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Early Language Exposure Supports Later Language Skills in Infants With and Without Autism

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Abstract

The way that parents communicate with their typically developing infants is associated with later infant language development. Here we aim to show that these associations are observed in infants subsequently diagnosed with autism spectrum disorder (ASD). This study had three groups: high-familial-risk infants who did not have ASD (n = 46); high-familial-risk infants who had ASD (n = 14); and low-familial-risk infants who exhibited typical development (n = 36). All-day home

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Supporting Information
Additional supporting information may be found online in the Supporting Information section at the end of the article.
Appendix S1: Supplementary Methods and Supplementary Results

language recordings were collected at 9 and 15 months, and language skills were assessed at 24 months. Across all infants in the study, including those with ASD, a richer home language environment (e.g., hearing more adult words and experiencing more conversational turns) at 9 and 15 months was associated with better language skills. Higher parental educational attainment was associated with a richer home language environment. Mediation analyses showed that the effect of education on child language skills was explained by the richness of the home language environment. Exploratory analyses revealed that typically developing infants experience an increase in caregiver–child conversational turns across 9–15 months, a pattern not seen in children with ASD. The current study shows that parent behavior during the earliest stages of life can have a significant impact on later development, highlighting the home language environment as means to support development in infants with ASD.

Lay Summary:

It has long been understood that caregiver speech supports language skills in typically developing infants. In this study, parents of infants who were later diagnosed with ASD and parents of infants in the control groups completed all-day home language recordings. We found that for all infants in our study, those who heard more caregiver speech had better language skills later in life. Parental education level was also related to how much caregiver speech an infant experienced.

Keywords

infancy; ASD; high familial risk; language; home language environment; caregiver speech; socioeconomic status

Introduction

In western societies, the home language environment has a well-established association with child language skills [Hart & Risley, 1995; Hirsh-Pasek et al., 2015; Hurtado, Marchman, & Fernald, 2008; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Pan, Rowe, Singer, & Snow, 2005; Rowe, 2012; Weisleder & Fernald, 2013]. Caregiver speech patterns change as infants develop new communication skills, but our understanding of this developmental sequence is still being refined. For example, 11–14 month old infants benefited from hearing child-directed speech, a speech style characterized by slower speech, elongated vowels, and wide ranges in pitch [Ramírez-Esparza, García-Sierra, & Kuhl, 2014]. By age 33 months, caregiver speech patterns shifted, with standard speech, and not infantdirected speech, showing significant positive associations with language skills [Ramírez-Esparza, García-Sierra, & Kuhl, 2017]. Many studies have also found that overall amount of adult speech, or total number of word tokens, is associated with later language skills [Hurtado et al., 2008; Huttenlocher et al., 1991, 2010; Mahr & Edwards, 2018]. Others report that specific qualitative features support child development, such as vocabulary diversity, contingency, mean length of utterance, responsiveness, and interrogatives [Hirsh-Pasek et al., 2015; Pan et al., 2005; Rowe, Leech, & Cabrera, 2017; Tamis-LeMonda & Bornstein, 2002; Weisleder & Fernald, 2013]. Taken together, this research highlights the important role parents play in supporting and shaping language development during the first years of life.

Researchers have begun to investigate the mechanisms that drive links between the home language environment and later language skills. In Hart and Risley's seminal study, children from lower socioeconomic status (SES) homes heard significantly fewer words compared to children from higher SES homes [Hart & Risley, 1995]. In addition, the quality of language heard by children also varied as a function of SES and was associated with language skills. Researchers have replicated these findings using samples of mostly 2 and 3 year old children [Cartmill et al., 2013; Hoff, 2003; Huttenlocher et al., 2010; Rowe, 2008, 2012]. Fewer studies have focused on the first 18 months of life, a time period during which infants transition from babbling to spoken words, and reciprocal vocal interactions with caregivers become more sophisticated as the infant's social-communicative repertoire rapidly expands.

While there has been extensive research on the association between the home language environment and later language skills in typically developing children, far less research has addressed this association for children with autism spectrum disorder (ASD). ASD is a neurodevelopmental disorder with a strong, but complex genetic basis, that is typically diagnosed after 4 years of age [Baio et al., 2018]. For families with one child with ASD, the recurrence risk for subsequently born infants is around 20% [Ozonoff et al., 2011]. Studying these infants allows for the prospective study of ASD. Previous research has found relatively comparable early language environments of infants with and without a family history of ASD [Campbell, Leezenbaum, Mahoney, Day, & Schmidt, 2015; Northrup & Iverson, 2015; Swanson et al., 2018; Talbott, Nelson, & Tager-Flusberg, 2016], while some subtle differences in the timing and synchrony of parent–child interactions have been reported [Northrup & Iverson, 2015; Wan et al., 2012]. Studies of older children with ASD showed that responsive caregiver language was associated with better joint attention and language skills [Bottema-Beutel, Yoder, Hochman, & Watson, 2014; McDuffie & Yoder, 2010; Siller & Sigman, 2002, 2008]. To our knowledge, no study has examined whether the home language environment during infancy is related to later language skills in infants later diagnosed with ASD.

The current study investigated the association between the early home language environment at 9 and 15 months and later language skills in infants with an older sibling with ASD who themselves met criteria for ASD, those who did not meet criteria for ASD, and typically developing control infants who did not have a first-degree relative with ASD. First, we tested the hypothesis that richer caregiver speech would positively impact later language skills in all groups. Second, we tested the hypothesis that caregiver speech would mediate the association between parental education and later child language skills. Exploratory analyses included (a) examination of how caregiver speech was associated with parental characteristics and child autism features, and (b) examination of potential group differences in caregiver speech from 9 to 15 months.

