






RESEARCH ARTICLE

Early predictors of language skills at 3 years of age vary based on diagnostic outcome: A baby siblings research consortium study

Meredith Pecukonis¹  | Gregory S. Young² | Jessica Brian³  | Tony Charman⁴  | Katarzyna Chawarska⁵  | Mayada Elsabbagh⁶  | Jana M. Iverson⁷ | Shafali Jeste⁸ | Rebecca Landa⁹ | Daniel S. Messinger¹⁰ | A. J. Schwichtenberg¹¹ | Sara Jane Webb¹² | Lonnie Zwaigenbaum¹³ | Helen Tager-Flusberg¹

¹Department of Psychological & Brain Sciences, Boston University, Boston, Massachusetts, USA

²Department of Psychiatry and Behavioral Sciences, University of California Davis, Davis, California, USA

³Department of Paediatrics, University of Toronto, Toronto, Canada

⁴Institute of Psychiatry, Psychology & Neuroscience, King's College, London, UK

⁵School of Medicine, Yale University, New Haven, Connecticut, USA

⁶Montreal Neurological Institute, McGill University, Montreal, Canada

⁷Department of Psychology, University of Pittsburgh, Pittsburgh, Pennsylvania, USA

⁸Department of Pediatrics, Department of Neurology, Department of Psychiatry and Biobehavioral Sciences, University of California, Los Angeles, California, USA

⁹Center for Autism and Related Disorders, Kennedy Krieger Institute, Baltimore, Maryland, USA

¹⁰Department of Psychology, University of Miami, Coral Gables, Florida, USA

¹¹Department of Human Development and Family Studies, Purdue University, West Lafayette, Indiana, USA

¹²Psychiatry and Behavioral Sciences, University of Washington, Seattle, Washington, USA

¹³Department of Pediatrics, University of Alberta, Edmonton, Canada

Correspondence

Meredith Pecukonis, Boston University, Department of Psychological & Brain Sciences, 64 Cummington Mall, Boston, MA 02215, USA. Email: mpecukon@bu.edu

Funding information

Autism Science Foundation; Autism Speaks; National Institutes of Health

Abstract

While previous work has identified the early predictors of language skills in infants at elevated familial risk (ER) and low familial risk (LR) for autism spectrum disorder (ASD), no studies to date have explored whether these predictors vary based on diagnostic outcome of ASD or no ASD. The present study used a large, multisite dataset to examine associations between a set of commonly studied predictor variables (infant gesture abilities, fine motor skills, nonverbal cognition, and maternal education level), measured at 12 months, and language skills, measured at 3 years, across three diagnostic outcome groups—infants with ASD (“ASD”), ER infants without ASD (“ER-no ASD”), and LR infants without ASD (“LR-no ASD”). Findings revealed that the predictors of language skills differed across groups, as gesture abilities were positively associated with language skills in the ER-no ASD group but negatively associated with language skills in the ASD group. Furthermore, maternal education level was positively associated with language skills in the ASD and LR-no ASD groups only. Variability in these early predictors may help explain why language skills are heterogeneous across the autism spectrum, and, with further study, may help clinicians identify those in need of additional and/or specialized intervention services that support language development.

Lay Summary: The present study identified predictors of language skills in infants with and without autism spectrum disorder (ASD). Maternal education level and 12-month gesture abilities predicted 3-year language skills in infants with ASD. Measuring these predictors early in life may help identify infants and families in need of additional and/or specialized intervention services that support language development.

KEY WORDS

gesture, infant sibling, language, maternal education, motor, nonverbal cognition

Meredith Pecukonis and Gregory S. Young are joint first author.

INTRODUCTION

Language skills vary greatly across the autism spectrum, from non or minimally verbal to verbally fluent. Research on infants at elevated familial risk (ER) for autism spectrum disorder (ASD) has found that variability in language skills begins early in life. ER infants, who have an older sibling with ASD, are more likely to receive an ASD diagnosis when compared to infants at low familial risk (LR) who have no family history of ASD (Messinger et al., 2015; Ozonoff et al., 2011). ER infants exhibit heterogeneous language skills, regardless of whether or not they receive an ASD diagnosis (Gamliel et al., 2009; Landa et al., 2012; Longard et al., 2017; Messinger et al., 2015). Identifying the early predictors of language skills will provide insights into what might underlie heterogeneity in this population.

Prospective longitudinal studies of ER infants afford the opportunity to study early predictors of language in those later diagnosed with ASD (Tager-Flusberg, 2018). It is particularly important to study predictors within the first 3 years of life, as this is a sensitive period of development characterized by rapid growth and dynamic changes in language skills. Identified predictors may serve as early markers for subsequent language difficulties. Furthermore, variables that reliably predict language skills may be targeted in early interventions to promote language development.

Most studies have focused on identifying behavioral predictors of language skills in infants with ASD and ER infants without ASD, such as gesture abilities, fine motor skills, and nonverbal cognition. Fewer studies have identified distal environmental predictors of language skills, such as maternal education level, a well-documented predictor of language skills in TD children (Hoff et al., 2013). Examining all of these commonly studied predictors of language within a single sample will inform our understanding of how these variables work together to shape language development, and will further support a multisystems approach to diagnosis and treatment of language difficulties in infants with ASD and ER infants without ASD.

Gesture supports language acquisition in children with and without ASD (Colonnese et al., 2010; Goldin-Meadow, 2015; Ramos-Cabo et al., 2019). Among ER infants with and without ASD and older children with ASD, gesture abilities are positively associated with concurrent (Hughes et al., 2019; Luyster et al., 2008; Stone et al., 2007) and longitudinal language skills (Manwaring et al., 2017). Two longitudinal studies reported that frequency of gesture use at 12 months was a positive predictor of language skills at 18 (Talbot et al., 2015) and 24 months (Choi, Shah, et al., 2020) in ER infants with and without ASD. To our knowledge, only one study has reported a negative relation between gesture and language in older children with ASD (Carpenter et al., 2002).

Gross and fine motor skills also support the development of language skills (Iverson, 2010; Leonard &

Hill, 2014). In ER infants with and without ASD, motor delays are related to language difficulties (Iverson, 2018). Fine motor skills play a particularly important role in language development. A meta-analysis reported that ER infants with and without ASD exhibited reduced fine motor skills by 12 months of age, which corresponded with reduced language skills throughout the first 3 years of life (Garrido et al., 2017). Moreover, fine motor skills, assessed from 6 to 24 months, were positively related to language skills at 3 years in ER infants with and without ASD and older children with ASD (Choi et al., 2018; LeBarton & Iverson, 2013; LeBarton & Landa, 2019). Less is known about how fine motor skills interact with other predictor variables, such as gesture abilities, to shape language in this population, although one might expect these variables to be related because gesture entails fine motor performance (Franchini et al., 2018).

Broader difficulties with nonverbal cognitive tasks, often reflected by lower visual reception scores, may contribute to language difficulties in infants with ASD and ER infants without ASD (Messinger et al., 2013; Stone et al., 2007). Positive relations between nonverbal cognition and language skills in older autistic children have been reported (Thurm et al., 2007; Wodka et al., 2013; although see Charman et al., 2003). However, few studies have directly assessed the relation between nonverbal cognition and language in ER infants with and without ASD, as nonverbal cognition is often a control variable rather than a predictor variable in analyses (Choi et al., 2018; Choi, Shah, et al., 2020; LeBarton & Iverson, 2013). Further research is needed to determine whether nonverbal cognition independently predicts longitudinal language skills in infants with ASD and ER infants without ASD when accounting for other commonly studied behavioral predictors (e.g., gesture abilities and fine motor skills).

