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Word comprehension mediates the link between gesture and word production: Examining language development in infant siblings of children with Autism Spectrum Disorder

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Abstract

Children's gesture production precedes and predicts language development, but the pathways linking these domains are unclear. It is possible that gesture production assists in children's developing word comprehension, which in turn supports expressive vocabulary acquisition. The present study examines this mediation pathway in a population with variability in early communicative abilities – the younger siblings of children with ASD (High Risk infants; HR). Participants included 92 HR infants and 28 infants at low risk (LR) for ASD. A primary caregiver completed the MacArthur-Bates Communicative Development Inventory (Fenson et al., 1993) at 12, 14, and 18 months, and HR infants received a diagnostic evaluation for ASD at 36 months. Word comprehension at 14 months mediated the relationship between 12-month gesture and 18-month word production in LR and HR infants ($ab = .263$; $p < .01$). For LR infants and HR infants with no diagnosis or language delay, gesture was strongly associated with word comprehension ($as = .666$; $.646$; $.561$; $ps < .01$). However, this relationship did not hold for infants later diagnosed with ASD ($a = .073$; $p = .840$). This finding adds to a growing literature suggesting that children with ASD learn language differently. Furthermore, this study provides an initial step towards testing the developmental pathways by which infants transition from early actions and gestures to expressive language.

How do children go from initial attempts at communication such as pointing, shaking their head “no”, and flapping their arms for “birdie” to spoken language? This question has been the subject of considerable research, and undoubtedly many processes contribute to this developmental pathway. It is clear that gesture and language are closely related in early communicative development. Gesture production both precedes and predicts subsequent language development (Iverson, Capirci, & Caselli, 1994; Iverson & Goldin-Meadow, 2005; Rowe & Goldin-Meadow, 2009). Individual lexical items frequently appear first in gesture before moving to speech (Iverson & Goldin-Meadow, 2005), and the number of meanings communicated in gesture at 18 months of age predicts vocabulary at 42 months (Rowe & Goldin-Meadow, 2009). This work supports the notion that children use gesture to communicate ideas before they are able to express them with language.

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This apparent link has prompted researchers to investigate whether gesture production may play a causal role in language acquisition (Goodwyn et al, 2000; LeBarton, Goldin-Meadow & Raudenbush, 2015). LeBarton, et al. (2015) found that following a gesture training intervention, 17-month-olds gestured more with their caregivers, and this increase was positively related to the number of words children produced. These results are consistent with those of Goodwyn and colleagues (2000), who also employed an experimental design in which infants were encouraged to use gestures, and subsequently demonstrated advantages in receptive and expressive language in toddlerhood relative to controls. Together, these studies suggest that gesture use facilitates language development. However, the specific mechanisms that underlie this relationship are less clear. Existing theories imply that gesture use supports the development of word comprehension, which in turn leads to an increase in expressive vocabulary (e.g., Bates, Thal, Whitesell, Fenson, & Oakes, 1989; Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007).

A study by Caselli, Rinaldi, Stefanini, & Volterra (2012) explored this idea by examining action and gesture production (action-gestures), word comprehension, and word production of 8 to 18-month-old infants as reported on the Italian version of the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al., 1993). Action-gestures were more strongly correlated with word comprehension than with word production. The authors interpret this finding as suggesting that word comprehension acts as a bridge between early action-gestures and later word production (i.e., comprehension mediates the relationship). However, they could not test this possibility statistically due to the cross-sectional design of their study. To our knowledge, this proposed pathway has not yet been directly tested. Thus, a central aim of the present study was to address this gap in the literature using a longitudinal design.

Associations between gesture, word comprehension, and word production may be best understood by examining populations with heterogeneity in communicative development. One such population is the infant siblings of children with Autism Spectrum Disorder (ASD). These infants have a heightened risk (HR) of developing ASD (18.7% receive an ASD diagnosis by 36 months; e.g., Ozonoff et al., 2011) compared to infants without a family history of ASD (Low Risk; LR). Understanding processes of language development is particularly important in this population as difficulty with language and communication is a core characteristic of ASD. Furthermore, HR infants as a group demonstrate substantial variability in their language and gesture development (e.g. Iverson et al., 2018; Cassel et al., 2007; Winder, Wozniak, Parlade, & Iverson, 2013). Indeed, even HR infants who do *not* receive an eventual ASD diagnosis are at heightened risk for language delay (e.g. Gamliel, Yirmiya, Jaffe, Manor, & Sigman, 2009; Messinger et al., 2013; Parlade & Iverson, 2015).

A recent study examined trajectories of action-gestures from 8 to 14 months and word comprehension and production from 8 to 24 months in three groups of HR infants: those later diagnosed with ASD (HR-ASD), those who demonstrated significant language delays but were not diagnosed with ASD (Language Delay; HR-LD), and those who developed typically (No Diagnosis; HR-ND; Iverson et al., 2018). Results revealed that patterns of communication development differed across groups. The HR-LD infants were generally more delayed than their HR-ND peers at 8 months but had developmental trajectories that

were similar in rate of growth over time. In contrast, the HR-ASD group progressively diverged from the other two groups across the study period. These distinct trajectories may foreshadow important differences in mechanisms underlying language development across these groups.

