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Title:
Early Predictors of Language Skills at 3 Years of Age Vary Based on Diagnostic Outcome: A Baby Siblings Research Consortium Study

Running Title:
Predictors of Language: BSRC Study

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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.

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, non-verbal 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.

Keywords: language, gesture, motor, non-verbal cognition, maternal education, infant sibling

Early Predictors of Language Skills at 3 Years of Age Vary Based on Diagnostic Outcome: A
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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 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 three 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 non-verbal 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 multi-systems 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 (Colonnesi 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 (Talbott et al., 2015) and 24 months (Choi et al., 2020b) 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 non-verbal 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 non-verbal 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 non-verbal cognition and language in ER infants with and without ASD, as non-verbal cognition is often a control variable rather than a predictor variable in analyses (Choi et al., 2018; Choi et al., 2020b; LeBarton & Iverson, 2013). Further research is needed to determine whether non-verbal 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, 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 and colleagues (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 et al., 2020a; 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, non-verbal 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 multi-site 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 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, non-verbal 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 non-verbal 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, non-autistic 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 (MSEL; Mullen, 1995). The MSEL 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 non-verbal 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 (MCDI;

Fenson et al., 1992). The MCDI 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 (ADOS; Lord et al., 2000; Lord et al., 2012). The ADOS is a semi-structured, 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 (CBE). CBE was determined by a licensed clinical psychologist, developmental pediatrician, or child psychiatrist at the 3-year visit. Clinical judgement 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 Autism Spectrum Disorder 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 -2LogLikelihood

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.

Baseline Model

The ICC for BSRC site as a random effect was .08, suggesting little variability in 3-year

language scores across testing sites, whereas the ICC for infant ID as a random effect was .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<.001).

Ages at the 12-month and 3-year visits were not significant predictors of 3-year language scores

(ps>.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<.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<.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 non-significant (X^2=0.58, df=1, *p*=0.45).

The main effect of outcome group was significant (X^2=169.27, df=2, *p*<.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*<.001, Cohen's *d*=0.99) and the LR-no ASD group

(EMM=40.5, *SE*=0.65; *t*(802)=13.59, *p*<.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*<.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 non-

significant.

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*<.05) and maternal education level (*F*=19.28, df=1442.68, *p*<.001), which were

retained in the model. The interactions between Late Gestures scores and outcome group

(*F*=4.47, df=431.96, *p*<.05), maternal education level and language subscale (*F*=3.44, df=442.93,

p<.05), and maternal education level and outcome group (*F*=7.71, df=432.06, *p*<.001) were also

significant. All other 2-way, as well as higher order 3- and 4-way, interaction effects were non-

significant (*p*s>.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<.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<.01) and LR-no ASD group (B=0.37, SE=0.15, t=2.50, p<.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<.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

additional analyses to investigate whether restricting Late Gestures scores to the range found

within the ASD group (1 to 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:

Mdiff=4.77, SEMdiff=0.80, t=5.94, p<.001, Cohen's d=0.25; College degree vs. Graduate

degree: Mdiff=2.54, SEMdiff=0.80, t=3.17, p<.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 (Mdiff=4.54, SEMdiff=0.81, t=5.64, p<.001, Cohen's

d=0.23); the difference in Expressive Language scores between levels of College degree and

Graduate degree was non-significant (Mdiff=1.23, SEMdiff=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 (Mdiff=10.36, SEMdiff=1.73,

t=5.99, p<.001, Cohen's d=1.18); the difference in overall language scores between levels of College degree and Graduate degree was non-significant (Mdiff=2.13, SEMdiff=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). 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: Mdiff=2.68, SEMdiff=1.08, t=2.48, p<.05, Cohen's d=0.24; College degree vs. Graduate degree: Mdiff=2.77, SEMdiff=0.90, t=3.07, p<.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 non-significant 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 and colleagues (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, non-verbal 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 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 & Mirenda, 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 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 (LaValle 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 with and without ASD (Choi et al., 2020a; 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 (Talbott et al., 2015; Wan et al., 2019; Woolard et al., 2021). 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 and colleagues (2021) 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 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., under review). 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.

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Table 1. Sample demographics and descriptives by outcome group

	LR-no ASD (*N*=248)	ER-no ASD (*N*=434)	ASD (*N*=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)*	53.23%[b]	52.07%[b]	70.18%[a]
Maternal education (% less than college degree)*	19.41%[b]	26.74%[a]	33.67%[a]
Maternal education (% college degree)*	41.77%	48.47%	45.92%
Maternal education (% graduate degree)*	38.82%[b]	24.79%[a]	20.41%[a]
Birth order (% 3rd born or later)*	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*	1.57 (1.57)[b]	1.81 (1.31)[b]	6.88 (1.82)[a]
MSEL Receptive Language AE score at 12-month visit*	11.62 (2.09)[c]	10.99 (2.34)[b]	9.68 (2.92)[a]
MSEL Expressive Language AE score at 12-month visit*	11.84 (2.44)[b]	11.48 (2.78)[b]	10.38 (2.72)[a]
MSEL Fine Motor AE score at 12-month visit*	14.85 (1.81)[c]	14.42 (2.06)[b]	13.84 (2.08)[a]
MSEL Visual Reception AE score at 12-month visit*	14.17 (1.83)[c]	13.59 (1.95)[b]	12.68 (1.84)[a]
MCDI Early Gestures total score at 12-month visit*	10.31 (2.70)[c]	9.16 (3.07)[b]	7.58 (3.10)[a]
MCDI Late Gestures total score at 12-month visit*	12.44 (7.39)[c]	9.96 (5.85)[b]	7.97 (4.94)[a]

Note: *Groups with differing superscripts (a,b,c) indicate significant group difference at *p*<.05 (a = sig difference from LR-no ASD group, b = sig difference from ASD group, c = sig difference from ER-no ASD group). Values in the table reflect means and standard deviations in parentheses unless otherwise specified. ADOS = Autism Diagnostic Observation Schedule, AE = Age Equivalent, MCDI = MacArthur-Bates Communicative Development Inventory, MSEL = Mullen Scales of Early Learning.

Figure Captions

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.

Figure 2. Interaction between maternal education level and MSEL language subscale. MSEL language scores reflect age equivalent scores at the 3-year visit. $**p<.01$, $***p<.001$. MSEL = Mullen Scales of Early Learning.

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. $*p<.05$, $**p<.01$, $***p<.001$. 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.