Maternal education level, a measure of socioeconomic status (SES), is a robust, positive predictor of TD children's language skills (Hoff, 2006; Hoff et al., 2012). Dollaghan et al. (1999) reported that children whose mothers attained some form of higher education had stronger language skills than children whose mothers attained education at the high-school level or below. Other work has documented that supporting mothers in education beyond high school indirectly benefits their children's language development (Magnuson et al., 2009). Positive associations between maternal education level and language skills have also been found for 24-month-old ER infants with and without ASD (Choi, Nelson, et al., 2020; Swanson et al., 2019) and older children with ASD (Olson et al., 2021). Most studies, however, have not explored how maternal education level interacts with behavioral predictors of language (although see Weismer & Kover, 2015).

To date, no studies on the predictors of language have examined infant gesture abilities, fine motor skills, nonverbal cognition, and maternal education level within the

same sample of infants with ASD and ER infants. Furthermore, prior infant studies have lacked sample sizes large enough to test whether predictors of language differ based on diagnostic outcome of ASD or no ASD. The present study aimed to address these limitations by identifying the early predictors of language skills at 3 years of age in a large sample of ER and LR infants drawn from the multisite baby sibling research consortium (BSRC). We examined whether the associations between language skills and our predictor variables of interest differed across three outcome groups—infants diagnosed with ASD by 3 years (“ASD”), ER infants not diagnosed with ASD by 3 years (“ER-no ASD”), and LR infants not diagnosed with ASD by 3 years (“LR-no ASD”). We hypothesized that across all groups, infant gesture abilities, fine motor skills, nonverbal cognition, and maternal education level, measured at 12 months, would be positively related to language skills, measured at 3 years. Because no studies have measured all these predictor variables within the same sample, we did not have *a priori* hypotheses about which predictors would remain in the model and which predictors would be eliminated after a backward elimination procedure. Based on the findings of Luyster et al. (2008), however, one possible hypothesis is that gesture abilities and nonverbal cognition remain significant predictors in the model, while motor skills does not.

METHOD

Participants

Data were collected from 13 BSRC sites between 2003 and 2015. Infants were drawn from two recruitment groups—ER infants, who had at least one older sibling with ASD, and LR infants, who had an older, nonautistic sibling and no family history of ASD. Data inclusion criteria were: (a) enrollment at 12 months or younger; (b) data from the Mullen Scales of Early Learning, the Autism Diagnostic Observation Schedule, and clinical best estimate at 3 years; (c) data from the MacArthur-Bates Communicative Development Inventory at 12 months; and (d) at least some available demographic data. Across all BSRC sites, exclusion criteria included identified genetic or neurologic conditions (e.g., fragile X syndrome, tuberous sclerosis). All BSRC sites obtained Institutional Review Board approval as well as individual family consent to collect and share data across sites.

Measures

Mullen scales of early learning

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) is a standardized assessment of early cognitive development that provides age equivalent (AE) scores on

four subscales—receptive language, expressive language, fine motor, and visual reception. The MSEL was administered at the 12-month and 3-year visits. AE scores for all MSEL subscales at 12 months were included as predictor variables in our analyses, while receptive language and expressive language AE scores at 3 years were included as outcome variables. Visual reception AE scores were used as our measure of nonverbal cognition. The gross motor subscale was not administered consistently across BSRC sites and thus it was not included as a predictor variable of interest in the present study.

MacArthur-Bates communicative development inventory—words and gestures

The MacArthur-Bates Communicative Development Inventory—Words and Gestures Form (MCDI; Fenson et al., 1993) is a parent-report measure that assesses the repertoire of different gestures and communicative actions in infants. The MCDI was administered at the 12-month visit across 6 of the 13 BSRC sites. Total scores from two MCDI subscales were used as predictor variables—early gestures, which includes items related to first communicative gestures (e.g., pointing) and games and routines (e.g., peekaboo), and late gestures, which includes actions with objects (e.g., push toy car), pretending to be a parent (e.g., put doll to bed), and imitating adult actions (e.g., wash dishes).

Demographics

Each BSRC site collected demographic information on race, ethnicity, and maternal education level at or before the 12-month visit. Given between-site variations in how demographic information was collected, categorical data were collapsed into fewer categories to merge multisite data. Maternal education level was collapsed into three categories—some college or less, college degree, and graduate degree. Similarly, race was collapsed into two categories based on minority status—non-White (including Hispanic/Latino) and White.

Autism diagnostic observation schedule

The Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000; Lord et al., 2012) is a semistructured, standardized assessment of social communication and repetitive behaviors that allows for the diagnosis of ASD. Module 1 (21.77%) or Module 2 (78.23%) of the ADOS was administered by trained study staff at the 3-year visit. 94.37% of infants in the current sample received the ADOS-G and 5.63% of infants were administered the ADOS-2; diagnostic information from both versions of the ADOS are equivalent (Lord et al., 2012).

Clinical best estimate

Clinical best estimate (CBE) was determined by a licensed clinical psychologist, developmental pediatrician, or child psychiatrist at the 3-year visit. Clinical judgment was informed by live observation, video review, and consideration of assessments. Diagnostic outcome of ASD or no ASD was determined using both the ADOS and CBE. DSM-IV diagnoses of autistic disorder, pervasive developmental disorder-not otherwise specified, Asperger syndrome, or ASD were classified under one unifying DSM-5 diagnosis of ASD (American Psychiatric Association, 2013).

Analytic plan

Analyses involved two multivariate regression models—a baseline model and a stepwise model. For the baseline model, 3-year scores from both MSEL language subscales were modeled as a single repeated measure with two values (receptive language AE scores and expressive language AE scores). BSRC site and infant ID were included as random effects to account for dependencies in the data. MSEL language subscale was included as a fixed factor repeated measure. Age in months at the 12-month and 3-year visits were included as covariates to account for variability in each infant's age around the visit time points. 12-month receptive language and expressive language scores were also included as covariates to account for autocorrelation. The modeling strategy then proceeded by examining the main effects and interaction effects of MSEL language subscale, sex, and outcome group. Given that language subscale was treated as a fixed factor repeated measure, main effects of sex and outcome group provided tests for differences in overall language scores (collapsing across the MSEL receptive language and expressive language subscales); interaction effects between sex and language subscale, as well as outcome group and language subscale, provided tests of whether differences between males and females or among outcome groups varied as a function of language subscale.

The next phase of analysis involved the examination of five additional predictor variables, in addition to the baseline model's predictor variables and covariates. Additional predictor variables included 12-month MCDI early gestures scores, MCDI late gestures scores, MSEL fine motor scores, MSEL visual reception scores, and maternal education level. These predictor variables were selected because they are some of the most commonly studied predictors of language skills in the literature, and because we had reliable, valid measures of these variables across BSRC sites. A backward elimination procedure was used wherein the full set of predictors was first considered in the stepwise model. Next, the least consequential predictors with the highest *p*-values were removed

from the model one at a time until a final parsimonious set of significant predictors could be identified. The main effects for remaining predictor variables were then evaluated. We also evaluated how remaining predictor variables interacted with baseline predictor variables (language subscale, sex, outcome group). Main effects and interaction effects were evaluated by comparing the model containing the effect in question with a simpler model without that effect using deviance testing of -2 log likelihood values, with the difference assessed as a Chi-square distribution in which the degrees of freedom were equivalent to the difference in the number of parameter estimates between the two models. Analyses were conducted in R v3.6.1 (R Core Team, 2019) using the lme4 package (Bates et al., 2015). Supplementary analyses conducted with MSEL raw scores revealed results that were similar to analyses conducted with MSEL AE scores.