The Present Study

Given the heterogeneity of communicative development in HR siblings (Messinger et al., 2013), and the possibility that different processes may be operating in infants later diagnosed with ASD vs. those with non-ASD language delay (e.g. Iverson et al., 2018), the present study had two aims. The first was to determine whether word comprehension mediates the relationship between action-gestures and word production—as proposed by Caselli et al. (2012)—in a population of HR infants and in a LR comparison group. The second was to examine whether this pathway may differ for HR-ASD and HR-LD infants. Specifically, we tested whether diagnostic outcome moderates the relationship between action-gestures and word comprehension and examined this relationship for each outcome group. We hypothesized that word comprehension would mediate the relationship between action-gestures and word production in a sample of LR and HR infants with a wide range of communicative abilities. However, in light of previous findings that communicative development is not only delayed but follows a distinct and divergent trajectory in infants and toddlers with ASD (e.g., Hudry et al., 2014; Iverson et al., 2018), we hypothesized that the relationship between action-gestures and word comprehension would be weaker for HR-ASD infants.

Although prior theoretical and empirical research has largely focused on the pathway from action-gestures to word comprehension (Goodwyn et al., 2000; LeBarton, Goldin-Meadow & Raudenbush, 2015), it remains a possibility that the proposed pathway from action-gestures to word comprehension is reversed (i.e. that word comprehension predicts gesture use), or that these relations are, in fact, bidirectional. Therefore, to explore these relationships more fully, we also examined an alternative model, with action-gestures as a mediator of the relationship between word comprehension and word production.

Method

Participants

The present study included 92 (48 male) HR siblings of children with ASD and 25 (10 male) infants at low risk (LR) for ASD (i.e. no first-degree relative with ASD). HR infants were involved in a longitudinal study investigating early language and motor development and were recruited through a university Autism Research Program as well as parent support organizations. Older siblings' diagnoses were confirmed prior to study enrollment using DSM-IV-TR criteria (APA, 2000) and the Autism Diagnostic Observation Schedule (ADOS-G; Lord et al., 2000). Families of LR infants were part of a separate longitudinal study of early infant development and were recruited through local newspaper birth announcements and word of mouth.

As part of both longitudinal studies, infants and their parents participated in home visits occurring within 3 days of the monthly anniversary of the infant's birth. HR infants were visited monthly from 5 to 14 months, with follow up visits at 18, 24, and 36 months. For LR infants, home visits occurred every 2 weeks from 2 to 19 months. Demographic characteristics for both samples, including racial or ethnic minority status, parental age and education and paternal occupational prestige (used as an index of socioeconomic status; Nakao & Treas, 1994) are provided in Table 1.

Measures

MacArthur-Bates Communicative Development Inventory.—The MacArthur-Bates Communicative Development Inventory (CDI) is a parent report measure of communication and language widely used in both typical and atypical development (e.g., Fenson et al., 1993; Heilmann, Weismer, Evans, & Hollar, 2005, Mitchell et al., 2006). The CDI is regarded as a reliable and valid measure of communicative ability, with high levels of internal consistency ($\alpha = .95$ to $.96$), test-retest reliability ($\alpha = .80$ to $.90$), and validity with experimenter-administered measures ($\alpha = .72$ to $.83$; Bates et al., 1988; Fenson et al., 1994). A primary caregiver (107 mothers, 9 fathers, caregiver could not be determined for 1 infant) completed the CDI at monthly intervals from 8 to 14 months, and again at 18 months. Parents of HR children also completed the CDI as part of their follow up visits at 24 and 36 months. For the present study, we focused on the 12-, 14-, and 18-month timepoints, a period marked by substantial and rapid changes in communication. Specifically, prior work finds that action-gestures begin to emerge and increase in frequency around 12 months (Caselli et al., 2012; Iverson et al., 2018), and 18 months is a period of dramatic growth in language production. Indeed, infants experience a “vocabulary spurt” during this time, often doubling their spoken vocabulary over the course of a month (e.g., Bloom, 1973; Dromi, 1987; Goldfield & Reznick, 1990).

Actions and Gestures (action-gestures). The Words and Gestures form of the CDI, which is designed for 8- to 18-month old children, was used to measure action-gesture production and word comprehension (described below). This form includes a checklist of 63 communicative and/or symbolic actions and gestures, for which the caregiver indicates the items performed by the child. These items include early gestures and routines (e.g., pointing, waving “bye-bye”, playing peekaboo) as well as later gestures including actions with objects (e.g., comb hair) and pretending and/or imitating adults (e.g., feeding a doll, vacuuming). In our primary hypothesized model, this measure was taken from the 12-month visit. In our alternative model, this measure was used as a mediating variable taken at the 14-month visit.

Word comprehension. The Words and Gestures form of the CDI also includes a 396-item checklist consisting of typical words in young children's vocabularies, for which the caregiver indicates words the infant *only understands* or *both says and understands*, with word comprehension being the sum of these endorsed items. In our primary hypothesized model, this measure was used as a mediating variable taken at the 14-month visit. In our alternative model, this measure was a predictor taken from the 12-month visit.

Word production (18 months).: The Words and Sentences form of the CDI, normed for children age 18 to 30 months, includes a 680-word vocabulary checklist for which the caregiver is asked to check all words the child says. This form was used at the 18-month visit, with the exception of 11 caregivers (2 LR, 9 HR) who were given the Words and Gestures form at 18 months. However, both forms provide a word production percentile score, and as noted below, percentile scores were used in all analyses.

