as the binary dependent variable (i.e., did/did not advance) (advancer  $n = 70$ ; non-advancer  $n = 38^{\dagger}$ ), including fixed effect independent variables (“sex assigned at birth,” using male as the reference, and “intervention type” using TEACCH as the reference) and all principal components comprising the continuous variables.

	beta	95% Confidence Intervals (CI)		<i>p</i>
Intercept	-2.0532831	-5.9145135	1.8079473	0.40025247
Sex	0.8235132	-0.8002455	2.4472719	0.40025247
EIBI	1.7028696	-2.0756613	5.4814005	0.4189637
NDBI	3.8127628	-0.6657342	8.2912598	0.1903761
ESDM	2.675869	-1.4632955	6.8150335	0.34187052
PC1	-0.8223599	-1.5321025	-0.1126172	0.07715665
PC2	1.5078015	0.6243171	2.3912859	0.00822706*
PC3	-0.9943669	-2.0945108	0.1057769	0.1903761
PC4	-1.1139321	-1.978801	-0.2490631	0.05794194
PC5	-0.3803502	-1.7289856	0.9682852	0.58042029

Legend – FDR: False Discovery Rate; ESDM: Early Start Denver Model; NDBI: Naturalistic Developmental Behavioral interventions; EIBI: Early Intensive Behavioral Intervention; PC: Principal Component.

The asterisks next to specific *p*-values indicates statistical significance after FDR multiple comparison correction at  $q < 0.05$ .

<sup>†</sup>Sample sizes are smaller in the logistic regressions as all data for all participants need to be completed for inclusion in the regression analyses.

correlated (Figure 2(a)). Thus, PCA was used to orthogonalize predictors as PCs. The first five PCs accounted for 90% of the variance in the original variables and were subsequently inserted into the model as fixed effects. Sex had no effect on advancer status ( $\beta = 0.82$ ,  $p = .32$ ). Intervention type also did not differentiate advancers from non-advancers at statistically significant levels (all pairwise comparisons between interventions  $p > .34$ ; see Figure 2(c) and Supplementary Table S5). As for the continuous variables summarized by principal components in the model, we identified PC2 as statistically significant after FDR correction ( $\beta = 1.50$ ,  $p = 8.22e-4$ ) (Figure 2(b); see Table 4 for full set of statistics for all PCs). PC2 accounted for ~14.69% of the variance in the continuous predictors (Supplementary Materials V) and was most heavily loaded on baseline motor imitation, ADOS CSS, and age at intervention start (see Figure 2). Plots of these variables with only variation retained from PC2 show the difference between advancers and non-advancers in the medium-to-large range (i.e., Cohen’s  $d > 0.69$ ), whereby initially non-speaking children who did not advance to acquire single words had lower motor imitation scores, higher ADOS CSS, and relatively earlier age at intervention start than advancers (Figure 2(d)).

### Subset 2 Analyses – Proportion and Profile of Children 48 Months and Younger Who Did Not Acquire Word Combinations

We repeated the same analyses reported in the “main analysis” section on the subset of 403 children who were

48 months or younger at intervention start and were meeting APPL Phase 1 or Phase 2 classification (Supplementary Table S3c). In this younger subset, 202 participants (50.1%) advanced to “word combination” or more advanced phases, whereas 201 (49.9%) did not advance in their spoken language phase during the intervention period. Using the same PCA approach utilized in the main analysis, we found the same pattern of results, whereby intervention type did not differentiate advancers from non-advancers, and non-advancers started intervention at a later age, had higher ADOS CSS, lower VABS ABC and verbal and nonverbal DQ, and lower motor imitation scores at baseline than did advancers. Full statistics are reported in Supplementary Materials VI.

### Discussion

The current study is, to our knowledge, the first to examine stability and change in spoken language status in a large sample of autistic children who received well-studied evidence-based early interventions that varied across conceptual and procedural dimensions but shared a focus on spoken language as a key target. Our findings indicate that two-thirds of initially non-speaking children acquired single words or moved to more advanced spoken language benchmarks by the end of intervention. Additionally, approximately half of the children who were minimally speaking at baseline acquired the ability to combine words or moved to more advanced phases during their intervention. This pattern was identified both in the analyses that included the entire sample, and in analyses restricted to a more

chronological-age- homogeneous subset of children 48 months or younger. The proportion of spoken language “advancers” in our sample is aligned with previous research on early intervention samples (Frazier et al., 2021), although it appears higher than estimates reported in some studies focused on preschoolers without a known early intervention history (e.g., Nitzan et al., 2023).