RESULTS

Sample characteristics

The full sample included $N = 796$ infants. $N = 114$ of these infants were in the "ASD" outcome group. While most infants in the ASD outcome group were from the ER recruitment group (as expected given our recruitment strategy), five infants in the LR infant recruitment group were diagnosed with ASD and were thus included in the ASD outcome group. These five infants were retained in the sample because we were interested in identifying the predictors of language skills in all infants with ASD, regardless of their familial risk status. Excluding these five infants from the sample did not change any results. The remaining infants who did not meet diagnostic criteria for ASD by 3 years included $N = 434$ infants in the "ER-no ASD" outcome group and $N = 248$ infants in the "LR-no ASD" outcome group. Seven infants in the ER recruitment group received a CBE of ASD but did not meet diagnostic criteria for ASD on the ADOS. In instances where CBE and ADOS classifications conflicted, infants were not classified as having an ASD outcome, as infants needed to meet criteria for ASD on both the ADOS and CBE. Thus, these infants were included in the ER-no ASD outcome group. These seven infants were retained in the sample to reflect the heterogeneity of autism symptoms that exists within the broader ER population, even when a formal ASD diagnosis is not present. Excluding these seven infants from the sample did not change any results. Given that only six of the BSRC sites collected MCDI data, the stepwise model included a subsample of $N = 463$ infants (60 ASD, 216 ER-no ASD, 187 LR-no ASD) who had data from all measures. Table 1 shows demographics and descriptives of the full sample by outcome group.

TABLE 1 Sample demographics and descriptives by outcome group

	LR-no ASD (<i>N</i> = 248)	ER-no ASD (<i>N</i> = 434)	ASD (<i>N</i> = 114)
Age first recruited (months)	5.79 (1.98)	5.46 (2.36)	6.00 (2.28)
Age at 12-month visit (months)	12.13 (0.38)	12.15 (0.38)	12.17 (0.40)
Age at 3-year visit (months)	36.16 (0.62)	36.25 (0.65)	36.32 (0.70)
Sex (% male) ^d	53.23% ^b	52.07% ^b	70.18% ^a
Maternal education (% less than college degree) ^d	19.41% ^b	26.74% ^a	33.67% ^a
Maternal education (% college degree) ^d	41.77%	48.47%	45.92%
Maternal education (% graduate degree) ^d	38.82% ^b	24.79% ^a	20.41% ^a
Birth order (% third born or later) ^d	9.52% ^c	51.06% ^b	37.93% ^a
Minority status (% non-White)	29.30%	31.91%	42.62%
ADOS severity score at 3-year visit ^d	1.57 (1.57) ^b	1.81 (1.31) ^b	6.88 (1.82) ^a
MSEL receptive language AE score at 12-month visit ^d	11.62 (2.09) ^c	10.99 (2.34) ^b	9.68 (2.92) ^a
MSEL expressive language AE score at 12-month visit ^d	11.84 (2.44) ^b	11.48 (2.78) ^b	10.38 (2.72) ^a
MSEL fine motor AE score at 12-month visit ^d	14.85 (1.81) ^c	14.42 (2.06) ^b	13.84 (2.08) ^a
MSEL visual reception AE score at 12-month visit ^d	14.17 (1.83) ^c	13.59 (1.95) ^b	12.68 (1.84) ^a
MCDI early gestures total score at 12-month visit ^d	10.31 (2.70) ^c	9.16 (3.07) ^b	7.58 (3.10) ^a
MCDI late gestures total score at 12-month visit ^d	12.44 (7.39) ^c	9.96 (5.85) ^b	7.97 (4.94) ^a

Note: Values in the table reflect means and standard deviations in parentheses unless otherwise specified.

Abbreviations: ADOS, autism diagnostic observation schedule; AE, age equivalent; MCDI, MacArthur-Bates communicative development inventory; MSEL, Mullen scales of early learning.

^aSig. difference from LR-no ASD group.

^bSig. difference from ASD group.

^cSig. difference from ER-no ASD group.

^dGroups with differing superscripts (a, b, c) indicate significant group difference at $p < 0.05$.

Baseline model

The ICC for BSRC site as a random effect was 0.08, suggesting little variability in 3-year language scores across testing sites, whereas the ICC for infant ID as a random effect was 0.75, suggesting a large amount of variability in 3-year language scores across infants. Model diagnostics did not reveal any issues with distributions or residuals.

The baseline model revealed a significant main effect of 12-month language scores as a covariate of respective 3-year language scores ($B = 0.48$, $SE = 0.06$, $t [1285.54] = 7.96$, $p < 0.001$). Ages at the 12-month and 3-year visits were not significant predictors of 3-year language scores ($ps > 0.20$), but were retained in the model for statistical control. The main effect of language subscale was significant ($X^2 = 26.01$, $df = 1$, $p < 0.001$; Cohen's $d = 0.13$), with expressive language scores (estimated marginal mean [EMM] = 37.9, $SE = 0.62$) 1 point higher than receptive language scores (EMM = 36.9, $SE = 0.62$). The main effect of sex was also significant ($X^2 = 22.88$, $df = 1$, $p < 0.001$; Cohen's $d = 0.31$), with males (EMM = 36.3, $SE = 0.63$) scoring 2.32 points lower on overall language scores than females (EMM = 38.6, $SE = 0.64$). The interaction between sex and language subscale was nonsignificant ($X^2 = 0.58$, $df = 1$, $p = 0.45$).

The main effect of outcome group was significant ($X^2 = 169.27$, $df = 2$, $p < 0.001$), with the ASD group (EMM = 30.9, $SE = 0.77$) scoring significantly lower than both the ER-no ASD group (EMM = 37.6, $SE = 0.58$; $t [799] = 10.26$, $p < 0.001$, Cohen's $d = 0.99$) and the LR-no ASD group (EMM = 40.5, $SE = 0.65$; $t [802] = 13.59$, $p < 0.001$, Cohen's $d = 1.41$) on overall language scores. The ER-no ASD group also had significantly lower overall language scores when compared to the LR-no ASD group ($t [782] = 5.67$, $p < 0.001$, Cohen's $d = 0.42$). The interactions between outcome group and language subscale ($X^2 = 1.89$, $df = 2$, $p = 0.39$), outcome group and sex ($X^2 = 1.77$, $df = 2$, $p = 0.41$), and outcome group, language subscale, and sex ($X^2 = 2.94$, $df = 2$, $p = 0.23$) were all nonsignificant.