Outcome classification.—All HR infants were classified into one of three mutually exclusive outcome categories at 36 months of age: Autism Spectrum Disorder (ASD), Language Delay without ASD (LD), and No Diagnosis (ND). These categories were defined as follows:

HR-ASD.: HR infants received an ASD diagnosis if they met or exceeded ADOS-G algorithm cutoffs for ASD *and* had this confirmed by a trained clinician with a clinical best estimate diagnosis of AD or PDD-NOS using DSM-IV-TR criteria. Using these criteria, 14 infants (10 male) were diagnosed with ASD.

HR-LD.: Language delay classification was based on scores from the CDI as well as the Mullen Scales of Early Learning (MSEL; Mullen, 1995), a normed, standardized developmental assessment of language, cognitive, and motor functioning. As part of the longitudinal study, HR infants were administered the Mullen Scales of Early Learning (MSEL) at 36 months. Infants were classified as language delayed (LD) if they *were not* diagnosed with ASD at 36 months and either (1) had standardized CDI scores at or below the 10th percentile at more than one administration between 18 and 36 months; and/or (2) had standardized CDI scores at or below the 10th percentile *and* standardized MSEL receptive and/or expressive language scores greater than or equal to 1.5 standard deviations below the mean at 36 months (Heilmann et al., 2005; Ozonoff et al., 2010; Paradé & Iverson, 2015). Using these criteria, 27 infants (15 male) were classified as LD.

HR-ND.: The remaining 51 HR infants (23 male) were classified as having no diagnosis (ND).

LR infants were only followed to 19 months of age and therefore we did not have access to comparable 24 and 36-month outcome data for these infants. To ensure that the LR group represented a group of typically developing infants, five LR infants with CDI scores below the 10th percentile at 19 months were excluded from analyses. For the remaining 25 LR infants included in this study, no developmental concerns were ever reported by parent or examiners during the course of their involvement in the study.

Data Analytic Approach

Percentile scores rather than raw scores were used for all variables in the present study. These are calculated using age and gender norms, so gender was not included in the analyses. It should be noted that data from one or more variables were missing for 10 participants (LR: n=2; ND: n=3; LD: n=4; ASD: n=1) due to visit cancellations and/or unforeseen circumstances; these participants were excluded from analyses using listwise deletion. Of these participants, 4 were male and 2 were of a racial or ethnic minority.

Preliminary analyses to examine differences between groups were completed using one-way ANOVAs.

To address our first aim, we analyzed whether word comprehension mediated the relationship between action-gesture production and word production within the entire sample. Mediation analyses were conducted using PROCESS software (version 2.15) for SPSS 23.0, which uses ordinary least squares regression-based path analysis to estimate direct and indirect effects in mediation models (Hayes, 2013). Two models are required to complete this analysis. First, 14-month word comprehension was regressed onto 12-month action-gestures (Model 1). Second, 12-month action-gestures and 14-month word comprehension were entered as predictors into a regression model estimating 18-month word production (Model 2).

Figure 1 shows a visual depiction of the mediation model. The indirect effect of action-gestures on word production through word comprehension (ab) is calculated by multiplying the effect of action-gestures on comprehension from the first regression (a) by the effect of comprehension on word production from the second regression (b). The direct effect of action-gestures on word production is estimated by c' in Model 2. Direct effects can be interpreted using standard null hypothesis testing, but indirect effects will be interpreted using the bias-corrected bootstrap confidence interval approach, as this approach does not make assumptions of normality of the ab distribution, and is widely recommended for inference about the indirect effect in mediation (Hayes, 2013).

To address our second aim, we examined outcome classification (HR-ND, HR-LD, HR-ASD, and LR) as a moderator of the relationship between 12-month action-gesture and 14-month word comprehension (path a in Figure 1). This analysis was also conducted using PROCESS. Outcome was coded using dummy variables, with LR as the reference group, and moderation was determined by examining interaction terms between action-gesture and each HR outcome group (HR-ND, HR-LD, HR-ASD). We also examined the conditional effects of action-gesture and word comprehension for each outcome group.

Finally, we report results of the alternative pathway model (word comprehension > action-gestures > word production) using the same methodology described for Aim 1 above.

Results

Descriptive statistics for each outcome classification group, including 12-month Visual Reception scores from the Mullen Scales of Early Learning (an index of nonverbal cognitive ability) for a subset of HR infants ($n=70$), are presented in Table 2. Bivariate correlations between action-gestures, word comprehension, and word production were calculated across infants; all were strongly correlated (r s ranging from .47 to .61; p s < .001). As can be seen in the table, both the HR-LD and HR-ASD groups had considerably lower scores in gesture and language in comparison to the LR and HR-ND groups. One-way ANOVAs confirmed these group differences (p s < .01). Games-Howell multiple comparisons, which allow for differing population variances, revealed significant differences in 12-month action-gesture, 14-month word comprehension, and 18-month word production between the LR and both

the HR-LD and HR-ASD groups ($p < .05$), but not between the HR-LD and HR-ASD groups ($p > .65$). No significant differences emerged between groups in 12-month nonverbal cognitive ability ($p > .25$).