Methods

Participants

This study included 96 infants from the Infant Brain Imaging Study (IBIS), a longitudinal study of infants at high and low probability of developing ASD based on family history. The IBIS network includes four clinical sites: University of North Carolina; University of

Washington; The Children's Hospital of Philadelphia; and Washington University in St. Louis. Local Institutional Review Boards approved the procedures for this study, and parents gave written informed consent prior to participation.

The collection of home language samples were added to the IBIS study in year 6 of the 10-year study. The present study included all infants who met the following criteria: (a) at least one home language recording at age 9 or 15 months, and (b) cognitive and diagnostic assessments at 24 months. Infants were separated into three groups. High-familial-risk ASD infants (HR-ASD, $n = 14$) had an older sibling who met ASD criteria on the Social Communication Questionnaire [SCQ; Rutter, Bailey, Lord, Cianchetti, & Fancello, 2003], and Autism Diagnostic Interview-Revised [ADI-R; Lord, Rutter, & Le Couteur, 1994], with diagnosis confirmed by medical records, and they themselves received a clinical best-estimate diagnoses of ASD at 24 months. Clinical best-estimate diagnoses were made by licensed clinicians based upon DSM-IV-TR criteria using all available assessment data including the Autism Diagnostic Observation Schedule [ADOS; Lord et al., 2000], ADI-R [Lord et al., 1994], Mullen Scales of Early Learning [MSEL; Mullen, 1995], and the Vineland Adaptive Behavior Scales II [Sparrow, Cicchetti, & Balla, 2005]. High-familial-risk negative infants (HR-Neg, $n = 46$) had a sibling with ASD, but did not receive a diagnosis of ASD at 24 months. Low-familial-risk negative infants (LR-Neg, $n = 36$) had typically developing older siblings as determined by parent interview [FIGS; Maxwell, 1992], did not have first-degree relatives with ASD, and did not receive a diagnosis of ASD at 24 months. LR-Neg infants all scored within normative ranges on the MSEL (>85 Early Learning Composite Score). See Supporting Information for full exclusionary criteria.

ADOS data were incomplete for three participants; these infants screened negative for ASD on the ADI-R (2 HR-Neg) or SCQ (1 LR-Neg), and all three had MSEL cognitive scores in the normative range. Demographic information appears in Table 1 and S1. See Estes et al. [2015] for further protocol information.

Five infants had siblings in the IBIS study who also contributed home language recordings (four HR sets of siblings, one LR set of siblings). A priori, one infant from each family was selected for inclusion in the current analyses based on the following criteria: (a) availability of diagnostic outcome data, or (b) if both infants had diagnostic outcome data, the infant with both home language recording time points was included in the analysis.

Procedures and Measures

The majority of families in the study completed 2 days of home language recordings when the infants were 9 and 15 months old (Table S2). Cognitive and diagnostic assessments were administered during a research visit at 24 months (Table 1).

Home language recordings.—Language samples were collected using small digital language recorders that are worn by the infant using clothing designed to provide optimal acoustic properties (LENA Research Foundation Digital Language Recorder). Families were mailed packets containing recording materials or were provided packets during a research visit (see Table S2 for age at recording). Families were instructed to complete 2 days of language recording (16 hr per day), starting the recording when the infant woke up for the first time in the morning and letting the recording run uninterrupted throughout the day and into the night.

Software was used to automatically process infant and adult vocalizations (LENA Pro software suite V3.3.4) [Xu, Yapanel, & Gray, 2009]. Initial validation reports of the LENA system indicated sensitivity of 82% for adult vocalizations and 76% for child vocalizations [Xu et al., 2009]. Other studies have found high correlation between hand-coding and LENA-based data [Soderstrom & Wittebolle, 2013].

The current study focuses on two aspects of the home language environment: language exposure (adult word counts, AWC) and caregiver-child interactions (conversational turn counts, CTC). Adult words are the estimated number of adult words spoken to and near the infant wearing the speech recorder. Conversational turns are defined when the infant vocalizes, and an adult responds within 5 sec, or vice versa. Both variables are summed across the 16-hr recording day and then averaged across both recording days to generate an average daily count of estimated adult words and conversational turns.

Cognitive and diagnostic assessments.—During the research visit at 24-months, cognitive development was measured via the MSEL, a widely used and normed assessment for children up to 68 months [Mullen, 1995]. The Early Learning Composite (MSEL ELC) and five subscale scores (visual reception, fine motor, gross motor, receptive language, and expressive language) were calculated. Verbal developmental quotients (MSEL VDQ) were calculated from the receptive and expressive subscales. Nonverbal cognitive skills were assessed using t-scores from the visual reception and fine motor subscales. The ADOS is a semistructured observational play assessment of social interaction, communication, and repetitive behaviors [Lord et al., 2000]. Module 1 or 2 was administered to all participants and conventional scoring algorithms were applied to create calibrated severity scores for the social affect (ADOS SA CSS) and restricted and repetitive behavior (ADOS RRB CSS) domains [Hus, Gotham, & Lord, 2014].

Statistical Analysis Plan

As of May 2, 2018, data were available for 96 infants. Home language recordings were collected between April 14th, 2012, and October 17th, 2017. All analyses were performed using SAS statistics software, version 9.4 (SAS Institute INC, Cary, NC).