Stepwise model with backward elimination procedure

The backward stepwise procedure eliminated 12-month MCDI early gestures scores ($p = 0.66$), MSEL fine motor scores ($p = 0.15$), and MSEL visual reception scores ($p = 0.46$). Significant main effects were found for 12-month MCDI late gestures scores ($F = 5.68$, $df = 1448.68$, $p < 0.05$) and maternal education level ($F = 19.28$, $df = 1442.68$, $p < 0.001$), which were retained

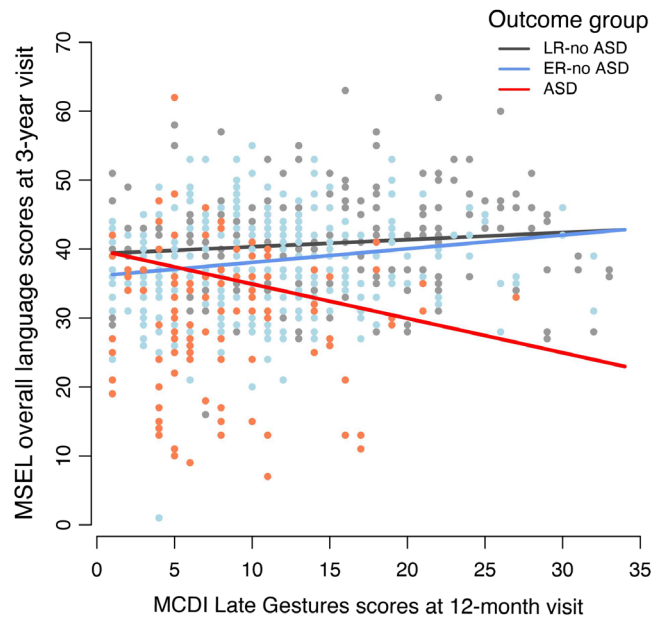


FIGURE 1 Interaction between MCDI late gestures total scores at the 12-month visit and outcome group. MSEL overall language scores reflect age equivalent scores from both the receptive language and expressive language subscales of the MSEL at the 3-year visit. ASD, infants who were diagnosed with ASD by 3 years of age; ER-no ASD, infants at elevated familial risk for ASD who were not diagnosed with ASD by 3 years of age; LR-no ASD, infants at low familial risk for ASD who were not diagnosed with ASD by 3 years of age; MCDI, MacArthur-Bates communicative development inventory; MSEL, Mullen scales of early learning

in the model. The interactions between late gestures scores and outcome group ($F = 4.47$, $df = 431.96$, $p < 0.05$), maternal education level and language subscale ($F = 3.44$, $df = 442.93$, $p < 0.05$), and maternal education level and outcome group ($F = 7.71$, $df = 432.06$, $p < 0.001$) were also significant. All other 2-way, as well as higher order 3- and 4-way, interaction effects were non-significant ($ps > 0.38$).

The interaction between late gestures scores and outcome group is shown in Figure 1. Simple effects post-hoc analyses revealed that for the ASD group, as 12-month late gestures scores increased, 3-year overall language scores decreased ($B = -0.28$, $SE = 0.14$, $t = -2.03$, $p < 0.05$). The negative slope for the ASD group was significantly different from the ER-no ASD group ($B = 0.45$, $SE = 0.15$, $t = 2.99$, $p < 0.01$) and LR-no ASD group ($B = 0.37$, $SE = 0.15$, $t = 2.50$, $p < 0.05$), although the slopes for the ER-no ASD and LR-no ASD groups did not significantly differ from each other ($p = 0.32$). The ER-no ASD group showed a positive slope that significantly differed from zero ($B = 0.17$, $SE = 0.06$, $t = 2.70$, $p < 0.01$). The LR-no ASD group slope was positive, but did not significantly differ from zero ($B = 0.09$, $SE = 0.06$, $t = 1.63$, $p = 0.10$). Because there was reduced variability in late gestures scores in the ASD group compared to the other groups, we conducted

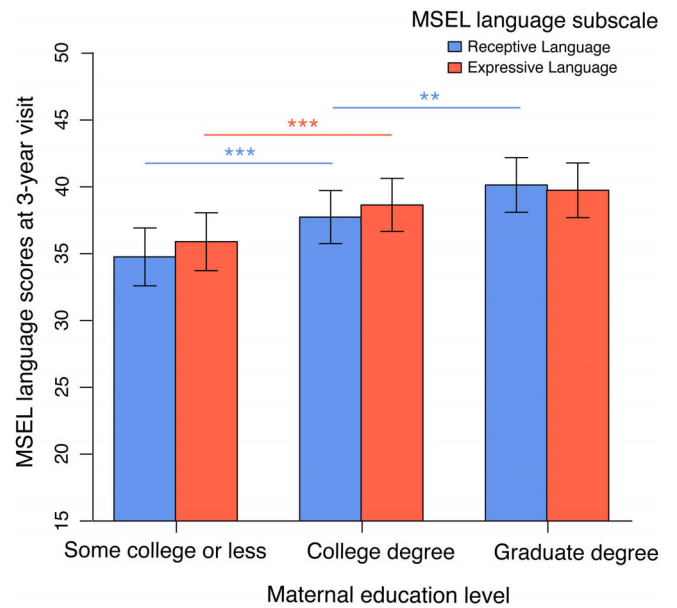


FIGURE 2 Interaction between maternal education level and MSEL language subscale. MSEL language scores reflect age equivalent scores at the 3-year visit. ** $p < 0.01$, *** $p < 0.001$. MSEL, Mullen scales of early learning

additional analyses to investigate whether restricting late gestures scores to the range found within the ASD group (1–25) changed the findings. These analyses showed the same pattern of results with the only change being a significant positive slope for the LR-no ASD group.

The interaction between maternal education level and language subscale is shown in Figure 2. For the receptive language subscale, 3-year scores significantly increased between each successive level of maternal education (some college or less vs. college degree: $M_{diff} = 4.77$, $SEM_{diff} = 0.80$, $t = 5.94$, $p < 0.001$, Cohen's $d = 0.25$; college degree vs. graduate degree: $M_{diff} = 2.54$, $SEM_{diff} = 0.80$, $t = 3.17$, $p < 0.01$, Cohen's $d = 0.18$). For the expressive language subscale, 3-year scores significantly increased between maternal education levels of some college or less and college degree ($M_{diff} = 4.54$, $SEM_{diff} = 0.81$, $t = 5.64$, $p < 0.001$, Cohen's $d = 0.23$); the difference in expressive language scores between levels of college degree and graduate degree was nonsignificant ($M_{diff} = 1.23$, $SEM_{diff} = 0.80$, $t = 1.53$, $p = 0.28$).

The interaction between maternal education level and outcome group is shown in Figure 3. For the ASD group, 3-year overall language scores significantly increased between maternal education levels of some college or less and college degree ($M_{diff} = 10.36$, $SEM_{diff} = 1.73$, $t = 5.99$, $p < 0.001$, Cohen's $d = 1.18$); the difference in overall language scores between levels of college degree and graduate degree was nonsignificant ($M_{diff} = 2.13$, $SEM_{diff} = 1.78$, $t = 1.20$, $p = 0.46$). For the ER-no ASD group, 3-year overall language scores did not significantly differ across maternal education levels ($ps > 0.39$).