To address our first aim, we conducted a mediation analysis using ordinary least squares path analysis to determine whether word comprehension mediates the relationship between 12-month action-gesture production and 18-month word production in LR and HR infants. Results of this mediation analysis are presented in Table 3, with unstandardized coefficients a and b representing the indirect effects and c' representing the direct effect (see Figure 1). As can be seen in the table, infants who produced more actions and gestures at 12 months had higher word comprehension scores at 14 months ($a = .673$), and infants higher in word comprehension at 14 months produced more words by 18 months ($b = .391$). A bias-corrected bootstrap confidence interval based on 10,000 bootstrap samples showed that the indirect effect ($ab = .263$) was significantly above zero (95% bcBootCI = .1050 to .4644), indicating that word comprehension mediates the relationship between action-gestures and word production. Note, however, that the direct effect was also significant ($c' = .247$, $p = .03$) suggesting that the mediator does not fully explain this relationship.

To address our second aim, we examined whether outcome classification acted as a moderator of this relationship, particularly the association of 12-month action-gesture production on 14-month word comprehension (path a in Figure 1). Results of this analysis are presented in Table 4, with data presented by outcome group in Figure 2. Consistent with our first analysis, 12-month action-gesture was significantly associated with 14-month word comprehension ($a_1 = .688$, $p < .001$), even with outcome group included in the model. Although none of the outcome group interaction terms were significant, examination of the data suggested that the association between action-gesture and word comprehension was attenuated in infants with ASD.

To further characterize this relationship across groups, we calculated the effect of action-gesture on word comprehension for each outcome group using PROCESS (Hayes, 2013). These results are presented in Table 5. As can be seen in the table and in Figure 2, for the HR-ND, HR-LD, and LR groups, 12-month action-gesture was significantly associated with 14-month word comprehension. For the LR and HR-ND groups, a one-percentile increase in action-gesture at 12 months was associated with a .666 and .646 percentile increase in 14-month word comprehension respectively ($p < .001$), and for the HR-LD group, a one-percentile increase in action-gesture was associated with a .561 percentile increase in word comprehension ($p < .01$). However, 12-month action-gesture was not significantly associated with 14-month word comprehension for infants later diagnosed with ASD ($a = .073$; $p = .84$). To assess potential differential effects of particular gesture types, we examined this relationship separately for early (e.g., pointing, playing peekaboo) and later action-gestures (e.g., comb hair, feed doll). While our outcome group interaction terms did not reach significance ($p > .05$), a similar pattern of results emerged across groups for both early and later action-gestures; these results are presented in Table 6. Thus, these findings are suggestive of a difference in the relationship between action-gestures and word comprehension in infants later diagnosed with ASD.

Alternate model

While prior research has primarily focused on the influence of action-gesture production on word comprehension and production, it remains a possibility that a developing understanding of words as symbols may also boost production of action-gestures, which in turn promotes communication. To explore this possibility, we examined an alternate model to determine whether 14-month action-gesture production mediates the relationship between 12-month word comprehension and 18-month word production. Results of this analysis are presented in Table 7. The indirect effect for this model ($ab = .236$) was also significantly above zero (95% bcBootCI = .102 to .384). As can be seen in Tables 3 and 7, coefficients for the original mediation model and the alternate model are similar in magnitude. To compare the models, the ratio of the indirect to total effect (a measure of effect size recommended for basic mediation models; Wen and Fan, 2015) was calculated. The original model was slightly stronger ($P_M = .516$; .450, for the original and alternate models, respectively); however, the similarity across both models suggests a bidirectional relationship between action-gestures and word comprehension.

Discussion

The present study sought to examine the pathway from early action-gestures to word production in a population of infants with considerable variability in their trajectories of communicative development. Consistent with our hypotheses, we found that word comprehension mediated this relationship. In addition, we found evidence that the relationship between action-gestures and word comprehension appears to differ in infants with ASD – a population characterized by delays and differences both in gesture and language development (see Jones, Gliga, Bedford, Charman, & Johnson, 2014, for a review). Below we discuss these findings in turn, highlighting possible explanations for the relationship between gesture and word comprehension and how it may differ in ASD.

To our knowledge, this is the first study to directly test the proposal that word comprehension mediates the well-documented relationship between gesture and expressive language (e.g., Iverson & Goldin-Meadow, 2005; Rowe & Goldin-Meadow, 2009). Our findings confirmed this pathway in a sample of LR and HR infants with enhanced variability in communicative and language development. However, language acquisition is complex, and this pathway is just one part of a broader system of processes by which infants acquire words. Results of the alternative model suggest that action-gestures and word comprehension may have bidirectional influences on one another; that is, using gestures may assist infants in learning words, and enhanced word comprehension may lead infants to produce more gestures (i.e. these processes may be synergistic and both lead to increases in expressive vocabulary). The present study represents a first step toward understanding processes by which infants' own actions and gestures contribute to their acquisition of language.

It should be noted that the present study utilized data from the CDI, and while this measure provides useful information about infants' general communicative ability, it does not provide information about the real-time behaviors and interactions from which these relationships emerge. Thus, the question of *how* gestures and word comprehension influence one another

remains open. One theoretical account that has been proposed to explain this relationship suggests that gesture may act as a signal to social partners that the infant is ready for word learning, eliciting targeted linguistic responses that provide a link between the referent of the gesture and the corresponding word (e.g., Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Of course, this is one of many possible mechanisms, and future research examining verbal input from social partners as a potential mediator would help to disentangle the processes by which gestures support word comprehension.