Group differences in demographics and home language recording variables were examined at both 9-and 15-months. Estimated AWC and CTC were visually inspected for normality and outliers using histograms. In the AWC data, one extreme outlier was identified (>4 SD from mean), and this recording day was subsequently excluded from all analyses. The other recording day for that participant was within the expected range and was thus included in the analyses. Distributions for AWC at 9 and 15 months, and CTC at 15 months were found to not approximate a normal distribution using the Shapiro-Wilks test. As such, generalized linear models with appropriate distribution and log link functions were utilized in the place of traditional regression models.

Home language environment variables were then examined for their association with later infant language skills (MSEL VDQ) using linear regression, with MSEL VDQ as the response variable, fixed effects including group, language environment, and a language environment × group interaction. Control variables, selected a priori, included clinical data collection site (to account for potential site differences in collected data), maternal education (to account for known associations between maternal education and child language skills [Hart & Risley, 1995], and sex of the infant (to account for potential sex differences in language acquisition [Bornstein, Haynes, Painter, & Genevro, 2000; Eriksson et al., 2012]. Variable selection was done a priori in lieu of empirical procedures such as stepwise selection, as they have been shown to result in invalid inference [Flom & Cassell, 2007]. Maternal education was a three-level variable (high school degree/college degree/graduate degree). This rationale for inclusion of covariates applies to all of the following analyses. For all analyses, when multiple tests were conducted using the same response variable, a false discovery rate (FDR) procedure was used to correct for multiple comparisons using Benjamini and Hochberg's [1995] one-step model. Adjusted *p*-values are presented as *q*-values.

Next, analyses were conducted to fully explore possible associations between the language environment and parent factors including: education, race, and age at child's birth. For all models, language environment variables served as the response variable, with fixed effects including group, parental factor, and group × parental factor. Control variables included clinical data collection site and sex of infant. For models including education and age at childbirth, over-dispersed Poisson regression models with log link function were used due to overdispersion of the response variable. For models including parental race, negative binomial distribution with log link function was used as it provided better fit than the Poisson distribution.

Mediation analyses using SAS PROC CAUSALMED were then conducted across all infants to determine the indirect effect of maternal education on language skills at 24 months, as mediated by home language variables at 15 months. Significance of indirect effects was based on 95% confidence intervals computed using the bias corrected bootstrap with 1,000 samples per Preacher and Hayes [2008]. Due to the model framework of this mediation analyses, a two-level maternal education variable was utilized (high school degree and college degree/graduate degree), and the AWC and CTC were rescaled using a min-max normalization (due to the large range in values). The results are visualized in Figure 2 using the traditional three-step model per Baron and Kenny [1986]. Supplementary analyses include models with diagnostic group as a covariate, and mediation models with AWC and CTC at 9 months.

Next, language environment variables were examined for their association with later autism symptoms (ADOS SA CSS and ADOS RRB CSS) using generalized linear models with Poisson distribution with log link function. ADOS SA CSS and ADOS RRB CSS were the response variables, and fixed effects included group, language environment, and language environment × group interaction. Control variables included clinical data collection site, maternal education, and sex of the infant.

Last, we examined data for potential group differences in longitudinal language environment data across 9 and 15 months using generalized linear mixed models. A Poisson regression model with log link function was fit, as the response variables, AWC and CTC, constitute integer count data. The intercept term was treated as a random effect. Control variables, selected a priori, included clinical data collection site, maternal education level, and sex of the infant. Planned post hoc tests of simple slopes were performed to determine if, within each group, the home language variable change from 9 to 15 months was different from zero. Tests of simple slopes were planned and thus analyzed regardless of omnibus results [Ruxton & Beauchamp, 2008].

Results

Demographics and Home Language Environment Recording Information

Table 1 includes participant demographic information, group numbers at each visit, and MSEL and ADOS scores. Groups did not differ on proportion of male and female participants, child race, parental race, age at child's birth, parental educational attainment, or chronological age at 24-month research visit. Child language skills did not differ by sex of the infant (see Supplement 1).

Of the 306 recording days collected, 94.77% ($n = 290$) were the full 16 hr, 4.25% ($n = 13$) were between 8 and 16 hr in length, and 0.98% ($n = 3$) were below 8 hr. A recording was considered valid and included in analyses if it contained at least 8 hr of audio data. This benchmark was selected as it represents both the average waking day and at least half of the maximum 16-hr recording time [Swanson et al., 2018]. Recordings less than 16 hr were not adjusted as shorter recordings were frequently a result of parents turning off the recorder at bed time. The majority of families generated two full-days of recordings at each time point (Table S2; a single day of recording has been shown to be stable in previous reports [Yoder, Oller, Richards, Gray, & Gilkerson, 2013]). The groups did not differ at either 9 or 15 months on chronological age at recording, number of recorded days, average daily length of recording, or time period between 9 and 15 month recording (Table S2).

AWC data were highly correlated across recording days at 9 months (r_s (70) = 0.852, $P < 0.0001$) and 15 months (r_s (69) = 0.735, $P < 0.0001$), and values did not differ across recordings days at 9 months ($Z = -89.5$, $P = 0.60$) or 15 months ($Z = -103.50$, $P = 0.43$). Similarly, CTC data were highly correlated across recording days at 9 months (r_s (70) = 0.586, $P < 0.0001$) and 15 months (r_s (69) = 0.652, $P < 0.0001$), and values did not differ across recordings days at 9 months ($Z = 148.50$, $P = 0.38$) or 15 months ($Z = -20.00$, $P = 0.90$).