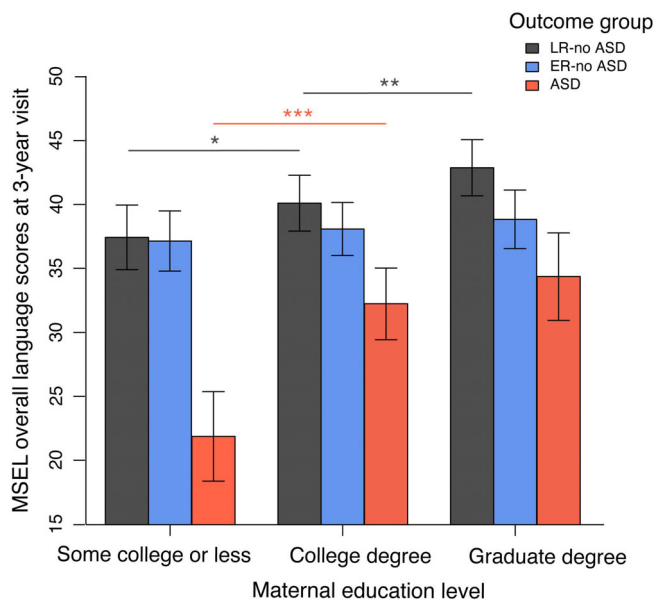


FIGURE 3 Interaction between maternal education level and outcome group. MSEL overall language scores reflect age equivalent scores from both the receptive language and expressive language subscales of the MSEL at the 3-year visit. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. ASD, infants who were diagnosed with ASD by 3 years of age; ER-no ASD, infants at elevated familial risk for ASD who were not diagnosed with ASD by 3 years of age; LR-no ASD, infants at low familial risk for ASD who were not diagnosed with ASD by 3 years of age; MSEL, Mullen scales of early learning

For the LR-no ASD group, 3-year overall language scores significantly increased between each successive level of maternal education (some college or less vs. college degree: $M_{diff} = 2.68$, $SEM_{diff} = 1.08$, $t = 2.48$, $p < 0.05$, Cohen's $d = 0.24$; college degree vs. graduate degree: $M_{diff} = 2.77$, $SEM_{diff} = 0.90$, $t = 3.07$, $p < 0.01$, Cohen's $d = 0.21$).

DISCUSSION

The present study aimed to identify the early predictors of language skills in a large sample of infants with ASD (“ASD”), ER infants without ASD (“ER-no ASD”), and LR infants without ASD (“LR-no ASD”). Findings revealed that early predictors of language vary based on diagnostic outcome of ASD or no ASD, particularly for two predictor variables—gesture abilities and maternal education level. There were no differences in predictors between males and females, despite an overall main effect of sex, with females having stronger language skills than males (see also Messinger et al., 2015).

The backward elimination procedure removed 12-month MCDI early gestures scores, MSEL fine motor scores, and MSEL visual reception scores from the stepwise model, as their associations with 3-year language skills were nonsignificant when accounting for other predictors in the model. This finding was unexpected given

the robust literature documenting significant, positive associations between these behavioral predictors and language skills in LR infants, ER infants with and without ASD, and older autistic children. One explanation for this finding is that we utilized different statistical methods than previous work. Most studies have assessed the relation between individual predictor variables and language skills without considering how these predictor variables might interact with other, unmeasured predictors. Thus, it is possible that these variables were removed from the stepwise model because 12-month late gestures scores and maternal education level were “stronger” predictors of language skills in this sample. Luyster et al. (2008) also used a stepwise model to study predictors of language skills in toddlers with ASD and found similar results to those reported here; motor skills was eliminated from their model when accounting for other predictor variables (e.g., gesture abilities, nonverbal cognition). While fine motor skills may be related to language skills in this population, these findings together suggest that other variables are stronger predictors of language skills.

MCDI late gestures scores, which was retained in the stepwise model, significantly interacted with outcome group. For the ER-no ASD group, the relation between 12-month late gestures scores and 3-year overall language scores was positive. This relation was also positive for the LR-no ASD group, although it did not significantly differ from zero. For the ASD group, however, the relation between late gestures scores and overall language scores was negative. In other words, having a larger repertoire of gesture types at 12 months predicted lower language skills at 3 years. This finding was unexpected, given previous work that has documented a positive relation between gesture and language in autistic children (Bopp & Miranda, 2011; Luyster et al., 2007).

When interpreting this negative relation, it is important to consider the behaviors measured in the MCDI. First, while the MCDI early gestures items gather information about deictic and conventional gesture use, late gestures items focus on more complex behaviors that require symbolic and communicative understanding. Thus, MCDI late gestures scores may better reflect other social communication skills (e.g., play, imitation) that are negatively associated with language skills in infants with ASD (although studies typically report positive relations between play, imitation, and language in ASD; see Charman et al., 2000; Pecukonis et al., 2019; Toth et al., 2006; van der Paelt et al., 2014). Additionally, the MCDI assesses *repertoire* of different gesture types rather than *frequency* of gestures produced. It is therefore possible that frequency of gesture use and repertoire of gesture types are differentially related to language skills in ASD. Finally, the MCDI is subject to parent-report biases. Previous work has shown that MCDI gesture scores are not related to behavioral observation-based measures of gesture abilities, such as the Autism Diagnostic Observation Schedule and the Early Social Communication Scales

(Ellawadi & Weismer, 2014). Parents under- or over-estimating their infants' gesture abilities could have produced a spurious correlation in the ASD group.

If this negative relation between gesture and language in the ASD group is valid and not an artifact of the measure used, why might this be the case? One possibility is that some infants in the ASD group may be experiencing developmental change in gesture abilities between 12 and 36 months. For instance, some infants may have strong gesture abilities at 12 months, followed by a developmental regression or plateau in gesture abilities that further contributes to reduced language skills at 36 months. This would be consistent with studies showing that some infants with ASD lose social communication skills, such as social smiling, eye contact, and initiation of joint attention (Landa et al., 2007; Ozonoff et al., 2010), during the second year of life. Another possibility is that gesture is serving a compensatory role for infants with ASD who have lower language skills (Riva et al., 2021). Studies have found evidence supporting this hypothesis in older, minimally verbal children with ASD (La Valle et al., 2021) and other developmental disorders, such as developmental language disorder (Evans et al., 2001; Iverson & Braddock, 2011) and Down Syndrome (Stefanini et al., 2007). Future studies should explore the relation between developmental changes in gesture abilities and language skills, as well as the potential compensatory role of gesture, in infants with ASD.

Maternal education level, our measure of SES, remained as a predictor in the stepwise model. Upon further investigation of significant interaction effects, we found that the relation between maternal education level and language skills varied between language subscales. Across all outcome groups, expressive language scores were higher for infants whose mothers attained a college degree compared to infants whose mothers completed some college or less, while Receptive Language scores increased with each successive level of maternal education measured. Previous work has reported that maternal education level may be differentially related to expressive and receptive language skills (Pungello et al., 2009; although see Olson et al., 2021; Reilly et al., 2010), suggesting that the mechanisms underlying language development may differ across these domains of language.

The relation between maternal education level and language skills also varied across outcome groups. For the LR-no ASD group, overall language scores increased with each successive level of maternal education. This finding aligns with numerous studies that have reported a positive relation between maternal education level and TD children's language skills (Hoff, 2013). For the ASD group, 3-year language scores were stronger in infants whose mothers had a college degree or above compared to infants whose mothers attained some college or less, suggesting that mothers' attainment of higher education is positively associated with language skills in infants

with ASD. Why might maternal education level be related to language skills in these two groups? One possibility is that maternal education level is positively related to proximal variables within the household environment that promote language development (e.g., high quantity and quality of language heard at home; Hoff, 2003; Swanson et al., 2020; Warlaumont et al., 2014). These proximal variables mediate the relation between maternal education level and language skills in LR infants and ER infants with and without ASD (Huttenlocher et al., 2010; Swanson et al., 2019). Nevertheless, because the present study did not include measures of the household language environment, we cannot draw definitive conclusions about why maternal education level was positively associated with language skills in these infants. Future studies should explore which proximal variables within the household environment mediate the relation between maternal education level and infants' language skills across outcome groups.