The second aim of this study was to test whether the pathway between action-gesture, word comprehension, and word production differs among infants with language delay and infants with an eventual ASD diagnosis. Results revealed that this pathway was not significantly moderated by outcome classification. However, we found that while HR-LD infants displayed a significant association between action-gestures and word comprehension (as found for LR and HR-ND infants), only HR-ASD infants did *not* demonstrate this association. Interestingly, this association was apparent in HR-LD infants despite their lower scores for both action-gestures and word comprehension compared to their typically developing peers. That this pathway is preserved in HR-LD infants is consistent with previous studies of gesture production in “late talkers” (Thal & Tobias, 1992, 1994). This raises the possibility that gesture may be a target for clinical intervention among infants with language delay (Thal & Tobias, 1994). Indeed, Thal & Tobias (1992) found that early gesture production differentiated late-talking infants who eventually caught up with typical peers (i.e. “late bloomers”) and those for whom delays persisted. Although these findings are observational, there is evidence that gesture production can be enhanced through intervention among typically developing infants, and that this induced increase is associated with larger receptive and productive vocabularies in childhood (Goodwyn et al., 2000; LeBarton et al., 2015).

Only HR-ASD infants did not show a significant association between gesture and word comprehension, and this was true for both early gestures and routines and for later gestures including actions with objects and pretend actions. Any explanation for these differences is speculative at this time, particularly given the small sample size and lack of a significant interaction effect. Here we suggest several possibilities for the purpose of guiding future work. One possibility is that the gestures produced by HR-ASD infants differ in form or function in meaningful ways. For instance, studies find that infants with ASD are less likely to point to objects of interest or to hold up objects to show social partners (e.g. Wetherby et al, 2004). Additionally, they are less likely to pair gestures with other communicative behaviors, such as vocalizations or gaze (Heymann et al., 2018; Parlade & Iverson, 2015; Sowden, Clegg, & Perkins, 2013). These differences may alter the social responses they receive from caregivers, thereby also altering opportunities to learn the labels for referents of their gestures. Although HR-ASD infants did not show an association between either developmentally early (e.g., pointing, routines) or more advanced (e.g., actions with objects, pretend actions) gestures and word comprehension, it is possible that gesture types not captured in these categories may be particularly important in eliciting opportunities for language learning. Future work will benefit from examining production of individual gesture types in more detail in infants later diagnosed with ASD.

A second, related possibility is that the social responses elicited by gesture may be less salient to HR-ASD infants, or these infants may differ in how effectively they are able to integrate those responses into their developing understanding of language (e.g., see Arunachalam & Luyster, 2016, for a review). Social attention differs as early as 12 months in infants with ASD: HR-ASD infants show less frequent social smiling and gaze to faces in comparison to typically developing infants (e.g., Ozonoff et al., 2010). Importantly, these differences in social attention are present even in situations when linguistic information is being presented (Chawarska, Macari, & Shic, 2012). If infants with ASD are less likely to attend to social information following their gestures, these social responses may be less effective in helping them with the task of learning words. Again, these explanations are not mutually exclusive, and it is likely that these and other mechanisms act in concert to account for the observed difference in the gesture-language link in ASD. Future research examining the role of parental responses in this pathway would shed light on these differences and further our understanding of children's differential abilities in learning from social responses to gesture.

While strengths of this study include a longitudinal design enabling us to directly test proposed mediation models of language development, and the inclusion of a language delay group, a few considerations must be kept in mind when interpreting the results. We cannot rule out the possibility that the lack of association between action-gesture and word comprehension was due to a relatively small sample and narrow distribution in the HR-ASD group. However, while both HR-LD and HR-ASD infants had lower action-gesture and word comprehension scores and similar distributions of action-gesture production compared to their LR peers, the relationship between action-gesture and word comprehension was preserved in HR-LD infants. Thus, it is unlikely that a restricted range of HR-ASD infants' action-gesture scores can explain these differences entirely.

It is also important to note that the present study used a parent-report measure for each variable in the mediation model, thus shared method variance may have impacted estimations of path coefficients. In addition, while the CDI is widely used and has excellent reliability with experimenter-administered measures (e.g., Fenson et al., 1993, Fenson et al., 1994), parent report of word comprehension may be influenced by many factors aside from the infant's understanding of words. For example, infants later diagnosed with ASD may be engaging differently with their parents; diminished social attention may then lead to differences in parents' perceptions of word comprehension. This challenge in disentangling comprehension from other factors is not limited to the CDI, and future work utilizing measures of visual attention (e.g., Swingley, 2011) may be especially well-suited to better understand links between gesture and word comprehension in infants at heightened risk for ASD. With these considerations in mind, findings from this study need to be replicated with larger samples and language measures that can begin to disentangle word comprehension from additional social and cognitive factors.