The Language Environment and Later Child Language Skills

Next, we investigated the potential effects of the language environment (at 9 and 15 months) on later language skills (MSEL VDQ at 24 months). Results revealed a significant main effect for AWC at 9 months, $F(1, 63) = 8.70$, $P = 0.004$, $\beta = 0.00077$ (Fig. 1A). For every 5,000 unit increase in adult words, MSEL VDQ increased by approximately 4 points. Results indicated the group × AWC interaction term did not reach statistical significance.

These results indicate that hearing more adult words at 9 months was significantly associated with better MSEL VDQ scores at 24 months, and that this association was not significantly different across the three diagnostic groups. This same pattern of results was found for all language environment variables; across all groups hearing more adult words and experiencing more conversational turns at both 9 and 15 months was significantly associated with better language skills at 24 months (Table 2, Fig. 1B–D). Table 2 includes FDR corrected *P*-values (*q*-values), and tests of simple slopes, which evaluate the association between home language and later child language skills within each group separately.

To determine if the language environment was related to general cognition or more specifically language skills, we added MSEL visual reception t-scores and fine motor *t*-scores at 24 months as a fixed effect to the models tested above. The significant association between language environment variables and MSEL VDQ remained significant even after adding nonverbal cognitive variables to the models (Table S3).

Maternal Factors and Language Environment Variables

To determine if maternal demographic factors are associated with the language environment, we tested several explanatory variables including: maternal education, maternal age at childbirth, and maternal race on four response variables including AWC and CTC at 9 and 15 months. Maternal education was significantly associated with AWC at both 9 and 15 months $F(2,65) = 6.42$, $P = 0.040$ and $F(2,65) = 9.92$, $P = 0.007$, respectively (see Table S4 for full fixed effects results). The effect of maternal education on AWC at 9 months did not survive multiple comparison correction. Maternal education level was not significantly associated with CTC at 9 months, but was significantly associated with CTC at 15 months, $F(2,65) = 9.25$, $P = 0.009$. Neither maternal age at childbirth nor maternal race was significantly associated with home language variables (Table S4).

Paternal Factors and Language Environment Variables

We similarly tested if paternal demographic factors were associated with the home language environment. Paternal education was not significantly associated with AWC or CTC at 9 months (Table S5). Paternal education was, however, found to be significantly associated with AWC at 15 months and CTC at 15 months ($F(2,63) = 10.08$, $P = 0.006$ and $F(2,63) = 8.65$, $P = 0.013$, respectively). Neither paternal age at childbirth nor paternal race was significantly associated with home language variables (Table S5).

The Language Environment as a Mediator of Maternal Education and Child Language

Next, we conducted two mediation analyses to determine if the language environment at 15 months (AWC and CTC) mediated the association between maternal education and later child language skills. Maternal education, rather than paternal education, was selected for these models based on previous work showing maternal education is the component of SES that has the strongest association to later child behavioral outcomes [Bornstein, Hahn, Suwalsky, & Haynes, 2003].

In the first mediation analysis, AWC at 15 months was the mediator, maternal education was the causal variable, and MSEL VDQ at 24 months was the outcome variable. Results indicated a significant indirect effect (coefficient = 5.79, 95% CI 1.94–11.91), with 60.36% of the effect of maternal education on language skills being attributed to AWC at 15 months. In a second mediation model, we tested whether the association between maternal education and child language skills was mediated by CTC at 15 months. The indirect effect for this model was also significant (coefficient = 6.30, 95% CI 2.17–12.94), with 65.70% of the effect of maternal education on language skills being attributed to CTC at 15 months. Figure 2 includes estimated beta values for each effect using the Baron and Kenny [1986] approach. Results based on the mediation models were consistent and significant after adding diagnostic group as a covariate (see Supplementary Results). While not a priori tests, we also tested mediation models for AWC and CTC at 9-months. These tests indicated 9-month language environment variables did not significantly mediate the association between maternal education and child language skills (see Supplementary Results).

The Language Environment and Later Autism Symptoms

In the next set of analyses, we aimed to examine the possible association between language environment variables and behaviors associated with ASD (ADOS RRB CSS and ADOS SA CSS at 24 months). We did not find evidence that AWC or CTC (at either time point) was associated with 24-month ADOS SA CSS scores, nor was AWC at 9 or 15 months associated with ADOS RRB CSS (Table S6).

Results did indicate a significant association between CTC at 9 months and ADOS RRB CSS at 24 months, $F(1, 62) = 14.59$, $P = 0.0001$; however, the group × CTC interaction term was not significant. These results suggest that across groups, infants who display more repetitive behaviors engaged in fewer conversational turns with their parents earlier in life. A similar pattern of results was found for the model testing the association between CTC at 15 months and ADOS RRB CSS at 24 months, although this association did not survive FDR correction (Table S6).