These findings indicate that spoken language might well be attainable by the majority (up to two-thirds) of children on the autism spectrum receiving evidence-supported early intervention that targets spoken language. Nevertheless, our results also support the notion that a substantial proportion of children will not experience the advancements in spoken language that the interventions are designed to promote (although long-term progress in our sample was not measured and cannot be ruled out).

Notably, EIBI, ESDM, TEACCH, and other NDBI interventions were associated with similar proportions of advancers/non-advancers despite differences in underlying theoretical tenets for spoken language development (i.e., Skinner’s analysis of verbal behavior vs social-pragmatic language development; Vivanti & Messinger, 2021) – a finding aligned with previous research (Chetcuti et al., 2025). Additionally, intervention duration, but not intensity, was associated with advancement to phrase speech for minimally speaking children. This suggests that improvements in this group might occur without the need for highly intensive intervention schedules (consistent with recent research; Rogers et al., 2021; Sandbank et al., 2024), while longer duration, continuity of services, and extended opportunities for practicing skills might play a role. Importantly, however, limitations in measurement precision, intervention characterization, and the pooling of studies may have constrained our ability to detect the effects of specific intervention programs and the influence of their dose.

Further, we found that children classified as non-advancers across the full sample as well as in the two subsets showed lower scores in motor imitation. This finding, which should be interpreted with caution given the variability in how imitation was assessed, is consistent with previous literature (Iao et al., 2023; Pittet et al., 2022; Sandbank et al., 2017; Toth et al., 2006). Imitation has been theorized to facilitate the acquisition of spoken language by virtue of enabling gestural and social routines foundational to communication development (Bates et al., 1988; Pecukonis et al., 2019; Rogers & Pennington, 1991). Imitation difficulties might also reflect motor impairments that affect gesture and oral motor execution, thus affecting speech production (Bal et al., 2020; Gernsbacher et al., 2008). Importantly,

imitation skills in autism have been shown to improve in response to targeted intervention (Ingersoll, 2010; Paparella & Freeman, 2021), suggesting that addressing imitative difficulties may help facilitate development of spoken language in non-speaking/minimally speaking children. Consistent with this notion, recent autism intervention studies documented that gains in communication were mediated by improvements in imitation (Xiao & Li, 2025; Yoder et al., 2021).

Our finding that ADOS scores predicted spoken language outcomes is also consistent with previous literature (Chenausky et al., 2018; Thomas et al., 2023; Trembath et al., 2019) and aligns with the idea that spoken language is “gated” by joint engagement and social learning experiences that involve joint attention, gestures, and other non-verbal communication processes measured by the ADOS (Kuhl, 2007; Paul et al., 2013). The finding that baseline verbal and nonverbal cognition and adaptive behavior were associated with the attainment of word combinations is also aligned with previous literature (Chetcuti et al., 2025; Latrèche et al., 2024; Thurm et al., 2015; Wodka et al., 2013) and suggests a role of early cognitive and functional skills in the acquisition of spoken language. The finding points to the importance of monitoring gains in both spoken language and prelinguistic areas that contribute to its progress, as well as timely modification of aspects of the intervention for those demonstrating the “non-advancer” profile, including greater focus on the prelinguistic skills that gate spoken language progress, or the introduction of additional services to support communication and language development using speech or other symbol systems (Charman et al., 2000; Gulsrud et al., 2014; Mundy et al., 1990).

Our finding that minimally speaking children who were younger when they started their intervention were more likely to demonstrate spoken language progress is consistent with previous literature (Guthrie et al., 2023). Importantly however, the effect of age on spoken language progress might differ for children with different pre-intervention language profiles. For example, some very young non-speaking children may not yet have attained developmental skills associated with spoken language advancement in response to the intervention.

Finally, while there were some notable effects for age at start, duration, imitation, ADOS scores, etc., the current study showed strong correlations between various intervention-related and child baseline characteristics. Thus, it is difficult to disentangle the specific contributions of each variable. Future work that a priori manipulates specific intervention-related factors in very large samples may help clarify their relative importance. However, intercorrelations between child baseline characteristics are common in young children

and in autism research (Mandelli et al., 2024). The reality that these variables are correlated in early development necessitated the decision to decompose such variability across measures into orthogonal latent variables (i.e., PCs) that reflect a weighted combination of related characteristics in young autistic children. While decomposing the independent contributions of each factor would be ideal to guide interpretation, it may be important to think about baseline child characteristics as a latent construct that in early development is spread across an array of correlated developmental and cognitive skills. This work suggests that baseline child characteristics indicated by such latent factors may be important for individualizing services to support communication.