Despite these limitations, our findings support two central conclusions. First, although the alternative model was also found to be significant, suggesting a bidirectional relationship between gesture production and word comprehension, this is the first study to our knowledge to confirm the previously theorized model of word comprehension mediating the

relationship between infants' gestures and their productive vocabularies. This pattern was observed across samples of infants representing a wide range of communicative abilities – including infants for whom language is delayed – indicating that this pattern is robust to individual differences in communication. Second, this pathway differed only among infants with an eventual ASD diagnosis. Although ample work has documented differences in individual communicative behaviors in ASD (e.g. Jones et al., 2014), relatively little work has taken up the task of examining whether the inter-relationships *between* these behaviors may also differ. Future work would benefit from examining these relationships in more detail in order to inform early interventions for both ASD and language delays. Investigating these linkages in HR populations not only informs our understanding of ASD; by understanding how these pathways differ in atypical development, we gain a more nuanced and complete understanding of the processes by which infants navigate the complex task of learning language.

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References

- American Psychiatric Association (2000). Diagnostic and statistical manual of mental disorders (4th ed., text revision). Washington, DC: APA.th
- Arunachalam S, & Luyster RJ (2016). The integrity of lexical acquisition mechanisms in autism spectrum disorders: A research review. *Autism Research*, 9(8), 810–828. [PubMed: 26688218]
- Bates E, Bretherton I & Snyder L (1988). *From first words to grammar: individual differences and dissociable mechanisms* New York: C.U.P.
- Bates E, Thal D, Whitesell K, Fenson L, & Oakes L (1989). Integrating language and gesture in infancy. *Developmental psychology*, 25(6), 1004.
- Bavin EL, Prior M, Reilly S, Bretherton L, Williams J, Eadie P, ... & Ukoumunne OC (2008). The Early Language in Victoria Study: Predicting vocabulary at age one and two years from gesture and object use. *Journal of Child Language*, 35(03), 687–701. [PubMed: 18588721]
- Bloom L *The transition from infancy to language: Acquiring the power of expression* Cambridge University Press; Cambridge, England: 1993.
- Capirci O, & Volterra V (2008). Gesture and speech: The emergence and development of a strong and changing partnership. *Gesture*, 8(1), 22–44.
- Caselli MC, Rinaldi P, Stefanini S, & Volterra V (2012). Early action and gesture “vocabulary” and its relation with word comprehension and production. *Child development*, 83(2), 526–542. [PubMed: 22304431]
- Cassel TD, Messinger DS, Ibanez LV, Haltigan JD, Acosta SI, & Buchman AC (2007). Early social and emotional communication in the infant siblings of children with autism spectrum disorders: An examination of the broad phenotype. *Journal of autism and developmental disorders*, 37(1), 122–132. [PubMed: 17186367]
- Chawarska K, Macari S, & Shic F (2012). Context modulates attention to social scenes in toddlers with autism. *Journal of Child Psychology and Psychiatry*, 53(8), 903–913. [PubMed: 22428993]

- Dromi E Early lexical development Cambridge University Press; Cambridge, England: 1987.
- Fenson L, Dale PS, Reznick JS, Bates E, Thal DJ, Pethick SJ, ... & Stiles J (1994). Variability in early communicative development. *Monographs of the society for research in child development*, i–185. [PubMed: 8047076]
- Fenson L, Dale PS, Reznick JS, Thal D, Bates E, Hartung JP, ... & Reilly JS (1993). *MacArthur communicative development inventories: user's guide and technical manual*, Singular Publishing Group San Diego.
- Gamliel I, Yirmiya N, Jaffe DH, 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. [PubMed: 19326200]
- Goldfield BA, Reznick JS. Early lexical acquisition: Rate, content, and the vocabulary spurt. *Journal of Child Language* 1990;17:171–183. [PubMed: 2312640]
- Goodwyn SW, Acredolo LP, & Brown CA (2000). Impact of symbolic gesturing on early language development. *Journal of Nonverbal behavior*, 24(2), 81–103.
- Goldin-Meadow S, Goodrich W, Sauer E, & Iverson J (2007). Young children use their hands to tell their mothers what to say. *Developmental science*, 10(6), 778–785. [PubMed: 17973795]
- Hayes AF (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* Guilford Press.
- Heymann P, Northrup JB, West KL, Paradé MV, Leezenbaum NB, & Iverson JM (2018). Coordination is key: Joint attention and vocalisation in infant siblings of children with Autism Spectrum Disorder. *International journal of language & communication disorders*
- Heilmann J, Weismer SE, Evans J, & Hollar C (2005). Utility of the MacArthur—Bates Communicative Development Inventory in Identifying Language Abilities of Late-Talking and Typically Developing Toddlers. *American Journal of Speech-Language Pathology*, 14(1), 40–51. [PubMed: 15966111]
- Hudry K, Chandler S, Bedford R, Pasco G, Gliga T, Elsabbagh M, ... & Charman T (2014). Early language profiles in infants at high-risk for autism spectrum disorders. *Journal of autism and developmental disorders*, 44(1), 154–167. [PubMed: 23748385]
- Iverson JM, Capirci O, & Caselli MC (1994). From communication to language in two modalities. *Cognitive Development*, 9(1), 23–43.
- Iverson JM, & Goldin-Meadow S (2005). Gesture paves the way for language development. *Psychological science*, 16(5), 367–371. [PubMed: 15869695]
- Iverson JM, Northrup JB, Leezenbaum NB, Paradé MV, Koterba EA, & West KL (2018). Early Gesture and Vocabulary Development in Infant Siblings of Children with Autism Spectrum Disorder. *Journal of autism and developmental disorders*, 48(1), 55–71. [PubMed: 28900778]
- Jones EJ, Gliga T, Bedford R, Charman T, & Johnson MH (2014). Developmental pathways to autism: a review of prospective studies of infants at risk. *Neuroscience & Biobehavioral Reviews*, 39, 1–33. [PubMed: 24361967]
- Lazenby DC, Sideridis GD, Huntington N, Prante M, Dale PS, Curtin S, ... & Akshoomoff N (2016). Language Differences at 12 Months in Infants Who Develop Autism Spectrum Disorder. *Journal of autism and developmental disorders*, 46(3), 899–909. [PubMed: 26476738]
- LeBarton ES, Goldin-Meadow S, & Raudenbush S (2015). Experimentally induced increases in early gesture lead to increases in spoken vocabulary. *Journal of Cognition and Development*, 16(2), 199–220. [PubMed: 26120283]
- Lord C, Risi S, Lambrecht L, Cook EH Jr, Leventhal BL, DiLavore PC, ... & 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. [PubMed: 11055457]
- Messinger D, Young GS, Ozonoff S, Dobkins K, Carter A, Zwaigenbaum L, ... & Hutman T (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. [PubMed: 23452686]
- Mitchell S, Brian J, Zwaigenbaum L, Roberts W, Szatmari P, Smith I, & Bryson S (2006). Early language and communication development of infants later diagnosed with autism spectrum