Changes in the Language Environment from 9 to 15 months

Last, we conducted exploratory analyses to examine AWC and CTC longitudinally. We compared group differences in the language environment across time and compared simple slopes within each group. For AWC, results indicated a significant effect for age, indicating a decrease in AWCs from 9 to 15 months ($F(2, 87) = 9.71$, $P = 0.002$); however, the main effect of group was not statistically significant ($F(2, 87) = 2.98$, $P = 0.056$), nor was the age × group interaction term ($F(2, 57) = 2.33$, $P = 0.106$). Tests of simple slopes indicated AWC decreased from 9 to 15 months in the HR-ASD group ($t = -2.06$, $P = 0.043$), and the LR-Neg group ($t = -2.85$, $P = 0.006$), but not in the HR-Neg group ($t = -0.34$, $P = 0.736$). For CTC, results indicated a significant effect for age with conversational turns increasing from 9 to 15 months, ($F(1, 57) = 5.12$, $P = 0.027$). The main effect of group and age × group interaction term was not statistically significant ($F(2, 87) = 0.38$, $P = 0.686$; $F(2, 57) = 2.23$, $P = 0.117$, respectively). Tests of simple slopes indicated CTC increased from 9 to 15 months in the LR-Neg group ($t = 3.39$, $P = 0.001$), but not in the HR-ASD ($t = -0.26$, $P = 0.796$) and HR-Neg groups ($t = 1.85$, $P = 0.070$).

Discussion

The current study examined the home language environment of infants with a family history of ASD (i.e., an older sibling) who did and did not go on to have autism themselves, and typically developing infants who did not have a family history of ASD. Two main findings emerged. First, across all infants in our study, including those with ASD, hearing more adult words and experiencing more conversational turns was significantly associated with better language skills a year later. Second, caregiver speech mediated the association between parental educational attainment and later child language skills. In a third, exploratory analysis, we found that typically developing children experienced a shift characterized by decreasing adult words and increasing conversational turns from 9 to 15 months. Infants who were diagnosed with ASD, however, experience a decrease in adult words, but not an accompanied increase in conversational turns.

The Language Environment Is Related to Later Language Skills

In the early 1990s, two seminal studies showed that infants as young as 7 months [Hart & Risley, 1995] and 14 months [Huttenlocher et al., 1991] who experienced richer language environments went on to have better language skills. Since then, this finding has been replicated many times, mostly with infants in their second and third year of life [Cartmill et al., 2013; Hirsh-Pasek et al., 2015; Hoff, 2003; Hurtado et al., 2008; Pan et al., 2005; Rowe, 2008, 2012; Weisleder & Fernald, 2013]. For the first time since Hart and Risley [1995], we report that the home language environment during the first year of life is strongly associated with later language skills in typically developing infants, and we extend these findings to infants subsequently diagnosed with ASD. Early language skills have a cascading effect on later development, including later reading and school readiness [Forget-Dubois et al., 2009; Pace, Alper, Burchinal, Golinkoff, & Hirsh-Pasek, 2018]. As such, the current study together with previous research underscore the important role caregivers play in children’s long-term development, while also highlighting the first year of life as a time when parent training could substantially support child development.

Parental Education, but Not Age or Race, Is Related to the Language Environment

After establishing the link between early language exposure and later language skills, we next aimed to determine if there were parental factors associated with caregiver speech patterns. We examined parental race and age at childbirth, as well as one component of SES, parental education. Higher maternal and paternal educational attainments were significantly associated with a richer home language environment. Parental race and age at childbirth did not have a significant effect on the home language environment. It should be noted that most of the families in the current study were of relatively high SES, and future studies should aim to include families across the socioeconomic stratum. There is a growing understanding that developmental pathways (like the link between adult talk and child language skills) are culturally specific rather than universal for all infants [Morelli et al., 2018], so the findings of the current study may not apply to non-Western cultures. It is also important to recognize that adult speech is only one way in which parent communication supports child development [Sperry, Sperry, & Miller, 2018].

Language Environment Variables Mediate the Association between Parental Education and Child Language Skills

Previous studies have found that caregiver speech mediates the association between SES and child language skills [Hoff, 2003; Huttenlocher et al., 2010]. We also found evidence that caregiver speech at 15 months mediates the association between maternal education and child language skills at 24 months for all infants in our study. However, it is likely that SES is distally related to caregiver speech, with research suggesting that more proximal factors might include parent knowledge of child development, views on teaching and learning, access to written material related to parenting, parental depression, and household organization (e.g., family instability, crowdedness of home, and high noise levels) [for a review of this literature see Rowe, 2018]. Understanding the mechanism behind the SES-caregiver speech association has the potential to inform large-scale early intervention programs (e.g., Providence Talks[1]) and move the field closer to an individualized intervention approach. For example, Andersen and Nielsen [2016] conducted a reading intervention with an embedded growth mindset component that teaches parents they can make a difference in their child's development (a growth mindset is in contrast to a fixed mindset where intelligence is viewed as a fixed trait that cannot be changed). They found that children of parents with the highest fixedness beliefs at study entry had the largest growth in reading skills post-intervention.

The Language Environment May Change Differentially across Groups

In this study, we conducted exploratory analyses to examine how features of the home language environment changed between 9 and 15 months. Tests of simple slopes indicated that caregivers of typically developing children decreased the number of adult words directed to children from 9 to 15 months, but increased their conversational turn-taking from 9 to 15 months. This pattern likely reflects the infants' growing communication skills allowing them to participate more fully in the social feedback loop, where speech-related vocalizations are more likely to receive a response from a caregiver than nonspeech vocalizations [Bell, 1968; Warlaumont, Richards, Gilkerson, & Oller, 2014]. This suggests greater "quality" of contingent exchanges over time, with a concurrent reduction in one-sided "quantity."