While previous studies have reported positive associations between maternal education level and language skills in ER infants with and without ASD (Choi, Nelson, et al., 2020; Swanson et al., 2019), the present study is the first to suggest that this relation varies based on diagnostic outcome of ASD or no ASD. In contrast to what was found in the LR-no ASD and ASD groups, language skills in the ER-no ASD group did not vary by maternal education level, suggesting no relation between these variables in ER infants without ASD. There may be something unique about the proximal environments and/or traits of ER-no ASD infants that washes out the impacts of maternal education level on language skills in this group. For instance, parents of ER infants without ASD may interact with their children in a unique way that promotes language development, regardless of their SES. Previous work has shown that ER infants receive different communicative inputs from their parents, such as increased gesture use, attention bids, and follow-in commenting, all of which may strengthen infants' language skills (Talbot et al., 2015; Wan et al., 2019; Woolard et al., 2022). Another possibility is that ER-no ASD infants have certain traits that support language development, making them less vulnerable to the impacts of SES. For example, when compared to ER infants with ASD, ER infants without ASD show greater social reciprocity, positive affect, attentiveness, and vocalizations during social interactions (Wan et al., 2019). A recent study by Plate et al. (2022) found that ER infants without ASD experienced steeper growth in vocalization production between 6 and 24 months when compared to both ER infants with ASD and LR infants. These traits may elicit better quantity and quality of language from parents, regardless of their education level.

Looking across all outcome groups and maternal education levels, infants in the ASD group whose mothers did not attain a college degree had the lowest 3-year overall language scores, on average. This finding suggests that

infants with ASD who are from lower SES families may be at increased risk for language difficulties. This highlights the importance of implementing policies that remediate socioeconomic disparities alongside early, parent-mediated interventions that target household language environments, especially for infants with ASD from lower SES families.

Strengths of the present study include collaborative, multisite data collection, which facilitated the enrollment of a sample large enough to examine differences between infants with ASD and ER infants without ASD. The use of various validated measures also allowed us to build multivariate models to determine the strongest predictors of language skills. Limitations of the present study are as follows. First, there are other commonly studied predictors of language skills that were not measured in the present study, such as imitation, joint attention, play, and gross motor skills (Edmunds et al., 2017; Luyster et al., 2008; McDuffie et al., 2005; Thurm et al., 2007; Yoder et al., 2015), as this study was conceived after data had already been collected. Future studies should explore how these additional predictor variables interact with the predictors studied here to influence language development in infants with ASD and ER infants. Related to this, the use of stepwise procedures to assess the relative strength of predictors is mainly an exploratory procedure and can be influenced by the idiosyncrasies of the dataset used. As such, future studies should attempt to replicate findings reported here. Another limitation of the present study is that we only included one measure of SES. Because of differences in how demographic data was collected across BSRC sites (e.g., different income ranges/brackets, different currencies across countries), we were unable to include annual household income as a predictor variable. Future studies exploring predictors of language skills should include additional predictors that evaluate aspects of infants' distal (e.g., annual household income) and proximal environments (e.g., quality of household language environment). Yet another limitation of the present study is that infants were from predominately high SES families in which mothers attained education at or beyond the college level. For this reason, we cannot draw conclusions about whether our findings generalize to mothers who attained education at or below the high school level (Pecukonis et al., 2022). Future studies should make concerted efforts to recruit infants with ASD and ER infants from a wide range of socioeconomic backgrounds. Finally, although the analyses performed here were novel, similarities between findings presented in the present study and previous BSRC studies could be the result of overlapping samples.

In summary, gesture abilities and maternal education level likely play an important role in language development for infants later diagnosed with ASD. Variability in these early predictors may help explain why language skills are heterogeneous across the autism spectrum. With

further replication of these findings, we may be able to reliably predict language skills longitudinally by measuring predictors within the first year of life. Clinically, these predictors may serve as early markers for subsequent language difficulties, which will help clinicians identify those in need of additional and/or specialized intervention services. Variables that reliably predict language skills may be targeted in early intervention to further support language development.

ACKNOWLEDGMENTS

The authors would like to extend their gratitude to the research staff who assisted with data collection at each BSRC site, as well as all of the infants and families who participated in this research.

FUNDING INFORMATION

Autism Speaks and Autism Science Foundation provided support for the creation and maintenance of the BSRC database. Data collection and analyses were supported by several grants funded by the National Institutes of Health (including R01 DC10290 [Helen Tager-Flusberg], R01 MH109541 [Gregory S. Young], P50 HD055782 [Sara Jane Webb], R01 MH115913 [Sara Jane Webb], R01 HD057284 [Daniel S. Messinger], R01 HD54979 [Jana M. Iverson], R00 MH092431 [A.J. Schwichtenberg]), as well as Autism Speaks (R324A170063 [Gregory S. Young]). Manuscript preparation was supported by the National Institutes of Health (F31 DC019562 [Meredith Pecukonis]).

CONFLICT OF INTEREST

Tony Charman receives royalties from Sage Publications and Guilford Publications and consulting fees from Servier. Sara Jane Webb receives consulting fees from Janssen Research & Development, LLC. All other authors have no conflicts of interest to disclose.

ETHICS STATEMENT

All BSRC sites obtained Institutional Review Board approval as well as individual family consent to collect and share data across sites.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Meredith Pecukonis  <https://orcid.org/0000-0002-3161-7607>