disorder. *Journal of Developmental & Behavioral Pediatrics*, 27(2), S69–S78. [PubMed: 16685188]

Mullen EM (1995). Mullen scales of early learning (pp. 58–64). Circle Pines, MN: AGS.

Nakao K, & Treas J (1994). Updating occupational prestige and socioeconomic scores: How the new measures measure up. *Sociological methodology*, 24(1), 1–72.

Ozonoff S, Iosif AM, Baguio F, Cook IC, Hill MM, Hutman T, ... & Steinfeld MB (2010). A prospective study of the emergence of early behavioral signs of autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, 49(3), 256–266. [PubMed: 20410715]

Ozonoff S, Young GS, Carter A, Messinger D, Yirmiya N, Zwaigenbaum L, ... & Hutman T (2011). Recurrence risk for autism spectrum disorders: a Baby Siblings Research Consortium study. *Pediatrics*, 128(3), e488–e495. [PubMed: 21844053]

Parladé MV, & Iverson JM (2015). The development of coordinated communication in infants at heightened risk for autism spectrum disorder. *Journal of autism and developmental disorders*, 45(7), 2218–2234. [PubMed: 25689930]

Rowe ML, & Goldin-Meadow S (2009). Early gesture selectively predicts later language learning. *Developmental science*, 12(1), 182–187. [PubMed: 19120426]

Rozga A, Hutman T, Young GS, Rogers SJ, Ozonoff S, Dapretto M, & Sigman M (2011). Behavioral profiles of affected and unaffected siblings of children with autism: Contribution of measures of mother–infant interaction and nonverbal communication. *Journal of autism and developmental disorders*, 41(3), 287–301. [PubMed: 20568002]

Swingley D (2011). The looking-while-listening procedure. *Guide to Research Methods in Child Language*

Thal DJ, & Tobias S (1992). Communicative gestures in children with delayed onset of oral expressive vocabulary. *Journal of Speech, Language, and Hearing Research*, 35(6), 1281–1289.

Thal D, & Tobias S (1994). Relationships between language and gesture in normally developing and late-talking toddlers. *Journal of Speech, Language, and Hearing Research*, 37(1), 157–170.

Wen Z, & Fan X (2015). Monotonicity of effect sizes: Questioning kappa-squared as mediation effect size measure. *Psychological methods*, 20(2), 193. [PubMed: 25664380]

Winder BM, Wozniak RH, Parladé MV, & Iverson JM (2013). Spontaneous initiation of communication in infants at low and heightened risk for autism spectrum disorders. *Developmental psychology*, 49(10), 1931. [PubMed: 23231694]

Research Highlights

- Word comprehension mediates the relationship between gesture and word production in a population with considerable variability in early communicative development.
- Gesture and word comprehension are significantly associated for infants with language delay and with typical development, but not for infants later diagnosed with ASD.
- Findings contribute to a more nuanced understanding of the processes by which infants with typical and atypical development navigate the complex task of learning language.

Figure 1.
Mediation model of the role word comprehension (WC) in the relationship between action-gesture (AG) and word production (WP).

Figure 2.
Relationship between action-gesture (AG) and word comprehension (WC) by outcome group.

Table 1.

Demographic Information for High Risk (HR) and Low Risk (LR) groups

	HR (n = 92)	LR (n = 25)
Racial or ethnic minority (%)	10 (11%)	1 (4%)
Mean age for Mothers (SD)	34.24 (4.04)	31.92 (4.95)
Mean age for Fathers (SD)	36.72 (5.12)	33.08 (4.08)
Mean Parent Education ^a (SD)	1.24 (0.48)	1.38 (0.51)
Mean Paternal Occupational Prestige ^b (SD)	54.85 (15.49)	55.06 (15.06)

^a Parent education based on averaging education scores for mothers and fathers.