In contrast, test of simple slopes revealed that caregivers of children with ASD decreased their speech but did not increase their conversational interchanges, which could be indicative of a disrupted social feedback loop. Further, across all infants, those who displayed more repetitive behaviors engaged in fewer conversational turns with adults. These results could reflect emergent communication difficulties [Iverson & Wozniak, 2007; Mayo, Chlebowski, Fein, & Eigsti, 2013; Swanson et al., 2017] and restricted and repetitive behaviors (RRBs) [Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012; Wolff et al., 2014] impacting parent–child communication in young children with ASD. It has been hypothesized that communication difficulties contribute to a diminished social feedback loop in toddlers with ASD [Warlaumont et al., 2014], but it is also plausible that RRBs impinge on the social

[1]http://www.providencetalks.org/

feedback loop. These exploratory findings require replication and should be interpreted accordingly.

Study Limitations

The current study is based on a family design where infants either do or do not have an older sibling with ASD. This type of prospective design often yields samples with higher developmental levels when compared to clinically referred toddlers with ASD, as such these findings may not generalize to all individuals with ASD. The sample of children with ASD in the current study is comparable to other similar family studies [Emerson et al., 2017; Jones & Klin, 2013; Miller et al., 2017], but smaller than many clinically referred samples of toddlers with ASD. Given the sample size, the statistically significant results reported herein require replication, and future efforts should fully explore possible group differences in caregiver speech, and the association between caregiver speech and later language skills. Subgroup analyses should be interpreted with caution as small sample sizes can increase the risk of false negative and false positive results. Nevertheless, the results showing that early caregiver speech is associated with later language scores are consistent with studies of older children with ASD [Siller & Sigman, 2002; Warren et al., 2010].

Conclusions

In conclusion, we observed that infants who heard more caregiver speech had better language skills later in life. Our study illustrated, for the first time, that the positive association between caregiver speech and later language ability previously reported in older children is also true for infants who are later diagnosed with ASD. Across all infants in our study, maternal education was the parental factor most strongly associated with a rich language environment. These findings highlight the language environment as both a means to support development in infants with ASD and as a potential treatment target for very early intervention studies, which often include a parent training component [Green et al., 2017]. However, given the diminished social feedback loop in ASD, it is unlikely that an intervention aimed at simply increasing caregiver talk without considering such factors as engagement state [Bottema-Beutel et al., 2014], would be optimally impactful. Rather, future studies should consider parental factors that may influence caregiver talk and include approaches to strengthen the social feedback loop.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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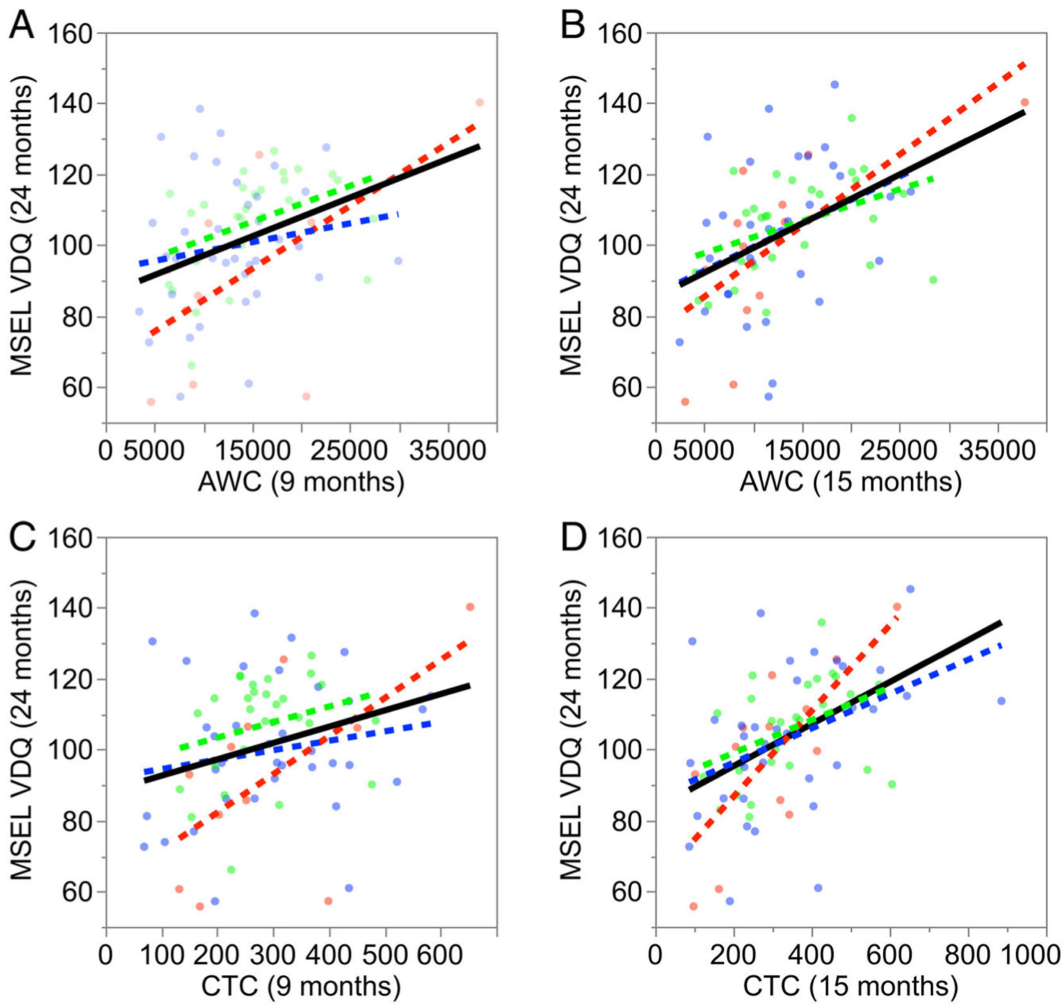

Figure 1.