Jessica Brian  <https://orcid.org/0000-0001-8181-4353>

Tony Charman  <https://orcid.org/0000-0003-1993-6549>

Katarzyna Chawarska  <https://orcid.org/0000-0002-1445-6346>

Mayada Elsabbagh  <https://orcid.org/0000-0002-7311-9059>

REFERENCES

- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Association.
- Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. *arXiv*, 1506.04967.
- Bopp, K. D., & Mirenda, P. (2011). Prelinguistic predictors of language development in children with autism spectrum disorders over four–five years. *Journal of Child Language*, *38*(3), 485–503.
- Carpenter, M., Pennington, B. F., & Rogers, S. J. (2002). Interrelations among social-cognitive skills in young children with autism. *Journal of Autism and Developmental Disorders*, *32*(2), 91–106.
- Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development*, *15*(4), 481–498.
- Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Drew, A., & Cox, A. (2003). Predicting language outcome in infants with autism and pervasive developmental disorder. *International Journal of Language & Communication Disorders*, *38*(3), 265–285.
- Choi, B., Leech, K. A., Tager-Flusberg, H., & Nelson, C. A. (2018). Development of fine motor skills is associated with expressive language outcomes in infants at high and low risk for autism spectrum disorder. *Journal of Neurodevelopmental Disorders*, *10*(1), 14.
- Choi, B., Nelson, C. A., Rowe, M. L., & Tager-Flusberg, H. (2020). Reciprocal influences between parent input and child language skills in dyads involving high-and low-risk infants for autism spectrum disorder. *Autism Research*, *13*(7), 1168–1183.
- Choi, B., Shah, P., Rowe, M. L., Nelson, C. A., & Tager-Flusberg, H. (2020). Gesture development, caregiver responsiveness, and language and diagnostic outcomes in infants at high and low risk for autism. *Journal of Autism and Developmental Disorders*, *50*(7), 2556–2572.
- Colonnesi, C., Stams, G. J. J. M., Koster, I., & Noom, M. J. (2010). The relation between pointing and language development: A meta-analysis. *Developmental Review*, *30*, 352–366.
- Dollaghan, C. A., Campbell, T. F., Paradise, J. L., Feldman, H. M., Janosky, J. E., Pitcairn, D. N., & Kurs-Lasky, M. (1999). Maternal education and measures of early speech and language. *Journal of Speech, Language, and Hearing Research*, *42*(6), 1432–1443.
- Edmunds, S. R., Ibañez, L. V., Warren, Z., Messinger, D. S., & Stone, W. L. (2017). Longitudinal prediction of language emergence in infants at high and low risk for autism spectrum disorder. *Development and Psychopathology*, *29*(1), 319–329.
- Ellawadi, A. B., & Weismer, S. E. (2014). Assessing gestures in young children with autism spectrum disorder. *Journal of Speech, Language, and Hearing Research*, *57*(2), 524–531.
- Evans, J. L., Alibali, M. W., & McNeil, N. M. (2001). Divergence of embodied knowledge and verbal expression: Evidence from speech and gesture in children with specific language impairment. *Language and Cognitive Processes*, *16*, 309–331.
- Fenson, L., Dale, P. S., Reznick, J. S., Thal, D. J., Bates, E., Hartung, J. P., Pethick, S., & Reilly, J. S. (1993). *MacArthur communicative development inventories: User's guide and technical manual*. Singular Publishing Group.
- Franchini, M., Duku, E., Armstrong, V., Brian, J., Bryson, S. E., Garon, N., Roberts, W., Roncadin, C., Zwaigenbaum, L., & Smith, I. M. (2018). Variability in verbal and nonverbal communication in infants at risk for autism spectrum disorder: Predictors and outcomes. *Journal of Autism and Developmental Disorders*, *48*(10), 3417–3431.
- Gamliel, I., Yirmiya, N., Jaffe, D. H., Manor, O., & Sigman, M. (2009). Developmental trajectories in siblings of children with autism: Cognition and language from 4 months to 7 years. *Journal of Autism and Developmental Disorders*, *39*(8), 1131–1144.
- Garrido, D., Petrova, D., Watson, L. R., Garcia-Retamero, R., & Carballo, G. (2017). Language and motor skills in siblings of children with autism spectrum disorder: A meta-analytic review. *Autism Research*, *10*(11), 1737–1750.
- Goldin-Meadow, S. (2015). Gesture as a window onto communicative abilities: Implications for diagnosis and intervention. *Perspectives on Language Learning and Education*, *22*(2), 50–60.
- Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*(5), 1368–1378.
- Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review*, *26*(1), 55–88.
- Hoff, E. (2013). Interpreting the early language trajectories of children from low-SES and language minority homes: Implications for closing achievement gaps. *Developmental Psychology*, *49*, 4–14.
- Hoff, E., Laursen, B., & Bridges, K. (2012). Measurement and model building in studying the influence of socioeconomic status on child development. In L. C. Mayes & M. Lewis (Eds.), *The Cambridge Handbook of Environment in Human Development* (pp. 590–606). Cambridge University Press.
- Hughes, K. R., Hogan, A. L., Roberts, J. E., & Klusek, J. (2019). Gesture frequency and function in infants with fragile X syndrome and infant siblings of children with autism spectrum disorder. *Journal of Speech, Language, and Hearing Research*, *62*(7), 2386–2399.
- Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*(4), 343–365.
- Iverson, J. M. (2010). Developing language in a developing body: The relationship between motor development and language development. *Journal of Child Language*, *37*(2), 229–261.
- Iverson, J. M. (2018). Early motor and communicative development in infants with an older sibling with autism spectrum disorder. *Journal of Speech, Language, and Hearing Research*, *61*(11), 2673–2684.
- Iverson, J. M., & Braddock, B. A. (2011). Gesture and motor skill in relation to language in children with language impairment. *Journal of Speech, Language, and Hearing Research*, *54*(1), 72–86.
- La Valle, C., Chenausky, K., & Tager-Flusberg, H. (2021). How do minimally verbal children and adolescents with autism spectrum disorder use communicative gestures to complement their spoken language abilities? *Autism & Developmental Language Impairments*, *6*, 1–16.
- Landa, R. J., Gross, A. L., Stuart, E. A., & Bauman, M. (2012). Latent class analysis of early developmental trajectory in baby siblings of children with autism. *Journal of Child Psychology and Psychiatry*, *53*(9), 986–996.
- Landa, R. J., Holman, K. C., & Garrett-Mayer, E. (2007). Social and communication development in toddlers with early and later diagnosis of autism spectrum disorders. *Archives of General Psychiatry*, *64*(7), 853–864.
- LeBarton, E. S., & Iverson, J. M. (2013). Fine motor skill predicts expressive language in infant siblings of children with autism. *Developmental Science*, *16*(6), 815–827.
- LeBarton, E. S., & Landa, R. J. (2019). Infant motor skill predicts later expressive language and autism spectrum disorder diagnosis. *Infant Behavior and Development*, *54*, 37–47.
- Leonard, H. C., & Hill, E. L. (2014). The impact of motor development on typical and atypical social cognition and language: A systematic review. *Child and Adolescent Mental Health*, *19*(3), 163–170.
- Longard, J., Brian, J., Zwaigenbaum, L., Duku, E., Moore, C., Smith, I. M., Dewaele, N., & Bryson, S. (2017). Early expressive and receptive language trajectories in high-risk infant siblings of children with autism spectrum disorder. *Autism & Developmental Language Impairments*, *2*, 1–11.
- Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., Pickles, A., & Rutter, M. (2000). The autism diagnostic observation schedule—generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, *30*(3), 205–223.