0 = High school, 1 = Some college or college degree; 2 = Graduate or professional school.

^b Nakao–Treas occupational prestige score; scores range from 0 to 100. Unable to calculate for 7 LR and 6 HR fathers.

Table 2.

Descriptive Statistics of CDI Percentile scores

	Low Risk (n=25)			HR-ND (n=51)			HR-LD (n=27)			HR-ASD (n=14)		
	n	M	SD (Range)	n	M	SD (Range)	n	M	SD (Range)	n	M	SD (Range)
12mo AG	24	43.75	27.71 (5–90)	49	33.67	24.43 (0–90)	25	23.60	21.77 (0–75)	14	17.14	15.90 (0–55)
14mo WC	25	41.40	27.63 (5–95)	50	37.98	28.24 (0–99)	24	16.25	18.37 (0–65)	13	10.38	13.76 (0–50)
18mo WP	24	43.33	28.16 (5–90)	49	37.65	25.54 (5–90)	27	7.59	10.60 (0–50)	14	5.71	8.96 (0–30)
12mo VR	0	--	--	37	55.19	9.68 (31–80)	21	55.71	10.96 (38–80)	12	47.84	14.54 (20–80)

Note. SD = Standard Deviation; ND = No diagnosis; LD = Language Delay; AG = Action and Gesture percentile; WC = Word comprehension percentile; WP = Word Production percentile. VR = Mullen Scales of Early Learning Visual Reception T-score, collected at 12 months for a subset of HR infants.

Table 3.

Mediation analyses (see Figure 1)

		Model 1 Y = 14mo WC			Model 2 Y = 18mo WP		
		Coeff.	SE	P	Coeff.	SE	P
X (12mo AG)	<i>a</i>	.673	.084	<.001*	<i>c'</i>	.247	.112
M (14mo WC)		---	---	---	<i>b</i>	.391	.103
Constant	<i>i_I</i>	9.542	3.394	.006*	<i>i₂</i>	8.331	3.712
		R ² = .382			R ² = .315		
		F(1,105) = 64.834, p < .001			F(2,104) = 23.936, p < .001		

Note. SE = Standard Error; AG = Action and Gesture percentile; WC = Word comprehension percentile; WP = Word Production percentile.

Table 4.

Moderation of AG's effect on WC by 36-month outcome classification

		Y = 14mo WC		
		Coeff.	SE	P
Constant	i_1	11.281	7.947	.159
12mo AG	a_1	.666	.154	< .001*
No Diagnosis	a_{2ND}	5.534	9.403	.557
Language Delay	a_{2LD}	-8.094	10.215	.430
ASD	a_{2ASD}	-2.154	11.575	.853
ND*(12mo AG)	a_{3ND}	-.021	.196	.917
LD*(12mo AG)	a_{3LD}	-.105	.249	.672
ASD*(12mo AG)	a_{3ASD}	-.593	.390	.131
Model Summary	$R^2 = .474$ $F(7,101) = 12.98$; $p < .001^*$			
R^2 increase due to interaction	R^2 change = .013 $F(3,101) = .843$; $p = .474$			

Note. SE = Standard Error; AG = Action and Gesture percentile; WC = Word Comprehension percentile

Table 5.

Conditional effect of AG on WC by 36-month outcome classification

Y = 14mo WC				
Outcome	Coeff.	SE	P	95% CI
Low Risk	.666	.154	<.001*	(.360, .972)
No Diagnosis	.646	.121	<.001*	(.405, .886)
Language Delay	.561	.195	.005*	(.174, .947)
ASD	.073	.358	.840	(-.638, .783)

Note. SE = Standard Error; AG = Action and Gesture percentile; WC = Word Comprehension percentile

Table 6.

Conditional effects of Early and Later AG on WC by 36-month outcome classification

Outcome	Coeff.	SE	P	95% CI
X = 12mo Early AG				
Low Risk	.573	.182	.002*	(.213, .934)
No Diagnosis	.421	.118	<.001*	(.187, .654)
Language Delay	.430	.188	.024*	(.057, .803)
ASD	.222	.265	.405	(−.304, .748)
X = 12mo Later AG				
Low Risk	.670	.160	<.001*	(.352, .978)
No Diagnosis	.567	.125	<.001*	(.320, .814)
Language Delay	.520	.199	.010*	(.126, .913)
ASD	−.021	.377	.957	(−.768, .727)

Note. SE = Standard Error; AG = Action and Gesture percentile; WC = Word Comprehension percentile

Table 7.

Alternative mediation model (12mo WC - 14mo AG - 18mo WP)

		Model 1 Y = 14mo AG			Model 2 Y = 18mo WP			
		Coeff.	SE	P				
		Coeff.	SE	P				
X (12mo WC)	<i>a</i>	.689	.095	<.001*	<i>c'</i>	.288	.112	.012*
M (14mo AG)		---	---	---	<i>b</i>	.342	.094	<.001*
Constant	<i>i_I</i>	19.42	3.432	<.001*	<i>i₂</i>	7.664	3.758	.044*
		R ² = .335			R ² = .310			
		F(1,105) = 64.834 , p < .001			F(2,102) = 23.113, p<.001			

Note. SE = Standard Error; AG = Action and Gesture percentile; WC = Word comprehension percentile; WP = Word Production percentile.