The home language environment at 9-months (panel **A** and **C**) and 15-months (panel **B** and **D**) is significantly associated with later language skills at 24 months, after controlling for clinical data collection site, maternal education, and sex of the infant. Dotted lines represent regression lines for each group (HR-ASD in red, HR-Neg in blue, and LR-Neg in green). Bold line is the model fit regression line across all infants.

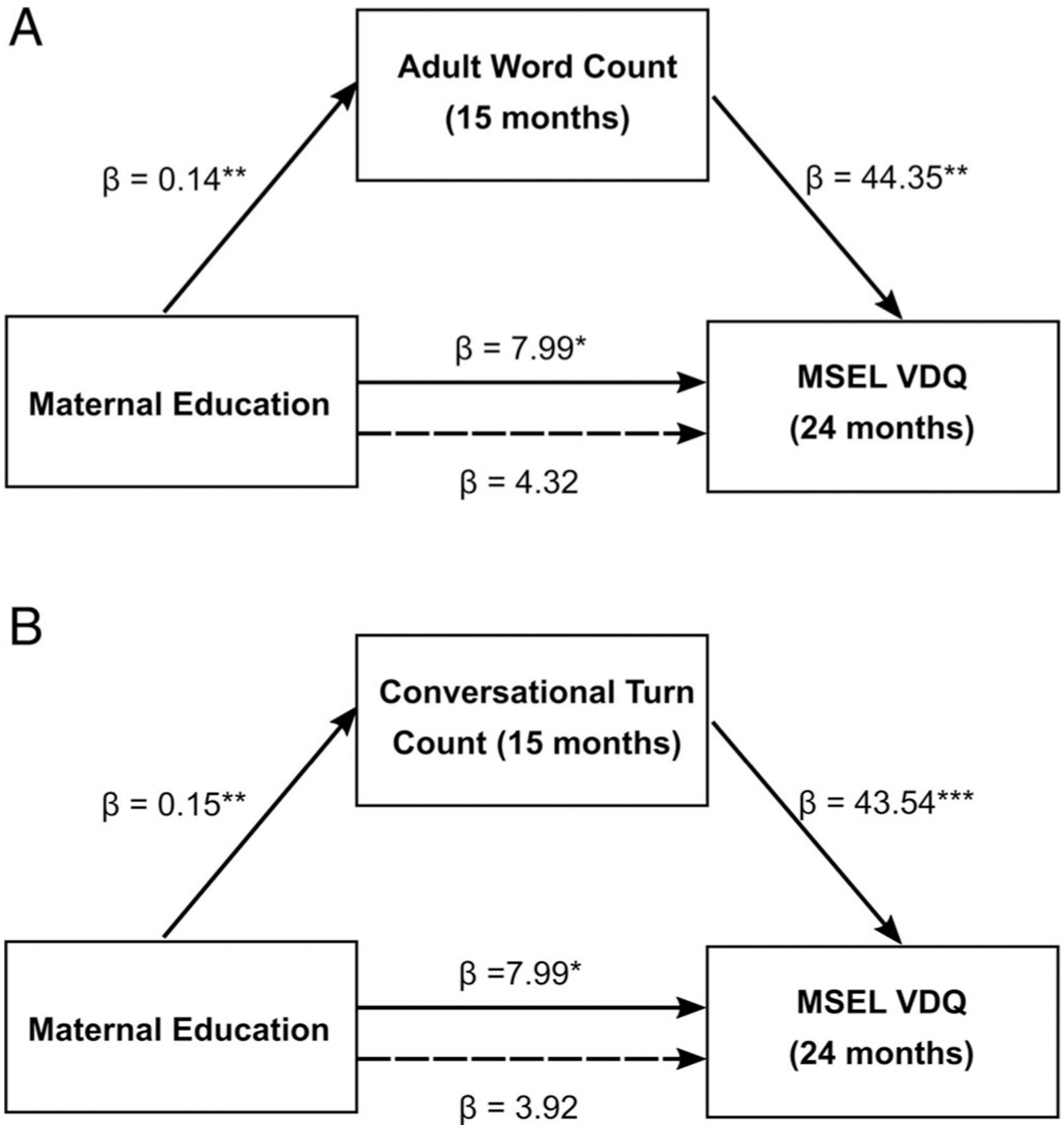

Figure 2.
Adult word count significantly mediates the association between maternal education and MSEL VDQ (panel **A**), after controlling for clinical data collection site, diagnostic group, and sex of the infant. Conversational turn count also significantly mediates the association between maternal education and MSEL VDQ (panel **B**), after controlling for clinical data collection site, diagnostic group, and sex of the infant. Along the lower path, a solid line shows results when the mediator is not included, dashed line was shows results when it is included. Asterisks indicate significance paths, *$P = 0.05$, **$P < 0.001$, ***$P < 0.0001$.

Table 1.