- Lord, C., Rutter, M., DiLavore, P., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism diagnostic observation schedule (ADOS-2)* (2nd ed., p. 284). Western Psychological Corporation.
- Luyster, R., Qiu, S., Lopez, K., & Lord, C. (2007). Predicting outcomes of children referred for autism using the MacArthur–Bates communicative development inventory. *Journal of Speech, Language, and Hearing Research, 50*(3), 667–681.
- Luyster, R. J., Kadlec, M. B., Carter, A., & Tager-Flusberg, H. (2008). Language assessment and development in toddlers with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 38*(8), 1426–1438.
- Magnuson, K. A., Sexton, H. R., Davis-Kean, P. E., & Huston, A. C. (2009). Increases in maternal education and young children's language skills. *Merrill-Palmer Quarterly, 55*(3), 319–350.
- Manwaring, S. S., Mead, D. L., Swineford, L., & Thurm, A. (2017). Modelling gesture use and early language development in autism spectrum disorder. *International Journal of Language and Communication Disorders, 52*, 637–651.
- McDuffie, A., Yoder, P., & Stone, W. (2005). Prelinguistic predictors of vocabulary in young children with autism spectrum disorders. *Journal of Speech, Language, and Hearing Research, 48*(5), 1080–1097.
- Messinger, D., Young, G. S., Ozonoff, S., Dobkins, K., Carter, A., Zwaigenbaum, L., Landa, R. J., Charman, T., Stone, W. L., Constantino, J. N., Hutman, T., Carver, L. J., Bryson, S., Iverson, J. M., Strauss, M. S., Rogers, S. J., & Sigman, M. (2013). Beyond autism: A baby siblings research consortium study of high-risk children at three years of age. *Journal of the American Academy of Child & Adolescent Psychiatry, 52*(3), 300–308.
- Messinger, D. S., Young, G. S., Webb, S. J., Ozonoff, S., Bryson, S. E., Carter, A., Carver, L., Charman, T., Chawarska, K., Curtin, S., Dobkins, K., Hertz-Picciotto, I., Hutman, T., Iverson, J. M., Landa, R., Nelson, C. A., Stone, W. L., Tager-Flusberg, H., & Zwaigenbaum, L. (2015). Early sex differences are not autism-specific: A baby siblings research consortium (BSRC) study. *Molecular Autism, 6*(1), 1–12.
- Mullen, E. M. (1995). *Mullen scales of early learning*. American Guidance Service Inc.
- Olson, L., Kinnear, M., Chen, B., Reynolds, S., Ibarra, C., Wang, T., Linke, A., & Fishman, I. (2021). Socioeconomic factors account for variability in language skills in preschoolers with autism spectrum disorders. *Journal of Developmental and Behavioral Pediatrics, 42*(2), 101–108.
- Ozonoff, S., Iosif, A.-M., Baugiuo, F., Cook, I., Hill, M., Hutman, T., Rogers, S. J., Rozga, A., Sangha, S., Sigman, M., Steinfeld, M. B., & Young, G. (2010). A prospective study of the emergence of early behavioral signs of autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 49*(3), 256–66.e1-2.
- Ozonoff, S., Young, G. S., Carter, A., Messinger, D., Yirmiya, N., Zwaigenbaum, L., Bryson, S., Carver, L. J., Constantino, J. N., Dobkins, K., Hutman, T., Iverson, J. M., Landa, R., Rogers, S. J., Sigman, M., & Stone, W. L. (2011). Recurrence risk for autism spectrum disorders: A baby siblings research consortium study. *Pediatrics, 128*(3), e488–e495.
- Pecukonis, M., Levinson, J., Chu, A., Broder-Fingert, S., Feinberg, E., Cabral, H., & Tager-Flusberg, H. (2022). Investigating the relation between parental education attainment and language skills in children at clinical risk for autism. Manuscript submitted for publication.
- Pecukonis, M., Skwerer, D. P., Eggleston, B., Meyer, S., & Tager-Flusberg, H. (2019). Concurrent social communication predictors of expressive language in minimally verbal children and adolescents with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 49*(9), 3767–3785.
- Plate, S., Yankowitz, L., Resorla, L., Swanson, M. R., Meera, S. S., Estes, A., Marrus, N., Cola, M., Petrulla, V., Faggen, A., Pandey, J., Paterson, S., Pruetz, J. R., Jr, Hazlett, H., Dager, S., St John, T., Botteron, K., Zwaigenbaum, L., Piven, J., Schultz, R. T., ... IBIS Network (2022). Infant vocalizing and phenotypic outcomes in autism: Evidence from the first 2 years. *Child Development, 93*(2), 468–483.
- Pungello, E. P., Iruka, I. U., Dotterer, A. M., Mills-Koonce, R., & Reznick, J. S. (2009). The effects of socioeconomic status, race, and parenting on language development in early childhood. *Developmental Psychology, 45*(2), 544–557.
- R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.
- Ramos-Cabo, S., Vulchanov, V., & Vulchanova, M. (2019). Gesture and language trajectories in early development: An overview from the autism spectrum disorder perspective. *Frontiers in Psychology, 10*, 1211.
- Reilly, S., Wake, M., Ukoumunne, O. C., Bavin, E., Prior, M., Cini, E., Conway, L., Eadie, P., & Bretherton, L. (2010). Predicting language outcomes at 4 years of age: Findings from early language in Victoria study. *Pediatrics, 126*(6), e1530–e1537.
- Riva, V., Caruso, A., Apicella, F., Valeri, G., Vicari, S., Molteni, M., & Scattoni, M. L. (2021). Early developmental trajectories of expressive vocabulary and gesture production in a longitudinal cohort of Italian infants at high-risk for autism spectrum disorder. *Autism Research, 14*, 1421–1433.
- Stefanini, S., Caselli, M. C., & Volterra, V. (2007). Spoken and gestural production in a naming task by young children with down syndrome. *Brain and Language, 101*(3), 208–221.
- Stone, W. L., McMahon, C. R., Yoder, P. J., & Walden, T. A. (2007). Early social-communicative and cognitive development of younger siblings of children with autism spectrum disorders. *Archives of Pediatrics & Adolescent Medicine, 161*(4), 384–390.
- Swanson, M. R. (2020). The role of caregiver speech in supporting language development in infants and toddlers with autism spectrum disorder. *Development and Psychopathology, 32*(4), 1230–1239.
- Swanson, M. R., Donovan, K., Paterson, S., Wolff, J. J., Parish-Morris, J., Meera, S. S., Watson, L. R., Estes, A. M., Marrus, N., Elison, J. T., Shen, M. D., McNeilly, H. B., MacIntyre, L., Zwaigenbaum, L., St John, T., St Botteron, K., Dager, S., Piven, J., & IBIS Network (2019). Early language exposure supports later language skills in infants with and without autism. *Autism Research, 12*(12), 1784–1795.
- Tager-Flusberg, H. (2018). Early predictors of language development in autism spectrum disorder. In M. Hickmann, E. Veneziano, & H. Jisa (Eds.), *Sources of variation in first language acquisition: Languages, contexts, and learners* (pp. 391–408). John Benjamins Publishing Company.
- Talbott, M. R., Nelson, C. A., & Tager-Flusberg, H. (2015). Maternal gesture use and language development in infant siblings of children with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(1), 4–14.
- Thurm, A., Lord, C., Lee, L. C., & Newschaffer, C. (2007). Predictors of language acquisition in preschool children with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 37*(9), 1721–1734.
- Toth, K., Munson, J., Meltzoff, A. N., & Dawson, G. (2006). Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. *Journal of Autism and Developmental Disorders, 36*(8), 993–1005.
- Van der Paelt, S., Warreyn, P., & Roeyers, H. (2014). Social-communicative abilities and language in preschoolers with autism spectrum disorders: Associations differ depending on language age. *Research in Autism Spectrum Disorders, 8*(5), 518–528.
- Wan, M. W., Green, J., & Scott, J. (2019). A systematic review of parent–infant interaction in infants at risk of autism. *Autism, 23*(4), 811–820.
- Warlaumont, A. S., Richards, J. A., Gilkerson, J., & Oller, D. K. (2014). A social feedback loop for speech development and its reduction in autism. *Psychological Science, 25*(7), 1314–1324.
- Weismer, S. E., & Kover, S. T. (2015). Preschool language variation, growth, and predictors in children on the autism spectrum. *Journal of Child Psychology and Psychiatry, 56*(12), 1327–1337.

- Wodka, E. L., Mathy, P., & Kalb, L. (2013). Predictors of phrase and fluent speech in children with autism and severe language delay. *Pediatrics, 131*(4), e1128–e1134.
- Woolard, A., Lane, A. E., Campbell, L. E., Whalen, O. M., Swaab, L., Karayanidis, F., Barker, D., Murphy, V., & Benders, T. (2022). Infant and child-directed speech used with infants and children at risk or diagnosed with autism spectrum disorder: A scoping review. *Journal of Autism and Developmental Disorders*. <https://doi.org/10.1007/s40489-021-00253-y>
- Yoder, P., Watson, L. R., & Lambert, W. (2015). Value-added predictors of expressive and receptive language growth in initially non-verbal preschoolers with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 45*(5), 1254–1270.

How to cite this article: Pecukonis, M., Young, G. S., Brian, J., Charman, T., Chawarska, K., Elsabbagh, M., Iverson, J. M., Jeste, S., Landa, R., Messinger, D. S., Schwichtenberg, A. J., Webb, S. J., Zwaigenbaum, L., & Tager-Flusberg, H. (2022). Early predictors of language skills at 3 years of age vary based on diagnostic outcome: A baby siblings research consortium study. *Autism Research, 15*(7), 1324–1335. <https://doi.org/10.1002/aur.2760>