Our study has several limitations. Although the retrospective aggregation and harmonization of intervention data from different sources and categorization of interventions according to broad categories is aligned with previous research (Chetcuti et al., 2025; Sandbank et al., 2023), uncontrolled sources of variation across sites and intercorrelations within sites could have affected the results. This risk was partially mitigated through the focus on standardized and harmonizable measures, as well as statistical approaches that factored sources of shared variance within each site. Additionally, recent large-scale research reported no effect of intervention format (e.g., 1:1 vs small group implementation) – one of the factors varying across interventions in our dataset – on early intervention outcomes (Chetcuti et al., 2025; see also Bent et al., 2024). Nevertheless, differences across sites, including in participant inclusion criteria and in unmeasured concurrent interventions participants might have received, preclude conclusions on the comparative value of different approaches in facilitating spoken language advancement. Therefore, our findings related to intervention type should be substantiated by prospective research equipped to establish comparative effectiveness. Future research should also incorporate more granular and targeted measures of spoken language outcomes, which in the present study were assessed primarily through parent report, albeit validated against direct assessments and natural language samples in large subsets of participants. Relatedly, standardized, multi-method measurement approaches are essential for more precisely characterizing both spoken language outcomes and predictors (e.g., specific autism characteristics, imitation) which in our study were assessed primarily through broad measures. Further, several factors that have been previously found to contribute to spoken language were not examined in our study, including motor skills, phonetic repertoire, verbal/vocal imitation, parental responsiveness, and response to joint attention (Brady

et al., 2021; Saul & Norbury, 2020, Smith et al., 2023; Yoder et al., 2015). Relatedly, because of inconsistencies across sites in the collection of demographic variables, we were unable to examine whether important variables such as race/ethnicity and SES contributes to advancer status. Therefore, the diversity of the sample and generalizability of results cannot be assumed. Further, many interventions included in the study were supported by university-based staff and expertise, which could have resulted in higher implementation intensity and fidelity compared to “ordinary” community-based early intervention programs. This focus on research-based intervention programs highlights the importance of avoiding over-interpretation of specific program effects. Additionally, several interventions aligned with NDBI principles were not included in our sample. Therefore, our findings related to the NDBI category cannot be generalized to all such interventions. Finally, progress in spoken language represents a relevant but circumscribed area of intervention focus and does not capture many important dimensions of communication, including use and complexity of alternative forms of communication (e.g., sign language, Alternative Augmentative Communication).

Despite the stated limitations, our study corroborates previous estimates on the proportion and profile of children remaining minimally speaking as they approach school age, and points to modifiable factors that might support spoken language advancement for those initially demonstrating the “non-advancer” profile: earlier access to and increased duration of intervention, and additional efforts to target imitation, cognitive and social-communication skills – all areas shown to be amenable to improvements in response to intervention (Rogers & Talbott, 2016). Early introduction to language via sign or other symbolic alternative to speech (AAC) is another such support for spoken language for children appearing not to advance in their spoken language. Importantly, although the interventions examined in our study targeted spoken language, they were comprehensive in scope and addressed a broad range of developmental outcomes. Future interventions may benefit from placing greater emphasis on communication and spoken language outcomes for children who appear less responsive to broad approaches. Further research is needed to substantiate the current findings and evaluate targeted alterations and adaptations to standard intervention delivery for children meeting the “non-advancer” profile, including dose escalation, and augmenting interventions with a more intensive focus on the prelinguistic areas that appear to gate spoken language progress.

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## Disclosure Statement

The sponsor has no role in the design of the study; in the collection, analysis, or interpretation of the data; and in the writing of the manuscript. Diana Robins is co-owner of M-CHAT LLC, which receives royalties from parties that license use of the M-CHAT in commercial products. Dr. Robins also serves on the Program Quality Committee of Bancroft. Dr. Lord receives royalties from the sale of the Autism Diagnostic Observation Schedule-2 (ADOS-2). Dr. Vivanti receives royalties from the book *Implementing the Group-based Early Start Denver Model for Young Children with Autism*. Dr. Rogers receives royalties from Guilford Press for three books related to the Early Start Denver Model. No royalties were received for the data presented in the current study.

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