Descriptive Data for Study Sample by Group

Variable	HR-ASD	HR-Neg	LR-Neg	Test statistic
9 months (*n*)	11	38	29	
15 months (*n*)	13	36	29	
9 & 15 months visit (*n*)	10	28	22	
Weeks between 9 and 15 months	23.73 (5.41)	26.71 (3.08)	25.87 (3.44)	$F = 2.43$, $P = 0.096$
Mean age 24 months visit	25.34 (2.12)	24.71 (0.88)	25.14 (1.72)	$F = 1.40$, $P = 0.252$
24 months MSEL ELC	92.78 (20.59)	103.73 (16.67)	109.85 (13.41)	$F = 5.63$, $P = 0.005$; $a < c$
24 months MSEL VDQ	96.06 (25.73)	102.38 (19.85)	105.49 (15.16)	$F = 1.20$, $P = 0.304$
24 months MSEL VR *t*-score	46.64 (12.30)	53.43 (10.64)	57.80 (8.63)	$F = 6.14$, $P = 0.003$ $a < c$
24 months MSEL FM *t*-score	41.86 (8.24)	50.43 (8.94)	54.49 (8.47)	$F = 12.58$, $P < 0.0001$; $a < b < c$
24 months ADOS RRB CSS	6.85 (1.77)	2.82 (2.24)	2.00 (1.88)	$F = 27.14$, $P < 0.0001$ $a > b, c$
24 months ADOS SA CSS	5.23 (1.43)	1.77 (0.94)	1.63 (0.91)	$F = 68.51$, $P < 0.0001$ $a > b, c$
% Male	71.43	58.70	58.33	$\chi^2 = 0.83$, $P = 0.659$
Maternal education				$\chi^2 = 7.44$, $P = 0.114$
High school diploma (%)	35.71	34.78	11.11	
College degree (%)	35.71	34.78	38.89	
Graduate degree (%)	28.57	30.43	50.00	
Paternal education[a]				$\chi^2 = 10.30$, $P = 0.119$
High school diploma (%)	42.86	39.13	16.67	
College degree (%)	21.43	39.13	41.67	
Graduate degree (%)	35.71	21.74	36.11	

Notes: MSEL ELC, MSEL Early Learning Composite Standard Score; MSEL VDQ, MSEL Verbal developmental quotients; MSEL VR *t*-score, MSEL visual reception *t*-score; MSEL FM *t*-score, MSEL fine motor *t*-score; ADOS Severity Score, Autism Diagnostic Observation Schedule Calibrated Severity Score.

[a]Data missing for two participants.

Table 2.

The Effects of the Home Language Environment on Later Child Language Skills

Response variable	**MSEL VDQ**			**MSEL VDQ**			**MSEL VDQ**			**MSEL VDQ**		
Predictor variable	AWC at 9 months			AWC at 15 months			CTC at 9 months			CTC at 15 months		
	F	*P*-value/*q*-value	β	*F*	*P*-value/*q*-value	β	*F*	*P*-value/*q*-value	β	*F*	*P*-value/*q*-value	β
Group	1.94	0.152	−19.81[a] 3.37[b]	0.57	0.567	−11.26[a] −2.97[b]	1.80	0.174	24.49[a] 0.30[b]	1.76	0.1809	−20.56[a] 1.48[b]
Home language Environment	8.70	0.004 0.005	0.0008	16.78	0.0001 0.0002	0.0007	7.61	0.007 0.007	0.0374	16.53	0.0001 0.0002	0.0358
Group × home Language	1.26	0.289	0.0009[a] 0.0003[b]	1.26	0.289	0.0011[a] 0.0005[b]	1.40	0.254	0.0598[a] 0.044[b]	2.23	0.1156	0.0739[a] .0033[b]
Control variables	***F***	***P*-value**	$\boldsymbol{\beta}$	***F***	***P*-value**	$\boldsymbol{\beta}$	***F***	***P*-value**	$\boldsymbol{\beta}$	***F***	***P*-value**	$\boldsymbol{\beta}$
Sex of infant	0.07	0.797	1.096	0.72	0.400	−3.30	0.00	0.972	0.153	0.40	0.531	−2.45
Site	1.84	0.148	0.17[c] −12.61[d] −5.47[e]	2.27	0.088	−6.09[c] −13.96[d] −10.29[e]	1.97	0.127	−4.01[c] −14.51[d] −8.07[e]	2.25	0.090	−6.90[c] −13.75[d] −10.76[e]
Maternal education	3.39	0.040	−13.02[f] −0.60[g]	3.53	0.034	−11.79[f] 0.77[g]	4.17	0.020	−14.91[f] −8.07[g]	2.05	0.136	−9.88[f] −0.58[g]
Tests of groups												
HR-ASD	2.78	0.007	0.0016	3.32	0.001	0.0006	2.70	0.008	0.0972	3.42	0.0011	0.0321
HR-Neg	0.87	0.386	0.0005	2.49	0.015	0.0005	1.28	0.205	0.0286	2.45	0.0172	0.0160
LR-Neg	1.43	0.156	0.0008	1.49	0.141	0.0005	0.96	0.341	0.0374	1.49	0.1417	0.0359

Notes: Covariates in all models include sex of the infant, maternal education, and clinical data collection site. *Q*-values are FDR corrected *p*-values. AWC, adult word count; CTC, conversational turn count. Unstandardized beta coefficients comparing the reference group (LR-Neg) to HR-ASD[a] and HR-Neg[b]. Unstandardized beta coefficients comparing the reference group (UNC Chapel Hill) to Children's Hospital Philadelphia[c], University of Washington[d], and Washington University of St. Louis[e]. Unstandardized beta coefficients comparing the reference group (Graduate Degree) to High School Degree[f] and College Degree[g].